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Genotype × environment interaction study for grain yield and its component traits in wheat (*Triticum aestivum* L.)

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Abstract
The experiment is put out in randomized block design with replicated three times and the experiment was studied over artificially created four environments *i.e.*, 15th November, 30th November, 15th December and 30th December for thirty sets of genotypes at Department of Seed Technology, SDAU during the *rabi* season 2021-22 for twelve sets of characters *viz.* days to heading, days to maturity, plant height (cm), number of effective tillers per meter, number of grains per spike, grain weight per spike (g), spike length (cm), grain yield per meter (g), test weight (1000 seeds weight) (g), biological yield per meter (g) and harvest index (%). The genotypes exhibiting average stability can be adapted across all studied environments. The genotype VA2020-10 showed stability in favourable environment for days to heading and plant height, VA2020-04 for days to maturity, grain filling period and number of effective tillers, 21th ESBWYT20 for number of effective tillers per meter, spike length, grain weight per spike, number of grains per spike and test weight, 21th ESBWYT21 for grain filling period, number of grains per spike and biological yield per meter, 28th SAWYT310 for plant height and number of grains per spike, VA2020-14 for number of effective tillers per meter and number of grains per spike indicating adaptation to favorable environments for these traits and 28th SAWYT321 showed above average stability for grain filling period, number of effective tillers per meter and biological yield per meter, VA2020-02 for number of grains per spike and grain yield per meter, VA2019-10 for number of effective tillers per meter and biological yield per meter, VA2020-14 for days to maturity and grain filling period showing adaptation to adverse environmental conditions. Genotype VA2020-02 give highest grain yield per meter with having stability in the unfavourable environmental condition. The estimation of genetic parameters showed closer affinity of GCV and PCV for the characters *viz.* days to heading, days to maturity, grain filling period and plant height indicated the scope for the selection for these traits.

Keywords: Stability, wheat, stable genotypes, grain yield per meter, environments

1. Introduction
Wheat (*Triticum aestivum* L.) is a cereal grass from the family *Gramineae* also known as *Poaceae* and from the genus *Triticum*. Wheat (*Triticum aestivum* L.), an allohexaploid (2n=6x=42, AABBDD), is an important world's largest growing and consuming cereal crop for the majority populations of world. On a global basis, wheat provides more nourishment than any other food crop (Breiman and Graur, 1995) [2]. The global wheat production area 2190 lakh ha and production is 760.92 million MT and at 3474 kg/ha stands its global wheat utilization (Anonymous, 2020-21). India's wheat growing area in 2020-2021 was 311.25 lakh ha with production 109.58 million MT and productivity 3521 kg/ha and Gujarat's wheat growing area is about 10.17 lakh ha with production 3.25 million MT and yield is 3205 kg/ha (Anonymous, 2020-21). When India got its Independence, production and productivity of wheat were quite low up to 6.46 million tonnes with the 663 kg/ha, respectively. So, Therefore, during 1966-1967, India adopted 'Green Revolution' as result the production of wheat in the country has increased significantly 75.81 million MT in 2006-07. India is the world's second largest producer of wheat accounted production of wheat during the year 2021 rose by 4.11% from 103,600 thousand tonnes in 2019 to 107,860 thousand tonnes in 2020, while in 2021 109,520 thousand tonnes. Since the 9.73% slump in 2015, wheat production soared by 25.60% higher in 2021. In India Uttar Pradesh is the largest producer of wheat in India. wheat cultivation in India started 5000 years ago (Feldman, 2001) [4].

A crop variety developed should show stable performance under different environments, especially in India where wide ranges of environments are prevailing. So, it is a need to develop genotypes with a higher degree of adaptability levels over a wide range of eco-geographical conditions for successful exploitation of its inherent potential. A variety is said to be stable which can adjust its phenotypic and genotypic status in response to changing environment.

The genotype × environment interaction studies are as important as crop improvement.

Genotype × Environment interaction is supposed to be one of the genetic parameters responsible for phenotypic stability and adaptation.

There are many investigations done in the past and continued till today to identify a stable and adaptable genotype for different yield contributing characters. Specific varieties can be suggested for specific environments to overcome the failure of the crop. Therefore, it is necessary to identify the genotype that responds to different artificially created environments like sowing time or climate change and should show stability for high yield potential.

2. Materials and Methods

The experimental material is comprised of 30 diversed genotypes of wheat. All genotypes were evaluated in the artificially created environments at Department of Seed Technology, SDAU, Sardarkrushinagar during the *rabi* season 2021-22 *i.e.,* 15th November,30th November,15th December, 30th December.

The genotypes were received from Wheat Research Station, SDAU, Vijapur. For twelve sets of characters *viz.* days to heading, days to maturity, plant height (cm), number of effective tillers per meter, number of grains per spike, grain weight per spike (g), spike length (cm), and grain yield per meter (g), test weight (1000 seeds weight) (g), biological yield per meter (g) and harvest index (%). The data were collected and analyzed for the analysis of variance, mean performance, genetic variability, heritability, genetic advance, analysis of variance and stability analysis. The analysis of variance for all the observed twelve characters of the thirty genotypes are revealed significant differences among the genotypes studied over different four environment, indicating sufficient amount of variability present among the characters. Environmental variances are found to be significant for all characters. For the statistical analysis of the data the analysis of variance (Panse and Sukhatme, 1967) [7], variability parameters like mean, range, genotypic coefficient of variance, phenotypic coefficient of variance, haritability, genetic advance and genetic advance as percent of mean are estimated. The traits which showed the significant G × E interactions were subjected to stability analysis using the Eberhart and Russell (1966) [3] model. As per the model, three parameters *viz*., overall mean performance of each genotype across the environments, the regression coefficient (b_i) and squared deviation from the regression (S^2d_i) were estimated.

3. Results and Discussion

The analysis revealed significant differences among the genotypes for all the observed characters under study in all four sowing seasons (*i.e*., 15th November, 30th November, 15th December, 30th December) indicating sufficient variability existing among genotypes. The mean performance of thirty genotypes across environments indicated the grain yield per meter was observed higher when planted in normal dates of sowing and genotypes grown under late sown conditions showed reduction in the grain yield per meter. This revealed that genotypes differed in yield and its component quantitative characters due to environmental effects.

The estimation of genetic parameters showed closer affinity of GCV and PCV for the characters *viz.* days to heading, days to maturity, grain filling period and plant height indicated the scope for the selection for these traits. The traits *viz.* number of effective tillers per meter, spike length, number of grains per spike, grain weight per spike, grain yield per meter, test weight (1000 grain weight), biological yield per meter and harvest index exhibited larger variation in the values of GCV and PCV expressed role of environment for the inheritance of these traits. High heritability with high genetic advance was reported for biological yield per meter indicated predominance of additive gene action with effective selection Whereas, High heritability with moderate genetic advance exhibited for plant height, spike length, grain yield per meter indicating predominance of additive gene action, hence mass selection can be used for the improvement of these traits. The greater the heritability value, the more effective the selection would be in improving these traits. The lower heritability suggested that there were less opportunities for improvement through selection.

Genotypes and environment interaction tested against pooled error were significant for all the characters except days to heading, plant height, number of effective tillers per meter, number of grains per spike, biological yield per meter and harvest index showing differential response of genotypes with environment.

The genotypes under the investigation didn't show stability for all the characters but some of the genotypes showed stability in more than two characters. The genotype VA2020-06 observed average stability for days to heading and number of effective tillers per meter. For days to maturity and grain filling period genotype 21th ESBWYT21 and 28th SAWYT320 showed average stability, respectively. While for grain yield per meter, Grain weight per spike (g) and Test weight, genotype VA2020-19, VA2019-10 and VA2020-04 had average stability with higher mean yield than population mean. Genotype VA2020-19 showed average stability for grain yield with higher mean yield than population mean. The genotype VA2020-02 had average stability with higher mean value in unfavourable environment, whereas VA2020-16, VA2020-04, VA2020-34, VA2020-16, VA2020-08, VA2019-14, 28th SAWYT320, 21th ESBWYT23 and HI1544 found average stable for these trait. The genotype VA2020-10 showed stability in favourable environment for days to heading and plant height, VA2020-04 for days to maturity, grain filling period and number of effective tillers, 21th ESBWYT20 for number of effective tillers per meter, spike length, grain weight per spike, number of grains per spike and test weight, 21th ESBWYT21 for grain filling period, number of grains per spike and biological yield per meter, 28th SAWYT310 for plant height and number of grains per spike, VA2020-14 number of effective tillers per meter and number of grains per spike indicating adaptation to favourable environments for these traits. The genotype 28th SAWYT321 showed above average stability for grain filling period, number of effective tillers per meter and biological yield per meter, VA2020-02 for number of grains per spike and grain yield per meter, VA2019-10 for number of effective tillers per meter and biological yield per meter, VA2020-14 for days to maturity and grain filling period showing adaptation to adverse environmental conditions.

On the basis of per se performance, heritability and stability the best genotypes were VA2020-19 and VA2020-02 for grain yield per meter and its component traits *viz.* number of effective tillers per meter, spike length, number of grains per spike, grain weight per spike, test weight. Genotypes 21th ESBWYT21, VA2020-04, GW451 and 21th ESBWYT 8 found stable for early maturity. Genotypes VA2020-13 and VA2020-10 had stable in dwarfness. Genotypes 21th ESBWYT8, HI1544, VA2020-10 and 21th ESBWYT21 found stable for days to heading, days to maturity and grain filling period.

Similar results were reported by Gulzar *et al.* (2015) [5] for days to heading, days to maturity, plant height, spike length, grain yield per meter and harvest index. Sidhi *et al.* (2018) [9] for traits days to heading, grain filling period, spike length, grain weight per spike, biological yield per meter. Pujer *et al.* (2020) [8] for traits days to maturity, number of effective tillers per meter, number of grains per spike, grain yield per meter, biological yield per meter and Hassan *et al.* (2013) [6] for the traits grain weight per spike and number of grains per spike.

Table 1: Estimation of coefficient of variations, broad sense heritability (h^2b), genetic advance as per cent of mean in twelve quantitative traits of thirty genotypes for different environments under study in bread wheat

Sr. No.	Characters	PCV (%)	GCV (%)	h^2 (%)	GAM (%)
1	Days to heading	6.49	5.09	75.49	8.27
2	Days to maturity	2.19	1.07	44.06	1.08
3	Grain filling period	7.21	6.51	59.17	7.81
4	Plant height (cm)	8.40	7.28	75.19	13.01
5	Number of effective tillers per meter	7.01	4.98	42.18	7.64
6	Spike length (cm)	8.45	6.98	68.27	11.88
7	Number of grains per spike	9.69	7.17	54.74	10.92
8	Grain weight per spike	13.9	10.6	58.19	16.66
9	Grain yield per meter (g)	11.17	8.69	60.57	13.93
10	Test weight (1000 seeds weight) (g)	9.46	7.15	57.04	11.11
11	Biological yield per meter (g)	17.27	13.48	60.95	21.68
12	Harvest Index (%)	18.65	13.34	51.14	19.64

Table 2: Stable genotypes in favourable and unfavourable environmental condition for grain yield and it's component traits

Sr. No.	Characters	Best five of genotypes mean for character
1	Days to heading	GW 451 (54.08 days), 21th ESBWYT 21 (54.33 days), 21th ESBWYT 23 (54.08 days), VA 2020-04 (56.91 days) and HI1544 (57.16 days).
2	Days to maturity	21th ESBWYT 21 (102.83 days), 21th ESBWYT 8 (103.08 days), 21th ESBWYT23 (103.08 days), HI1544 (103.41 days) and VA 2020-11 (104.16 days).
3	Grain filling period	28th SAWYT 320 (42.91 days), VA2019-14 (43.08 days), VA 2020-34 (43.41 days), VA 2020-8 (43.66 days) and VA 2019-10 (43.75 days).
4	Plant height (cm)	VA2020-34 (99.22 cm), VA2020-04 (93.74 cm), 28th SAWYT321 (91.75 cm), VA2019-10 (89.10 cm) and VA2020-10 (88.40 cm).
5	Number of effective tillers per meter	VA2020-06 (101.83),GW322 (100.50), 28th SAWYT 321 (99.66), VA2020-02 (99.41) and VA2019-06 (99.16).
6	Spike length (cm)	VA 2020-02 (11.78 cm), 28th SAWYT 321 (11.59 cm), 28th SAWYT 305 (11.53 cm), VA 2020-19 (11.37 cm) and VA 2020-06 (11.34 cm).
7	Number of grains per spike	28th SAWYT347 (53.85), 28th SAWYT305 (53.16), 21th ESBWYT20 (50.60), 28th SAWYT 305(49.88) and VA2019-10 (48.55).
8	Grain weight per spike (g)	28th SAWYT321 (2.57 g), 28th SAWYT305 (2.48 g), VA2019-06 (2.33 g), VA2020-10 (2.29 g) and 28th SAWYT 347 (2.24 g).
9	Grain yield per meter (g)	VA2020-02 (96.98 g), 28th SAWYT321 (92.75 g), VA2019-06(90.67 g), VA2020-19 (89.07 g) and 28th SAWYT 347 (86.43 g).
10	Test weight (1000 seeds weight) (g)	28th SAWYT305 (49.48 g), VA2020-10 (49.34 g), VA2019-06(49.34 g), 28th SAWYT310 (48.30 g) and VA2019-02 (47.56 g).
11	Biological yield per meter (g)	VA 2020-13 (313.92 g), VA 2019-06 (300.35 g), VA 2020-34 (296.77 g), VA 2019-10 (291.33 g) and VA 2020-19 (283.66 g).
12	Harvest Index (%)	VA2020-02 (42.84%), VA2020-16 (42.32%), VA2020-14 (41.68%), VA2020-06 (38.68%) and GW451 (38.83%).

Table 3: Analysis of variance (Mean square) for phenotypic stability for different characters in wheat

Sr. No.	Sources of variation	G × E	Environment (linear)	G × E (linear)	Pooled deviation	Pooled error
	df	87	1	29	60	232
1	Days to heading	5.27	76.53**	4.04	5.69	1.57
2	Days to maturity	4.79*	1277.63**	7.29**	3.42**	1.34
3	Grain filling period	10.29*	1366.73**	17.16**	6.63**	2.23
4	Plant height (cm)	34.65	763.729**	53.57**	24.35	3.98
5	Number of effective tillers per meter	10.29	3862.91**	17.94*	6.26	10.05
6	Spike length (cm)	0.56*	4.78**	0.61	0.52	0.08
7	Number of grains per spike	17.19	1542.28**	25.83**	12.44	3.04
8	Grain weight per spike (gm)	0.05*	16.82**	0.06	0.05	0.01
9	Grain yield per meter (g)	38.55*	13281.01**	74.93**	19.69**	10.36
10	Test weight (1000 seeds weight) (g)	12.65*	7025.98**	18.08*	9.60	2.48
11	Biological yield per meter (g)	665.52	161783.53**	495.53	725.50	235.36
12	Harvest Index (%)	21.89	75.41*	31.62*	16.46	7.14

* and **: Significant at 5 and 1 per cent levels of significance, respectively

Table 4: Stable genotypes in favourable and unfavourable environmental condition for grain yield and it's component traits

Traits	Average Stability over all environment	Stable in favourable environment	Stable in unfavourable environment
Days to heading	VA 2020-06, 11, 21th ESBWYT 8 VA 2020-15 and HI 1544	VA 2020-10	-
Days to maturity	21th ESBWYT 21	VA2020-04, 21th ESBWYT 8 and GW451	VA2020-14 and VA2019-02
Grain filling period	28th SAWYT 320	VA 2020-19, VA 2020-04, VA 2020-13, 21th ESBWYT 21, GW 322 and HI 1544	VA 2020-14 and 28th SAWYT 321
Plant height	VA 2020-13	VA 2020-10, 28th SAWYT 310 and 28th SAWYT 324	-
Number of effective tillers per meter	VA 2020-06	VA 2020-02, VA 2020-04, VA 2020-14, VA 2020-15, VA 2019-02, 28th SAWYT 305, 28th SAWYT 328, 21th ESBWYT 20 and 21th ESBWYT 322	VA 2020-19,34, VA 2020-08, VA 2019-10, 28th SAWYT 321 and 21th ESBWYT 21
Spike length	-	21th ESBWYT 20	28th SAWYT 305
Number of grains per spike	-	VA 2020-19, VA 2020-06, VA 2020-14, VA 2019-14, 28th SAWYT 310, 21th ESBWYT 20, 21th ESBWYT 21 and 23	VA2020-02 and VA2020-04
Grain weight per spike	VA2019-10	VA2019-06 and 21th ESBWYT 20	-
Grain yield per meter	VA2020-19	-	VA2020-02
Test weight	VA 2020-04	21th ESBWYT 20	-
Biological yield	VA2020-34	21th ESBWYT 21	VA 2019-10 and 28th SAWYT 321
Harvest Index	-	VA 2020-16	-

The best five genotypes on the basis of *per se* performance over the environments, were GW451 (54.08 days), 21th ESBWYT21 (54.33 days, 21th ESBWYT 23 (54.08 days), VA2020-04 (56.91 days) and HI1544 (57.16 days) for days to heading; 21th ESBWYT21 (102.83 days), 21th ESBWYT8 (103.08 days), 21th ESBWYT23 (103.08 days), HI1544 (103.41 days) and VA2020-11 (104.16 days) for days to maturity; 28th SAWYT320 (42.91 days), VA2019-14 (43.08 days),VA2020-34 (43.41 days), VA2020-8 (43.66 days) and VA2019-10 (43.75 days) for grain filling period; VA2020-34 (99.22 cm), VA2020-04 (93.74 cm), 28th SAWYT321 (91.75 cm), VA2019-10 (89.10 cm) and
VA2020-10 (88.40 cm) for plant height; VA2020-06 (101.83), GW322 (100.50), 28th SAWYT321 (99.66), VA2020-02 (99.41) and VA2019-06 (99.16) for number of effective tillers per meter; VA2020-02 (11.78 cm), 28th SAWYT321 (11.59 cm), 28th SAWYT305 (11.53 cm), VA2020-19 (11.37 cm) and VA2020-06 (11.34 cm) for spike length; 28th SAWYT347 (53.85), 28th SAWYT305 (53.16), 21th ESBWYT20 (50.60),28th SAWYT305 (49.88) and VA2019-10 (48.55) for number of grains per spike; 28th SAWYT321 (2.57 g), 28th SAWYT 305 (2.48 g), VA2019-06 (2.33 g), VA2020-10 (2.29 g) and 28th SAWYT347 (2.24 g) for grain weight per spike; VA2020-02 (96.98 g), 28th SAWYT321 (92.75 g), VA2019-06 (90.67 g), VA2020-19 (89.07 g) and 28th SAWYT347 (86.43 g) for grain yield per meter; 28th SAWYT305 (49.48 g), VA2020-10 (49.34 g), VA2019-06 (49.34 g), 28th SAWYT310 (48.30 g) and VA2019-02 (47.56 g) for thousand grain weight; VA2020-13 (313.92 g), VA2019-06 (300.35 g), VA2020-34 (296.77 g), VA2019-10 (291.33 g) and VA2020-19 (283.66 g) for biological yield per meter and VA2020-02 (42.84%), VA2020-16 (42.32%), VA2020-14 (41.68%), VA2020-06 (38.68%) and GW451 (38.83%) for harvest index. The genotypes which found better in grain yield per meter expressed through one, two or more of its component traits.

4. Conclusion

It was concluded from this study that the genotypes *viz.* VA2020-19, VA2020-02, 21th ESBWYT20 found stable across the environments for grain yield and its component traits *viz.* number of effective tillers per meter, spike length, number of grains per spike, grain weight per spike and test weight. When are as genotypes 21th ESBWYT8, HI1544, VA2020-10 and 21th ESBWYT21 found potential for days to heading, days to maturity and grain filling period traits. So, these genotypes an be better evaluated across the environment for region in late sown condition and to be used for further breeding programme for improvement of bread wheat through the crossing programme and subsequent selection of derived transgressive segregants from segregating generations.

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