RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
55 (2) 388-398, 2023
http://doi.org/10.54910/sabrao2023.55.2.11
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

APPRAISAL OF BREAD WHEAT GERMPLASM FOR QUALITY ATTRIBUTES AND THEIR RELATIONSHIP WITH GRAIN YIELD

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SUMMARY

The increasing global population demands potential high-yielding wheat genotypes, even under changing climatic conditions. Wheat Research Institute (WRI), Faisalabad, designed a two-year study during 2018–2020, following augmented block design, to assess the association between yield and quality parameters in 245 bread wheat genotypes, including 10 checks. Separating all genotypes into four sets was according to their origin, i.e., local landraces, exotic material from CIMMYT (International Maize and Wheat Improvement Center), Pakistani accessions, and miscellaneous. A sufficient amount of genetic variation among all the genotypes for the measured traits was evident from the analysis of variance (ANOVA). Correlation studies demonstrated a similar trend of association among traits in Pakistani and CIMMYT lines, but distinct patterns of association among landraces and mixed genotypes occurred. The whole population of diversified germplasm showed a positive association of yield with all the traits except chapatti quality, pH of flour, and gluten during 2018–2019. Similarly, in 2019–2020, grain yield was positively associated with all the traits except test weight, chapatti quality, and pH of flour. The attributes responsible for the grain size, i.e., grain length, width, thickness, and a thousand kernel weight, expressed a strong association among each other and with the grain yield. A positive correlation between grain yield and grain quality characters (bread and chapatti quality, test weight, gluten, and protein) emerged in the pre-green revolution germplasm during both years, which can benefit wheat quality improvement. The study concluded that for future wheat breeding programs for high-yield potential, more attention should focus on the traits responsible for grain size.

Keywords: wheat, population, hunger, grain size, quality, trait association

Key findings: For the selection of wheat genotypes with high-yielding potential, the seed traits (grain size: length, width, thickness, a thousand kernel weight, and test weight) should require more importance. The study indicated that to improve the quality of modern wheat cultivars, more focus on using pre-green revolution era wheat materials should materialize in the wheat breeding programs.

Communicating Editor: P Prof. Soon-Wook Kwon

Manuscript received: September 15, 2022; Accepted: March 8, 2023.

Citation: Ahmad N, Rehman A, Gulnaz S, Javed A, Sultana R, Ajmal S, Ahsan A, Shamim S, Nadeem M, Shair H, Abdullah M, Ahmad J, Sarwar M (2023). Appraisal of bread wheat germplasm for quality attributes and their relationship with grain yield. *SABRAO J. Breed. Genet.* 55(2): 388-398. http://doi.org/10.54910/sabrao2023.55.2.11.

INTRODUCTION

Wheat is a highly recognized essential cereal food crop worldwide because of its bumper utilization as a staple. Wheat is a primary source of calories for humans (Ahmad *et al.,* 2022). It is the chief source of food for about 1200 million poor people with limited resources globally (Ojha *et al*., 2018). In 2020, global wheat production recording was at 772.64 million t (Ramadas *et al.,* 2019). In Pakistan, wheat production was 26.4 million t during 2021–2022. But it is insufficient to fulfill the rising consumption demand of the country. A report concluded that Pakistan is among the countries in the world with the highest annual population growth rate of about 2% annually (Donley, 2021).

The practice of major crop cultivation is often in the rural areas of a country. Recent studies suggested that the rural cultivated lands are decreasing day by day. Agriculture is the prime source of the economy in Pakistan, as it contributes 18.9% to the country's gross domestic product (GDP) and absorbs 42.3% of its labor force. Agriculture provides food crops and also helps the country by exporting various products. Even then, the farmers leave the agricultural profession every day (Rajpar *et al.,* 2019).

In past years, yield enhancement was the focal target for a breeder in a wheat breeding program (Iqbal *et al.,* 2022; Qulmamatova *et al*., 2022)). With the advancement of the industry, grain quality is also a key parameter (Javed *et al.,* 2022; Khan *et al*., 2023). The different industrial wheat products demand varied parameter requirements for determining the quality of the end product. Hence, plant breeders should focus on quality parameters as much as on improving grain yield parameters (Sajjad *et al.,* 2012). Ahmad *et al.* (2022) and Javed *et al.* (2022) concluded that thousand-grain weight, number of spikes, spike length, chlorophyll content, and number of grains per spike had a positive association with yield. Some scientists reported a negative association between yield and quality in their reports (O'Brien and Ronalds, 1987; Kaya and Akura, 2014). On the other hand, the positive correlation between quality and yield also came from many researchers (Kanwal *et al.,* 2019; Rathod *et al.,* 2019).

The information about yield relationship with its contributing traits, along with the grain quality parameters, are beneficial for the genetic improvement of a specific attribute in any crop breeding program. The knowledge about the association of grain yield and its related traits is very helpful for selecting top genotypes with desirable plant traits. The correlation studies among yield contributing features may support an indirect selection of yield components. Past studies revealed that the association between the different plant traits depends on various genetic and environmental factors (Dutamo *et al.,* 2015).

A wheat improvement breeding program highly requires its establishment to meet the accelerating wheat consumption demand in the country. The two-year experiment transpired to find the correlation pattern in grain yield and quality characters in a diverse wheat population to establish a target-oriented for specific traits breeding program regarding harvest and quality improvement. It will also help deliver such wheat genotypes that will have potential to produce a better yield in the farmer's fields.

MATERIALS AND METHODS

Plant material and growth conditions

The plant material included 245 wheat genotypes comprising sub-continental landraces, Pakistani semi-dwarf varieties, exotic germplasm from CIMMYT, and miscellaneous material available in the gene pool of WRI, Faisalabad. Grouping all the genotypes into four sets consisted of their origin, mentioned earlier (local landraces, exotic material from CIMMYT, Pakistani accessions, and miscellaneous). The plant material sowing occurred under normal irrigated conditions. The weather data during the crop season for both years is available in Figure 1, which includes rainfall (mm) and minimum and maximum temperatures (°C).

Experimental design and layout

The experiment sowing during the cropping seasons of 2018–2019 and 2019–2020 used an augmented field design. Two hundred forty-five entries with 10 checks, viz., Yecora-73, Chakwal-86, Inqlab-91, Parwaz-94, GA-2002, Seher-06, Shafaq-06, Faisalabad-08, Lasani-08, and AARI-11 underwent testing for yield and quality traits. The experimental material had a division of six blocks. Each of the five blocks consisted of 50 genotypes with 10 checks, with the sixth block containing only 40

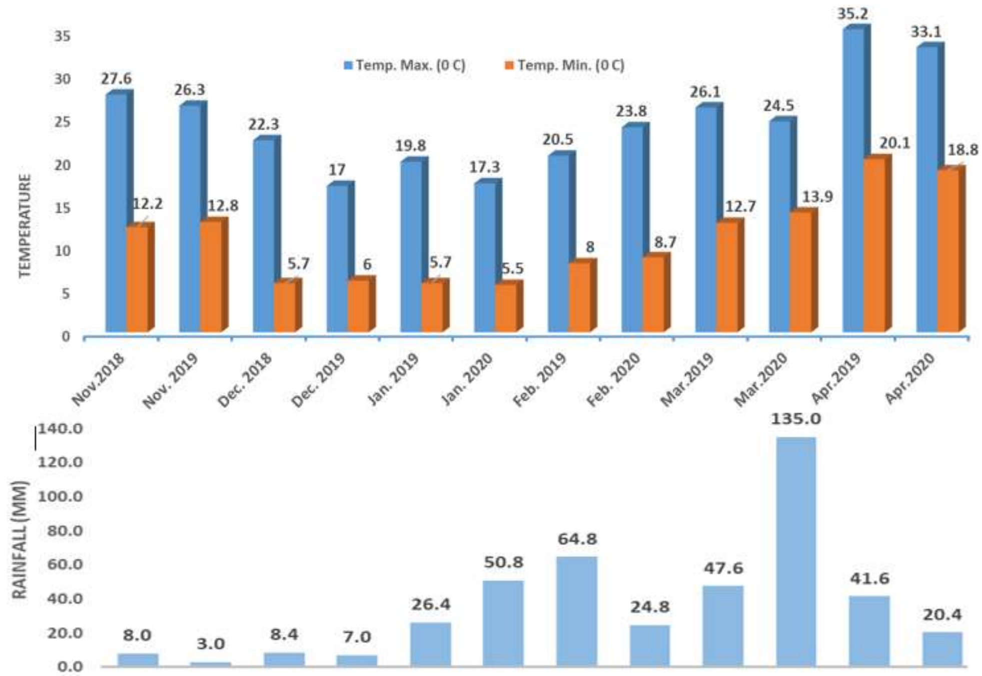

Figure 1. Weather data during the 2018–2019 and 2019–2020 crop season.

genotypes with checks. The plot size for each genotype was 5 m × 1.2 m (length × width) with six rows. Crop planting was in the second week of November in the study years, following standard agronomic practices.

Experimental site

The trial proceeded at the field area of WRI, Faisalabad. The experimental site had an elevation of 184 m, with longitudes of 73°74 East and a latitude of 30°31.5 North. Given the high evapotranspiration rate in the region of Faisalabad, it comes under the semi-arid climatic zone, with an average rainfall of 200 mm annually.

Evaluation of quality parameters

Harvest of the crop used an experimental combine harvester. Weighing cleaned grains occurred before sending them to the cereal quality lab of WRI, Faisalabad. Using standard methods recorded the data for quality characters like test weight (kg hL^{-1}), thousand-grain weight (g), grain length (mm), grain width (mm), and grain thickness (mm). Employing the Omeg Analyzer analyzed the quality traits (grain protein content%, gluten content%, starch%, and moisture%). The grain hardness analysis followed the procedure defined in AACC (2000) method no. 39-70A. On the other hand, adopting AACC (2000) method no. 55-10 revealed the test weight. Flour pH determination followed the procedure described in AACC (2000) method no. 2-52. Recording data on chapatti quality was according to Haridas *et al.* (1986). Analysis of the bread quality was according to the method of Samuel (1960) after preparing bread by the procedures in AACC (2000) Method No 10-10B.

Statistical analysis

The data underwent analysis of variance (ANOVA) using Statistix-8.1, with the means compared using Tukey's test as described by Steel *et al.* (1997) and followed by Javed *et al.* (2022). Correlation calculation for each group and whole material revealed the association of yield with quality traits. Pearson's Correlation method was adopted for correlation studies, as employed by Ahmad *et al.* (2022).

RESULTS

Analysis of variance

The whole germplasm data underwent ANOVA, indicating significant variation in total germplasm during both years among all the quality traits except flour pH and moisture content (Tables 1 and 2). On the other hand,

Table 1. Analysis of Variance of different traits in whole germplasm of bread wheat (*Triticum aestivum* L.) during 2018–2019.

S.O.V.	DF	Pr	Ms	St	Glu	TGWt g.	T.Wt kghl $^{-1}$	B.Q	C.Q	Sd.L	Sd.W	Sd.T	H	pH F	Y
Corrected model	249	0.814**	0.165	1.177**	7.880**	20.259**	3602**	10.019**	1.090*	0.090**	0.01**	0.054**	5.709**	0.016	95.243**
Intercept	1	43518.70 **	31464.64 **	729259.71**	143127.12**	271226.37 **	1411090.60 **	1310852.43 **	3158.80 **	9899.98 **	2372.67 **	17898.49 **	112201.12 **	9591.50 **	342742.89 **
Treatment	244	0.722**	0.176	0.994**	7.545**	19.199**	3.619**	9.317**	1.100*	0.086**	0.021**	0.134**	5.599**	0.016	82.541**
Block	5	0.612*	0.055	2.90**	23.900**	1.601*	2.211*	35.240**	2.547**	0.005	0.001	0.002	1.069	0.023	0.961
Error	45	0.385	0.121	0.570	6.201	6.800	1.852	5.131	0.699	0.09	0.003	0.039	2.50	0.013	2.270
Total	295														
Corrected total	294														

S.O.V.: Source of variation, df: Degree of freedom Pr: Protein; Ms: Moisture; St: Starch; Glu: Gluten; TGWt: Thousand-grain weight; T.Wt: Test weight; B.Q: Bread quality; C.Q: Chapatti quality; Sd.L: Seed length; Sd.W: Seed width; Sd.T: Seed thickness; H: Grain hardness; pHF: pH of Flour ; Y: Yield ha $^{-1}$

Table 2. Analysis of Variance of different traits in the whole germplasm of bread wheat (*Triticum aestivum* L.) during 2019–2020.

S.O.V.	DF	Pr	Ms	St	Glu	TGWt g.	T. Wt kghl $^{-1}$	B.Q	C.Q	Sd.L	Sd.W	Sd.T	H	pH F	Y
Corrected model	249	1.19**	0.340	2.106**	11.152**	21.633**	5.416**	10.360**	1.210*	0.241**	0.059**	0.080**	7.137**	0.014	96.190**
Intercept	1	41342.9 **	32002.7**	739108.6**	139960.3**	277173.8**	1421484.5**	1311180.4 **	3135.5**	9899.5**	2505.0**	1997.8**	12306691.5 **	9594.5	327979.8**
Treatment	244	1.09**	0.339	2.103**	11.000**	19.999**	5.398*	9.809**	1.100*	0.230**	0.059**	0.076**	6.878**	0.016	85.65**
Block	5	0.757*	0.19	2.089**	13.300*	8.302	4.730	33.002**	1.610*	0.200	0.049	0.081**	2.454	0.020	3.21*
Error	45	0.291	0.249	1.814	5.598	12.129	3.398	5.299	0.676	0.129	0.048	0.029	3.816	0.009	4.298
Total	295														
Corrected total	294														

S.O.V.: Source of variation, df: Degree of freedom Pr: Protein; Ms: Moisture; St: Starch; Glu: Gluten; TGWt: Thousand grain weight; T.Wt: Test weight; B.Q: Bread quality; C.Q: Chapatti quality; Sd.L: Seed length; Sd.W: Seed width; Sd.T: Seed thickness; H: Grain hardness; pHF: pH of Flour ; Y: Yield ha $^{-1}$

Table 3. Quantitative values range of different quality characters of whole wheat germplasm during 2018–2019 and 2019–2020.

Variables		Pr	Ms	St	Glu	TGWt	T. Wt	B.Q	C.Q	Sd.L	Sd.W	Sd.T	H	pH F	Y
2018-2019	Mean	13.1	10.9	54.0	23.89	34.72	74.5	72.01	3.52	6.21	3.10	2.69	66.83	6.22	3793
	S.E	0.49	0.19	0.04	0.16	0.19	0.12	0.19	0.05	0.03	0.01	0.01	0.14	0.02	53.45
	Min.	11.2	11.1	49.0	17.0	21.00	66.09	63.00	1.00	5.45	2.74	2.16	63.05	5.99	1329
	Max.	15.4	12.1	55.7	28.9	43.49	78.01	81.00	6.00	6.89	3.61	3.11	72.40	6.40	6329
	St.D	0.76	0.40	0.90	2.70	4.19	1.50	3.20	1.01	0.31	0.14	0.18	2.30	0.13	89.10
2019-2020	Mean	13.1	11.2	54.30	23.97	34.71	75.02	72.10	3.59	6.23	3.13	2.80	67.10	6.21	3659
	S.E	0.05	0.02	0.07	0.20	0.25	0.13	0.20	0.05	0.02	0.02	0.01	0.14	0.01	51.45
	Min.	10.9	11.0	51.0	17	22.6	66.80	61.9	1.1	5.07	2.60	2.01	60.84	5.89	1232
	Max.	15.9	12.8	58.1	32.9	45.1	78.99	80.99	5.99	7.31	3.80	3.41	74.12	6.39	6101
	S.D	1.10	0.56	1.32	3.19	4.41	2.05	3.20	1.01	0.47	0.23	0.25	2.15	0.09	890

Pr:Protein; Ms: Moisture; St: Starch; Glu: Gluten; TGWt: Thousand grain weight; T.Wt: Test weight; B.Q: Bread quality; C.Q: Chapatti quality; Sd.L: Seed length; Sd.W: Seed width; Sd.T: Seed thickness; H: Grain hardness; pHF: pH of Flour the block differences showed as non-significant for characters like seed width, seed length, seed thickness, grain hardiness, moisture, pH of flour, and yield, with their differences significant for the rest of the traits. Using adjusted means for further testing ensued in the case of traits where the block effect was significant, while for other traits, used original means.

Table 3 depicts the range and mean values of all the traits under study. It showed that protein percentage ranged from 11.2% to 15.4% during 2018–2019 and 10.9%–15.9% during 2019–2020. Moisture content ranged from 11.1% to 12.1% for the first year and 11.0% to 12.8% for the second year. The starch range varied from 49.0% to 55.7% for 2018–2019 and 51.0% to 58.1% for the study year 2019–2020. During the first and second study years, the values for gluten ranged from 17% to 28.9% and 17% to 32.9%, respectively. The minimum and maximum values for thousand-grain weight for 2018–2019 and 2019–2020 were 21.0–43.5g and 22.6–45.1g, respectively.

The range for test weight remained 66.1 to 78.0 kg hL^{-1} during 2018–2019 and 66.8 to 79.9 kg hL^{-1} in 2019–2020. The score range of bread quality was 63.0–81.0 for the first year and 61.9–80.9 for the second year, while chapatti quality was 1.0–6.0 (1st year) and 1.1-5.99 (2nd year). The traits seed width, length, and thickness varied from 2.16 to 3.11 mm, 5.45 to 6.89 mm, and 2.16 to 3.11 mm during 2018–2019 and 2.6 to 3.8 mm, 5.03 to 7.31 mm, and 2.6 to 3.8 mm during 2019–2020, respectively. The grain hardness ranged from 63.05 to 72.40 (2018–2019) and 60.84 to 74.12 (2019–2020). In the first year, the flour pH ranged from 5.99 to 6.40, and during the second, 5.89 to 6.39. The observed range for grain yield in year one and year two was from 1329 to 6329 kg ha^{-1} and 1232 to 6101 kg ha^{-1}, respectively.

Correlation analysis

The key objective of a plant breeder is to improve the grain yield and quality parameters. Therefore, breeders should consider the association pattern among the quality, yield, and yield-contributing traits in pre-breeding trials. The correlation analysis among various traits determined the extent of association, which may vary in different environments and plant populations. Tables 4 to 8 present the correlation coefficients among quality, yield, and yield-contributing traits in the whole germplasm population of WRI, Faisalabad, and its subpopulation (Pakistani germplasm, CIMMYT germplasm, local landraces, and miscellaneous germplasm) for 2018–2020.

Correlation coefficients of whole wheat germplasm were almost comparable for most of the subpopulations (Pakistani, CIMMYT, and miscellaneous germplasms) except local landraces, which showed their distinctness from post-green revolution semi-dwarf breeding material for both years. In the whole wheat germplasm, the association between moisture and flour pH indicated non-significant during 2018–2019 (0.001) but in 2019–2020 (0.150^{*}), it was significant. On the other hand, the association between moisture and flour pH emerged to be positive during both years. The moisture content showed a significant but negative association with grain hardiness in the first and second years (-0.105 and -0.151^{*}). The protein showed a highly relevant and positive association with gluten at 0.553^{**} (1st year) and 0.531^{**} (2nd year); however, during both years, it showed a negative and non-significant association with the moisture content (-0.01 and -0.025). Seed thickness (-0.054 and -0.061) and seed width (-0.0008 and -0.064) showed a non-significant and negative association with grain protein during both years (Table 4).

Starch showed a significant but negative correlation with protein during 2018–2019 (-0.41^{**}) and 2019–2020 (-0.382^{**}). Grain hardness (0.072 and 0.025), pH of the flour (0.062 and 0.035), and grain yield (0.031 and 0.039) showed a positive association with the protein content for both years, respectively. Grain hardness showed a significant and positive correlation with bread quality at 0.181^{**} (1st year) and 0.130^{*} (2nd year), yet showed a negative but non-significant association with chapatti quality (-0.056 and -0.065) during both years. The bread quality gave a positive association with protein (0.155^{*} and 0.067), starch (0.015 and 0.150^{*}), seed length (0.151^{*} and 0.089), seed thickness (0.131^{*} and 0.128), grain hardness (0.130^{*} and 0.181^{**}) and grain yield (0.320^{**} and 0.130) during 2018–2019 and 2019–2020, respectively. In the whole germplasm of bread wheat, the grain yield exhibited a positive association with the thousand-grain weight (0.267^{**} and 0.041), seed length (0.235^{***} and 0.157^{*}), seed width (0.121 and 0.099), seed thickness (0.220^{**} and 0.11), and seed hardness (0.141^{*} and 0.116^{*}), but a negative association with the pH of the flour during both years (Table 4).

The grain yield and thousand-grain weight exhibited positive and significant correlation with seed characters like seed length, thickness, and width for both study years and in all four sets of the population (Pakistani accessions [Table 5], CIMMYT germplasm [Table 6], local landraces [Table 7], and miscellaneous germplasm [Table 8]). The CIMMYT (Table 6) and Pakistani germplasms (Table 5) generally showed similar patterns in the association of traits. These population sets displayed a negative correlation between yield, protein percentage, and chapatti quality while a non-significant but positive association with bread quality. The correlation of grain protein with the grain yield resulted as significant but negative in Pakistani accessions during 2018–2019, yet emerged as non-significant during 2019–2020 (Table 5). The same trend of these correlation values also surfaced in CIMMYT germplasm in both years (Table 6).

The population set consisting of local landraces that include tall-stature, pre-green revolution wheat varieties, exhibited quite a different pattern, which displayed a significant and positive correlation of grain yield with thousand-grain weight (0.566**), test weight (0.440**), bread quality (0.230*), and chapatti quality (0.379*) during 2018–2019. Similarly, a significant and positive correlation of grain yield with test weight (0.466**), chapatti quality (0.48*), gluten (0.378*), and protein (0.298*) also occurred during 2019–2020. Generally, a positive correlation trend of grain yield ha^{-1} and grain quality characters resulted in pre-green revolution era materials for both years (Table 7).

Table 4. Correlation coefficient matrix of whole germplasm in years 2018–2019 and 2019–2020.

Traits	Pr	Ms	St	Glu	TGWt	T. Wt	B.Q	C.Q	Sd.L	Sd.W	Sd.T	H	pH F	Y
Pr	1	-0.010	-0.451**	0.553**	0.073	0.003	0.155*	0.543**	0.147*	-0.008	-0.054	0.072	0.062	0.031
Ms	-0.025	1	-0.016	-0.047	-0.033	-0.027	0.038	-0.037	0.074	-0.055	-0.101	-0.105	0.001`	0.113
St	-0.382**	-0.066	1	-0.334**	0.070	0.175**	0.015	-0.310**	-0.033	-0.061	-0.038	0.072	0.008	0.015
Glu	0.531**	-0.055	-0.238**	1	0.151*	-0.020	0.025	0.940**	0.196**	0.099	0.091	-0.041	0.015	-0.070
TGWt	-0.074	-0.024	0.057	0.121	1	0.187**	0.314**	0.205**	0.591**	0.444**	0.481**	-0.176**	0.002	0.267**
T.Wt	-0.079	0.010	0.036	-0.066	0.075	1	0.054	0.012	0.042	-0.043	-0.014	-0.010	-0.097	0.023
B.Q	0.067	0.020	0.150*	-0.014	0.090	0.017	1	0.043	0.151*	0.074	0.131*	0.130*	-0.071	0.320**
C.Q	0.590**	-0.023	-0.251**	0.945**	0.102	-0.079	0.012	1	0.133**	0.102	0.110	-0.056	0.030	-0.025
Sd.L	0.024	0.169*	-0.045	0.089	0.255**	-0.057	0.089	0.081	1	0.320**	0.383**	-0.217**	0.024	0.235**
Sd.W	-0.064	-0.052	0.039	-0.027	0.234**	-0.091	-0.095	-0.036	0.073	1	0.571**	-0.129*	-0.077	0.121
Sd.T	-0.061	-0.050	0.032	0.031	0.291**	-0.041	0.128	0.026	0.318**	0.230**	1	-0.052	0.022	0.220**
H	0.025	-0.151*	0.013	-0.046	-0.104	0.015	0.181**	-0.065	-0.102	-0.053	0.065	1	0.049	0.141*
pHF	0.035	0.150*	0.014	0.050	-0.090	-0.101	0.002	0.024	0.064	0.016	-0.053	0.027	1	-0.041
Y	0.039	0.019	0.010	0.001	0.041	-0.049	0.103	-0.011	0.157*	0.099	0.110	0.116*	-0.024	1

The above diagonal values represent the year 2018–2019 and the below diagonal represents the year 2019–2020. ** *P* = < 0.05, *P* = < 0.01
Pr: Protein; Ms: Moisture; St: Starch; Glu: Gluten; TGWt: Thousand grain weight; T.Wt: Test weight; B.Q: Bread quality; C.Q: Chapatti quality; Sd.L: Seed length; Sd.W: Seed width; Sd.T: Seed thickness; H: Grain hardness; pHF: pH of Flour; Y: Yield ha^{-1}

Table 5. Correlation coefficient matrix of Pakistani germplasm in years 2018–2019 and 2019–2020.

Traits	Pr	Ms	St	Glu	TGWt	T. Wt	B.Q	C.Q	Sd.L	Sd.W	Sd.T	H	pH F	Y
Pr	1	0.004	-0.557*	0.602**	-0.002	0.018	-0.040	0.573**	0.081	-0.031	-0.159	-0.037	0.036	-0.214*
Ms	-0.024	1	-0.026	-0.031	-0.066	-0.007	0.064	-0.025	0.082	-0.081	-0.180*	-0.12	-0.016	0.143
St	-.345**	-0.073	1	-0.48**	0.041	0.091	0.213*	-0.489**	-0.086	0.028	0.017	0.168	-0.070	0.120
Glu	0.559**	0.012	-0.324**	1	0.177*	-0.081	-0.075	0.945**	0.185*	0.088	0.041	-0.02	0.063	-0.143
TGWt	-0.020	-0.030	0.133	0.122	1	0.105	0.195*	0.169	0.530**	0.422**	0.490**	-0.13	-0.014	0.169
T.Wt	-0.033	0.021	0.080	-0.163	0.025	1	0.133	-0.080	-0.054	-0.035	-0.042	0.098	-0.01	0.054
B.Q	-0.031	-0.054	0.212*	-0.093	0.267**	0.014	1	-0.099	0.091	0.210*	0.174	0.084	-0.231**	0.171
C.Q	0.561**	0.018	-0.320**	0.960**	0.092	-0.137	-0.073	1	0.215*	0.088	0.057	-0.01	0.059	-0.120
Sd.L	-0.091	0.184*	0.055	0.008	0.299**	-0.017	0.157	0.013	1	0.240**	.314**	-.26*	0.031	0.130
Sd.W	-0.079	0.046	0.091	-0.048	0.267**	-0.132	0.094	-0.073	0.053	1	0.461**	-0.16	-0.001	0.047
Sd.T	-0.101	0.021	0.124	-0.037	0.283**	-0.022	0.169	-0.017	0.192*	0.190*	1	-0.019	0.030	0.102
H	-0.060	-0.183*	0.011	0.012	-0.071	0.095	0.132	0.016	-0.099	-0.039	0.043	1	-0.043	0.072
pHF	0.041	0.197*	-0.055	0.074	-0.024	-0.013	-0.140	0.064	0.115	0.095	-0.044	-0.101	1	-0.051
Y	-0.162	0.020	0.008	-0.090	0.158	0.023	0.079	-0.127	0.154	0.147	0.103	0.083	-0.011	1

The above diagonal values represent the year 2018–2019 and the below diagonal represents the year 2019–2020.** $P = < 0.05$, $P = < 0.01$
Pr: Protein; Ms: Moisture; St: Starch; Glu: Gluten; TGWt: Thousand grain weight; T.Wt: Test weight; B.Q: Bread quality; C.Q: Chapatti quality; Sd.L: Seed length; Sd.W: Seed width; Sd.T: Seed thickness; H: Grain hardness; pHF: pH of Flour; Y: Yield ha^{-1}

Table 6. Correlation coefficient matrix of CIMMYT germplasm for the years 2018–2019 and 2019–2020.

Traits	Pr	Ms	St	Glu	TGWt	T. Wt	B.Q	C.Q	Sd.L	Sd.W	Sd.T	H	pH F	Y
Pr	1	-.383**	-.382**	.502**	-0.101	0.112	0.115	.525**	0.081	-0.080	-0.131	0.029	-0.045	-0.160
Ms	-0.201	1	-0.101	-0.353**	-0.016	-0.087	-0.121	-.0370**	0.082	-0.061	0.081	-0.193	0.124	0.099
St	-0.253*	-0.115	1	-0.117	0.154	0.185	0.021	-0.130	0.117	-0.149	-0.063	0.024	0.130	0.029
Glu	0.410**	-0.184	-0.013	1	0.121	0.038	0.107	.965**	.266*	0.127	0.053	-0.148	0.079	-0.076
TGWt	-0.195	0.042	-0.019	0.101	1	0.118	0.008	0.122	0.713**	0.510**	0.478**	-0.233	0.134	0.124
T.Wt	-0.055	-0.095	-0.101	-0.030	0.280*	1	0.090	0.064	0.131	-0.002	-0.018	-0.107	0.073	-0.100
B.Q	0.095	-0.106	0.112	0.091	0.133	-0.050	1	0.130	0.162	-0.052	0.035	0.086	-0.013	0.210
C.Q	0.091	-0.106	0.122	0.089	0.135	-0.050	0.095	1	0.279*	0.138	0.079	-0.154	0.011	-0.088
Sd.L	0.031	0.139	-0.168	0.264*	0.322**	-0.040	-0.011	0.221	1	.359**	0.418**	-0.141	0.176	0.056
Sd.W	-0.210	-0.068	0.001	0.007	0.214	0.072	-0.220	0.014	0.037	1	0.693**	-0.052	-0.124	0.012
Sd.T	-0.060	-0.185	0.010	0.163	0.429**	0.017	0.102	0.126	0.322**	.311*	1	-0.118	0.093	0.256*
H	0.072	-0.210	0.038	-0.133	-0.106	-0.081	0.081	-0.165	0.027	-0.120	0.101	1	0.003	0.274*
pHF	-0.157	0.083	0.103	0.062	0.151	-0.042	0.082	0.018	0.081	0.079	-0.056	0.099	1	-0.010
Y	-0.182	-0.112	0.215	-0.046	0.072	-0.183	0.150	-0.073	-0.073	-0.076	0.133	0.295*	-0.005	1

The above diagonal values represent the year 2018–2019 and the below diagonal represents the year 2019–2020. ** $P = < 0.05$, $P = < 0.01$
Pr: Protein; Ms: Moisture; St: Starch; Glu: Gluten; TGWt: Thousand grain weight; T.Wt: Test weight; B.Q: Bread quality; C.Q: Chapatti quality; Sd.L: Seed length; Sd.W: Seed width; Sd.T: Seed thickness; H: Grain hardness; pHF: pH of Flour; Y: Yield ha^{-1}

Table 7. Correlation coefficient matrix of local landraces for the years 2018–2019 and 2019–2020.

Traits	Pr	Ms	St	Glu	TGWt	T. Wt	B.Q	C.Q	Sd.L	Sd.W	Sd.T	H	pH F	Y
Pr	1	0.221	.354*	.582**	0.300	0.021	0.329*	.590**	0.270	-0.004	0.249	0.514*	0.278	0.087
Ms	0.276	1	0.187	0.224	-0.046	0.105	0.024	0.180	-0.012	-0.265	-0.121	0.291	0.051	-0.088
St	0.183	0.101	1	0.102	0.124	0.275	0.025	0.279	-0.032	-.339*	-0.031	0.212	0.132	0.213
Glu	0.683**	0.138	0.026	1	0.245*	0.256	0.108	0.799**	0.083	0.101	0.321	0.117	-0.219	0.211
TGWt	0.025	-0.034	-0.161	0.073	1	0.380*	0.419*	0.365*	0.624**	0.606**	0.651**	-0.134	-0.111	0.566**
T.Wt	-0.011	0.088	0.024	0.57	-0.019	1	0.153	0.265	0.105	-0.077	0.108	0.064	-0.393*	0.440**
B.Q	0.131	0.119	0.367*	0.011	-0.129	.385*	1	0.221	0.358*	0.137	0.115	0.142	0.140	0.230*
C.Q	0.684**	0.023	-0.024	0.918**	0.092	0.183	0.038	1	0.134	0.027	0.250	0.111	0.022	0.379*
Sd.L	0.025	0.124	0.039	-0.071	-0.169	-0.076	0.271	-0.132	1	0.140	0.260	-0.199	-0.123	0.314
Sd.W	-0.081	-0.417*	-0.050	-0.042	0.120	-0.208	-0.391*	-0.019	-0.119	1	0.787**	-0.242	-0.118	0.017
Sd.T	-0.090	-0.201	-0.314	-0.001	0.041	-0.139	-0.051	-0.041	0.131	0.159	1	-0.029	-0.121	0.121
H	0.257	0.123	-0.092	0.071	0.169	0.130	0.210	0.129	-0.151	-0.131	0.117	1	0.382*	-0.216
pHF	0.210	0.165	0.091	0.044	-0.123	-0.459**	0.143	0.079	-0.056	-0.217	0.043	0.251	1	0.019
Y	0.298*	0.021	0.084	0.378*	-0.229	0.466**	0.142	0.408*	0.076	-0.190	-0.086	0.036	-0.029	1

The above diagonal values represent the year 2018–2019 and the below diagonal represents the year 2019–2020.** $P = < 0.05$, $P = < 0.01$
Pr: Protein; Ms: Moisture; St: Starch; Glu: Gluten; TGWt: Thousand grain weight; T.Wt: Test weight; B.Q: Bread quality; C.Q: Chapatti quality; Sd.L: Seed length; Sd.W: Seed width; Sd.T: Seed thickness; H: Grain hardness; pHF: pH of Flour; Y: Yield ha^{-1}

Table 8. Correlation coefficient matrix in miscellaneous germplasm for the years 2018–2019 and 2019–2020.

Traits	Pr	Ms	St	Glu	TGWt	T. Wt	B.Q	C.Q	Sd.L	Sd.W	Sd.T	H	pH F	Y
Pr	1	0.006	-0.499	0.645*	-0.041	-0.314	-0.151	0.566*	0.064	0.021	0.160	-0.015	-0.090	0.112
Ms	-0.348*	1	-0.314	-0.134	0.214	0.234	0.031	-0.022	0.343	-0.097	-0.122	0.022	0.167	0.151
St	-0.353*	-0.025	1	-0.703**	-0.096	0.255	0.00	-0.651**	-0.358	-0.210	-0.213	0.078	0.130	-0.401
Glu	0.581*	-0.398	-0.381	1	0.161	-0.306	-0.042	0.947**	0.315	0.401	0.207	-0.138	-0.187	0.111
TGWt	0.011	-0.043	-0.033	0.240	1	-0.106	0.081	0.327*	0.821**	0.138	0.215	-0.649**	0.111	-0.229
T.Wt	-0.308	0.134	0.273	-0.379	-0.299	1	-0.437	-0.321	-0.201	-0.119	-0.470	-0.173	-0.265	-0.151
B.Q	-0.064	0.440	0.266	-0.214	-0.125	-0.331	1	-0.119	-0.123	-0.265	0.091	0.079	0.115	-0.035
C.Q	0.663**	-0.266	-0.514	0.971**	0.269	-0.355	-0.243	1	0.312	0.413	0.102	-0.228	-0.107	0.014
Sd.L	0.001	0.067	-0.312*	0.203	0.568*	-0.242	-0.228	0.328	1	0.573*	0.655*	-0.412	-0.134	0.156
Sd.W	0.183	-0.156	-0.121	0.278	-0.136	-0.072	-0.213	0.290	0.244	1	0.585*	-0.029	-0.124	-0.153
Sd.T	-0.117	-0.064	0.212	0.102	0.171	-0.164	0.156	0.019	-0.154	0.325	1	-0.081	-0.077	0.432**
H	-0.087	0.061	0.001	-0.203	-0.814**	-0.023	0.293	-0.258	-0.511*	-0.142	-0.153	1	0.414	0.172
pHF	-0.047	-0.180	0.020	-0.259	0.061	-0.302	-0.020	-0.261	-0.017	-0.539*	-0.271	0.243	1	-0.113
Y	0.185	0.305*	-0.390*	0.032	-0.216	-0.182	0.094	0.130	0.084	0.023	0.226	0.219	-0.035	1

The above diagonal values represent the year 2018-19 and the below diagonal represents the year 2019-20. ** $P = < 0.05$, $P = < 0.01$
Pr: Protein; Ms: Moisture; St: Starch; Glu: Gluten; TGWt: Thousand grain weight; T.Wt: Test weight; B.Q: Bread quality; C.Q: Chapatti quality; Sd.L: Seed length; Sd.W: Seed width; Sd.T: Seed thickness; H: Grain hardness; pHF: pH of Flour; Y: Yield ha^{-1}

DISCUSSION

The use of a fast, reliable, and non-destructive technique (NIR), which is inexpensive in terms of cost (Osborne, 2000), analyzed protein, starch, gluten, and moisture. Analysis of variance (ANOVA) of the recorded traits exhibited the presence of genetic diversity within the whole germplasm population for almost all the characters. Significant differences occurred regarding protein, starch, gluten, bread quality, and chapatti quality for all the blocks of augmented design. Meanwhile, non-significant block effects showed for yield and grain size. Environmental conditions can play an important role in the expression of quality traits. It can significantly affect the quality traits of wheat crops (Murray *et al.,* 2016).

The protein content is highly essential in wheat breeding (Javed *et al.,* 2022). It gets influenced mainly by the rate and time of nitrogen fertilizer application, genotype, and crop environment (Zecevic *et al.,* 2010). A wide range of genetic diversity emerged for protein percentage, which ranged from 11.2 to 15.4 and 10.9 to 15.9 during 2018–2019 and 2019–2020, respectively. Guttieri *et al.* (2004) also studied three different wheat populations and reported the same range, i.e., 12.00%–17.7% regarding protein. Similarly, Giroux *et al.* (2000) observed a wide range of diversity regarding protein content, i.e., 14.2% to 15.8% in five different spring wheat populations, which is lesser than the presented study.

Hruskova and Famera (2003) found the range of grain moisture content, i.e., 11.7% to 14.1% by using NIR in a bread wheat population, which is comparable with the current findings. The obtained results of protein and gluten content are in agreement with the results of Dencic *et al.* (2010), who studied 140 genotypes of wheat collected from 28 different countries and found a range of 11.8%–15.9% and 21.3%–40.6% regarding protein and gluten content, respectively. The collected range of thousand-grain weight in all the population sets is at par with the findings of Sajjad *et al.* (2012). Maqbool *et al.* (2010) also reported a similar range of thousand-grain weight, i.e., 21.0–43.9 and 22.6–45g in their studies. In agreement with the study findings, Martin *et al.* (2001) recorded the same score range regarding test weight, which ranged from 66.2–80.2 kg m^{-3} in 130 recombinant inbred lines of red spring wheat. Zahoor (2003) also reported a wide range of test weights in Pakistani wheat varieties, which were 68.30–81.0 kg hl^{-1}. In the presented study, higher grain yield showed for both years (1329–6329 Kg ha^{-1} and 1232–6101 Kg ha^{-1}), which is more than the range observed by Kotal *et al.* (2010) in their findings.

Correlation among quality traits

Bread-making quality is a highly vital character of the wheat crop. It depends on all the yield-related parameters associated with bread quality. The bread quality is significantly affected by the protein, starch, test weight, and gluten content (Yang *et al.,* 2020). Protein and gluten are very crucial for bread quality (Ahmad *et al.,* 2022). In the whole wheat germplasm, protein and starch showed a positive association with the bread quality during both study years. In CIMMYT germplasm and local landraces, the bread quality correlates positively with protein, starch, and gluten. On the other hand, in Pakistani and miscellaneous germplasms, the bread quality gave a positive association with starch during both years, while a non-significant and negative association with protein and gluten. This association pattern explained that for the improvement in the quality of wheat, breeders should consider the local landraces and CIMMYT material in their crossing program. Dirkvand *et al.* (2013) examined 92 bread wheat genotypes and confirmed the positive correlation of bread quality with protein and gluten content. Similarly, Dirkvand *et al.* (2013) also found that protein percentage had a positive and significant relation with the thousand-grain weight and seed length, which is similar to these findings. In the current results in whole germplasm, the protein content showed a positive association (0.073) with thousand-grain weight during 2018–2019, while in 2019–2020, protein showed a non-significant but negative association with the thousand-grain weight.

The grain protein in the wheat crop depends on the availability of nitrogen. The need for nitrogen in a plant also depends on environmental conditions at the grain-filling stage. A report found that grain yield and protein content are usually negatively associated with each other (Nuttall *et al.,* 2017). The Pakistani and CIMMYT germplasms gave a negative association for yield and grain protein. The seed characters, i.e., test weight, thousand-grain weight, and seed length, width, thickness, and hardness, are very important yield-contributing characters in cereals (Ficco *et al.,* 2020). In the whole germplasm of bread wheat, the grain yield gave a positive association with all the seed traits. i.e., test weight, thousand-grain weight, seed length, width, thickness, and hardness during both years, which confirmed these traits in the enhancement of grain yield. Higher grain yield is the outcome of better and heavier grains. Similar results appeared from previous works (Dirkvand *et al.,* 2013; Kanwal *et al.*, 2019). The grain yield is the ultimate goal of the plant breeder to fulfill the boosting demand of wheat consumption under the world's climate change scenario with a continuously decreasing culturable land in the country.

Being an international institute, CIMMYT continuously supplies elite germplasm of wheat and maize to Pakistan each year since the 1960s. With this collaboration, CIMMYT germplasm use is extensive in a wheat breeding program of WRI, Faisalabad, Pakistan. Therefore, the parentage of advanced lines of WRI, i.e., the parentage of Uqab-2000 is Crow 'S'/NAC//BOW'S, can be traced back to materials from CIMMYT. Presently, these lines are also extensively utilized in the crossing scheme of WRI for developing new climate-resilient wheat varieties.

CONCLUSION

Wheat grain with better quality parameters is the foremost requirement for developing varieties with high yield potential. The knowledge of the mutual association of these traits is indispensable. Correlation studies demonstrated a similar trend of correlating traits in Pakistani and CIMMYT lines, but distinct patterns of association occurred among old varieties (landraces) and miscellaneous genotypes. A strong association of seed traits, such as, grain length, width, thickness, test weight, and thousand-kernel weight, appeared with each other and the grain yield. Therefore, for selecting genotypes with high yield potential, such grain size traits should have more consideration. A positive but non-significant association of grain yield with protein, moisture content, starch, gluten, and bread quality emerged, which indicated that these traits have no significant effects on yield. However, these traits should gain focus for improving the quality attributes of selected genotypes. Pre-green revolution varieties (local landraces) exhibited better quality traits (test weight, bread and chapatti quality, protein, and gluten) with grain yield. It indicated that for quality enhancement of modern wheat cultivars, pre-green revolution era wheat material requires utilization in the wheat breeding programs.

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