Research Article

Stability Analysis of Bread Wheat Lines using Regression Models

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Abstract | Stability of performance is one of the most important characteristics of any variety. To evaluate stability of 40 bread wheat lines (30 introduced lines and 5 check cultivars), a multi-environment experiment was conducted at three locations for two years; The University of Agriculture, Peshawar; Agriculture Research Station, Baffa, Mansehra; Agriculture Research Station, Buner; and at one location for one year; Agriculture Research Station , Kohat, during 2016-17 and 2017-18. Data were recorded on tillers m^{-2}, grains spike^{-1} and kernel weight. Analysis of variance indicated that the main environmental effects, genotypic effects as well as interaction effects were significant for all the traits studied, indicating that the performance of most of the genotypes was not the same across the environments. Various stability parameters; Eberhart and Russell, Perkin and Jinks and Finlay and Wilkinsons models were used to determine stability. Considering the Eberhart and Russell's approach G.27, G.34, G.11, G.17, Siran and G.35 for tillers m^{-2} and G.22, G.23, G.31 for kernel weight had the b_i (regression coefficient) values near to unity and had higher (coefficient of determination) R_i^2. Based on the stability measure of Freeman and Perkin's genotypes G.20, G.6 and G.29 for tillers m^{-2}, G.11, G.10, G.34 for grains spike^{-1} and G.11, G.24, G.29, G.32 and G.21 for kernel weight, were having b_i values almost equal to one while the R_i^2 value were higher . Based on Finlay and Wilkinson's model for tillers m^{-2} G.4, G.33 and G.5, for grains spike^{-1} G.30, G.24, G.2 and G.15, while for the weight of kernel G.19, G.21, G.28, G.25, G.11, G.29, G.32 and G.10 had b_i value close to one. Near to unity b_i value and higher R_i^2 indicate that most of these genotypes performance is consistent for the mentioned traits under the tested environments.

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Introduction

In Pakistan, bread wheat is the most consumed cereal crop. It is an essential diet component and constitutes around 60% of the daily diet intake. On average 135 kg of wheat is consumed per person per year in Pakistan. According to FAO's estimates, majority (38%) of the world's food shortage and mal-nourished people are living in South Asia (FAO *et al*., 2015). Food security in numerous countries including Pakistan largely relies on wheat; it is the most produced edible grain, which fulfills a major part of human nutritional requirements, and in some cases, it provides around one half of the human's food calories. To ensure the highly increasing agricultural/food demands of the growing population, an increase in agriculture production can be achieved by increasing yield per unit area from the limited available land.

Pakistan produced 24.35 million tons of wheat from

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8.68 million hectares during 2019 (FAOSTAT, 2019). Average wheat yield during 2019 was 2086 kg ha^{-1} in Pakistan whereas average wheat yield of the world was 3247 kg ha^{-1}. In Pakistan the yield of most of the agricultural crops including bread wheat is comparatively low to the rest of the world; therefore, there is big scope to increase the yield and production of most of crops. One of the reasons of low wheat yield in Pakistan is the diverse agro ecosystems, where climate, soil texture and other environmental conditions vary significantly. The use of non-specific wheat varieties in these diverse agro zones make the situation even worse. Another reason is the inadequacy of improved wheat cultivars or the use of non-registered seeds.

Breeding and testing of genotypes is a complex procedure and it becomes more complicated when the environmental conditions of the target region are diverse (Bondari, 1999). Considerable changes occur in the performance of a genotype when it is grown under different environmental conditions. These changes are usually the result of the varying environmental conditions at any specific site or season and is known as genotype × environment interactions (GEI) (Bassi and Garcia, 2017; Baye *et al*., 2011). This GEI affect the selection of genotypes and decreases the progress from selection (Sohail *et al*., 2016). Therefore, in plant breeding programs, genotypes are tested in different environments (Ahmadi *et al*., 2012; Casanoves *et al*., 2005). This study was designed to test the exotic genotypes in different environments, to see the effect of environmental changes and the response of the genotypes towards those changes. The genotypes that perform uniformly to some extent regardless of the environmental variations are desirable and these genotypes are considered as stable genotypes. Several different procedures are used to determine stability of genotypes. The simplest and most common among those are the procedures based on regression method (Dia, 2017). The main objective of the present study is to evaluate stability of wheat lines across different environments using three different stability parameters.

Materials and Methods

This study was conducted to evaluate the stability of 40 bread lines including five check cultivars (Atta Habib, CSA, Ghanimat, Morocco and Siran). The study was conducted at four different locations during 2016-17 wheat growing season and at three locations during 2017-18 wheat growing season. The experimental locations were Research Farm, The University of Agriculture, Peshawar, Agriculture Research Station Baffa, Mansehra, Agriculture Research Station, Amnawar, Buner for two seasons and Barani Agriculture Research Station, Jarma, Kohat for one growing season. RCB design with three replications was used for all the experimental trials.

Each plot had four rows of two-meter length, distance between the rows was kept 0.3 m (total plot area was 2.4 m^2) and the seed rate was 28g per plot (120kg/ha). Data on tillers m^{-2}, grains $spike^{-1}$ and kernel weight were recorded on randomly selected plants from each experimental unit.

Data collected from separate trials was analyzed as combined over the environments using the following ANOVA outline;

Source of variation	DF	Mean Squares	F.Test
Environments (E)	e-1	EnMS	EnMS/ R(E)MS
Replications (Environments)	e(r-1)	R(E)MS	
Genotypes (G)	g-1	GMS	GMS/GEMS
G × E	(g-1)(e-1)	GEMS	GEMS/EMS
Pooled Error	e(g-1)(r-1)	EMS	
Total	(erg)-1		

Upon significant GEI, the stability of the genotypes was analyzed using stability models suggested by Eberhart and Russell (1966), Freeman and Perkin's (1971) and Finlay and Wilkinson (1963).

Results and Discussion

Tillers m^{-2}

Significant differences were revealed by pooled analysis of variance for both the main effects, genotypes and environments as well as for interaction effects (Table 1). This shows that the performances of genotypes as well as the environments were different; the genotypes also had differential response to the changes in the environmental conditions. Similar results were reported by Ajmal *et al*. (2009). Considering Eberhart and Russell's model of analysis no genotype had $b_i = 1$, however, G.27, G.34, G.11, G.17, Siran and G.35 had b_i value near to one (0.963, 0.971, 1.013, 1.023, 1.035 and 1.039, respectively); showing that most of these genotypes almost produced similar number of tillers under all the environments. For Atta Habib higher b_i values were noted, G.5, G.33 and G.4, whereas, lower b_i values were detected for G.16, G.15 and G.10. Lower values of b_i indicate that these genotypes show more resistance to unfavorable environments (Yaghotipoor *et al*., 2017). Based on the Freeman and Perkin stability analysis approach; Morocco, G.20, G.6 and G.29 showed regression coefficient values of 0.966, 1.009, 1.011 and 1.049, respectively; these values are near unity and are coupled with higher values of coefficient of determination indicating good fit of the model, which suggests that the genotypes are stable and their tillering performance has not been significantly altered with changes in the environment. (Polat *et al*., 2016). G.5 had the maximum value of b_i, followed by Atta Habib and G.4, showing comparatively larger change in tillering densities across the different environments, these can be recommended for favorable environments (Bassi and Garcia 2017; Ali *et al*., 2012). G.16 demonstrated minimum value of b_i, which was followed by G.7, G.23 and G.15. Based on the Finlay and Wilkinson's approach the regression coefficients for tillers m^{-2} of most of the genotypes was less than one, with only four genotypes having b_i values more than one. The highest b_i value was of Atta Habib had (1.192). Close to unity b_i values were observed for Ghanimat (0.966), G.4 (1.064), G.33 (1.072) and G.5 (1.087); these genotypes can be considered phenotypically stable based on tillering capacity across the different environments. The smallest b_i value was noted for G.16, followed by G.10, G.15 and G.19 (Table 2). Yaghotipoor *et al*. (2017) and Jhinjer *et al*. (2017) suggested that varieties with lower b_i values can be recommended for environments with poor growing conditions.

Grains spike^{-1}

Combined analysis of variance based on seven different environments showed highly significant differences (p≤0.01) among genotypes and environments. Similar results of significant differences among genotypes and environments were also reported by Alemu *et al*. (2018) and Haydar *et al*. (2018). The interactions between the environments and genotypes likewise were highly significant for grains spike^{-1} (Table 1) which is similar with the findings of Trakanovas and Ruzagas (2006) and Temasgen *et al*. (2015). None of the genotypes had b_i =1 coupled with higher coefficient of determination based on the Eberhart and Russell's model. Only three genotypes G.24, G.23 and G.15 had b_i values near to unity but they had lower R_i^2 values which suggest that the model was not a good fit. Morocco, G.9 and G.12 showed higher values of b_i accompanied with higher R_i^2 values. Ali *et al*. (2012) suggested that genotypes with b_i value more than unity are more responsive and recommended for better environments. Lowest value of b_i was noted for G.18, followed by G.2, Atta Habib and G.3. These genotypes can be regarded as suitable for unfavorable environmental conditions (Thakur *et al*., 2019; Jhinjer *et al*., 2017). Based on the Freeman and Perkin's model of stability, the b_i value near to one was observed for G.11, G.10, G.34 and G.14. R_i^2 value for these genotypes was observed to be low to medium (0.614, 0.253, 0.468 and 0.744, respectively). For Atta Habib Minimum value of b_i was recorded, which was followed by G.3 and G.2. The Maximum value of b_i was recorded for Morocco, G.9 and G.17. Based on Finlay and Wilkinson approach of stability, b_i values of close to one was recorded for G.30, G.24, G.23 and G.15. The maximum value of b_i was noted for G.9, which was followed by Morocco and G.32 while the minimum b_i value of was observed for G.18 followed, by G.2 and Atta Habib (Table 3).

Table 1: *Mean squares of the studied traits as combined over 7 environments planted in Khyber Pakhtunkhwa, Pakistan in 2016-18 growing seasons.*

SoV	DF	Tillers	Grains spike^{-1}	Kernel weight
Environments	6	923147***	920***	1631***
Reps(Environ)	13	12546	93	205
Genotypes	39	6904*	334***	433***
G×E	234	4343***	78***	46**
Expt'l Error	507	2169	52	38
Total	799	10122	81	74

Kernel weight

Highly significant differences were observed among the environments and the genotypes, as well as the interaction between them (Table 1) these results are in agreement with Alemu at al. (2018) and Ali *et al*. (2008). The three regression models; Finlay and Wilkinson's model, Eberhart and Russell's model and Freeman and Perkins model were used to analyze the stability genotypes based on the values of b_i and R_i^2. None of the genotypes had a perfect combination of b_i = 1 and higher R_i^2 values based on Eberhart and Russell's approach of stability. Nevertheless, G.22, G.23, G.31, G.21, G.25, Siran, G.17, G.32 and G.19 had b_i values close to one and the R_i^2 values were moderate to high, therefore, these genotypes can be considered stable for kernel weight (Thakur at al., 2019;

Table 2: *Means and regression coefficients (with R^2) as stability measures of productive tillers m^{-2} of wheat genotypes.*

Genotype	Mean		Eberhart & Russell			Freeman & Perkins			Finlay & Wilkinson		
	Value	Rank D	b_i	Rank A	R^2	b_i	Rank A	R^2	b_i	Rank A	R^2
G.1	254	8	0.839	10	0.9041	0.712	13	0.773	0.626	9	0.889
G.2	205	40	0.944	18	0.8924	0.811	19	0.812	0.685	16	0.905
G.3	209	39	0.887	14	0.9503	0.837	23	0.948	0.646	12	0.946
G.4	276	2	1.374	37	0.8690	1.293	38	0.917	1.064	37	0.927
G.5	292	1	1.411	39	0.8129	1.446	40	0.912	1.087	39	0.877
G.6	245	13	1.045	27	0.8644	1.011	33	0.866	0.769	23	0.841
G.7	230	30	0.861	13	0.9285	0.464	2	0.558	0.647	13	0.889
G.8	223	33	1.045	26	0.9227	0.807	18	0.868	0.772	25	0.922
G.9	254	11	0.838	9	0.7148	0.749	15	0.650	0.629	10	0.733
G.10	224	32	0.669	3	0.7113	0.616	6	0.634	0.467	2	0.772
G.11	228	31	1.013	22	0.8694	0.849	25	0.739	0.731	21	0.905
G.12	241	18	0.828	8	0.9559	0.671	10	0.899	0.632	11	0.926
G.13	245	14	1.147	32	0.9428	0.830	22	0.891	0.856	29	0.910
G.14	231	29	0.943	17	0.9222	0.682	11	0.821	0.704	17	0.889
G.15	215	38	0.668	2	0.6352	0.582	4	0.541	0.469	3	0.583
G.16	232	26	0.538	1	0.8513	0.357	1	0.601	0.396	1	0.869
G.17	271	4	1.023	23	0.9172	0.954	30	0.879	0.802	27	0.899
G.18	220	36	0.924	15	0.9594	0.755	16	0.780	0.678	15	0.951
G.19	235	24	0.710	4	0.7633	0.616	7	0.911	0.538	4	0.826
G.20	232	28	1.141	31	0.8863	1.009	32	0.929	0.862	30	0.935
G.21	242	16	1.141	30	0.9620	0.913	27	0.899	0.865	31	0.944
G.22	242	17	0.804	7	0.9475	0.661	9	0.830	0.600	7	0.927
G.23	233	25	0.767	6	0.8460	0.517	3	0.650	0.568	5	0.845
G.24	241	19	1.077	28	0.9689	0.948	29	0.916	0.817	28	0.943
G.25	240	20	0.853	11	0.6586	0.811	21	0.568	0.613	8	0.685
G.26	232	27	0.858	12	0.8951	0.609	5	0.745	0.649	14	0.841
G.27	240	21	0.963	20	0.9408	0.943	28	0.827	0.725	20	0.928
G.28	254	10	1.242	35	0.8264	1.182	35	0.815	0.950	35	0.725
G.29	236	23	1.219	33	0.9602	1.049	34	0.956	0.928	34	0.960
G.30	254	9	0.932	16	0.8459	0.786	17	0.843	0.739	22	0.842
G.31	215	37	0.766	5	0.9465	0.640	8	0.929	0.588	6	0.912
G.32	222	35	0.950	19	0.9405	0.811	20	0.902	0.714	19	0.898
G.33	245	15	1.381	38	0.9228	1.257	36	0.978	1.072	38	0.936
G.34	222	34	0.971	21	0.9386	0.840	24	0.815	0.710	18	0.920
G.35	247	12	1.039	25	0.9784	0.709	12	0.805	0.782	26	0.985
CSA	259	6	1.140	29	0.9419	0.904	26	0.881	0.871	32	0.913
Moroc	238	22	1.242	34	0.8983	0.966	31	0.763	0.915	33	0.955
AttaH	272	3	1.505	40	0.8867	1.304	39	0.949	1.192	40	0.895
Ghani	256	7	1.267	36	0.9784	1.263	37	0.977	0.966	36	0.963
Siran	259	5	1.035	24	0.9118	0.734	14	0.760	0.770	24	0.944

b_i = 1 is stable, Rank A ranking in ascending order, Rank D ranking in descending order

Table 3: *Means and regression coefficients (with R^2) as stability measures of grains $spike^{-1}$ of wheat genotypes.*

Genotype	Mean		Eberhart & Russell			Freeman & Perkins			Finlay & Wilkinson		
	Value	Rank D	b_i	Rank A	R^2	b_i	Rank A	R^2	b_i	Rank A	R^2
G.1	52.1	10	0.318	8	0.015	-0.420	5	0.048	0.321	8	0.017
G.2	45.6	37	-0.443	3	0.086	-0.492	4	0.141	-0.531	2	0.092
G.3	42.2	40	-0.316	4	0.041	-0.724	2	0.233	-0.349	4	0.040
G.4	51.9	12	1.469	32	0.516	1.195	33	0.483	1.387	27	0.490
G.5	51.4	15	1.236	24	0.772	0.861	26	0.887	1.222	23	0.747
G.6	46.6	33	1.347	27	0.192	0.040	9	0.000	1.751	35	0.271
G.7	56.9	3	-0.119	6	0.006	0.308	14	0.039	-0.135	6	0.009
G.8	46.0	35	1.564	33	0.554	0.824	23	0.179	1.657	34	0.534
G.9	46.7	32	2.773	39	0.834	1.970	39	0.691	3.075	40	0.831
G.10	46.1	34	1.220	23	0.238	0.869	27	0.190	1.430	31	0.233
G.11	49.8	19	1.200	22	0.342	0.826	24	0.431	1.139	21	0.297
G.12	50.1	18	2.174	38	0.924	1.671	37	0.712	2.126	38	0.918
G.13	53.6	6	1.617	34	0.666	1.344	35	0.548	1.587	33	0.699
G.14	47.3	29	1.264	26	0.736	1.009	29	0.712	1.325	25	0.740
G.15	53.1	8	1.039	19	0.362	0.159	11	0.005	1.017	20	0.390
G.16	50.3	17	0.362	9	0.145	1.397	36	0.543	0.323	9	0.112
G.17	51.8	13	2.040	37	0.403	1.895	38	0.508	1.989	36	0.388
G.18	45.6	36	-0.454	2	0.092	-0.177	8	0.017	-0.516	3	0.093
G.19	47.5	28	1.163	21	0.197	0.855	25	0.164	1.344	26	0.217
G.20	54.0	4	1.406	30	0.590	0.396	17	0.052	1.217	22	0.537
G.21	53.1	9	0.192	7	0.015	-0.670	3	0.230	0.079	7	0.003
G.22	50.7	16	1.443	31	0.669	1.204	34	0.542	1.396	29	0.644
G.23	53.9	5	1.010	18	0.371	0.558	20	0.129	1.005	18	0.417
G.24	51.5	14	0.912	16	0.539	0.234	13	0.203	0.955	17	0.583
G.25	48.2	26	1.379	29	0.519	0.626	21	0.176	1.398	30	0.489
G.26	43.9	39	0.574	12	0.097	0.392	16	0.174	0.641	15	0.085
G.27	49.1	21	0.530	10	0.154	0.358	15	0.107	0.577	12	0.174
G.28	47.1	31	0.621	14	0.555	0.180	12	0.023	0.689	16	0.567
G.29	47.1	30	-0.280	5	0.084	-0.266	6	0.126	-0.311	5	0.093
G.30	44.3	38	0.951	17	0.376	0.792	22	0.340	1.010	19	0.343
G.31	48.5	25	0.582	13	0.184	0.491	19	0.234	0.588	13	0.158
G.32	48.6	24	2.005	36	0.549	1.107	31	0.381	2.103	37	0.515
G.33	47.6	27	1.347	28	0.392	1.007	28	0.372	1.391	28	0.363
G.34	48.8	23	1.667	35	0.619	1.022	30	0.436	1.549	32	0.588
G.35	53.3	7	0.561	11	0.589	0.427	18	0.251	0.520	11	0.558
CSA	63.8	1	0.642	15	0.079	-0.195	7	0.009	0.404	10	0.044
Moroc	57.0	2	3.457	40	0.822	1.978	40	0.431	2.926	39	0.778
AttaH	49.6	20	-0.755	1	0.104	-0.993	1	0.244	-0.698	1	0.092
Ghani	49.1	21	1.244	25	0.369	1.144	32	0.284	1.312	24	0.360
Siran	52.1	11	1.057	20	0.468	0.057	10	5.9	0.612	14	0.001

b_i = 1 is stable, Rank A ranking in ascending order, Rank D ranking in descending order

Table 4: *Means and regression coefficients (with R^2) as stability measures of kernel weight (mg) of wheat genotypes.*

Genotype	Mean §		Eberhart & Russell			Freeman & Perkins			Finlay & Wilkinson		
	Value	Rank D	b_i	Rank A	R^2	b_i	Rank A	R^2	b_i	Rank A	R^2
G.1	26.05	40	1.60	37	0.72	1.48	35	0.63	2.55	40	0.77
G.2	27.15	39	1.13	27	0.58	0.89	24	0.29	1.87	39	0.65
G.3	46.96	4	-0.22	1	0.06	-0.02	2	0.00	-0.16	1	0.05
G.4	40.64	27	0.58	6	0.61	0.54	9	0.69	0.60	6	0.62
G.5	41.07	23	0.66	9	0.56	0.18	3	0.10	0.63	9	0.55
G.6	42.67	18	0.63	8	0.08	0.60	13	0.05	0.63	8	0.10
G.7	40.89	24	0.40	4	0.38	-0.23	1	0.15	0.37	3	0.33
G.8	41.83	20	0.57	5	0.73	0.60	12	0.42	0.53	5	0.71
G.9	40.75	26	0.84	14	0.63	0.85	23	0.42	0.76	13	0.54
G.10	43.97	11	1.25	29	0.57	1.34	32	0.88	1.09	27	0.52
G.11	45.24	8	1.10	26	0.61	0.91	25	0.76	1.04	24	0.67
G.12	46.31	5	0.86	15	0.85	0.47	7	0.39	0.73	11	0.83
G.13	43.38	14	0.81	13	0.53	0.46	6	0.21	0.70	10	0.49
G.14	38.71	35	1.31	32	0.71	1.53	38	0.66	1.50	35	0.75
G.15	44.17	10	1.35	33	0.79	1.52	37	0.55	1.16	31	0.75
G.16	43.36	15	0.80	12	0.15	0.83	21	0.37	0.83	15	0.22
G.17	40.27	29	1.04	22	0.60	1.64	39	0.70	1.15	30	0.64
G.18	43.61	13	1.37	34	0.72	0.28	4	0.03	1.22	32	0.71
G.19	45.99	6	1.08	24	0.70	0.73	16	0.39	0.94	19	0.73
G.20	41.63	21	0.61	7	0.26	0.35	5	0.09	0.62	7	0.29
G.21	43.12	16	0.97	19	0.69	1.15	29	0.62	0.95	20	0.69
G.22	40.82	25	0.91	16	0.62	0.48	8	0.05	0.83	16	0.56
G.23	39.41	32	0.92	17	0.54	0.80	20	0.58	0.92	18	0.56
G.24	44.24	9	1.28	30	0.64	0.94	26	0.44	1.11	29	0.59
G.25	36.38	37	0.99	20	0.52	0.55	10	0.14	1.04	23	0.52
G.26	48.20	1	0.38	3	0.16	0.62	14	0.41	0.32	2	0.16
G.27	40.00	30	1.71	38	0.90	1.42	33	0.56	1.65	36	0.89
G.28	47.67	2	1.20	28	0.58	0.78	18	0.24	0.97	21	0.59
G.29	47.34	3	1.29	31	0.81	0.99	27	0.59	1.05	25	0.82
G.30	43.83	12	1.75	39	0.76	2.15	40	0.84	1.68	37	0.73
G.31	45.41	7	0.94	18	0.79	0.85	22	0.35	0.82	14	0.80
G.32	39.08	34	1.07	23	0.63	1.02	28	0.60	1.06	26	0.61
G.33	39.74	31	1.83	40	0.95	1.49	36	0.51	1.86	38	0.97
G.34	41.52	22	1.40	35	0.88	1.45	34	0.55	1.36	34	0.88
G.35	39.19	33	0.35	2	0.05	0.59	11	0.24	0.50	4	0.09
CSA	37.61	36	1.09	25	0.56	0.78	17	0.38	1.10	28	0.53
Moroc	33.64	38	0.75	10	0.16	0.78	19	0.12	0.75	12	0.14
AttaH	42.39	19	0.80	11	0.32	1.19	31	0.51	0.88	17	0.36
Ghani	42.68	17	1.55	36	0.78	1.17	30	0.52	1.35	33	0.74
Siran	40.61	28	1.02	21	0.79	0.70	15	0.45	1.04	22	0.78

b_i = 1 is stable, Rank A ranking in ascending order, Rank D ranking in descending order

Ozturk and Korkut, 2017). Lower values of b_i were observed for G.3, G.35 and G.26 while G.33, G.30 and G.27 had higher values of b_i. Genotypes with higher b_i values perform better in environments with high inputs as they are more responsive (Haydar *et al*., 2018; Bassi and Garcia, 2017). Freeman and Perkin's model for stability indicated that G.11, G.24, G.29, G.32 and G.21 can be considered stable genotypes as they had near to one b_i value. G.30 had the maximum value of b_i (2.15) while G.7 had the minimum value of b_i (-0.23). Genotypes having lower value of b_i perform fairly better in low yielding environments (Jhinjer *et al*., 2017; Polat *et al*., 2016). According to the stability model of Finlay and Wilkinson G.19, G.21, G.28, Siran, G.25, G.11, G.29, G.32 and G.10 had consistent performance for the weight of kernel. Minimum b_i was noted for G.3, followed by G.26 and G.7 while the maximum b_i value was documented for G.1, followed by G.2 and G.33 (Table 4).

Conclusions and Recommendations

Significant differences were found among the genotypes and environments for all the studied traits. Genotypes by environment interactions were also highly significant for the studied traits showing that performance of these genotypes varied in different environments. G.16 and G.2 were capable of producing more productive tillers under low yielding environments while G.5, Atta Habib, and G.33 performed better under favorable environments in terms of the tillering capacity. G.21 had more grains spike^{-1} under the low yielding environments while CSA and Morocco produced more grains spike^{-1} in the favorable environments. G.3 produced bigger kernels compared to the other genotypes in the low yielding environments while under favorable environments G.29 and G.33 produced heavier kernels. The above mentioned genotypes can be used as parents in a breeding program to develop genotypes having higher wheat yield under low yielding environments and also under favorable environments.

Novelty Statement

This study focuses on the importance of GEI and regression models of stability analysis.

Author's Contribution

Hafsa Naheed: Experiment conduction, data analysis, interpretation and write up.

Hidayat ur Rahman: Research supervision, designing of experiment, provision of research material, review and editing.

Conflict of interest

The authors have declared no conflict of interest.

References

Ahmadi, J., B. Vaezi and M.H. Fotokian. 2012. Graphical analysis of multi-environment trials for barley yield using AMMI and GGE-biplot under rain-fed conditions. J. Plant Physio. Breed., 2(1): 43-54.

Ajmal, S., N. Zakir and M.Y. Mujahid. 2009. Estimation of genetic parameters and character association in wheat. J. Agric. Biol. Sci., 1(1): 15-18.

Alemu, G., H. Mohammed and D. Asnake. 2018. Analysis of genotype by environment interaction for agronomic traits of bread wheat (*Triticum aestivum* L) genotype in Ethiopia. J. Agri. Res., 3(8): 000191. https://doi.org/10.23880/OAJAR-16000191

Ali, A., M.A. Masood and M.A. Zahid. 2012. Identifying the most promising genotypes in lentil for cultivation in a wide range of environments of Pakistan using various yield stability measures. Pak. J. Bot., 44(6): 1919-1922.

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

Bassi, F.M. and M.S. Garcia. 2017. Adaptation and stability analysis of ICARDA durum wheat elites across 18 countries. Crop Sci., 57: 2419-2430. https://doi.org/10.2135/cropsci2016.11.0916

Baye, T.M., T. Abebe and R.A. Wilke. 2011. Genotype-environment interactions and their translational implications. Per. med., 8(1): 59-70. https://doi.org/10.2217/pme.10.75

Bondari, K. 1999. Statistical analysis of genotype by environment interaction in agricultural research. Experimental statistics, Coastal Plain Station, University of Georgia, Tifton, GA. 31793-0748.

Casanoves, F., J. Baldessari and M. Balzarini. 2005. Evaluation of multi environment trials of peanut cultivars. Crop Sci., 45: 18-26. https://doi.org/10.2135/cropsci2005.0018

Dia, M., T.C. Wehner and C. Arellano. 2017. RGxE: An R program for genotype x environment interaction analysis. Am. J. Plant Sci., 8: 1672-1698. https://doi.org/10.4236/ajps.2017.87116

Eberhart, S.A. and W.A. Russell. 1966. Stability parameters for comparing varieties. Crop Sci., 6: 36-40. https://doi.org/10.2135/cropsci1966.0011183X000600010011x

FAO, IFAD and WFP. 2015. The state of food insecurity in the world 2015: Meeting the 2015 international hunger targets: taking stock of uneven progress. Rome, FAO.

FAOSTAT production book. Food and Agriculture Organization, United Nations, Rome.

Finlay, K.W. and G.N. Wilkinson. 1963. The analysis of adaptation in a plant-breeding programme. Aust. J. Agric. Res., 14: 742-754. https://doi.org/10.1071/AR9630742

Freeman, G.H. and J.M. Perkins. 1971. Environmental and genotype-environmental components of variability. VIII. Relations between genotypes grown in different environments and measures of these environments. Heredity, 27: 15-23. https://doi.org/10.1038/hdy.1971.67

Haydar, F.M. A., M.N. Uddin, U.K. Roy, G.M. Uddin and A.B. Siddique. 2018. Stability analysis of yield performance in wheat (*Triticum aestivum L.*). Plant Environ. Dev. 7(2): 10-15.

Jhinjer, R.K., G.S. Mavil, A. Malhotra, N. Sood, B. Singh, B. Kaur, V. Kumar, I. Bhagat and V.S. Sohu. 2017. Stability analysis for grain yield and micronutrients in bread wheat genotypes. Adv. Res., 11(1): 1-8. https://doi.org/10.9734/AIR/2017/35461

Ozturk, I. and K.Z. Korkut. 2017. Stability parameters for yield and yield component of the bread wheat genotypes under various drought stress condition. J. Tekirdag Agric. Fac., 77-82.

Polat, P.O. K., E.A. Cifci1 and K. Yagdı1. 2016. Stability performance of bread wheat (*Triticum aestivum* L.) lines. J. Agric. Sci. Tech., 18: 553-560.

Sohail, Q., H. Naheed and R. Mohammadi. 2016. Breeding and genetic enhancement of dryland crops. Pp 257-296. *In*: M.Farooq and K.H. M. Siddique (Ed). Innovations in dryland agriculture. Springer International Publishers AG, Switzerland. https://doi.org/10.1007/978-3-319-47928-6_10

Yaghotipoor, A., E. Farshadfar and M. Saeidi. 2017. Evaluation of phenotypic stability in bread wheat accessions using parametric and non-parametric methods. J. Anim. Plant Sci., 27(4): 1269-1275.

Tarakanovas, P. and V. Ruzgas. 2006. Additive main effect and multiplicative interaction analysis of grain yield of wheat varieties in Lithuania. Agron. Res., 4(1): 91-98.

Temesgen, M., S. Alamerew and F. Eticha. 2015. GGE biplot analysis of genotype by environment interaction and grain yield stability of bread wheat genotypes in South East Ethiopia. World J. Agric. Sci., 11(4): 183-190.

Thakur, P., L.C. Prasad, R. Prasad, Omprakash, K. Chandra and K. Rashmi. 2019. Stability analysis for yield and related traits over four environments in wheat (*Triticum aestivum L.*). Plant Arch., 19(2): 3541-3545.