Saudi Journal of Biological Sciences 28 (2021) 5714–5719

Contents lists available at ScienceDirect

Saudi Journal of Biological Sciences

journal homepage: www.sciencedirect.com

Original article

Grain yield and correlated traits of bread wheat lines: Implications for yield improvement

Muhammad Irfan Ullah [a], Shahzadi Mahpara [a,*], Rehana Bibi [b], Rahmat Ullah Shah [c], Rehmat Ullah [d], Sibtain Abbas [a], Muhammad Ihsan Ullah [e], Aziza M. Hassan [f], Ahmed M. El-Shehawi [f], Marian Brestic [g], Marek Zivcak [g], Muhamad Ifnan Khan [a,*]

[a] Department of Plant Breeding & Genetics, Ghazi University, Dera Ghazi Khan 32200, Pakistan
[b] Department of Plant Protection, Ghazi University, Dera Ghazi Khan 32200, Pakistan
[c] Department of Soil Science, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan 60800, Pakistan
[d] Soil and Water Testing Laboratory for Research, Dera Ghazi Khan 32200, Pakistan
[e] Sorghum Research Substation, Department of Agriculture, Dera Ghazi Khan, Pakistan
[f] Department of Biotechnology, College of Science, Taif University, P.O. Box 11099, Taif 21944, Saudi Arabia
[g] Department of Plant Physiology, Slovak University of Agriculture, Nitra, Slovakia

A R T I C L E I N F O

Article history:
Received 24 April 2021
Revised 29 April 2021
Accepted 2 June 2021
Available online 10 June 2021

Keywords:
Correlation
Heritable variability
Coefficient of variation
Grain yield
Wheat

A B S T R A C T

Global wheat yields are suffering due to differences in regional climatic conditions and soil fertility. Plant breeders are continuously working to improve the yield per unit area of wheat crop through selecting superior lines as parents. The screening and field evaluation of available lines allow the selection of superior ones and subsequently improved varieties. Therefore, heritable distinctions among 33 bread wheat lines for yield and related attributes were assessed under field conditions. The experiment included thirty lines and three check varieties. Data relating to different plant characteristics was collected at maturity. Significant differences were recorded for yield and related traits of tested wheat lines and check varieties. Wheat lines V_6, V_{12} and V_{20} proved better with reduced number of days to reach anthesis and other desirable traits compared to check varieties. Days to start heading had strong correlation with spike length and number of spikelets spike^{-1}. Flag leaf area had positive relationship with peduncle length and yield related traits. The 1000-garin weight and grain yield were also correlated with each other. It is concluded that V_6, V_{10} and V_{20} proved better for all studied traits than the rest of the lines. Therefore, these lines could be used in wheat breeding program as parents to improve yield.

1. Introduction

Wheat (*Triticum aestivum* L.) is regarded as a major crop among cereals and integral part of daily diet in different geographic regions of the world. Wheat contains gluten protein available in the form of bread. In cereal crops, this protein is found in wheat and to small extent in triticale and rye. Wheat is utilized to make flour for confectionery foods, bread and brunch cereal. It has numerous uses, good storage quality and nutritive value; thus, accepted as a major foodstuff for one third global population (Sleper and Poehlman, 2006). Wheat yield can be increased by 25% through development of abiotic and biotic stresses tolerant genotypes (Gill et al., 2004). Genotypes × environment interaction play a vital role in yield and quality improvement in wheat (Amanuel et al., 2018; Johansson et al., 2020; Nehe et al., 2019). Wheat is a strategic and major cereal crop around the globe. Wheat provides ~55 and 20% carbohydrates and calories, respectively (Aravind and Prasad, 2005).

Wheat contains proteins, essential minerals, lipids and vitamins. Approximately 1.2 billion people rely on wheat for protein in the developing countries. The demand of wheat will increase by 60% in these areas by 2050. Wheat is cultivated on 219 million hectares representing 15.4% of the total arable land in the world. All other crops have lesser cultivation area than wheat.

* Corresponding authors.
E-mail addresses: smahpara@gudgk.edu.pk (S. Mahpara), mifnan@gudgk.edu.pk (M. Ifnan Khan).

Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.sjbs.2021.06.006
1319-562X/

Nonetheless, it is cultivated in all countries of the world where climate is suitable for its production (Mateo-Sagasta et al., 2018). Wheat is cultivated as a major cereal crop in Pakistan. Wheat contributes 1.6% towards GDP of Pakistan and shares of 8.9% to the value added in agriculture. It was cultivated on an area of 8.74 million hectares with total production of 25.195 million tons during 2019 (GOP, 2019).

Grain yield is a quantitatively inherited trait readily affected by environment. Adverse environmental conditions and abiotic stresses negatively affect grain yield, causing serious economic consequences. Hence, better hereditary of wheat genotype is inevitable for higher yields under favorable and non-favorable agro-ecological conditions (Baranski, 2015; Mahpara et al., 2012; Reynolds and Borlaug, 2006). Numerous studies have indicated that yield can be enhanced through improvement in source-sink association (Foulkes et al., 2011; Lawlor and Paul, 2014). Adapting improved varieties and suitable planting dates are compulsory for improving wheat productivity. Utilizing improved wheat varieties could significantly enhance yield. Various new varieties of wheat have been developed in Pakistan; however, there is still space for the development of more high yielding varieties. About 35 to 50% of wheat yield improvement has been attained through the introduction of newly-developed genotypes (Sabri et al., 2020). The yield can be evaluated through its related traits, like number of productive tillers, spike length, 1000-grain weight and number of spikelets per spike etc. (Li et al., 2020). Genetic makeup of a variety is expressed under favorable environmental conditions; however, could differ in stressful environments (Foulkes et al., 2011; Li et al., 2020).

Genetic variability in wheat varieties and their F_1 hybrids has been observed for different traits, including flag leaf area, plant height and increase in leaf area improved grain yield. (Ibrahim, 2019; Mahpara et al., 2018a) found that wheat yield was dependent on plant height, number of tillers per plant and dry weight. Similarly, increase in number of tillers per plant and other yield related traits improved wheat yield in different studies observed hereditary variation in seven wheat parents during an experiment on RAPD markers for estimation of genetic diversity (Awaad, 2021; Kiss et al., 2021; Mahpara et al., 2017b). (Tariq et al., 2020) worked on sixty-three wheat genotypes and found maximum genetic divergence for anti-oxidant enzymes and phenolic compounds.

An efficient selection of parent material is vital for success of breeding program. Therefore, this study was conducted to estimate inherent variability in growth and yield related of different wheat lines under agro-climatic conditions of Dera Ghazi Khan, Pakistan. The promising wheat lines sorted during the experiment would be exploited in advanced wheat breeding programs to improve yield per unit area in Pakistan.

2. Materials and methods

This experiment was executed at Farmer's field near Ghazi University, Dera Ghazi Khan, Pakistan. Experimental materials were collected from different sources in Punjab province, Pakistan (Table 1).

Soil pH for the experimental site was 7–7.5. Thirty wheat lines and three check varieties were sown in randomized compete block design (RCBD) with three replications. All agronomic practices were kept optimum for all lines and check varieties. Data relating to number of days to spike emergence, flag leaf area, peduncle length and plant height, days taken to maturity, spike length, number of productive tillers/plant, spikelets/spike, number of grains/plant, 1000-grain weight and grain yield/pant were randomly collected from each line at maturity.

2.1. Statistical analysis

The collected data on various traits were analyzed by one-way analysis of variance (ANOVA). The normality and homogeneity of variance in the data were tested prior to ANOVA. The data were normally distributed; therefore, the analysis was conducted on original data. Least significant difference (LSD) test at 5% probability was used as post-hoc test to separate the means where ANOVA indicated significant differences (Steel and Torrie, 1960)..

2.2. Components of variance

Genotypic as well as phenotypic variances were computed according to (Garbade et al., 2019; Sodini et al., 2018). Correlation analysis among yield and yield-related traits was performed as suggested by (Kwon and Torrie, 1964). Heritability was calculated following (Burton and Devane, 1953). Genetic advance (%) was assessed through the formula recommended by (Johnson et al., 1955; Riaz et al., n.d).

3. Results & Discussion

3.1. Analysis for variance

Existence of genetic variation is a crucial step in crop breeding programs aimed at producing new varieties with improved yield potential and consistency of yield under diverse climatic conditions. Mean squares for various yield-related traits indicated significant differences among tested lines and check varieties (Table 2).

The results for genetic variation for grain yield and related traits is in agreement with the findings of several earlier studies (Cooper et al., 2013; Hussain et al., 2004; Mahpara et al., 2017b, 2018a). studied the impact of environment germination and growth of wheat. They concluded that genotypes significantly altered the number of days taken for heading, spike length, plant stature, number of productive tillers per plant and grain yield (Kamaran et al., 2019). also found presence of genotypic variability in four varieties and F1 hybrids in wheat following 4×4 diallel fashion.

3.2. Mean performance

Days to start heading is an important plant trait to find whether crop is early maturing. Wheat line V_{10} and V_{20} took the lowest number of days to start anthesis. Likewise, V_{11}, V_{19}, V_{22} and V_{23} followed V_{10} and V_{20} and took comparatively lesser number of days to spike emergence than the rest of the lines (Table 3). An earlier study found that wheat variety taking less number of days for heading is categorized early maturing (Siyal et al., 2020; Takumi et al., 2020; Tiwari et al., 2019).

Flag leaf area had a key role in photosynthesis; thus, larger leaf area is desirable in wheat. Mean values for flag leaf area indicated that V_6 (106.4 cm^2) and V_{23} (95.3 cm^2) lines had the highest flag leaf area, whereas the lowest was noted for check varieties (Table 3). Due to increase in leaf area of these lines, plants had increased amount of photosynthates, which increased grain yield per plant. Thus, V_6 and V_{10} lines performed best in this regard. Some researchers also worked on flag leaf area of wheat and found that flag leaf area played a key role in improving grain yield of wheat (Luo et al., 2018; Ma et al., 2020; Zhao et al., 2018).

Significant variation was noted for peduncle length among tested lines and check varieties. The lines V_6, V_{12} and V_{20} had higher peduncle length values than check varieties. Increase in peduncle length of wheat genotypes has been observed by (Bilgrami et al., 2018; Farooq et al., 2018; Ojha and Ojha, 2020).

Table 1
List of different wheat lines and check varieties used in the experiment.

Code	Line	Code	Line	Code	Line
V_1	6039	V_{12}	29SAWSN11-12/54	V_{23}	7-63-0944
V_2	7-63-0949	V_{13}	ZA1	V_{24}	228
V_3	29SAWSN11-12/60	V_{14}	ZA2	V_{25}	WN-2
V_4	2 Kco 50	V_{15}	ZA4	V_{26}	7-62-0925
V_5	29SAWSN11-12/101	V_{16}	ZA6	V_{27}	8965
V_6	29SAWSN11-12/57	V_{17}	Line 2	V_{28}	9268
V_7	BK 129	V_{18}	Line 1	V_{29}	7-59-873
V_8	7-63-0951	V_{19}	7-56-0806	V_{30}	7-65-0989
V_9	7-59-866	V_{20}	9945	V_{31}	Galaxy-13*
V_{10}	7-61-0918	V_{21}	Fsd-82	V_{32}	Ujala-2015*
V_{11}	7-62-0936	V_{22}	WN 153	V_{33}	Lasani-2008*

* Check varieties used in the experiment.

Table 2
Means squares for various plant traits of 33 wheat lines.

Traits	Replication	Wheat lines	Error	CV (%)
Number of days to heading	43.97	2.98**	1.83	2.36
Flag leaf area	26.66	1036.21**	0.31	0.69
Peduncle length	0.36	65.35**	0.34	2.00
Plant height	0.87	17.79**	2.65	2.44
Days to reach maturity	15.98	4.11**	2.56	1.35
Spike length	16.95	478.4**	0.01	0.92
Number of productive tillers per plant	66.33	106.76**	0.01	1.71
Number of spikelets per spike	330.06	231.91**	0.06	1.71
Number of grains per spike	114.38	730.56**	0.19	1.00
1000-grain weight	460.8	1156.29**	0.04	0.46
Grain yield per plant	261.33	14517.1**	0.01	0.45

Semi-dwarf stature is a desirable trait in wheat as it provides not only resistance to lodging but also develops the mechanism to utilize nitrogenous fertilizer efficiently. Most of the tested lines exhibited medium stature like V_6, V_{12} except V_{11} (70.4), V_{12} (80.6 cm), V_{13} (75.4 cm), V_{15} (72.5 cm), V_{17} (69.1 cm), V_{18} (72.5 cm), V_{19} (76.4 cm), V_{20} (69.4) and V_{21} (71.4), whereas minimum value for plant height was observed for V_{29} (59.9 cm).(Siyal et al., 2020; Zhao et al., 2018) reported that medium statured genotypes had higher grain yield than tall statured genotypes.

Early maturity is preferable trait in most crop plants. Data regarding days to maturity indicated that V_{20} (114 days) took minimum mean days to reach maturity. Similarly, V_1 (116 days), V_{10} and V_{12} (115 days each) also took lesser number of days to reach maturity compared with check varieties. Similar findings have been observed by (Siyal et al., 2020) who confirmed that days to reach maturity play a role in wheat yield.

Spike length is the most important yield component in wheat as increased spike length would have more number of spikelets per spike and subsequently higher grain yield. In this experiment, the line V_{20} produced longer spikes than check varieties. Likewise, genotypes V_{23} (11.3 cm) and V_6 (11.1 cm) also had higher values for spike length (Table 3). (Mahpara et al., 2017a) also reported similar results and confirmed that enlarged spike length contributed to increase grain yield in wheat.

Number of productive tillers per plant contributes directly towards yield. Results indicated that V_6 (8 tillers per plant) produced more productive tillers than check varieties. Likewise, V_2 and V_{20} (7 tillers each) also had higher number of productive tillers per plant. Many researchers also worked on wheat crop and found that increased number of productive tillers along with other yield components increased grain yield of wheat crop (Abdelkhalik, 2019; Liu et al., 2019; Mahpara et al., 2017a, 2018a).

Number of spikelets per spike plays a crucial role in enhancing grain yield of wheat crop. The line V_{20} (20) produced maximum number of spikelets per spike followed by V_6, V_{23} and V_{25}. Many researchers have confirmed that increased number of spikelets increased grain yield (Philipp et al., 2018; Sakuma and Schnurbusch, 2020; Würschum et al., 2018).

Higher numbers of grains per spike are important trait directly linked with grain yield of wheat. Data regarding number of grains per spike indicated that V_{20} and V_6 had the highest number of grains/spike. Likewise, V_{23}, V_{25} and V_{27} also had higher number of grains/spike. These results coincided with findings of different researchers who reported that number of grains per spike augment grain yield of wheat crop (Sakuma and Schnurbusch, 2020; Wolde et al., 2019)

Mean values of 1000-grain weigh revealed that V_{20} had the highest (53.5 g) value. Similarly, V_6, V_{23} and V_{25} also had maximum 1000-grain weight. (Bilgrami et al., 2018; Kamaran et al., 2019) concluded that increased 1000-grain weight directly contributed to enhanced grain yield.

Data pertaining to grain yield/plant indicated that V_{20} (25.3) produced maximum grain yield, followed by V_6 (24.3 g). Likewise, V_{25} (21.7 g), V_{12} (21.4 g), V_{26} (19.4 g), V_{23} (19.4 g), V_{27} (19.3 g) and V_{28} (19.3 g) followed for grain yield. These findings endorsed the results presented by (Mahpara et al., 2018b, 2017a).

3.3. Interrelationship between grain yield and related components

Association between different traits and grain yield can be explored by correlation analysis (Table 4). Correlation analysis indicated that days to start heading had significant positive link with spike length (0.042*) only. Flag leaf area had significant and positive genotypic and phenotypic association with peduncle length (0.899**, 0.883**), spike length (0.699, 0.698), spikelets per spike (0.724, 0.720), grains per spike (0.699**, 0.697**), 1000-grain weight (0.693**, 0.691**) and grain yield per plant (0.665**, 0.664**), respectively. Peduncle length had significant genotypic and phenotypic connection with spike length (0.759**, 0.748**), spikelets/spike (0.787**, 0.773**), grains/spike (0.762**, 0.750**),

Table 3
Mean values for various yield related traits of different wheat lines and check varieties included in the study.

Lines	Days to heading	Flag leaf area (cm^2)	Peduncle length (cm)	Plant height (cm)	Days to maturity	Spike length (cm)	Number of fertile tillers/plant	Number of spikelets/ spike	Number of grains/spike	1000-grain weight (g)	Grain yield per plant (g)
V_1	57.5 bcd	77.935 j	29.53 ef	66.01 hij	115.5 fgh	7.77 m	6.4 de	12.5 e	36.5 f	39.5 g	9.1 s
V_2	57.5 bcd	86.296 g	28.47 fg	64.95 ijk	116.5 efgh	10.17 e	7.15 c	16 c	48 c	47.5 c	13.3 k
V_3	60.5 a	85.043 h	29.47 ef	62.32 kl	117.5 defgh	9.46 g	6.5 d	14.5 d	42.5 d	43.5 d	10.5 mn
V_4	56.5 cde	90.222 e	30.55 de	60.31 l	116.5 efgh	8.47 j	5.5 fg	14.5 d	42.5 d	43.5 d	11.3 l
V_5	57.5 bcd	88.201 f	28.49 fg	64.34 jk	117 defgh	8.85 i	6.3 e	12 e	36 f	39.5 g	9.4 r
V_6	56.5 cde	106.439 a	32.58 bc	65.99 hij	119.5 bcde	11.14 bc	8 a	18.5 b	54.5 b	49.5 b	24.3 b
V_7	58.5 abc	65.615 o	26.52 hi	62.59 kl	120 bcd	8.22 kl	6.3 e	12.5 e	36.5 f	39.5 g	9.1 s
V_8	57.5 bcd	73.375 kl	28.59 fg	60.5 l	116.5 efgh	9.23 h	7.4 b	14 d	41 e	43 e	10.3 op
V_9	56.5 cde	53.657 q	24.49 j	65.28 ijk	117 defgh	7.16 n	5.3 hi	10.5 f	30.5 g	35.5 h	7.3 u
V_{10}	54 e	73.975 k	27.47 gh	60.61 l	115 gh	9.25 h	5.3 hi	14.5 d	42 d	43.5 d	10.1 pq
V_{11}	55.5 ed	65.531 o	28.65 fg	70.38 def	116.5 efgh	8.85 i	5.3 hi	12.5 e	36.5 f	39.5 g	9.3 r
V_{12}	57.5 bcd	93.462 d	33.51 b	80.55 a	115 gh	10.15 e	5.35 gh	16.5 c	48.5 c	47.5 c	21.4 d
V_{13}	58.5 abc	69.789 m	25.55 ij	75.4 bc	117.5 defgh	8.28 k	5.3 hi	12.5 e	36.5 f	39.5 g	10.4 no
V_{14}	58.5 abc	72.765 l	26.62 hi	64.5 jk	117.5 defgh	8.29 k	5.35 gh	12.5 e	36.5 f	41 f	10.3 op
V_{15}	59.5 ab	77.718 j	27.62 gh	72.49 cd	123.5 a	8.06 l	5.3 hi	12.5 e	36.5 f	39.5 g	10.2 pq
V_{16}	56.5 cde	52.831 q	21.12 k	64.49 jk	123.5 a	7.1 n	5.25 hi	10.5 f	30.5 g	35 i	7.3 u
V_{17}	55.5 ed	63.985 p	24.59 j	69.07 efgh	121 abc	8.24 k	5.35 gh	12.5 e	36.5 f	39.5 g	10.3 op
V_{18}	57.5 bcd	68.306 n	25.53 ij	72.52 cd	118.5 bcde	9.1 h	5.25 hi	12 e	36.5 f	39.5 g	10.6 *m*
V_{19}	55.5 ed	81.63 i	28.62 fg	76.38 b	118 cdefg	7.17 n	5.15 i	10.5 f	30.5 g	35.5 h	7.7 t
V_{20}	54.5 e	94.989 bc	36.76 a	69.35 defg	114 h	12.33 a	7.0 c	20.5 a	60.5 a	53.5 a	25.3 a
V_{21}	56 cde	87.646 f	33.74 b	71.43 de	121.5 ab	10.3 e	5.25 hi	16.5 c	48.5 c	47.5 c	21.2 e
V_{22}	55.5 ed	78.013 j	28.44 fg	66.3 ghij	119 bcde	9.43 g	5.5 fg	14.5 d	42.5 d	43.5 d	11.3 l
V_{23}	55.5 ed	95.257 bc	32.7 bc	64.41 jk	118.5 bcde	11.25 b	5.3 hi	18.5 b	54.5 b	49.5 b	19.4 g
V_{24}	56.5 cde	81.818 i	29.51 ef	62.5 kl	118.5 bcde	10.79 d	5.25 hi	16.5 c	48.5 c	47.5 c	16.6 i
V_{25}	58.5 abc	77.514 j	28.43 fg	64.46 jk	120 bcd	11 c	5.3 hi	18.5 b	54.5 b	49.5 b	21.7 c
V_{26}	59.5 ab	81.743 i	29.54 ef	65.2 ijk	120 bcd	10.15 e	5.3 hi	16.5 c	48.5 c	47.5 c	19.4 g
V_{27}	60.5 a	87.579 f	31.52 cd	65.41 ijk	120 bcd	10.98 c	5.35 gh	18.5 b	54.5 b	49.5 b	19.3 g
V_{28}	59.5 ab	94.489 cd	33.55 b	64.47 jk	119.5 bcde	10.25 e	5.15 i	16.5 c	48.5 c	47.5 c	19.3 g
V_{29}	58.5 abc	77.628 j	30.46 de	59.91 l	118.5 bcdef	9.83 f	5.5 fg	16 c	48.5 c	47.5 c	15.3 j
V_{30}	58.5 abc	64.022 p	25.48 ij	62.4 kl	114.5 h	10.26 e	5.3 hi	16.5 c	48.5 c	47.5 c	16.7 i
V_{31}	56.5 cde	94.632 bc	33.28 b	68.03 fghi	117.5 defgh	11.08 bc	5.65 f	18.5 b	54.5 b	49.5 b	20.3 f
V_{32}	55.5 ed	95.63 b	33.7 b	66.46 ghij	115.5 fgh	11.25 b	5.3 hi	18.5 b	55 b	49.5 b	24.3 b
V_{33}	57.5 bcd	86.162 gh	30.58 de	68.27 efghi	117.5 defgh	10.15 e	5.5 fg	16.5 c	36.5 f	39.5 g	10.5 mn

Means sharing the same letter within a column are statistically non-significant.

Table 4
Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficient between various plant traits in different wheat genotypes.

Traits	Days to start heading	Flag leaf area	Peduncle length	Plant height	Days to reach maturity	Spike length	Number of productive tillers per plant	Number of spikelets per spike	Number of grains per spike	1000-grain weight	Grain yield per plant
Days to start heading		−0.037	−0.154	−0.130	0.176	0.042*	0.179	0.002*	−0.009	0.025	−0.025
Flag leaf area	−0.03		0.899**	0.085	−0.087	0.699**	0.248*	0.724**	0.699**	0.693**	0.665**
Peduncle length	−0.091	0.883**		0.119	−0.084	0.759**	0.059	0.787**	0.762**	0.760**	0.774**
Plant height	−0.113	0.079	0.112		0.132	−0.105	−0.304*	−0.145	−0.155	−0.180	0.079
Days to reach maturity	0.084	−0.05	−0.04	0.090		−0.028	−0.190	−0.001	0.016	−0.026	0.104
Spike length	−0.035	0.698**	0.748**	−0.104	−0.006		0.055	0.972**	0.946**	0.940**	0.891**
Number of productive tillers per plant	0.082	0.244*	0.054	−0.284*	−0.164	0.052		0.040	0.057	0.066	−0.132
Number of spikelets per spike	−0.019	0.720**	0.773**	−0.124	0.008	0.965**	0.041		0.968**	0.957**	0.912**
Number of grains per spike	−0.012	0.697**	0.750**	−0.147	0.016	0.943**	0.058	0.965**		0.991**	0.935**
1000-grain weigh	0.018	0.691**	0.745**	−0.170	−0.020	0.938**	0.066	0.953**	0.990**		0.921**
Grain yield per plant	−0.015	0.664**	0.763**	0.074	0.083	0.889**	−0.131	0.908**	0.933**	0.920**	

** Highly significant at P = ≤0.01
* Significant at P = ≤.

1000-grain weight (0.760**, 0.745**) and grain yield per plant (0.774**, 0.763**), correspondingly. Significant positive relationships at genotypic and phenotypic levels were noted between grain yield and related traits, including spike length, number of spikelets/spike, grains/spike and 1000-grain weight. Genotypic as well as phenotypic correlation for number of spikelets/spike indicated that spikelets per spike increased number of grains per spike.

Grain yield/plant had highly significant positive link with 1000-grains weight. These assessments are in agreement with findings concluded by several earlier studies (Bede and Petrović, 2006; Bilgin et al., 2011; Ibrahim, 2019). All of these studies reported significant variation among all parameters of wheat. Similar findings were reported by (Bilgrami et al., 2018; Khayatnezhad et al., 2010; Okuyama et al., 2005).

3.4. Components of variability and heritability

Effectiveness of a plant-breeding program depends on genetic variation in the existing germplasm. Therefore, diverse heritability, heritable advance, genetic and phenotypic co-efficient of variation in yield and yield components were found in wheat for most of the studied traits as listed in Table 5. Days to start heading had med-

Table 5
Genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability (%) and genetic advance (%) for various plant traits in wheat.

Traits	GCV	PCV	h^2 (%)	G.A (%)
Days to start heading	2.35	3.33	49.75	3.42
Flag leaf area	15.84	15.86	99.82	32.61
Peduncle length	11.35	11.52	96.98	23.03
Plant height	7.09	7.5	89.35	13.8
Days to reach maturity	1.68	2.16	60.84	2.71
Spike length	14.27	14.3	99.58	29.33
Number of productive tillers per plant	12.43	12.55	98.14	25.38
Number of spikelets per spike	18.48	18.56	99.14	37.9
Number of grains per spike	19.11	19.14	99.72	39.32
1000-grain weight	11.29	11.3	99.82	23.24
Grain yield per plant	38.45	38.5	99.98	79.21

Here; GCV = genotypic coefficient of variation; PCV = phenotypic coefficient of variation; h^2 = broad sense heritability and GA = genetic advance.

ium heritability (49.75%) and low genetic advance mean (3.42), GCV (2.35) and PCV (3.33), which exhibited the role of non-additive heritable effect. Findings of this study are in accordance with (Kaur et al., 2021; Kumar et al., 2020) who found that days taken for heading also possessed medium heritability. Direct selection of wheat variety based on this trait will not be effective; thus, indirect selection will be effective.

Similarly, days to reach maturity also had medium heritability (60.84%) and low genetic advance (2.71%), GCV (1.68) and PCV (2.71). Grain yield/plant showed maximum value of heritability (99.98%), genetic advance (79.21%), GCV (38.45) and PCV (38.50), and signifying additive gene act involvement in the constitution of traits. The elevated value of heritability in grain yield depends upon selection of those traits having increased heritability.

Many researchers working on heritability of wheat reported different results as they reported low heritability for yield (Arya et al., 2017; Tripathi et al., 2011), while (Mahpara et al., 2018a) observed significant heritability. Similarly, high heritability was noticed for number of grains per spike (99.72%) followed by spike length (99.58%), spikelets per spike (99.14%) and peduncle length (96.98%) with genetic advance of 39.32, 29.33, 37.90 and 23.03%, respectively. Similarly, spike length and plant height are more heritable having high to medium genetic advance. Flag leaf area contributed much in yield and possessed high heritability. All the studied attributes were quantitatively inherited. Mode of their inheritance is complex due to involvement of many genes for each trait. Some morphological traits are more heritable than yield components. Estimates of heritability were found high for days taken to heading, relatively elevated in grain weight, plant height and productive tillers and low for spikelets/spike, grains/spike and yield (Mahpara et al., 2008). (Tripathi et al., 2011) also found moderate genotypic and phenotypic variances for days taken to heading, while plant height and days taken for maturity possessed high genotypic and phenotypic variances. Similarly, findings of (Bartaula et al., 2019; Jamil et al., 2017; Mofokeng et al., 2020; Uzma et al., 2017) were also in agreement with results in this manuscript as he found that most of yield related traits possessed moderate genotypic and phenotypic variances and high heritability with increased genetic advance .

4. Conclusion

Results indicated that the line V_{20} proved better for some morphological attributes, grain yield and yield-related traits. Similarly, V_6, V_{12} and V_{20} lines seemed suitable on the basis flag leaf area, plant height, spike length, days to reach maturity, number of spikelets/spike, number of productive tillers/plant and grain yield/plant. Thus, wheat production can be enhanced if these selected lines could undergo the process yield trials for selection as varieties as well as further wheat breeding program at national level.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported by the projects VEGA 1/0589/19 and APVV-18-0465. The current work was funded by Taif University Researchers Supporting Project number (TURSP-2020/76), Taif University, Taif, Saudi Arabia.

References

Abdelkhalik, S.A.M., 2019. Assessment of some genetic parameters for yield and its components in four bread wheat crosses using six parameter model. Egypt. J. Plant Breed 23, 719–736.
Amanuel, M., Gebre, D., Debele, T., 2018. Performance of bread wheat genotypes under different environment in lowland irrigated areas of Afar Region, Ethiopia. African J. Agric. Res. 13, 927–933.
Aravind, P., Prasad, M.N.V., 2005. Zinc mediated protection to the conformation of carbonic anhydrase in cadmium exposed Ceratophyllum demersum L. Plant Sci. 169, 245–254.
Arya, V.K., Singh, J., Kumar, L., Kumar, R., Kumar, P., Chand, P., 2017. Genetic variability and diversity analysis for yield and its components in wheat (Triticum aestivum L.). Indian. J. Agric. Res. 51.
Awaad, H.A., 2021. Performance and Genetic Diversity in Water Stress Tolerance and Relation to Wheat Productivity Under Rural Regions. Mitigating Environ. Stress. Agric. Sustain. Egypt, 63–103.
Baranski, M., 2015. The Wide Adaptation of Green Revolution Wheat. Arizona State University.
Bartaula, S., Panthi, U., Timilsena, K., Acharya, S.S., Shrestha, J., 2019. Variability, heritability and genetic advance of maize (Zea mays L.) genotypes. Res. Agric. Livest. Fish. 6, 163–169.
Bede, M., Petrović, S., 2006. Genetska varijabilnost roditelja-uvjet uspješnom oplemenjivanju pšenice. Sjemenarstvo 23, 5–11.
Bilgin, O., Korkut, K.Z., Başer, I., Dağlioğlu, O., Öztürk, İ., Kahraman, T., Balkan, A., 2011. Genetic variation and inter-relationship of some morpho-physiological traits in durum wheat (Triticum durum (L.) Desf.). Pak. J. Bot 43, 253–260.
Bilgrami, S.S., Fakheri, B.A., Razavi, K., Mahdinezhad, N., Tavakol, E., Ramandi, H.D., Ghaderian, M., Shariati, J.V., 2018. Evaluation of agro-morphological traits related to grain yield of Iranian wheat genotypes in drought-stress and normal irrigation conditions. Aust. J. Crop Sci. 12, 738–748.
Burton, G.W., Devane, de E.H., 1953. Estimating heritability in tall fescue (Festuca arundinacea) from replicated clonal material 1. Agron. J. 45, 478–481.
Cooper, J.K., Ibrahim, A.M.H., Rudd, J., Hays, D., Malla, S., Baker, J., 2013. Increasing hard winter wheat yield potential via synthetic hexaploid wheat: II. Heritability and combining ability of yield and its components. Crop Sci. 53, 67–73.
Farooq, M.U., Cheema, A.A., Ishaaq, I., Zhu, J., 2018. Correlation and genetic component studies for peduncle length affecting grain yield in wheat. Int. J. Adv. Appl. Sci. 5, 67–75.
Foulkes, M.J., Slafer, G.A., Davies, W.J., Berry, P.M., Sylvester-Bradley, R., Martre, P., Calderini, D.F., Griffiths, S., Reynolds, M.P., 2011. Raising yield potential of wheat. III. Optimizing partitioning to grain while maintaining lodging resistance. J. Exp. Bot. 62, 469–486.
Garbade, S.F., Shen, N., Himmelreich, N., Haas, D., Trefz, F.K., Hoffmann, G.F., Burgard, P., Blau, N., 2019. Allelic phenotype values: a model for genotype-based phenotype prediction in phenylketonuria. Genet. Med. 21, 580–590.
Gill, S., Loprinzi, C.L., Sargent, D.J., Thomé, S.D., Alberts, S.R., Haller, D.G., Benedetti, J., Francini, G., Shepherd, L.E., Francois Seitz, J., 2004. Pooled analysis of

fluorouracil-based adjuvant therapy for stage II and III colon cancer: who benefits and by how much? J. Clin. Oncol. 22, 1797–1806.
Go, P., 2019. Economic survey of Pakistan.
Hussain, N., Abid, M., Raza, I., 2004. Response of wheat (Triticum aestivum) to phosphorus in the presence of Farmyard manure. Indus J. Plant Sci 3, 298–302.
Ibrahim, A.U., 2019. Genetic variability, Correlation and Path analysis for Yield and yield components in F6 generation of Wheat (Triticum aestivum Em. Thell.). IOSR J. Agric. Vet. Sci. 12, 17–23.
Jamil, A., Khan, S., Sayal, O.U., Waqas, M., Ullah, Q., Ali, S., 2017. Genetic variability, broad sense heritability and genetic advance studies in bread wheat (Triticum aestivum L.) germplasm. Pure Appl. Biol. 6, 538–543.
Johansson, Eva, Branlard, Gérard, Cuniberti, Marta, Flagella, Zina, Hüsken, Alexandra, Nurit, Eric, Peña, Roberto Javier, Sissons, Mike, Vazquez, Daniel, 2020. In: Wheat Quality For Improving Processing And Human Health. Springer International Publishing, Cham, pp. 171–204. https://doi.org/10.1007/978-3-030-34163-3_8.
Johnson, H.W., Robinson, H.F., Comstock, R.E., 1955. Estimates of genetic and environmental variability in soybeans 1. Agron. J. 47, 314–318.
Kamaran, S., Khan, T.M., Bakhsh, A., Hussain, N., Mahpara, S., Manan, A., Chattha, W. S., Jilani, T.A., Sherani, J., Iqbal, M., 2019. Assessment of morphological and molecular marker based genetic diversity among advanced upland cotton genotypes. Pakistan J. Agric. Sci. 56.
Kaur, A., Chhuneja, P., Srivastava, P., Singh, K., Kaur, S., 2021. Evaluation of Triticum durum–Aegilops tauschii derived primary synthetics as potential sources of heat stress tolerance for wheat improvement. Plant Genet. Resour., 1–16
Khayatnezhad, M., Zaefizadeh, M., Gholamin, R., Jamaati-e-Somarin, S., 2010. Study of genetic diversity and path analysis for yield in durum wheat genotypes under water and dry conditions. World Appl. Sci. J. 9, 655–665.
Kiss, T., Balla, K., Cseh, A., Berki, Z., Horváth, Á., Vida, G., Veisz, O., Karsai, I., 2021. Assessment of the genetic diversity, population structure and allele distribution of major plant development genes in bread wheat cultivars using DArT and gene-specific markers. Cereal Res. Commun., 1–9
Kumar, P., Solanki, Y.P.S., Singh, V., 2020. Genetic Variability and Association of Morpho-physiological Traits in Bread Wheat (Triticum aestivum L.). Curr. J. Appl. Sci. Technol. 95–105.
Kwon, S.H., Torrie, J.H., 1964. Heritability and interrelationship among traits of two soybean populations. Crop. Sci. 4, 196–198.
Lawlor, D.W., Paul, M.J., 2014. Source/sink interactions underpin crop yield: the case for trehalose 6-phosphate/SnRK1 in improvement of wheat. Front. Plant Sci. 5, 418.
Li, J., Wen, S., Fan, C., Zhang, M., Tian, S., Kang, W., Zhao, W., Bi, C., Wang, Q., Lu, S., 2020. Characterization of a major quantitative trait locus on the short arm of chromosome 4B for spike number per unit area in common wheat (Triticum aestivum L.). Theor. Appl. Genet. 133, 2259–2269.
Liu, C., Khodaee, M., Lopes, M.S., Sansaloni, C., Dreisigacker, S., Sukumaran, S., Reynolds, M., 2019. Multi-environment QTL analysis using an updated genetic map of a widely distributed Seri× Babax spring wheat population. Mol. Breed. 39, 1–15.
Luo, F., Deng, X., Liu, Y., Yan, Y., 2018. Identification of phosphorylation proteins in response to water deficit during wheat flag leaf and grain development. Bot. Stud. 59, 1–17.
Ma, J., Tu, Y., Zhu, J., Luo, W., Liu, H., Li, C., Li, S., Liu, J., Ding, P., Habib, A., 2020. Flag leaf size and posture of bread wheat: genetic dissection, QTL validation and their relationships with yield-related traits. Theor. Appl. Genet. 133, 297–315.
Mahpara, S., Ali, Z., Ahsan, M., 2008. Combining ability analysis for yield and yield related traits among wheat varieties and their F1 hybrids. Int. J. Agri. Biol 10, 599–604.
Mahpara, S., Ali, Z., Rehmani, M.I.A., Iqbal, J., Shafiq, M.R., 2017a. Studies of genetic and combining ability analysis for some physio-morphological traits in spring wheat using 7× 7 diallel crosses. Int. J. Agric. Appl. Sci. 9, 33–40.
Mahpara, S., Farooq, J., Ali, Z., Petrescu-Mag, I.V., Hussain, F., 2012. Assessment of genetic distance among wheat genotypes through RAPD markers. Adv. Agric. Bot. 4, 31–35.
Mahpara, S., Hussain, S.T., Iqbal, J., Noorka, I.R., Salman, S., 2018a. 12. Analysis of generation means for some metric plant traits in two wheat (Triticum aestivum L.) hybrids. Pure Appl. Biol. 7, 93–102.
Mahpara, S., Hussain, S.T., Iqbal, J., Rasool, I., Salman, S., 2018b. Analysis of generation means for some metric plant traits in two wheat (Triticum aestivum L.) hybrids. Pure Appl. Biol.
Mahpara, S., Rehmani, M.I.A., Hussain, S., Iqbal, J., Qureshi, M.K., Shehzad, M.A., Dar, J.S., 2017b. Heterosis for some physio-morphological plant traits in spring wheat crosses. Pure Appl. Biol. 6, 1103–1110.
Mateo-Sagasta, J., Zadeh, S.M., Turral, H., 2018. More people, more food, worse water?: a global review of water pollution from agriculture.
Mofokeng, M.A., Mashilo, J., Rantso, P., Shimelis, H., 2020. Genetic variation and genetic advance in cowpea based on yield and yield-related traits. Acta Agric. Scand. Sect. B—Soil. Plant Sci. 70, 381–391.
Nehe, A., Akin, B., Sanal, T., Evlice, A.K., Ünsal, R., Dinçer, N., Demir, L., Geren, H., Sevim, I., Orhan, Ş., 2019. Genotype x environment interaction and genetic gain for grain yield and grain quality traits in Turkish spring wheat released between 1964 and 2010. PLoS One 14, e0219432.
Ojha, A., Ojha, B.R., 2020. Assessment of Morpho-Physiological, Yield and Yield Attributing Traits Related to Post Anthesis Drought in Wheat Genotypes Under Rainfed Condition in Rampur, Chitwan. Int. J. Appl. Sci. Biotechnol. 8, 323–335.
Okuyama, L.A., Federizzi, L.C., Barbosa Neto, J.F., 2005. Plant traits to complement selection based on yield components in wheat. Cienc. Rural 35, 1010–1018.
Philipp, N., Weichert, H., Bohra, U., Weschke, W., Schulthess, A.W., Weber, H., 2018. Grain number and grain yield distribution along the spike remain stable despite breeding for high yield in winter wheat. PLoS One 13, e0205452.
Reynolds, M.P., Borlaug, N.E., 2006. Impacts of breeding on international collaborative wheat improvement. J. Agric. Sci. 144, 3.
Riaz, A., Tahir, M.H.N., Rizwan, M., Fiaz, S., Chachar, S., Razzaq, K., Riaz, B., Sadia, H., n.d. Developing a Selection Criterion Using Correlation and Path Coefficient Analysis.
Sabri, R.S., Rafii, M.Y., Ismail, M.R., Yusuff, O., Chukwu, S.C., Hasan, N., 2020. Assessment of agro-morphologic performance, genetic parameters and clustering pattern of newly developed blast resistant rice lines tested in four environments. Agronomy 10, 1098.
Sakuma, S., Schnurbusch, T., 2020. Of floral fortune: tinkering with the grain yield potential of cereal crops. New Phytol. 225, 1873–1882.
Siyal, A.L., Siyal, F.K., Jatt, T., 2020. Yield from genetic variability of bread wheat (Triticum aestivum L.) genotypes under water stress condition: A case study of Tandojam, Sindh. Pure Appl. Biol. 10 (3), 841.
Sleper, D.A., Poehlman, J.M., 2006. Breeding Field Crops. Blackwell Publishing.
Sodini, S.M., Kemper, K.E., Wray, N.R., Trzaskowski, M., 2018. Comparison of genotypic and phenotypic correlations: Cheverud's conjecture in humans. Genetics 209, 941–948.
Steel, R.G.D., Torrie, J.H., 1960. Principles and procedures of statistics. Princ. Proced. Stat.
Takumi, S., Mitta, S., Komura, S., Ikeda, T.M., Matsunaka, H., Sato, K., Yoshida, K., Murai, K., 2020. Introgression of chromosomal segments conferring early heading date from wheat diploid progenitor, Aegilops tauschii Coss., into Japanese elite wheat cultivars. PLoS One 15, e0228397.
Tariq, H., Awan, S.I., Sabir, S.M., Ilyas, M., 2020. Hexaploid-Tetraploid Landraces and Wild Species of Wheat Revealed Diversity for Antioxidants and Total Phenolics. Philipp. Agric. Sci. 103, 29–37.
Tiwari, D.N., Tripathi, S.R., Tripathi, M.P., Khatri, N., Bastola, B.R., 2019. Genetic variability and correlation coefficients of major traits in early maturing rice under rainfed lowland environments of Nepal. Adv. Agric. 2019.
Tripathi, S.N., Marker, S., Pandey, P., Jaiswal, K.K., Tiwari, D.K., 2011. Relationship between some morphological and physiological traits with grain yield in bread wheat (Triticum aestivum L. em. Thell.). Trends. Appl. Sci. Res. 6, 1037.
Uzma, J., Ghulam, S., Tabassum, M.I., 2017. Genetics of some physio-morphic traits of hexaploid wheat genotypes under rainfed conditions. J. Agric. Res. 55, 463–468.
Wolde, G.M., Mascher, M., Schnurbusch, T., 2019. Genetic modification of spikelet arrangement in wheat increases grain number without significantly affecting grain weight. Mol. Genet. Genomics 294, 457–468.
Würschum, T., Leiser, W.L., Langer, S.M., Tucker, M.R., Longin, C.F.H., 2018. Phenotypic and genetic analysis of spike and kernel characteristics in wheat reveals long-term genetic trends of grain yield components. Theor. Appl. Genet. 131, 2071–2084.
Zhao, C., Bao, Y., Wang, X., Yu, H., Ding, A., Guan, C., Cui, J., Wu, Y., Sun, H., Li, X., 2018. QTL for flag leaf size and their influence on yield-related traits in wheat. Euphytica 214, 1–15.