



Genetic Attributes and Correlation Studies for Important Traits in Wheat Under Irrigated and Rainfed Conditions

Aftab Ahmad³ · Muhammad Nasir Iqbal³ · Muhammad Mehran Anjum^{1,2} · Bismillah Khan¹ · Salman Khan³ · Saeed Ullah³ · Rooh Ullah³ · Muhammad Yousaf Afridi³

Received: 21 December 2022 / Accepted: 27 March 2023 / Published online: 8 May 2023
© The Author(s), under exclusive licence to Springer-Verlag GmbH Deutschland, part of Springer Nature 2023

Abstract

Development of new and high yielding cultivars is the main goal of plant breeders. This research was conducted to determine genetic diversity, heritability, genetic advance and correlations among various traits in wheat advance lines under rainfed and irrigated conditions. A set of 20 wheat genotypes was evaluated in a randomized complete block design (RCBD) with three replications at The University of Agriculture, Peshawar, during 2020–21. Pooled analysis showed highly significant diversity among genotypes for all the studied parameters. Genotypes by environment (G × E) interaction was also highly significant for all the studied traits except spike length and grain weight spike⁻¹. The best performing genotype for yield related attributes was G202 for spikes m⁻² (385.0), grain weight spike⁻¹ (3.2 g), grains spike⁻¹ (68.0 g) and G149 for 1000-grain weight (55.1 g) under irrigated condition, while under rainfed condition the best genotype was G131 for spikes m⁻² (303.3), grain weight spike⁻¹ (2.5 g) and grains spike⁻¹ (59.7) and genotype G148 for 1000-grain weight (51.1 g). High heritability and expected genetic advance were observed for all the traits except plant height, spike length and grain weight spike⁻¹ which showed low to moderate broad sense heritability under irrigated and rainfed conditions. Grain yield showed highly significant positive genotypic and phenotypic correlations under irrigated condition with spikelets spike⁻¹ ($r_g = 0.80^{**}$, $r_p = 0.60^{**}$), grains spike⁻¹ ($r_g = 0.83^{**}$, $r_p = 0.59^{**}$), grain weight spike⁻¹ ($r_g = 0.99^{**}$, $r_p = 0.62^{**}$) and 1000-grain weight ($r_g = 0.81^{**}$, $r_p = 0.59^{**}$). Similarly, the genotypic and phenotypic correlations of grain yield were highly significant and positive with spikes m⁻² ($r_g = 0.71^{**}$, $r_p = 0.69^{**}$), spikelets spike⁻¹ ($r_g = 0.64^{**}$, $r_p = 0.59^{**}$), biological yield ($r_g = 0.74^{**}$, $r_p = 0.66^{**}$) and harvest index ($r_g = 0.83^{**}$, $r_p = 0.72^{**}$) under rainfed condition. These characters having high correlations with grain yield could be utilized for development of high yielding wheat cultivars. The promising genotypes under irrigated condition were G202, PS-15 and G106 while under rainfed condition the promising genotypes were G131, G148 and G116. Thus, these genotypes could be used in the future breeding programs.

Keywords Genotypes · Correlation · Heritability · Genetic advance · Irrigated and rainfed conditions

Introduction

Wheat is the leading cereal crops cultivated all over the world under different environmental conditions. Wheat is

one of the most important species in Graminae family. It was the first domesticated cereal crop from prehistoric time. Flour is the important produce of wheat from which other kinds of food products are made such as nans, pastries, chapattis and roti. Wheat straw is the important source of animal's feed. Wheat usually takes 140–170 days from planting till its harvest, depending upon soil, quality of the seeds and climatic conditions. Globally 36% of the population directly depends on wheat (Singh and Chaudhary 2006).

Pakistan is ranked 4th high producer country in the Asia and 10th among the wheat producing countries. In Pakistan wheat was cultivated on an area of (9168.2 ha) with total production of (27,464.1 tons) Pakistan bureau of statistics (PBS 2020). In Khyber Pakhtunkhwa (KPK) wheat was

✉ Bismillah Khan
bismillahaup@gmail.com

¹ Department of Agronomy, The University of Agriculture Peshawar, Peshawar, Pakistan
² Botany Section, Pakistan Council of Scientific and Industrial Research (PCSIR), Peshawar, Pakistan
³ Department of Plant Breeding and Genetics, The University of Agriculture Peshawar, Peshawar, Pakistan

Table 1 List of genotypes and their pedigrees used in the experiment

S. No	Genotypes	Pedigrees
1	G106	WBLL1*2/4/YACO/PBW65/3/KAUZ*2/TRAP//KAUZ/5/KACHU #1*2/6/FRET2/KUKUNA//FRET2/3/TNMU/5/FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ
2	G116	WAXWING/KIRITATI/6/PVN//CAR422/ANA5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1/7/SERI.1B//KAUZ/HEVO/3/AMAD*2/4/KIRITATI/8/ATTILA*2/PBW65*2/4/BOW/NKT//CBRD/3/CBRD
3	G125	ATTILA*2/PBW65/5/CNO79//PF70354/MUS/3/PASTOR/4/BAV92/6/TRCH/SRTU//KACHU//U/P2338*2/KKTS*2//YANAC
4	G130	ROLF07/SAUAL*2/5/SERI.1B//KAUZ/HEVO/3/AMAD*2/4/KIRITATI
5	G131	ROLF07/SAUAL*2/5/SERI.1B//KAUZ/HEVO/3/AMAD*2/4/KIRITATI
6	G134	TACUPETOF2001/BRAMBLING/5/NAC/TH.AC/3*PVN/3/MIRLO/BU/4/2*PASTOR*2/6/TRCH/SRTU//KACHU
7	G144	KACHU/SAUAL*2/5/SERI.1B//KAUZ/HEVO/3/AMAD*2/4/KIRITATI
8	G145	KACHU/SAUAL*2/5/SERI.1B//KAUZ/HEVO/3/AMAD*2/4/KIRITATI
9	G147	KACHU/SAUAL*2/8/ATTILA*2/PBW65/6/PVN//CAR422/ANA5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1/7/ATTILA2*PASTOR
10	G148	KACHU/SAUAL*2/8/ATTILA*2/PBW65/6/PVN//CAR422/ANA5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1/7/ATTILA2*PASTOR
11	G149	KACHU/SAUAL*2/8/ATTILA*2/PBW65/6/PVN//CAR422/ANA5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1/7/ATTILA2*PASTOR
12	G155	SAUAL/MUTUS*2/3/TRCH/SRTU//KACHU
13	G159	SAUAL/MUTUS*2/3/TRCH/SRTU//KACHU
14	G160	SAUAL/MUTUS*2/3/TRCH/SRTU//KACHU
15	G163	SAUAL/MUTUS*2//PICAFLO #1
16	G197	BCN/RIALTO/2*MUNAL #1
17	G202	SOKOLL/3/PASTOR//HXL7573/2*BAU/4/SOKOLL//PBW343*2/KUKUNA/3/ATTILA/PASTOR
18	G206	PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1/5/CROC_1/AE.SUARROSA(213)//PGO/3/CMH81.38/2*KAUZ/4/BERKUT/6/W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1
19	PS-15	Check cultivar
20	Wadan	Check cultivar

cultivated on an area (0.73 m ha^{-1}) with the production of (1.3 m tons) (CSKP 2019). Low yield of wheat is due to poor quality seed, late sowing, low yielding varieties and low water (Fatima et al. 2018).

For predicting the performance of wheat genotypes plant breeders focus on high heritable traits (Khan et al. 2008; Mangi et al. 2008). Higher heritability makes selection process simple for the plant breeders. Efficient progress in the breeding approaches is made due to high heritability and genetic advance (Gite et al. 2018). To gain high yield the breeders developed improved wheat varieties (Abdullah et al. 2002). Genetic and environmental factors highly influence wheat grain yield. Environment plays a major role in low heritability of wheat grain yield. High yielding varieties development is the major goal for Pakistani plant breeders (Maqbool et al. 2010).

For effective crop breeding progress, it is important to know the association between various components with yield and yield related traits. Genotypic and phenotypic correlations provide opportunity to plant breeders to measure the associations of one trait with another. Correlation coefficient helps the plant breeders to determine the selection criteria for progress of various traits with yield. The yield was increased by understanding the associations of yield with other traits. Some breeders showed positive association between yield and other traits that contribute to yield such as grains spike⁻¹ (Kashif and Khaliq 2004), 1000-grain weight (Anjum et al. 2022), harvest index (%) (Ali and Shakor 2012) and plant height (Anjum et al. 2022).

The inheritance of grain yield is very complex in wheat and is related to other yield contributing traits (Sajjad et al. 2011). Genotypes perform differently in different environments which indicate the impact of various environmental factors on the expression of traits (Aucamp et al. 2006). Developing high yielding and stable varieties can reduce the gap of yield under both irrigated and rainfed areas. The most important aspect of plant breeding is to find out genetic differences among the genotypes for population improvement. The current study was conducted to achieve the following objectives to; (i) estimate heritability and expected genetic advance for grain yield and other yield related traits under irrigated and rainfed conditions (ii) find out association of yield and yield contributing traits under the two environments (iii) identify the best performing genotypes for irrigated and rainfed conditions.

Materials and Methods

This research was performed at The University of Agriculture, Peshawar, during 2020–21. The experimental material comprised 18 advance wheat lines procured from International Maize and Wheat Improvement Center (CIMMYT) along with two local check cultivars (Table 1). A total of 20 genotypes were sown under irrigated and rainfed conditions independently. The experiment was conducted using RCB design with three replications. All the genotypes were

Fig. 1 Average means monthly maximum and minimum temperature and precipitation during 2018–19 and 2019–20 in the experimental location. (Peshawar Metrological Department)

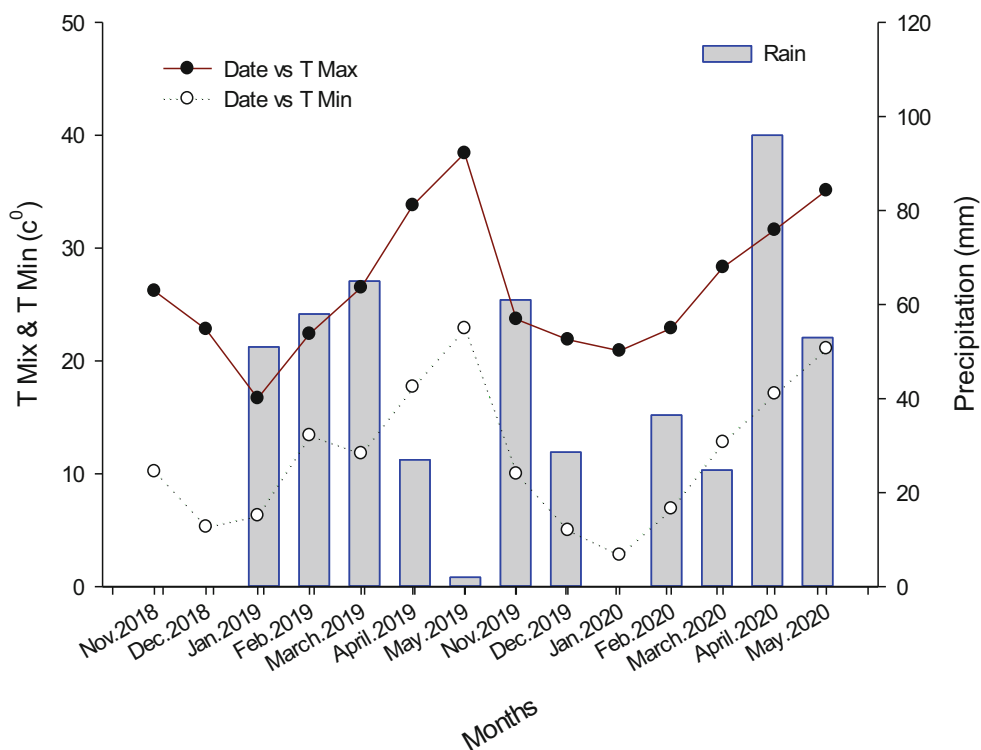


Table 2 Physico-chemical properties of soil (15–30 cm) of the experimental site

Properties	Values
pH(H ₂ O)	8.01
Electrical conductivity (dS m ⁻¹)	0.86
Bulk density (g ⁻¹ cm ³)	1.67
Sand (%)	8.67
Silt (%)	52.43
Clay (%)	41.32
Textural class	Silty clay loam
CaCO ₃ (%)	14.2
Total organic C (g kg ⁻¹)	8.21
Total N (g kg ⁻¹)	0.52
Field Capacity (%)	32
Permanent Wilting Point (%)	18
<i>AB-DTPA extractible nutrients</i>	
P (mg kg ⁻¹)	3.78
K (mg kg ⁻¹)	104
Zn (mg kg ⁻¹)	0.84
Mg (mg kg ⁻¹)	2.2
Na (mg kg ⁻¹)	2.3

assigned to a plot of 4 rows by keeping a row to row distance of 30 cm with a row length of 3 m.

Procedure for Recording Parameters

Phenological Attributes

Days to heading in each genotype was recorded from date of sowing till the emergence of spike from flag leaf sheath in 50% of the plants. The data for days to physiological maturity was recorded from date of sowing till the loss of

green pigment from peduncle bearing the spike in 50% of the plants (Khan et al. 2022).

Growth Parameters

Flag leaf area was recorded in each genotype on 10 randomly selected plants by using the following formula (Muller 1991):

$$\text{Flag leaf area} = \text{leaf length} \times \text{leaf width} \times 0.75$$

Plant height was taken after physiological maturity. The plant height was measured by selecting ten randomly plants in each genotype from the soil surface to the tip of spike excluding awns. Spike length was recorded on ten randomly selected spikes from the base to the tip of last spikelet excluding awns in each genotype (Anjum et al. 2022; Khan et al. 2023).

Yield and Yield Attributes

Productive tillers were counted in one m² area in three central rows in each genotype randomly. Data on spikelets spike⁻¹ was noted by counting productive spikelets on ten randomly selected spikes in each genotype at physiological maturity. Data on grains spike⁻¹ was recorded by counting total number of grains in ten randomly selected spikes by threshing each genotype individually. Grains of ten randomly selected spikes were threshed separately in each genotype and weighed on electric balance. Data on thousand grains weight was taken from the bulk grains of the selected plants in each genotype with the help of electric balance. Each plot was harvested individually at maturity and the whole bundle after sun drying was weighed with

Table 3 Mean squares for various traits of 20 wheat lines across two environments (irrigated and rainfed)

Traits	Source of variation with degree of freedom					
	Environments (1)	Reps (E) (4)	Genotypes (19)	G × E (19)	Error (76)	CV (%)
Days to heading	313.63**	0.61	54.25**	15.70**	1.59	1.13
Flag leaf area	437.7**	0.71	18.51**	8.16**	1.08	6.23
Days to maturity	2.41 ^{ns}	2.08	8.30**	10.44**	0.94	0.66
Plant height	832.13**	43.15	34.40**	15.75**	6.91	3.15
Spike length	21.11**	0.54	2.08**	0.32 ^{ns}	0.41	6.15
Spikelets spike ⁻¹	29.40**	0.25	9.92**	4.41**	0.86	5.04
Spikes m ⁻²	122000.51**	164.44	4926.03**	2267.57**	79.26	3.05
Grains spike ⁻¹	311.37**	2.92	98.69**	32.26**	7.56	5.20
Grains weight spike ⁻¹	7.09**	0.11	0.27**	0.10 ^{ns}	0.10	13.6
1000-grain weight	276.2**	0.38	26.5**	8.47**	1.13	2.2
Biological yield	230050182.3**	56246.29	2258921**	592842.7**	176942.3	8.1
Grain yield	12867475.2**	43896.16	407152.8**	168459.6**	76674.91	13.6
Harvest index (%)	2029.49**	1.01	146.13**	100.3**	33.3	14

*, **Significant at 5% and 1% probability level; ^{ns} non-significant

an electric balance before threshing to record biological yield. For the analysis the biological yield was converted to kg ha⁻¹. Grain yield was determined from weight of the grains obtained after threshing the whole produce in each plot. Harvest index was calculated by using the following formula (Anjum et al. 2022):

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

Statistical Analysis

The data recorded for the traits was subjected to pooled analysis (Gomez and Gomez 1984) to analyze the genetic diversity among 20 wheat genotypes (Fig. 1, Table 2).

Results and Discussion

Days to Heading

Pooled analysis of heading showed highly significant diversity among the genotypes, environments and genotype

by environment (G×E) interaction (Table 3). Khan et al. (2020) and Kumar et al. (2017) also observed significant diversity among wheat genotypes for days to heading. Coefficient of variation across the two environments was 1.13% for days to heading (Table 3). Mean values of the genotypes for heading ranged from 104.7–116.3 days under irrigated conditions, while under rainfed condition it ranged from 106.0–117.0 days (Table 4). Under irrigated conditions maximum days were recorded for genotype PS-15 (116.3 days), followed by G202 (113.7 days), while minimum days were recorded for G197 (104.7 days), followed by G155 (105.0 days). In contrast, under rainfed condition maximum mean value of days to heading was observed for Wadan (117.0 days), followed by G202 (116.3 days), while minimum days were recorded for G155 (106.0 days), followed by G130 (108.0 days). The mean values across the two environments for heading ranged from 105.5–115.8 days (Table 4). Genetic variance for days to heading was recorded higher (10.98) than the environmental variance (1.51) under irrigated condition. Similarly, the genetic variance under rainfed condition was higher (11.30) than the environmental variance (1.56) (Table 5). For days to heading high heritability was recorded both under irrigated (0.88) and rainfed (0.88) condition. Genetic

Table 4 Means for various traits of 20 wheat lines under irrigated and rainfed conditions

Traits	Environments	Ranges	Means	Best Genotypes
Days to heading	Irrigated	104–116	109	G197, G145, G155
	Rainfed	106–117	112	G155, G130, G144
Flag leaf area (cm ²)	Irrigated	13.9–22.7	18.6	PS-15, G159, G125
	Rainfed	10–18.9	14.8	G131, G130, PS-15
Days to maturity	Irrigated	141–150	145	G145, G131, G125
	Rainfed	142–147	144	G163, G160, G155
Plant height (cm)	Irrigated	82–87	86	PS-15, G131, G134
	Rainfed	73–85	81	PS-15, G160, G206
Spikes (m ⁻²)	Irrigated	220–385	323	G202, G131, G149
	Rainfed	188–303	259	G131, G116, G206
Spike length (cm)	Irrigated	10–12.5	10.7	G106, G155, G160
	Rainfed	9.3–11.2	10.2	G159, PS-15, G163
Spikelets spike ⁻¹	Irrigated	16–24	18	G202, G149, G148
	Rainfed	16–21	17	G131, G148, PS-15
Grains spike ⁻¹	Irrigated	47–68	54	G202, G149, G148
	Rainfed	45–59	51	G131, G148, G116
Grains weight spike ⁻¹ (g)	Irrigated	2–3.2	2.5	G202, G131, PS-15
	Rainfed	1.7–2.5	2.1	G131, G116, G159
1000-grain weight (g)	Irrigated	45–55.1	49	G149, G160, G125
	Rainfed	43.1–51.1	46.4	G148, G155, G131
Biological yield (kg ha ⁻¹)	Irrigated	4388.3–8101.1	6521.4	G148, G149, G163
	Rainfed	3038.2–4706.7	3752.2	G148, G155, G131
Grain yield (kg ha ⁻¹)	Irrigated	1816.5–2942.5	2349.4	G202, G149, G131
	Rainfed	1172.3–2250	1694.5	G131, G116, PS-15
Harvest index (%)	Irrigated	24.8–54.9	36.9	G106, G125, G131
	Rainfed	36.8–57.3	45.1	G131, PS-15, G116

Table 5 Genetic advance, heritability and variance components for various traits of 20 wheat lines evaluated under irrigated and rainfed conditions

Traits	Envir	V _g	V _e	h ²	GA
Flag leaf area (cm ²)	Irrigated	5.04	0.90	0.85	2.90
	Rainfed	3.15	1.15	0.73	2.13
Days to heading	Irrigated	10.98	1.51	0.88	4.35
	Rainfed	11.30	1.56	0.88	4.41
Plant height (cm)	Irrigated	1.43	4.58	0.24	0.82
	Rainfed	11.57	6.55	0.64	3.80
Days to maturity	Irrigated	3.78	1.15	0.77	2.38
	Rainfed	1.85	0.68	0.73	1.63
Spike length (cm)	Irrigated	0.21	0.64	0.25	0.32
	Rainfed	0.23	0.43	0.35	0.40
Spikelets spike ⁻¹	Irrigated	2.59	0.96	0.73	1.92
	Rainfed	1.64	0.66	0.71	1.51
Spikes (m ⁻²)	Irrigated	1260.83	112.77	0.92	47.63
	Rainfed	1085.97	40.41	0.96	45.30
Grains spike ⁻¹	Irrigated	25.97	8.46	0.75	6.20
	Rainfed	12.66	6.56	0.66	4.04
Grain weight spike ⁻¹ (g)	Irrigated	0.02	0.14	0.13	0.07
	Rainfed	0.02	0.10	0.20	0.10
1000-grain weight (g)	Irrigated	5.28	1.71	0.76	2.80
	Rainfed	5.10	2.32	0.69	2.62
Biological yield (kg ha ⁻¹)	Irrigated	845576.99	291339.77	0.74	1110.24
	Rainfed	108214.79	59048.57	0.65	370.44
Grain yield (kg ha ⁻¹)	Irrigated	56813.28	142146.71	0.29	178.32
	Rainfed	84253.57	10265.14	0.89	383.67
Harvest index (%)	Irrigated	32.13	49.86	0.39	4.97
	Rainfed	27.98	16.24	0.63	5.89

Table 6 Genotypic (above diagonal) and phenotypic correlation (below diagonal) under irrigated condition among various traits in wheat

Traits	FLA	DTH	PH	DTM	SL	SM	SPS	GPS	GWPS	TGW	GY	BY	HI
FLA	–	0.19	–0.54*	0.10	0.41	–0.02	–0.05	–0.13	0.60**	0.16	0.09	–0.25	0.21
DTH	0.18	–	–0.42	0.42	–0.07	0.58**	0.46*	0.43	0.73**	0.24	0.61**	0.39	0.01
PH	–0.35	–0.28	–	0.09	0.08	–0.54*	–0.30	–0.29	–0.99**	–0.14	–0.99**	–0.14	–0.31
DTM	0.07	0.44*	0.00	–	0.18	0.00	0.16	0.22	0.06	0.03	0.13	0.35	–0.16
SL	0.35	–0.07	0.02	–0.05	–	–0.36	–0.40	–0.38	–0.99**	–0.48*	–0.19	–0.54*	0.49*
SM	0.00	0.58*	–0.32	0.04	–0.04	–	0.68**	0.67**	0.99**	0.42	0.42	0.64**	–0.39
SPS	–0.03	0.41	–0.19	0.18	–0.21	0.62**	–	0.99**	0.99**	0.71**	0.80**	0.60**	–0.00
GPS	–0.11	0.39	–0.12	0.22	–0.21	0.61**	0.97**	–	0.99**	0.73**	0.83**	0.70**	–0.09
GWPS	0.36	0.39	–0.32	0.09	–0.06	0.61**	0.72**	0.63**	–	0.99**	0.99**	0.80**	–0.12
TGW	0.18	0.21	–0.04	0.10	–0.17	0.30	0.66**	0.64**	0.65**	–	0.81**	0.36	0.09
GY	0.08	0.42	–0.39	0.09	–0.06	0.30	0.60**	0.59**	0.62**	0.59**	–	0.39	0.30
BY	–0.27	0.36	–0.04	0.47*	–0.01	0.50*	0.57**	0.57**	0.24	0.18	0.28	–	–0.72**
HI	0.21	0.06	–0.27	–0.24	–0.16	–0.16	0.10	0.08	0.30	0.36	0.63**	–0.50*	–

advances were 4.35 in irrigated and 4.41 under rainfed conditions. In accordance to our results, high heritability for the mentioned parameter was also justified by Dave et al. (2021) in wheat lines. Correlation data exhibited significant positive associations of days to heading with days to maturity ($r_p=0.44^*$) and spikes m⁻² ($r_p=0.58^{**}$) under

irrigated condition (Table 6). Similarly, days to 50% heading revealed significant positive genotypic correlations with grain yield ($r_g=0.61^{**}$), spike m⁻² ($r_g=0.58^{**}$), spikelets per spike ($r_g=0.46^*$) and grain weight spike⁻¹ ($r_g=0.73^{**}$) under irrigated conditions (Table 6). Heidari et al. (2020) also justified highly significant correlation of days to 50%

Table 7 Genotypic (above diagonal) and phenotypic correlation (below diagonal) under rainfed condition among various traits in wheat

Traits	FLA	DTH	PH	DTM	SL	SM	SPS	GPS	GWPS	TGW	GY	BY	HI
FLA	–	–0.01	–0.05	–0.14	0.25	0.02	0.46*	0.35	0.07	–0.03	0.14	–0.01	0.31
DTH	–0.01	–	–0.28	0.28	0.01	0.38	0.16	0.13	0.11	–0.05	0.25	0.39	0.31
PH	–0.04	–0.25	–	–0.27	–0.32	–0.20	0.02	0.31	0.45*	0.24	0.08	0.27	–0.12
DTM	–0.12	0.28	–0.25	–	0.36	0.20	0.34	0.42*	0.53**	0.33	0.18	0.03	0.47*
SL	0.21	–0.02	–0.28	0.23	–	0.38	0.08	–0.17	–0.07	–0.43*	0.36	–0.25	0.26
SM	0.03	0.36	–0.19	0.20	0.29	–	0.43*	0.28	0.50*	–0.17	0.71**	0.48*	0.63**
SPS	0.40	0.16	0.00	0.28	0.16	0.42	–	0.98**	0.99**	0.41	0.64**	0.41	0.97**
GPS	0.32	0.12	0.22	0.33	–0.17	0.26	0.84**	–	0.99**	0.55**	0.40	0.44*	0.64**
GWPS	0.08	0.06	0.62	0.35	0.01	0.31	0.59**	0.71**	–	0.60**	0.48*	0.45*	0.36
TGW	–0.07	–0.02	0.27	0.27	–0.39	–0.17	0.26	0.42	0.33	–	0.20	0.47*	0.15
GY	0.16	0.22	0.04	0.16	0.29	0.69**	0.59**	0.38	0.34	0.15	–	0.74**	0.83**
BY	0.04	0.35	0.21	0.05	–0.23	0.44*	0.33	0.38	0.33	0.36	0.66**	–	0.38
HI	0.25	0.23	–0.12	0.29	0.33	0.52**	0.71**	0.49*	0.16	0.06	0.72**	0.22	–

FLA Flag leaf area, DTH Days to heading, PH Plant height, DTM Days to maturity, SL Spike length, SM Spikes (m^{-2}), SPS Spikelets spike $^{-1}$, GPS Grains spike $^{-1}$, GWPS Grain weight spike $^{-1}$, TGW 1000-grain weight, GY Grain yield, BY Biological yield, HI Harvest index

heading with days to maturity under irrigated condition in different wheat lines.

Flag Leaf Area (cm^2)

Combined analysis across the environments revealed highly significant variations among the genotypes, environments and $G \times E$ interaction for flag leaf area (Table 3). Ullah et al. (2021) and Sohail et al. (2018) also justified same results for flag leaf among wheat lines. Across the two environments coefficient of variation was (6.23%) for flag leaf area (Table 3). Mean values of the genotypes for flag leaf area under irrigated condition and 10–18.9 cm^2 was observed for rainfed condition (Table 4). Under irrigated condition maximum leaf area was justified for genotype PS-15 (22.7 cm^2), followed by G159 (22 cm^2), while minimum values recorded for G116 (13.9 cm^2), followed by G206 (15.9 cm^2). In contrast, under rainfed condition maximum mean value of flag leaf area was observed for G131 (18.9 cm^2), followed by G130 (18.7 cm^2), while minimum leaf area was noted for G116 (10.0 cm^2), followed by G206 (13.1 cm^2). Leaf area across the environments ranged from 12.0–19.6 cm^2 . Maximum mean value across environments were recorded for genotype G131 (19.6 cm^2), while minimum mean value was recorded for genotype G116 (20.0 cm^2) (Table 4) for flag leaf area. Genetic variance for flag leaf area was higher (5.04) than the environmental variance (0.90) under irrigated condition. Similarly, the genetic variance under rainfed condition was higher (3.15) than the environmental variance (1.15) (Table 5). The analysis revealed high heritability for flag leaf area both under irrigated (0.85) and rainfed (0.73) condition (Table 5). The genetic advances for flag leaf area under irrigated were 2.90 and under rainfed were 2.13, respectively. Khan and Hassan (2017) also found high heritability (0.89) for flag leaf area

in different wheat lines. Flag leaf area show significant positive genotypic associations with grain weight spike $^{-1}$ ($r_g=0.60^{**}$) but negatively correlated with plant height ($r_g=-0.54^*$) under irrigated condition (Table 6). However, under rainfed condition leaf area showed significant and positive association with spikelets spike $^{-1}$ ($r_g=0.46^*$) (Table 7). Chowdhry et al. (2000) and Saleem et al. (2006) also reported significant positive genotypic correlation of the mentioned parameter with the spikelets spike $^{-1}$ and other yield related traits.

Days to Physiological Maturity

Analysis showed highly significant diversity among the candidate wheat lines and $G \times E$ interaction (Table 3) for days to maturity. Baloch et al. (2013) also recorded significant variation among different wheat lines for days to physiological maturity. Coefficient of variation days to maturity across the two environments was 0.66% (Table 3). Mean for days taken to maturity among the genotypes ranged from 141–150 days under irrigated and 142–147 days in rainfed condition (Table 4). Maximum number of days were recorded for genotype G148 (150 days), followed by check cultivar PS-15 (148.0 days), while minimum days were recorded for genotype G145 (141 days) under irrigated conditions. In contrast, under rainfed condition maximum mean value of days to maturity was observed for genotype G206 (147 days), while minimum days were recorded for G163 (142 days), followed by G160 (142.3 days). Across the two environments the mean values ranged from 143–148 days among the genotypes. Maximum mean value across two environments (irrigated and rainfed) was recorded for genotype G148 (148 days), while minimum was recorded for genotype G163 (143 days) (Table 4). Higher genetic variance was observed for days to maturity than environmental

variance across the two environments (Table 5). The genetic and environmental differences in irrigated condition were 3.78 and 1.15, and under rainfed conditions were 1.85 and 0.68, respectively. High heritability was observed for both irrigated (0.77) and rainfed (0.73) conditions (Table 5). The genetic advances for days to maturity were 2.38 and 1.63, respectively, under irrigated and rainfed conditions. Kumar et al. (2018) and Rajput (2018) also estimated high heritability for maturity among different lines in wheat. Days to maturity revealed significant and positive phenotypic associations with biological yield ($r_p=0.47^*$) under irrigated condition (Table 6). Under rainfed conditions, it justified positive significant genotypic associations with grain spike⁻¹ ($r_g=0.42^*$), grain weight spike⁻¹ ($r_g=0.53^{**}$) and with harvest index ($r_g=0.47^*$) (Table 7). In contrast to our results, Ali et al. (2007) justified positive genotypic associations of grain yield with days taken to physiological maturity.

Plant Height (cm)

The ANOVA revealed highly significant variations across environments, among the genotypes and G×E relations for plant height (Table 3). Our results get support from those of Tomar et al. (2019) who also found significant diversity among wheat lines for plant height. Degewione et al. (2013) also justified significant diversity in wheat genotypes across different environment. Coefficient of variation across the two environments was 3.15% for plant height (Table 3). Mean of the wheat genotypes for plant height ranged from 81.5–88.6 cm under irrigated and under rainfed conditions it ranged from 73.4–85.3 cm (Table 4). Maximum height was recorded for genotype G148 (88.6 cm), while minimum was recorded for genotype PS-15 (81.5 cm), followed by G131 (83.9 cm) in irrigated condition. In contrast, under rainfed condition maximum mean value of plant height was observed for genotype G163 (85.3 cm), while minimum was recorded for PS-15 (73.4 cm), followed by G160 (75.2 cm). Plant height across environments in wheat lines ranged from 77.5–85.9 cm. Maximum mean values across two environments was recorded for genotype G163 and G197 (85.9 cm), while minimum was recorded for genotype PS-15 (77.5 cm) (Table 4). Genetic variance (1.43) for plant height was found to be lower than the environmental variance (4.58) under irrigated condition. In contrast, the genetic variance for plant height in rainfed condition was higher (11.57) than the environmental variance (6.55) (Table 5). For plant height low heritability (0.24) was recorded under irrigated conditions, while high heritability (0.64) was observed for rainfed condition. For plant height high heritability was also reported by Gerema (2020). Resultant genetic advance under irrigated and rainfed environment was 0.82 and 3.80, respectively for plant height. Plant height revealed highly significant but negative geno-

typic correlations with grain weight per spike ($r_g=-0.99^{**}$) and grain yield ($r_g=-0.99^{**}$) and significant negative correlations with flag leaf area and spikes m⁻² ($r_g=-0.54^*$) under irrigated condition (Table 6). Plant height under rainfed condition justified significant genotypic correlation with grain weight spike⁻¹ ($r_g=0.45^*$) (Table 7). Zeeshan et al. (2014) also recorded significant negative correlation of plant height with grain yield.

Spike Length (cm)

Spike length exhibited highly significant diversity among the genotypes and the two environments. The data showed non-significant differences for G×E interaction for spike length (Table 3). Similar to our finding Sabit et al. (2017) and Hussain et al. (2012) also found significant variations among wheat lines for spike length. Coefficient of variation across the two environments was 6.15% for spike length (Table 3). Means values of the genotypes for spike length were ranged from 9.9–12.5 cm under irrigated and 9.3–11.2 cm in rainfed condition (Table 4). Maximum length of spike was noted for G106 (12.5 cm) and G155 (11.6 cm), whereas minimum was observed for G116 (9.9 cm) in irrigated condition. In contrast, under rainfed condition maximum mean value of spike length was observed for genotype G159 (11.2 cm) followed by check cultivar PS-15 (11.1 cm), while minimum was recorded for G116 (9.3 cm). Across the environments mean values among the genotypes for spike length were ranged from 9.6–11.5 cm. Maximum mean value across the two environments (irrigated and rainfed) was noted for G106 (11.5 cm), and minimum value was justified for G116 (9.6 cm) (Table 4). The genetic variance recorded was less than the environmental variance under both the irrigated and rainfed environments for spike length (Table 5). The genetic and environmental variance in irrigated condition for spike length was 0.21 and 0.64, while under rainfed condition 0.23 and 0.43, respectively. Low heritability (0.25) was recorded in irrigated and moderate heritability (0.35) was observed for spike length under rainfed condition. The genetic advance for spike length was 0.32 in irrigated condition and it was 0.40 under rainfed conditions. In accordance to our results (Mohsin et al. 2009; Sohail et al. 2018) also noted moderate heritability for the mentioned traits in wheat lines. Highly significant but negative genotypic correlations of spike length was observed with grain weight spike⁻¹ ($r_g=-0.99^{**}$) and significant negative associations with 1000-grain weight ($r_g=-0.48^*$) and biomass yield ($r_g=-0.54^*$), while it had positive correlation with harvest index ($r_g=0.49^*$) under irrigated condition (Table 6). However, under rainfed condition spike length was negatively correlated with 1000-grain weight ($r_g=-0.43$) (Table 7).

Patel et al. (2021) also recorded negative genotypic correlation of spike length with thousand grain weights.

Spikelets Spike⁻¹

Mean square values revealed highly significant diversity among genotypes, across environments and G×E interaction for spikelets spike⁻¹ (Table 3). Tomar et al. (2019) also justified significant variation for spikelets per spike among wheat lines. Significant variation among the wheat line was also reported by Khan et al. (2020). Coefficient of variation across the two environments was 2.41% for spikelets per spike (Table 3). The means of genotypes for spikelets spike⁻¹ ranged from 16.7–24.0 under irrigated condition, while under rainfed conditions the mean values ranged from 16.0–21.7 (Table 4). Maximum spikelets spike⁻¹ were recorded for G202 (24.0), while minimum were recorded for genotype G197 (16.7) in irrigated condition. In contrast, under rainfed the genotype G131 (21.7) showed maximum mean value for spikelets spike⁻¹, whereas minimum was recorded for G197 (16.0). Mean values across the environments among the genotypes for spikelets spike⁻¹ ranged from 16.3–20.8. Maximum mean value across two environments was observed for G202 (20.8) while, minimum was recorded for genotype G197 (16.3) (Table 4). Genetic variance was recorded higher than the environmental variance in both irrigated and rainfed environments (Table 5). For spikelets spike⁻¹ heritability recorded was high under irrigated (0.73) as well as under rainfed condition. The genetic advance computed for spikelets spike⁻¹ was 1.92 in irrigated and 1.51 under rainfed condition (Table 5). Similar to our results across environments high heritability for spikelets spike⁻¹ was also reported by Mwadzingeni et al. (2017). Spikelets spike⁻¹ under irrigated conditions justified strong positive phenotypic associations with grain spike⁻¹ ($r_p=0.97^{**}$), grain weight per spike ($r_p=0.72^{**}$), thousand grain weight ($r_p=0.66^{**}$), grain yield ($r_p=0.60^{**}$) and biological yield ($r_p=0.57^{**}$) (Table 6). Similarly, under rainfed condition it exhibited highly significant strong positive phenotypic associations with grain per spike ($r_p=0.84^{**}$), grains weight spike⁻¹ ($r_p=0.59^{**}$), grain yield ($r_p=0.59^{**}$) and harvest index ($r_p=0.71^{**}$) (Table 7). Spikelets spike⁻¹ also indicated highly significant genotypic correlations with grain per spike ($r_g=0.99^{**}$), grains weight spike⁻¹ ($r_g=0.99^{**}$), thousand grain weight ($r_g=0.71^{**}$), grain yield ($r_g=0.80^{**}$) and biological yield ($r_g=0.60^{**}$) under irrigated conditions (Table 6). In contrast under rainfed condition the mentioned parameter showed highly significant positive genotypic associations with grain per spike ($r_g=0.98^{**}$), grains weight spike⁻¹ ($r_g=0.99^{**}$), grain yield ($r_g=0.64^{**}$) and harvest index ($r_g=0.97^{**}$) (Table 7). Similar to our finding (Ghafoor et al. 2013; Baloch et al. 2013)

also observed significant association of spikelets spike⁻¹ with grain yield.

Spikes (m⁻²)

Spikes (m⁻²) analysis revealed highly significant variations between the two environments, genotypes and for G×E interaction (Table 3). Tahmasebi et al. (2013), Ali and Shakor (2012) also found similar results among wheat genotypes for spikes (m⁻²). Coefficient of variation across the two environments was 3.05% for spikes (m⁻²) (Table 3). The mean values for spikes (m⁻²) under irrigated condition ranged from 220.0–385.0, while under rainfed condition it ranged from 188.7–303.3 among the genotypes (Table 4). Maximum spikes (m⁻²) under irrigated condition were recorded for genotype G202 (385.0), followed by G131 (376.7), while minimum were recorded for genotype G197 (220.0). In contrast, under rainfed condition maximum mean value of spikes (m⁻²) was observed for genotype G131 (303.3), while minimum was recorded for G155 (188.7). Across the two environments the mean values among the genotypes ranged from 223.8–340.0 for spikes (m⁻²). Maximum mean values for spikes (m⁻²) across two environments was observed for genotype G131 (340.0), while minimum was recorded for genotype G197 (223.8) (Table 4). Genetic variance for spikes (m⁻²) was recorded to be higher than the environmental variance in both irrigated and rainfed conditions (Table 5). The genetic and environmental variance in irrigated condition for spikes (m⁻²) was 1260.8 and 112.7, while, under rainfed conditions were 1085 and 40.4, respectively. For spikes (m⁻²) high heritability were computed under irrigated (0.92) and rainfed (0.96) conditions. The genetic advance for spikes (m⁻²) was 47.6 under irrigated condition and 45.30 in rainfed condition (Table 5). Alemu and Molla (2015) also reported moderate broad sense heritability for spikes (m⁻²) among the local wheat cultivar in Ethiopia. Correlation analysis showed highly significant positive phenotypic associations of spikes (m⁻²) with spikelets per spike ($r_p=0.62^{**}$), grains spike⁻¹ ($r_p=0.61^{**}$), grain weight spike⁻¹ ($r_p=0.61^{**}$) and significant phenotypic correlation with biological yield ($r_p=0.50^*$) under irrigated condition (Table 6), while under rainfed condition spikes m⁻² revealed significant positive phenotypic correlations with grain yield ($r_p=0.69^{**}$), biomass yield ($r_p=0.44^*$) and harvest index ($r_p=0.52^{**}$) (Table 7). The mentioned parameter showed significant positive genotypic correlations with spikelets per spike ($r_g=0.68^{**}$), grains spike⁻¹ ($r_g=0.67^{**}$), grain weight spike⁻¹ ($r_g=0.99^{**}$) and biological yield ($r_g=0.64^*$) in irrigated condition (Table 6), while under rainfed condition it showed significant positive genotypic correlations with spikelets per spike ($r_g=0.43^*$), grain weight spike⁻¹ ($r_g=0.50^*$), grain yield ($r_g=0.71^{**}$), biological yield ($r_g=0.48^*$) and with harvest index ($r_g=0.63^*$)

(Table 7). Thus, increase in number of spike (m^{-2}) results in high economic yield. Aydin and Mut Ozecan (2010) also reported similar results of spikes (m^{-2}) with the mentioned traits. Chowdhry et al. (2000) and Singh et al. (2018) also revealed phenotypic correlations of spikes (m^{-2}) with spikelets spike^{-1} and grain spike^{-1} . Similar to our finding Kashif and Khaliq (2004) also justified significant relations of grain yield with spikes (m^{-2}).

Grains Spike⁻¹

The combined analysis revealed significant variations across the two environments and genotype by environment ($G \times E$) interaction for grains spike⁻¹ (Table 3). Also, significant diversity was detected among the genotypes across the environments (irrigated and rainfed). Mollasadeghi et al. (2011) also recorded significant variation for $G \times E$ interaction. Coefficient of variation across the two environments was 5.2% for grains spike⁻¹ (Table 3). Mean values among the wheat lines for grain spike⁻¹ ranged from 47–68 under irrigated and from 45.3–59.7 under rainfed condition (Table 4). Maximum grains per spike was recorded for G202 (68) while, minimum were recorded for genotype G197 (47), followed by G160 (48.3) in irrigated condition. In contrast, under rainfed condition maximum mean values of grains spike⁻¹ was computed for G131 (59.7), while minimum was recorded for genotypes G163 (45.3). Across the two environments the mean value for the mentioned trait among the genotypes ranged from 46.3–60.9. Maximum mean value across two environments was recorded for G149 (60.9), while minimum was recorded for genotype G197 (46.3) (Table 7). For grains per spike the genetic variance across both the environments (irrigated and rainfed) were observed to be higher than the environmental variance (Table 5). Genetic and environmental variances under irrigated were 25.97 and 8.46, while in rainfed were 12.66 and 6.56, respectively. Analysis revealed high heritability in irrigated (0.75) and rainfed (0.66) condition (Table 5). Resultant genetic advance for grains spike⁻¹ recorded was 6.20 in irrigated and 4.04 under rainfed condition (Table 5). Similar to our finding Dave et al. (2021) and Rathwa et al. (2018) also recorded similar result of heritability for grains per spike among wheat lines. Grain spike⁻¹ revealed highly significant strong positive phenotypic correlations with grain weight per spike ($r_p=0.63^{**}$), 1000-grain weight ($r_p=0.64^{**}$), grain yield ($r_p=0.59^{**}$) and biological yield ($r_p=0.57^{**}$) under irrigated condition (Table 6). In contrast grain per spike under rainfed condition showed significant phenotypic associations with grain weight per spike ($r_p=0.71^{**}$) and harvest index ($r_p=0.49^*$) (Table 7). Likewise, grain spike⁻¹ justified highly significant genotypic correlations with grain weight spike⁻¹ ($r_g=0.99^{**}$), 1000-grain weight ($r_g=0.73^{**}$), grain yield ($r_g=0.83^{**}$) and bi-

ological yield ($r_g=0.70^{**}$) in irrigated condition (Table 6), while under rainfed condition the mentioned parameter indicated highly significant positive genotypic correlations with grain weigh per spike ($r_g=0.99^{**}$), harvest index ($r_g=0.64^{**}$), 1000-grain weight ($r_g=0.55^{**}$) and significant association with biological yield ($r_p=0.44^*$) (Table 7). Iftikhar et al. (2013) and Ghafoor et al. (2013) also observed strong positive correlations of grain yield with grain spike⁻¹.

Grain Weight Spike⁻¹ (g)

Grain weight spike⁻¹ justified highly significant diversity among the genotypes and across the environments (Table 3). The $G \times E$ interaction was non-significantly different across the environments (Table 3). Khan et al. (2012b) also recorded considerable diversity in wheat lines. For grain weight spike⁻¹ coefficient of variation was 13.6% (Table 3). Mean values among the genotypes ranged from 2.0–3.2 g under irrigated and from 1.7–2.5 g for rainfed condition for grain weight spike⁻¹ (Table 4). Maximum weight was recorded for genotype G202 (3.2 g), followed by G131 (2.8 g), whereas minimum was recorded for genotype G106 (2.0 g) in irrigated condition. In contrast, under rainfed maximum mean value of grain weight spike⁻¹ was noted for G131 (2.5 g), while minimum was recorded for genotype G160 (1.7 g). Across the environments the mean for grain weight spike⁻¹ among genotypes ranged from 2.0–2.7 g. Maximum value across two environments was recorded for G131 (2.7 g), while the minimum was recorded for genotype G106 (2.0 g) (Table 4). For grain weight spike⁻¹ genetic variances across both the environments were observed to be lower than the environmental variances (Table 5). The genetic and environmental variance under the irrigated environment was 0.02 and 0.14, while under rainfed environment were 0.02 and 0.10, respectively. For grain weight spike⁻¹ low heritability was recorded under both irrigated (0.13) and rainfed (0.20) conditions. Resultant genetic gain for grain weight spike⁻¹ was 0.07 in irrigated and 0.10 under rainfed condition (Table 5). Highly significant phenotypic associations of grain weight spike⁻¹ were observed with 1000-grain weight ($r_p=0.65^{**}$) and with grain yield ($r_p=0.62^{**}$) under irrigated condition (Table 6). The mentioned parameter under irrigated condition also revealed highly significant positive genotypic correlations with thousand grain weight ($r_g=0.99^{**}$), grain yield ($r_g=0.99^{**}$) and with biological yield ($r_g=0.80^{**}$) (Table 6), while under rainfed grain weight per spike showed significant positive genotypic correlations with 1000-grain weight ($r_g=0.60^{**}$), grain yield ($r_g=0.48^*$) and biological yield ($r_g=0.45^*$) (Table 7). Similar to our finding, Khan et al. (2012) also testified

significant genotypic as well as phenotypic associations of grain weight spike⁻¹ with grain yield.

1000-Grain Weight (g)

The mean square analysis for 1000-grain weight justified highly significant variations across the environments, among genotypes and for G×E interaction (Table 3). Similar to our results among the genotypes was also recorded by Bhutto et al. (2016) for 1000-grain weight. Across the environments the observed coefficient of variation for thousand grain weight was 2.2% (Table 3). Mean values under irrigated condition for thousand grain weight ranged from 45.0–55.1 g and 43.1–51.1 g under rainfed condition (Table 4). 1000-grains weight was maximum for genotype G149 (55.1 g) followed by G202 (53.5 g), while it was minimum for G163 (45.0 g) in irrigated condition. In contrast, maximum 1000-grain weight under rainfed condition was recorded for genotype G148 (51.1 g), while minimum for genotype G130 (43.1 g). Mean values across the two environments for thousand grain weight ranged from 44.1–50.9 g (Table 4). Maximum value across the environments was justified for G202 (50.9 g), while minimum was recorded for genotype G163 (44.1 g) (Table 4). Genetic variances across both conditions were found higher than the environmental variances for 1000-grain weight. The genetic and environmental variances were 5.28 and 1.71 under irrigated and 5.10 and 2.32 under rainfed conditions, respectively (Table 5). High heritability for thousand grain weight was recorded under both, irrigated (0.76) and rainfed (0.69) conditions. The genetic advances for 1000-grain weight were 2.80 and 2.62 under irrigated and rainfed conditions, respectively. Gerema (2020) also found high heritability for 1000-grain weight. Similarly, Khan and Hassan (2017) also found high heritability (0.79) for thousand kernel weights. Similarly, high heritability was also noted by Khan et al. (2012a) and Farshadfar et al. (2013). Thousand grain weight revealed highly significant strong positive phenotypic correlation with grain yield ($r_p=0.59^{**}$) (Table 6). Similarly, the mentioned trait indicated positive genotypic association with grain yield ($r_g=0.81^{**}$) under irrigated condition (Table 6), while it also revealed positive genotypic association with biological yield ($r_g=0.47^*$) under rainfed condition (Table 7). Similar to our results, Waqas et al. (2014) and Mohibullah et al. (2011) also testified significant positive association of grain yield with thousand grain weight.

Biological Yield (kg ha⁻¹)

Biological yield revealed significant diversity among genotypes. The data also exhibited highly significant variation across environments and G×E interaction (Table 3).

Similar result across the two environments was also justified by Saleem et al. (2017). Coefficient of variation across the two environments was 8.1% for biological yield (Table 3). The mean for biological yield ranged from 4388.3–8101.1 kg ha⁻¹ in irrigated condition, while under rainfed condition it ranged from 3028.2–4706.7 kg ha⁻¹ (Table 4). Under irrigated conditions maximum biological yield was noted for genotype G148 (8101.1 kg ha⁻¹) which is statistically followed by G149 (7988.3 kg ha⁻¹), while minimum for genotype G106 (4388.3 kg ha⁻¹). Under rainfed condition biological yield was recorded maximum for genotype G148 (4706.7 kg ha⁻¹) and minimum for genotype G159 (3038.2 kg ha⁻¹). The mean value across the two environments ranged from 3987.1–6403.9 kg ha⁻¹. Across the two environments maximum mean values was observed for genotype G148 (6403.9 kg ha⁻¹), while minimum was recorded for genotype G106 (3987.1 kg ha⁻¹) (Table 4). Analysis revealed that genetic variances both under irrigated and rainfed conditions were higher than the environmental variance for biological yield (Table 5). The observed genetic and environmental variance components were 845576.99 and 291339.77 under irrigated environment, while in rainfed conditions they were 108214.79 and 59048.57, respectively (Table 5). The analysis revealed high heritability for biological yield under both irrigated (0.74) and rainfed (0.65) conditions. Similar to our results, Kumar and Kumar (2021) also estimated high heritability among the wheat genotypes for biological yield. For biological yield the genetic advance in irrigated condition was 1110.24, while under rainfed condition it was 370.44 (Table 5). Biological yield revealed significant negative phenotypic associations with harvest index ($r_p=-0.50^{**}$) under irrigated condition (Table 6). The mentioned parameter also indicated highly significant but negative genotypic association with harvest index ($r_g=-0.72^{**}$) under irrigated condition (Table 6). Biological yield showed highly significant and positive genotypic correlations with spikelets per spike ($r_g=0.60^{**}$), grains per spike ($r_g=0.70^{**}$), spikes m⁻² ($r_g=0.64^{**}$) and grain weight per spike ($r_g=0.80^{**}$) under irrigated and rainfed conditions (Tables 6 and 7). Similar association of biological yield with spikes m⁻² was also justified by Abd-Allah et al. (2018).

Grain Yield (kg ha⁻¹)

Grain yield analysis exhibited highly significant diversity among genotypes, the environment and G×E interaction (Table 3). Heidari et al. (2020) also reported sufficient diversity among the genotypes across different environments in wheat. Coefficient of variation for the two environments was 13.6% for grain yield (Table 3). Mean values of grain yield were ranged from 1816.5–2942.5 kg ha⁻¹ in irrigated conditions and from 1172.3–2250.0 kg ha⁻¹

under rainfed condition (Table 4). The genotype G202 (2942.5 kg ha⁻¹) showed maximum yield, while minimum yield was recorded for genotype G159 (1816.5 kg ha⁻¹) under irrigated condition. In contrast, under rainfed condition biological yield was maximum for genotype G131 (2250.0 kg ha⁻¹) and was minimum for genotype G159 (1172.3 kg ha⁻¹). The mean value across the two environments ranged from 1494.4–2516.7 kg ha⁻¹. Maximum mean value across the two environments was noted for genotype G131 (2516.7 kg ha⁻¹), while minimum was recorded for genotype G159 (1494.4 kg ha⁻¹) (Table 4). The environmental variance for grain yield was recorded higher than the genetic variance under irrigated conditions, while it was higher under rainfed condition (Table 5). The genetic and environmental variances were respectively 56813.28 and 142146.71 under irrigated conditions while, under rainfed conditions genetic and environmental variances were 84253.57 and 10265.14, respectively (Table 5). Low heritability (0.29) was observed in irrigated, while high heritability (0.89) was recorded under rainfed condition. Similar to our finding, Zhang et al. (2019) also testified high heritability for grain yield. The genetic advances for grain yield recorded were 178.32 and 383.67 in irrigated and rainfed conditions, respectively (Table 5). Correlation analysis under irrigated condition revealed highly significant phenotypic association of grain yield with harvest index ($r_p=0.63^{**}$) (Table 6), while under rainfed condition the mentioned parameter revealed highly significant phenotypic correlations with biological yield ($r_p=0.66^{**}$) and with harvest index ($r_p=0.72^{**}$) (Table 7). Similarly grain yield revealed highly significant genotypic correlations with biological yield ($r_g=0.74^{**}$) and harvest index ($r_g=0.83^{**}$) under rainfed environment (Table 7). Sial et al. (2013) also recorded significant associations of grain yield with biomass yield. Khan et al. (2011) also revealed significant associations of grain yield with harvest index both at phenotypic and genetic level.

Harvest Index (%)

The pooled ANOVA for harvest index indicated highly significant variations among genotypes, across the environments (irrigated and rainfed) and G×E interaction (Table 3). Ikramullah et al. (2011) and Afridi and Khalil (2007) and also observed significant G×E interaction in wheat lines for the mentioned traits. Mohsin et al. (2009) also recorded sufficient variability for harvest index among genotypes in wheat. Coefficient of variation across the environments for harvest index observed was 14% (Table 3). Mean values for harvest index among genotypes under irrigated condition ranged from 24.8–54.9% and under rainfed condition the range was from 36.8–57.3% (Table 4). Under irrigated conditions, harvest index was maximum for

genotype G106 (54.9%), followed by G125 (44.9%), while it was minimum for genotype G163 (24.8%). Under rainfed condition harvest index was maximum for genotype G131 (57.3%) and minimum for genotype G149 (36.8%). The mean values across the two environments ranged from 34.9–51.3%. Maximum mean value across the two environmental conditions was noted for genotype G106 (51.3%), while minimum was recorded for genotype G159 (34.9%) (Table 4). Genetic variance under irrigated condition was recorded lower than the corresponding environmental variance, while it was found higher under rainfed condition for harvest index (Table 5). Genetic and environmental variances under irrigated condition were 32.13 and 49.86, similarly under rainfed conditions they were 27.98 and 16.24, respectively (Table 5). Moderate heritability (0.39) was observed in irrigated and high heritability (0.63) was recorded under rainfed condition for harvest index. The observed genetic advances for harvest index under irrigated were 4.97 and 5.89 under rainfed conditions (Table 5). Similar to our results, Mohsin et al. (2009) also noted high heritability among the wheat lines for harvest index.

Conclusions and Recommendations

Highly significant diversity among the genotypes was observed for all the traits revealed the presence of sufficient variability among the genotypes for improvement. Highly significant genotype by environment interaction (G×E) for most of the traits revealed differential performance of the genotypes under the two environments. The promising genotypes under irrigated condition observed were G202, PS-15 and G106, while under rainfed condition the promising genotypes were G131, G148 and G116. Thus, for yield improvement these genotypes could be utilized in the future breeding research. High heritability and expected genetic advance were noted for grain yield and most of the yield related traits under irrigated and rainfed conditions. Grain yield showed positive correlations with days to heading, spikelets spike⁻¹, grains spike⁻¹, grains weight spike⁻¹ and thousand grain weight under irrigated while, with spikes (m⁻²), spikelets spike⁻¹, grain spike⁻¹, biological yield and with harvest index under rainfed conditions. These traits could be used as indirect selection criteria for improving grain yield in wheat.

Conflict of interest A. Ahmad, M. N. Iqbal, M. M. Anjum, B. Khan, S. Khan, S. Ullah, R. Ullah and M. Y. Afridi declare that they have no competing conflict of interests.

References

Abd-Allah HT, Rabie HA, Mansour E, Swelam AA (2018) Genetic variation and interrelationship among agronomic traits in wheat

- genotypes under water deficient and normal irrigation condition. *Zigzag J Agric Res* 45(4):1209–1129
- Abdullah GM, Khan AS, Ali Z (2002) Heterosis study of certain important traits in wheat. *Int J Biol* 4(3):326–328
- Afridi N, Khalil IH (2007) Genetic improvement in yield related traits of wheat under irrigated and rainfed environments. *Sarhad J Agric* 23(4):965–972
- Alemu A, Molla T (2015) Agromorphological studies for variability, heritability and their association of local wheat varieties (*Triticum aestivum* L.) grown in south Gondar zone, Ethiopia. *J Nat Sci* 5(11):15–20
- Ali H, Shakor EF (2012) Heritability, variability, genetic correlation and path analysis for quantitative traits in durum and bread wheat under dry farming condition. *Mesopotamia J Agric* 40(4):27–39
- Ali SM, Shah A, Hussain A, Shah Z, Munir I (2007) Genotypic variation for yield and morphological traits in wheat. *Sarhad J Agric* 23(4):43–46
- Anjum MM, Arif M, Ali N, Khan B, Khan GR (2022) Chinese wheat hybrids 18A-1 and 18A-2 surpass local check (Ghaneemat-2016) under deficit irrigation when sown early in semiarid climatic conditions. *Gesunde Pflanzen* 75:343–359. <https://doi.org/10.1007/s10343-022-00705-3>
- Aucamp U, Labuschagne MT, Denventer CS (2006) Stability analysis of kernel and milling characteristics in winter and facultative wheat. *S Afr J Plant Soil* 23(3):152–156
- Aydin N, Mut Ozecan H (2010) Estimation of broad sense heritability for grain yield and some agronomic and quality traits of bread wheat (*Triticum aestivum* L.). *J Food Agric Environ* 8(2):419–421
- Baloch MJ, Baloch E, Jatoi WA (2013) Correlation and heritability estimate of yield and yield attributing traits in wheat (*Triticum aestivum* L.). *Pak J Agric Eng Vet Sci* 29(2):96–105
- Bhutto AH, Rajpar AA, Kalhoro SA, Ali A, Kalhoro FA, Ahmad M, Kalhoro NA (2016) Correlation and regression analysis for yield traits in wheat (*Triticum aestivum* L.) genotypes. *J Sci* 8(32):96–104
- Chowdhry MA, Ali M, Subhani GM, Khaliq I (2000) Path analysis for water use efficiency, evapo-transpiration efficiency and some yield related traits in wheat. *Pak J Biol Sci* 3:313–317
- CSK (2019) Crop statistics of Khyber Pakhtunkhwa, pp 64–65
- Dave M, Dashora A, Saiprasad SV, Ambati D, Malviya P, Choudhary U, Yadav N, Mishra A (2021) Genetic variability, heritability and genetic advance in durum wheat (*Triticum durum* Desf.) genotypes. *Pharma Inno J* 10(9):221–224
- Degewione A, Dejene T, Sharif M (2013) Genetic variability and traits association in bread wheat (*Triticum aestivum* L.) genotypes. *Int Res J Agric Sci* 1(2):19–29
- Farshadfar E, Rafiee F, Hasheminasab H (2013) Evaluation of genetic parameters of agronomic and morpho-physiological indicators of drought tolerance in bread wheat (*Triticum aestivum* L.) using diallel mating design. *Aust J Crop Sci* 7(2):268–275
- Fatima M, Ahmed Z, Aslam M, Zaynab M (2018) Drought effect and tolerance potential of wheat: a mini-review. *Int J Nanotechnol Allied Sci* 2(2):16–21
- Gerema G (2020) Evaluation of durum wheat (*Triticum turgidum* L.) genotypes for genetic variability, heritability, genetic advance and correlation studies. *J Agric Nat Res* 3(2):150–159
- Ghafoor G, Hassan G, Ahamd I, Khan SN, Suliman S (2013) Correlation analysis for different parameters of F₂ bread wheat population. *Pure Appl Biol* 2(1):28–31
- Gite VD, Bankar DN, Yashavantha KJ, Bavisar VS, Honrao BK, Chavan AM, Surve VD, Raskar SS, Khairnar SS, Bagwan JH, Khade VM (2018) Genetic variability parameters and correlation study in elite genotypes of bread wheat (*Triticum aestivum* L.). *J Pharm Phytoche* 7(4):3118–3123
- Gomez KA, Gomez AA (1984) Statistical procedure for agriculture research. John Wiley and Sons Inc., New York
- Heidari S, Heidari P, Azizinezhad R, Etmianans A, Khosroshahli M (2020) Assessment of genetic variability, heritability and genetic advance for agro-morphological and some in-vitro related traits under stress and non-stress environment in durum wheat. *Bulg J Agric Sci* 26:120–127
- Hussain M, Khan AS, Khaliq I, Maqsood M (2012) Correlation studies of some qualitative and quantitative traits with grain yield in spring wheat across two environments. *Pak J Agric Sci* 49(1):1–4
- Iftikhar R, Hussain SB, Khaliq I, Samiullah (2013) Study of inheritance for grain yield and related traits in bread wheat. *SABRAO J Breed Genet* 45(2):283–290
- Ikramullah, Khalil IH, Rehman H, Mohammad F, Hidayatullah, Khalil SK (2011) Magnitude of heritability and selection response for yield traits in wheat under two different environments. *Pak J Bot* 43(5):2359–2363
- Kashif M, Khaliq I (2004) Heritability, correlation and path coefficient analysis for some metric traits in wheat. *Int J Agric Biol* 6(1):138–142
- Khan SA, Hassan G (2017) Heritability and correlation studies of yield and yield related traits in bread wheat. *Sarhad J Agric* 33(1):103–107
- Khan, Rahman H, Ahmad H, Ali H (2008) Magnitude of heterosis and heritability in sunflower over environment. *Pak J Bot* 39(1):301–308
- Khan A, Mohammad F, Hussain G, Khalil IH (2012a) Genotypic competition among elite wheat breeding lines under irrigated condition. *Sarhad J Agric* 28(1):47–52
- Khan B, Arif M, Munsif F, Anjum MM, Wójcik-Gront E, Khan A, Ahmad I, Ren Y, Zhao C, Liao X, Zhang S (2022) Optimizing sowing window for local and Chinese elite lines under changing climate. *Agronomy* 12(9):2232
- Khan B, Anjum MM, Ali N, Ullah M, Khan GR (2023) Grain quality, biochemical traits, and internal water status of Chinese elite wheat lines by sowing interval in semiarid conditions. *Gesunde Pflanzen* <https://doi.org/10.1007/s10343-022-00806-z>
- Khan FU, Inamullah, Khalil IH, Khan S, Munir I (2012b) Yield stability, genotypic and phenotypic correlation among yield contributing traits in spring wheat under two environments. *Sarhad J Agric* 28(1):27–36
- Khan MAU, Malik T, Sayed JA, Abbas I, Khan A, Malik M, Asghar S (2011) Study of genetic variability and correlation among various traits of F₅ wheat (*Triticum aestivum* L.) populations. *Int Res J Agric Soil Sci* 1(8):344–348
- Khan N, Hassan G, Ahmad N, Iqbal T, Ahad F, Hussain I, Hussain Q (2020) Estimation of heritability and genetic advance in F₂ populations of wheat. *PSM Biol Res* 5(2):61–73
- Kumar M, Kumar S (2021) Estimation of heritability and genetic advance in 24 genotypes of bread wheat (*Triticum aestivum* L.). *J Pharmacogn Phytochem* 10(1):1110–1113
- Kumar A, Kuma A, Rathi V, Tomer KPS (2017) Variability, heritability and genetic advance analysis in bread wheat (*Triticum aestivum* L.) genotypes. *Int J Curr Microbiol Appl Sci* 6(8):2687–2691
- Kumar A, Swati, Kumar A, Adhikari S, Prasad B (2018) Genetic dissection of wheat genotypes using morpho-physiological traits for terminal heat tolerance. *Int J Curr Microbiol Appl Sci* 7(2):367–372
- Mangi SA, Sial MA, Ansari BA, Arain MA (2008) Study of genetic parameters in segregating populations of spring wheat. *Pak J Bot* 39(7):2407–2413
- Maqbool R, Sajjid M, Khaliq I, Rehman A, Khan AS, Khan SH (2010) Morphological diversities and traits association in bread wheat (*Triticum aestivum* L.). *Am Eurasian J Agric Environ Sci* 8(2):216–224
- Mohibullah M, Rabbani MA, Zakiullah SJ, Amin A, Ghazanfarullah (2011) Genetic variability and correlation analysis of bread wheat (*Triticum aestivum* L.) accessions. *Pak J Bot* 43(6):2717–2720

- Mohsin T, Khan N, Naqvi FN (2009) Heritability, phenotypic correlation and path coefficient studies for some agronomic characters in synthetic elite lines of wheat. *J Food Agric Environ* 7(3–4):278–282
- Mollasadeghi V, Gizilasheg YM, Hazejsn RH, Mazhabi H (2011) Evaluation of 14 winter bread wheat genotypes in normal irrigation and stress condition. *Afric J Biotechnol* 10(54):11188–11195
- Muller J (1991) Determining leaf surface area by linear measurements in wheat and triticale. *Arch Fuchtungsforsch* 21(2):121–123
- Mwadingeni L, Shimelis H, Tsilo TJ (2017) Variance components and heritability of yield and yield components of wheat under drought-stressed and non-stressed condition. *Aust J Agric* 32(3):212–217
- Patel JM, Vekariya RD, Patel SK, Patel CR, Malviya AV, Chaudhary SM (2021) Evaluation of bread wheat (*Triticum aestivum*) genotypes using drought susceptible and tolerance efficiency indices under irrigated and drought stress environment. *Res Crop* 22(3):492–500
- PBS (2020) Pakistan economic survey. Pakistan Bureau of Statistics, pp 49–50
- Rajput RS (2018) Correlation, path analysis, heritability and genetic advance for morpho-physiological character on bread wheat (*Triticum aestivum* L.). *J Pharmacogn Phytochem* 7(1):107–112
- Rathwa HK, Pansuriya AG, Patel JB, Jalu RK (2018) Genetic variability, heritability and genetic advance in durum wheat (*Triticum aestivum* L.). *Int J Curr Microbiol Appl Sci* 7(1):1208–1215
- Sabit Z, Yadav DB, Rai PK (2017) Genetic variability, correlation and path analysis for yield and its components in F₅ generation of bread wheat (*Triticum aestivum* L.). *J Pharmacogn Phytochem* 6(4):680–687
- Sajjad M, Khan SH, Khan AS (2011) Exploitation of germplasm for grain yield improvement in spring wheat (*Triticum aestivum* L.). *Int J Agric Biol* 13(05):695–700
- Saleem B, Khan AS, Shahzad MT, Ijaz F (2017) Estimation of heritability and genetic advance for various morphological traits in seven F₂ population of bread wheat (*Triticum aestivum* L.). *J Agric Sci* 61(1):351–363
- Saleem U, Khaliq I, Muhamood T, Rafiq M (2006) Phenotypic and genotypic correlation coefficient between yield and yield components in wheat. *J Agric Res* 44(1):1–8
- Sial MA, Akhtar J, Mirbahar AA, Jamali KD, Ahmad N, Bux H (2013) Genetic studies of some yield contributing traits of F₂ segregation generation of bread wheat. *Pak J Bot* 45(5):1841–1846
- Singh G, Chaudhary H (2006) Selection parameters and yield enhancement of wheat (*Triticum aestivum* L.) under different moisture stress condition. *Asian J Plant Sci* 5(4):894–898
- Singh SK, Singh VP, Choudhary D, Dobhal P, Kumar S, Srivastava S (2018) Estimation of genotypic and phenotypic correlations coefficients for yield related traits rice under sodic soil. *Asian J Crop Sci* 10(3):100–106
- Sohail A, Rahman H, Ullah F, Shah SM, Burni T, Ali S (2018) Evaluation of F₄ bread wheat (*Triticum aestivum* L.) genotypes for genetic variability, heritability, genetic advance and correlation studies. *J Plant Breed Genet* 6(1):1–7
- Tahmasebi G, Javad H, Aboughadareh JA (2013) Evaluation of yield and yield components in some of promising wheat lines. *Int J Agric Crop Sci* 5(20):2379–2384
- Tomar P, Chand P, Maurya BK, Kumar S, Singh RS, Kumar P, Yadav MK (2019) Estimation of variability and genetic parameters for yield and quality traits in spring wheat (*Triticum aestivum* L.). *J Pharmacogn Phytochem* 8(4):2006–2009
- Ullah MI, Mahpara S, Bibi R, Shah RU, Ullah R, Abbas S, Ullah MI, Hassan AM, Elshehawi AM, Brestic M, Zivcak M (2021) Grain yield and correlated traits of bread wheat lines: Implications for yield improvement. *Saudi J Biol Sci* 28(2021):5714–5719
- Waqas M, Faheem M, Khan AS, Shahzad M, Ansari MAA (2014) Estimation of heritability and genetic advance for some yield traits in eight F₂ population of wheat (*Triticum aestivum* L.). *Sci Lett* 2(2):43–47
- Zeeshan M, Arshad W, Khan MI, Ali S, Tariq M (2014) Character association and casual effects of polygenic trails in spring wheat (*Triticum aestivum* L.). *Int J Agric For Fish* 2(1):16–21
- Zhang Y, Wang Z, Fan Z, Li J, Gao X, Zhang H, Liu Z (2019) Phenotyping and evaluation of CIMMYT WPHYSGP nursery lines and local wheat varieties under two irrigation regimes. *Breed Sci* 69(5):55–67

Springer Nature oder sein Lizenzgeber (z.B. eine Gesellschaft oder ein*e andere*r Vertragspartner*in) hält die ausschließlichen Nutzungsrechte an diesem Artikel kraft eines Verlagsvertrags mit dem/den Autor*in(nen) oder anderen Rechteinhaber*in(nen); die Selbstarchivierung der akzeptierten Manuskriptversion dieses Artikels durch Autor*in(nen) unterliegt ausschließlich den Bedingungen dieses Verlagsvertrags und dem geltenden Recht.