Genetic variability for production traits of winter wheat genotypes at Miandam (Swat), KPK, Pakistan.

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ABSTRACT- The Current research was carried using ten Elite lines with one check of Winter wheat (E_1, E_2, E_3… and E_{11}) under climatic condition of Miandam (swat) under research wing of The University of Agriculture Peshawar, during the crop season of 2017-18. Eleven lines were evaluated in randomized complete block design with three replications to estimate heritability, and selection response of various morphological and yield traits. Data was recorded on days to heading, days to maturity, plant height, spike length, spikelets per spike, grains per spike^{-1}, 1000-grain weight, biological yield, grain yield and harvest index. Analysis of variance revealed high significant differences among all the traits. The highest grain yield was noted for line E_2 (5333 kg ha^{-1}) followed by E_1 (4913 kg ha^{-1}) and E_8 (4629 kg ha^{-1}), thus these line be used as parents in future breeding programs for evolving high yielding genotypes.

Key words: Coefficient of variation, Genetic variability, Heritability, Phenotypic variance, Selection response

I. INTRODUCTION

Wheat (*Triticumaestivum* L.) is a widely consumed staple food crop that is hexaploid specie containing 42 chromosomes. In Pakistan, the wheat crop is the most popular and is recognized as the major dietary crop among other cereals. The wheat crop has been grown in this region since the beginning. According to several researchers, wheat was reviewed for the first time in the Indus Valley. When compared to other crops, wheat is produced over the largest area of 36% of agriculture land and is also the most dominating in production. However, the crop is used in varied purposes. Pakistan is the

4th largest producer of wheat in Asia and the 11th largest producer in the world (PAR, 2016). Being the country's most valued and first crop in staple meal (Ahmad *et al.,* 2010) it attracts growers, breeders and other researchers (Chen *et al.,* 2021) to put their efforts to boost the production of wheat in order to resolve the food shortage problems resulting from the exploding population (Botyanszka *et al.,* 2020).

Due to the continuous increase in population, an increase in food production, particularly wheat, is necessary (Pronin *et al.,* 2020). As every environment is different, it is important to release relative high yielding genotypes across a wide range of conditions (Zhang *et al.,* 2020). Wheat was cultivated on 8.74 million hectares in Pakistan throughout 2018-19, yielding 25.20 million tonnes of grain with an average yield of 2883 kg ha^{-1}, whereas it was grown on 0.74 million hectares in Khyber Pakhtunkhwa, yielding 1.33 million tonnes of grain with an average production of 1795 kg ha^{-1} (Pakistan Economic Survey, 2018-19). Grain yield is considered a complex trait which is influenced both by genotype, environment and their combined interaction (Bazai *et al.,* 2020). Breeders who develop varieties that meet their specific needs (Sohail *et al.,* 2018) have focused on strains with a high level of variability for yield and yield related features (Mangi *et al.,* 2007; Roy *et al.,* 2021). In order to meet the current need of the world the breeders are working hard and utilizing all the available resources to improve the existing varieties as well as release new varieties (Farooq *et al.,* 2018)

To evaluate a trait's effectiveness, as well as its genetic stability and performance, the concepts heritability, genetic advance and variance are utilized by the breeders (Memon *et al.,* 2018; Shenoda *et al.,* 2021). For selection of a particular trait the presence of large amount of variability is the most convenient way. (Regmi *et al.,* 2021). In order to study the amount of variance in the wheat crop, the heritability and genetic advance is used the most (WAHYU *et al.,* 2018), (Khan *et al.,* 2020; Channa *et al.,* 2021). Heritability is a term used to describe the percentage of a trait that passed down to the next generation (Gandahi *et al.,* 2020; Shamuyarira *et al.,* 2019). Heritability data aids plant breeders in estimating the behavior of later generations and making suitable selections. However studies suggest that heritability estimation is most effective when coupled with genetic advance values. Genetic advance along with heritability is used to put increment in the utility of heritability (Kumar *et al.,* 2021). It indicates the degree of gain in a character obtained under a particular selection pressure (Olbana *et al.*, 2021). Thus, genetic advance is yet another important selection parameter that aids breeder in a selection program (Laghari *et al.*, 2021). If yield and its key contributing traits have more heritability and genetic advance value it may be considered as a better genetic stock (Al-Kharkhi and Mousa, 2021; Thungo *et al.*, 2021).

II. MATERIALS AND METHODS

Study Site

This experiment was conducted at Miandam (Swat), under research wing of The University of Agriculture Peshawar during 2017-18 rabi season. Ten Elite lines of winter wheat with one check were evaluated in Randomized Complete Block Design (RCBD) with three replications. Each genotype was planted in five rows. The row length was five meter and row to row distance was 0.30 meter. Date of sowing was 27th November. Standard agronomics practices were followed from sowing till harvesting. For data collection ten randomly plants were selected from three rows. Data was recorded on following parameters.

Days to heading

From the date of plating till the date when the spikes were emerged 50% in number, so we counted these days and was considered days to heading.

Plant height

At the time of physiological maturity the stature of the plant was measured using graduated rod from the base to tip of plant while the awns were not measured.

Flag leaf area

Flag leaf area (cm^2) for each genotype was determined by the following formula.

Flag leaf area = Leaf length × Leaf width × 0.75

Spike length

The mentioned trait was studied by selecting ten phenotypically random plants and then the spikes were collected and the length was measured base of the spike to the topmost portion except awns.

Grain weight spike^{-1}

Spikes of ten randomly selected plants were threshed and weighed to determine grain weight per spike.

1000-grain weight

With the help of an electronic balance the weight of 1000 grains of each genotype was measured and the weight was taken in grams.

Biological yield plant^{-1}

After drying every bundle of each genotypes in the sun for eight days it was weight using balance and all the observed data was then converted to kg ha^{-1}.

Grain yield

The mentioned parameter was recorded when every genotype of each replication was trashed separately and then it was weighted with the help of electric balance and the weight was then converted to kg ha^{-1} using excel.

Harvest index

Harvest index was determined as the ratio of grain yield to the biological yield from each plant. The following formula was used to estimate harvest index:

$$\text{Harvest index} = \frac{\text{Grain yield per plant}}{\text{Biological yield per plant}} \times 100$$

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) technique as outlined by Steel and Torrie (1980). Least Significant Difference (LSD) test was also used for means separation and comparison.

Heritability and Genetic advance

Broad sense heritability for yield and its contributing traits was computed using variances of parental lines/cultivars and F4 populations of each cross combinations using the general formula:

$$h^2_{B.S} = \frac{Vg}{Vg + Ve} = \frac{Vg}{Vp}$$

Where,

$h^2_{B.S}$ = broad sense heritability, Vg = Genotypic variance, Ve = Environmental variance, Vp = Phenotypic variance

Expected genetic advance (GA) was computed using the following method (Allard, 1960).

$GA = i \times vp \times h^2$

Where,

GA = Expected genetic advance

i = 1.40 at 20% selection intensity

Vp = phenotypic variance of a trait

$h^2_{B.S}$ = broad sense heritability for a trait

III. RESULTS

Data regarding different morphological traits of 10 Elite lines with one check are presented in this portion. The mean squares for various morphological traits are presented in the Table 1, while means are given in the Table 2. Heritability, variance components and selection response for various morphological traits are given in Table 3.

A. Days to heading

Statistical analysis of the data for days to heading showed highly significant differences among winter wheat genotypes (Table1). The coefficient of determination (R^2) and variance for days to maturity were 0.95% and 0.56 respectively. Days to heading of winter wheat genotype ranged from 116 to 123 days. The lowest days to heading was observed for winter wheat genotype E_1 (116 days) while the highest days to heading was noted for genotype E_6 (123 days) (Table2). Genetic variance (5.95) for days to heading was much greater than environmental variance (0.466). The broad sense heritability for days to heading was 0.92 while selection response was 3.288 (Table 3).

B. Days to maturity

From the ANOVA it was yielded that the winter wheat genotypes were significantly varied (Table 1). The R^2 (coefficient of determination) value and variance for the mentioned trait were 0.615% and 0.567. Maturity days of winter wheat genotype ranged from 154 to160 days. The lowest days to maturity was observed for winter wheat genotype E_7 (154 days) while the highest days to maturity was noted for genotype E_4 (160days) (Table2). Genetic variance (2.56) for days to heading was much greater than environmental variance (3.603). Heritability in broad sense yielded for the studied trait was 0.415 while the genetic advance was 1.44 (Table 3).

C. Plant height

The ANOVA yielded that statue of plant was recorded significantly varied. The analysis of variance showed highly significant differences among winter wheat genotypes for Plant height (Table 1). The coefficient of determination (R^2) and variance for plant height were 0.95% and 0.94 respectively. Plant height of winter wheat genotype ranged from 101 to112 cm. The lowest plant height was observed for winter wheat genotype E_4 (101 cm) while the highest plant height was noted for genotype E_6 (112 cm) (Table2). Genetic variance (13.49) for plant height was much greater than environmental variance (1.009). The broad sense heritability for plant height was 0.93 while selection response was 4.96 (Table 3).

D. Spike length

The analysis of variance exhibited highly significant differences among winter wheat genotype for spike length (Table 1). The coefficient of determination (R^2) and variance for spike length was 0.79% and 4.35 respectively. Spike length of winter wheat genotype ranged from 8.7 to 11.01cm. The lowest spike length was observed for winter wheat genotype E_8 (8.77cm). While the highest spike length was noted for genotype E_{11} (11.01cm) (Table2). Genetic variance (0.388) for spike length was much greater than environmental variance (0.179). The broad sense heritability for spike length was 0.68 while selection response was 0.72 (Table 3).

E. Spikelets per spike

The analysis of variance for single spike weight revealed highly significant differences among winter wheat genotypes (Table 1). The coefficient of determination (R^2) and variance for single spike weight were 0.82% and 2.66 respectively. Spikelets per spike of winter wheat genotype ranged from 18.7 to 21.6 spiklets. The lowest single spikelets per spike were observed for winter wheat genotype E_4 (18.7spiklets) while the highest spikelets per spike were noted for genotype E_1 (21.6 spikelets) (Table2). Genetic variance (0.725) for spikelets per spike was recorded greater than environmental variance (0.277). The broad sense heritability for spiklets per spike was 0.723 while selection response was 1.013 (Table 3).

F. Grains per spike

The analysis of variance showed highly significant differences among winter wheat genotype for grains per spike (Table 1). The coefficient of determination (R^2) and variance for grains per spike were 0.602% and 4.22 respectively other researches also reported highly significant among genotype for grain per spike like Suleiman et al (2014). Grains per spike of winter wheat genotype ranged from 60.7 to70.4 grains. The lowest grains per spike was observed for winter wheat genotype E_5 (60.7 grains) while the highest grains per spike was noted for genotype E_9 (70.3 grains) (Table2). Genetic variance (4.96) for grains per spike was much lower than environmental variance (7.43). The broad sense heritability for grains per spike was 0.40 while selection response was1.97 (Table 4).

G. 1000 Grain weight

Analysis of variance of thousand grain weight revealed highly significant difference among winter wheat genotypes (Table 1). The coefficient of determination (R^2) and variance for thousand grain weight was 0.805% and 9.311 respectively. Thousand grain weight of winter wheat genotype ranged from 22.6 to 36.3 gm. The lowest value for grain for thousand grain weight was observed for winter wheat genotype E_5 (22.6gm) while the highest value for thousand grain weight was noted for genotype E_1 (36.3gm) (Table2). Genetic variance (16.96) for thousand grain weight were much greater than environmental variance (7.34). The broad sense heritability for thousand grain weight was0.69 while selection response was 4.81 (Table 4).

H. Biological yield

The analysis of variance showed highly significant differences among winter wheat genotype for biological yield (Table 1). The coefficient of determination (R^2) and variance for biological yield were 0.955% and (2.371) respectively. Biological yield of winter wheat genotype ranged from 10975.3kg per hectare to 13901.2. The lowest biological yield was observed for winter wheat genotype E_7 (10975 kg per hectare) while the highest biological yield was noted for genotype E_2 (13901.2 kg per hectare) (Table2). Genetic variance (1098581) for biological yield was much greater than environmental variance (88376). The broad sense heritability for biological yield was 0.92 while selection response was 1411.7 (Table 4).

I. Grain yield

The analysis of variance showed highly significant differences among winter wheat genotype for grain yield (Table 1). The coefficient of determination (R^2) and variance for grain yield was 0.792% and 9.661 respectively grain yield of winter wheat genotype ranged from 3382.6 to 5333.3 kg per hectare. The lowest grain yield was observed for winter wheat genotype E_7 (3382.6 kg per hectare) while the highest grain yield was noted for genotype E_2 (5333.3 kg per hectare) (Table2). Genetic variance (268180) for grain yield was much greater than environmental variance (167130). The broad sense heritability for grain yield was (0.616) while selection response was (569.05) (Table 4).

j. Harvest index

The analysis of variance showed highly significant differences among winter wheat genotype for harvest index (Table 1). The coefficient of determination (R^2) and variance for harvest index were 0.67% and9.015 respectively. Harvest index of winter wheat genotype ranged from 29.63 to38.33. The lowest harvest index was observed for winter wheat genotype E_5 (29.63) while the highest harvest was noted for genotype E_2 (38.33) (Table 2). Genetic variance (7.25) for harvest index were less than environmental variance (9.19). The broad sense heritability for harvest index was 0.441 while selection response was 2.503 (Table 4).

Table 1. Means squares for morphological and yield traits of winter wheat genotypes at Miadam during 2017-18.

Source	Df	Days to heading	Days to maturity	Plant height (cm)	Spike length (cm)	Spikelets per spike	Grains per spike	Thousand grain weight (g)	Biological yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Harvest index (%)
REP	2	3.6	1.3	1.9	0.3	0.3	0.93	12.2	224124	1513932	32.2
GEN	10	18	11.2	41.4	1.3	2.5	22.3	58.2	3384120	971670	30.9
ERROR	20	0.46	3.6	1	0.2	0.3	7.4	7.3	88376	167130	9.2
R^2		0.95	0.61	0.94	0.79	0.82	0.60	0.80	0.95	0.79	0.67
CV		0.567	1.2	0.9	4.35	2.66	4.22	9.31	2.37	9.66	9.01

Table 2. Means for morphological and yield traits of winter wheat genotypes at Miandam during 2017-18.

Geno	Days to heading	Days to maturity	Plant height (cm)	Spike length (cm)	Spikelets per spike	Grains per spike	Thousand grain weight (g)	Biological yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Harvest index (%)
E_1	116	155	111	10.4	21	64	36.3	13888	4913	35.3
E_2	119	157	110	9.7	20	65	24.7	13901	5333	38.3
E_3	120	157	108	9.1	19	62	28.1	12814	3888	30.1
E_4	123	160	101	10.1	18	61	25.6	12975	4296	32.9
E_5	119	155	107	9.7	19	61	22.7	13654	4061	29.6
E_6	123	159	112	10.1	20	65.6	27.7	12926	4012	30.9
E_7	121	154	102	9.1	18	66.5	29.3	10975	3382	30.7
E_8	123	157	106	8.7	19	65.7	33.7	12209	4629	37.9
E_9	122	159	105	9.3	21	70.3	27.9	11629	4172	35.7
E_{10}	118	156	104	9.5	20	64.03	28.2	11111	3543	31.8
E_{11}	117	155	104	11	19	64.03	35.7	11814	4308	36.4
Min	116.3	154. 3	101.5	8.77	18.7	60.7	22.6	10975.3	3382.67	29.63
Max	123.6	160.3	112.9	11.01	21.6	70.3	36.3	13901.1	5333.3	38.3
LSD	1.16	3.23	1.71	0.72	0.89	4.64	4.61	506.32	696.29	5.16

Table 3. **Variance components, heritability and selection response for morphological traits of winter wheat genotypes at Miandam (Swat) during 2017-18.**

	Days to heading	Days to maturity	Plant height (cm)	Spike length (cm)	Spikelets per spike
Vg	5.95	2.56	13.49	0.39	0.725
Ve	0.46	3.60	1.01	0.18	0.277
Vp	6.418	6.16	14.503	0.58	1.00
h^2	0.92	0.41	0.93	0.68	0.723
Re	3.28	1.44	4.96	0.72	1.014

Table 4. **Variance components, heritability and selection response for yield traits of winter wheat genotypes at Miandam (Swat) during 2017-18.**

	Grains per spike	Thousand grain weight (g)	Biological yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Harvest index (%)
Vg	4.96	16.96	1098581	268180	7.25
Ve	7.43	7.34	88376.4	167130	9.19
Vp	12.40	24.31	1186958	435310	16.44
h^2	0.40	0.69	0.92554	0.62	0.441
Re	1.97	4.82	1411.7	569.056	2.503

IV. DISCUSSIONS

The aim of the study was to determine the suitability of ten elite lines of spring wheat according to their competitive potential. All genotypes were grown under well irrigated condition while all other culture practices were uniformly applied to each genotype in each row. Results demonstrated highly significant differences for all the investigated traits amongst genotypes which indicated the existence of considerable genetic variability. For most genotypes, the mean values of all the investigated traits fluctuated. Mean values for yielding traits in spring wheat were also not consistent, Saleem *et al.* (2017) and Tremmel-Bede *et al.* (2020) found a similar pattern of variation in spring wheat genotypes under well irrigated conditions. Grain yield indicated significant differences among genotypes which revealed that vernalization had impact on the grain filling duration and the performance of other yield related parameters. Similar to our results, Matlala *et al.* (2019) also observed highly significant differences for the mentioned studied traits. They use randomized complete block design and also their genotypes were passed on vernalization period. They suggested that these genotypes need further testing across different environments and locations. Furthermore, in the current study it was observed that grain yield of wheat is directly influenced by yield attributing traits i.e. spikes meter^{-2}, spikelets spike^{-1}, grains spike^{-1}, grain weight spike^{-1}, 1000-grain weight and biological yield. Therefore, plant breeder should pay more attention to these parameters for improving yield and adaptation of new cultivars to environmental stresses in breeding programs as concluded by Mdluli *et al.* (2020). Significant genetic variation in various traits among genotypes suggested that selection for these characters would be beneficial. However, absolute variability in distinct characters cannot be used to determine which character has the greatest degree of variability. For the purpose of determining the selection criteria, heritability and genetic advance were computed. The results of our study indicated that genetic variance was greater than environmental variance for days to heading, plant height, spike length, spikelets spike^{-1}, thousand grain weight, biological yield, and grain yield, implying that variation due to genetic was significantly larger than environmental. Similarly, Jain *et al.* (2017) and Khan *et al.* (2020) also observed high value of genetic variance compared to environmental variance in their results. Moreover, for days to maturity, grains spike^{-1} and harvest index genetic variance were recorded lower than environmental variance, these results shows similarity with the results of Ali *et al.* (2008) and Channa *et al.* (2021) they also observed such type of results in their analysis. The heritability estimates ranged from 40% for grains per spike to 93.0% for plant height. The magnitude of heritability and expected genetic advance are important for the prediction of response to selection in diverse environment and provide the basis for planning and evaluating breeding programs Ahmed *et al.* (2007), Botyanszka *et al.* (2020) and Zhang *et al.* (2020). High value of heritability coupled with high genetic advance value for days to heading, plant height, spike length, spikelets spike^{-1}, thousand grain weight, biological yield and grain yield was also recorded by Farhan *et al.* (2016) while Rahman *et al.* (2016) estimated moderate to low value of heritability for days to maturity, grain spike^{-1} and harvest index indicated that environmental effects constitute a sufficient portion of the total phenotypic variation and hence, selection for these characters will be less effective.

V. CONCLUSION

Significant differences among genotypes for all traits revealed presence of genetic variability among genotypes. Most of the traits showed high heritability (0.60-0.93). Higher grain yield was observed for genotypes WWE_2, WWE_1 and WWE_8. Therefore, above winter wheat genotypes should be tested at more locations of upper Swat.

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.

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REFERENCES

Ahmed, N., Chowdhry, M. A., Khaliq, I., & Maekawa, M. (2007). The inheritance of yield and yield components of five wheat hybrid populations under drought conditions. *Indonesian Journal of Agricultural Science*, *8*(2), 53-59.

Ali, Y., Atta, B. M., Akhter, J., Monneveux, P., & Lateef, Z. (2008). Genetic variability, association and diversity studies in wheat (Triticum aestivum L.) germplasm. *Pak. J. Bot*, *40*(5), 2087-2097.

Al-Kharkhi, M. H. S., & Mousa, M. A. (2021). THE EFFECT OF WHEAT GERMINATION PROCESSES ON THE NUTRITIONAL PARAMETERS OF WHEAT FLOUR. *Plant Archives*, *21*(1), 789-797.

Bazai, K. K., Baloch, M., Sootaher, J. K., Baloch, T. A., Naeem, M., Abro, T. F., ... & Menghwar, K. K. (2020). Correlation, heritability and genetic distance analysis in bread wheat (Triticum aestivum L.) genotypes: Different genetic analyses for the exploitation of bread wheat genotypes. *Proceedings of the Pakistan Academy of Sciences: B. Life and Environmental Sciences*, *57*(1), 75-83.

Botyanszka, L., Zivcak, M., Chovancek, E., Sytar, O., Barek, V., Hauptvogel, P., ... & Brestic, M. (2020). Chlorophyll fluorescence kinetics may be useful to identify early drought and irrigation effects on photosynthetic apparatus in field-grown wheat. *Agronomy*, *10*(9), 1275.

Channa, Q. A., Jatoi, W. A., Memon, S., Lund, M. M., Kaimkhani, M. S., Khokhar, R. A., ... & Bhatti, H. A. (2021). 24. Estimation of genetic variability and heritability in F2 populations of wheat (Triticum aestivum L.) genotypes under drought stress conditions. *Pure and Applied Biology (PAB)*, *11*(1), 232-248.

Chen, R., Xiong, X. P., & Cheng, W. H. (2021). Root characteristics of spring wheat under drip irrigation and their relationship with aboveground biomass and yield. *Scientific Reports*, *11*(1), 1-14.

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.

Gandahi, N., Baloch, A. W., Sarki, S. M., Lund, M. M., & Kandhro, M. N. (2020). CORRELATION ANALYSIS BETWEEN MORPHOLOGICAL, PHYSIOLOGICAL AND YIELD TRAITS UNDER SALINITY STRESS CONDITION IN WHEAT (TRITICUM AESTIVUM L.) GENOTYPES. *Pakistan Journal of Agriculture, Agricultural Engineering and Veterinary Sciences*, *36*(2), 129-134.

Hossain, M. M., Azad, M. A. K., Alam, M. S., & Eaton, T. E. J. (2021). Estimation of variability, heritability and genetic advance for phenological, physiological and yield contributing attributes in wheat genotypes under heat stress condition. *American Journal of Plant Sciences*, *12*(04), 586.

Jain, N., S. Marker and S. Kanwar. (2017). Assessment of genetic variability in late sown wheat (*Triticum aestivum* L.) germplasm. *Chemical Science Review and Letter* 6(22): 1295-1300.

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 and Applied Biology (PAB)*, *6*(2), 538-543.

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, R., Bozdar, H. B., Jamali, K. D., & Sial, M. A. (2021). Evaluation of yield and its components in bread wheat (triticum aestivum l.) genotypes. *Journal of Applied Research in Plant Sciences*, *2*(1), 76-82.

Laghari, F. H., Mari, S. N., Sootaher, J. K., Gadahi, A. A., Chang, M. S., Maree, A., ... & Shah, A. G. (2021). Heritability and genetic advance studies in F2 population of bread wheat (Triticum aestivum L.). *International Journal of Biology and Biotechnology*, *18*(1), 157-167.

Mangi, S. A., Sial, M. A., Ansari, B. A., & Arain, M. A. (2008). Study of genetic parameters in segregating populations of spring wheat. *Pak. J. Bot*, *39*(7), 2407-2413.

Matlala, M., Shimelis, H., & Mashilo, J. (2019). Genotype-by-environment interaction of grain yield among candidate dryland wheat genotypes. *South African Journal of Plant and Soil*, *36*(4), 299-306.

Mdluli, S. Y., Shimelis, H., & Mashilo, J. (2020). Screening for pre-and post-anthesis drought responses in selected bread wheat (Triticum aestivum L.) genotypes. *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science*, *70*(4), 272-284.

Memon, S., Iqbal, N., Zaman, F., Abro, M. A., Jatoi, G. H. J., & Mangi, A. R. (2018). Heritability estimates in F2 segregating population in hexaploid wheat (Triticum aestivum L.). *Pakistan Journal of Biotechnology*, *15*(3), 803-810.

Olbana, T. M., Mekbib, F., & Tadesse, W. (2021). Assessment of genetic variability among bread wheat genotypes for agronomic and morphological traits under optimum and stress condition.

Pakistan Agriculture Research Council (PAR). 2016. Importance of Wheat in Pakistan. http://edu.par.com.pk/wiki/wheat/#wheat-crop-overview.

Pakistan Economic Survey. 2018-19. Agricultural Statistics of Pakistan, Govt. of Pakistan, Islamabad.

Pronin, D., Börner, A., & Scherf, K. A. (2021). Old and modern wheat (Triticum aestivum L.) cultivars and their potential to elicit celiac disease. *Food Chemistry*, *339*, 127952.

Pronin, D., Börner, A., Weber, H., & Scherf, K. A. (2020). Wheat (Triticum aestivum L.) breeding from 1891 to 2010 contributed to increasing yield and glutenin contents but decreasing protein and gliadin contents. *Journal of Agricultural and Food Chemistry*, *68*(46), 13247-13256.

Rahman, M., Barma, N. C. D., Biswas, B. K., Khan, A. A., & Rahman, J. (2016). Study on morpho-physiological traits in spring wheat (Triticum aestivum L.) Under rainfed condition. *Bangladesh Journal of Agricultural Research*, *41*(2), 235-250.

Regmi, S., Poudel, B., Ojha, B. R., Kharel, R., Joshi, P., Khanal, S., & Kandel, B. P. (2021). Estimation of genetic parameters of different wheat genotype traits in Chitwan, Nepal. *International Journal of Agronomy*, *2021*.

Roy, A., Kumar, A., Singh, A., Mandi, A., & Barman, M. (2021). Analysis of genetic diversity and correlation studies on grain yield and its component characters in bread wheat (Triticum aestivum L. em Thell) genotypes. *Pharm. Innov. J*, *10*(5), 341-345.

Saleem, B., Khan, A. S., Shahzad, M. T., & Ijaz, F. (2016). Estimation of heritability and genetic advance for various metric traits in seven F2 populations of bread wheat (Triticum aestivum L.). *Journal of Agricultural Sciences, Belgrade*, *61*(1), 1-9.

Shamuyarira, K. W., Shimelis, H., Tapera, T., & Tsilo, T. J. (2019). Genetic advancement of newly developed wheat populations under drought-stressed and non-stressed conditions. *Journal of Crop Science and Biotechnology*, *22*(2), 169-176.

Shenoda, J. E., Sanad, M. N., Rizkalla, A. A., El-Assal, S., Ali, R. T., & Hussein, M. H. (2021). Effect of long-term heat stress on grain yield, pollen grain viability and germinability in bread wheat (Triticum aestivum L.) under field conditions. *Heliyon*, *7*(6), e07096.

Sohail, A., Rahman, H., Ullah, F., Shah, S. M., Burni, T., & Ali, S. (2018). Evaluation of F4 bread wheat (Triticum aestivum L.) genotypes for genetic variability, heritability, genetic advance and correlation studies. *Journal of Plant Breeding and Genetics*, *6*(1), 01-07.

Steel, R. G. D., & Torrie, J. H. (1980). *Principles and procedures of statistics, a biometrical approach* (No. Ed. 2). McGraw-Hill Kogakusha, Ltd..

Thungo, Z., Shimelis, H., Odindo, A., & Mashilo, J. (2021). Genetic gain for agronomic, physiological, and biochemical traits and quality attributes in bread wheat (Triticum aestivum L.): a meta-analysis. *Euphytica*, *217*(6), 1-33.

Thungo, Z., Shimelis, H., Odindo, A. O., & Mashilo, J. (2020). Assessment of terminal drought tolerance among elite wheat (Triticum aestivum L.) genotypes using selected agronomic and physiological traits. *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science*, *70*(3), 177-194.

Tremmel-Bede, K., Szentmiklóssy, M., Tömösközi, S., Török, K., Lovegrove, A., Shewry, P. R., ... & Rakszegi, M. (2020). Stability analysis of wheat lines with increased level of arabinoxylan. *PloS one*, *15*(5), e0232892.

Ullah, M. I., Mahpara, S., Bibi, R., Shah, R. U., Ullah, R., Abbas, S., ... & Khan, M. I. (2021). Grain yield and correlated traits of bread wheat lines: Implications for yield improvement. *Saudi Journal of Biological Sciences*, *28*(10), 5714-5719.

WAHYU, Y., PUTRI, N. E., NINGTYAS, T. K., SUTJAHJO, S. H., & NURa, A. M. I. N. (2018). Correlation, path analysis, and heritability of phenotypic characters of bread wheat F2 populations. *Biodiversitas Journal of Biological Diversity*, *19*(6), 2344-2352.

Zhang, S., Chen, Y., Zhao, P., Zhang, H., & Cui, Z. (2020). Increasing wheat yield for smallholder farmers with technology transfer. *Agronomy Journal*, *112*(6), 5096-5104.