Research Article

Stability and yield performance of different wheat genotypes across multi-locations of Khyber Pakhtunkhwa

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Abstract

Knowledge of genotype by environment interaction (GEI) is essential for identifying environment-specific and widely adapted genotypes. Multi-environment trials were conducted to evaluate the extent of genotype (G), environment (E) and GEI effects on grain yield of wheat. Thirty wheat genotypes were evaluated under five environments within Khyber Pakhtunkhwa, Pakistan during 2017/18 cropping seasons. Combined ANOVA for G and GEI were significant for almost all traits. Significant GEI suggested that the performance of genotypes was not consistent across environments, revealing strong influence of environments. Generally, GEI explained major portion of total variation and thus had larger effect than G and E on the expression of phenotype of wheat yield per hectare. In present study, the contribution to total sum of squares, regardless of trait, revealed that environments (11.51 to 96.27%) and genotypes (0.98 to 13.28%) play major role in managing the given traits. However, shares of genotype $\times$ environment and experimental error were 1.63 to 34.24% and 0.93 to 39.65%, respectively. Regarding genotypic performance, the genotype WADAAN-17 (4330.80 kg per hectare) revealed maximum grain yield, whereas the minimum was exhibited by the genotype 25 TH SAWYT 305 (2837.50 kg per hectare). In case of genotype $\times$ environment interactions, maximum desirable seed yield was produced by genotype WADAAN-17 (5666.7 kg ha⁻¹) at Mansehra, genotype HYT 65 (S) E-51 (5091.7 kg ha⁻¹) at CCRI, genotype HYT 70 (N) E-40 (2308.3 kg ha⁻¹) at Buner, genotype 38TH ESWYT 138(5625.0 kg ha⁻¹) at Tarnab and genotype HYT 70 (N) E-16 (4879.2 kg ha⁻¹) at DI Khan. According to Eberhart and Russell (1966) stability model none of the genotype were found to show ideal stability ($S^2_{di}=0$). However, based on their conditions genotypes HYT 65 (S) E-51, KHAISTA-17, 38TH ESWYT 110 and HYT 70 (N) E-1 were identified as relatively stable for grain yield. Considering the Wricke's covalence (W_i) model genotypes 38 TH ESWYT 103, 38 TH ESWYT 102, 38TH ESWYT 106, HYT 70 (N) E-1, 38TH ESWYT 140, PASEENA-17, 25th SAWYT 307 and KHAISTA-17 showed better stability across the locations. Both Eberhart and Russell and Wricke's covalence stability models similarly described the stability of 38TH ESWYT 110 and KHAISTA-17 for grain yield. Therefore, these genotypes could be used in wheat improvement program for enhancing stability.

Keywords: Genotype $\times$ environmental interaction, Stability in wheat genotypes, Grain yield

Introduction

Wheat is the primary food source of people in Pakistan. At national level, wheat was grown on 9.2 million hectares which produced 25.1 million tons with an average yield of 2.7 ton/ha⁻¹, while in Khyber Pakhtunkhwa, it was grown on 0.73 million hectares which produced 1.2 million tons with an average yield 1.7 ton/ha⁻¹ (Pak. Bureau Stat. 2014-15) [1]. The average national wheat yield of Pakistan is far below than agro-technologically advanced countries of the world. In Khyber Pakhtunkhwa province the situation is even worse where yield is lower than the national average yield. Factors for lower grain yield include lack of irrigation water, inadequate rainfall, heat stress, unavailability of high yielding cultivars and absence of quality seed. Demand for wheat being a staple food crop, would rise with the increase in population. Wheat production could be increased either by developing high yielding cultivars or growing more area under cultivation. The choice for wheat cultivation on larger area is partial; however, development of high yielding wheat cultivars with wider adaptability would play significant role.

Cultivars performance largely depends on their genetic makeup (G), environment (E) and their interaction (GEI). Fluctuating response of genotypes across test environments is a usual phenomenon, known as GEI [2, 3]. Yield potential of a cultivar is the result of its performance over locations and years. Therefore, stability analysis of genotypes is required in the presence of GEI to ascertain high yielding and relatively

stable genotypes. For several test environments, the GEI governs the credentials of the most stable genotypes that are suitable for specific environment [4]. Thus, the genotypes possessing genetic homeostasis are essential to increase average yield.

Wheat production can boost up through cultivars having broader genetic base and better performance under various agro-climatic conditions. In wheat, genetic improvement is slow process in nature however, the selective process of man can speed it up through appropriate management of environmental factors. Improvement gets complicated when a trait is environment-driven and selection gets more complex [5]. Keeping in view the importance of GEI in reference to its application for identifying stable genotypes, the present experiment was conducted using 30 lines including three check cultivars Waadan-17, Khaista-17 and Paseena-17. The experiment was planted across five environments to; i) assess GEI effects on grain yield, ii) identify high yielding and stable genotypes for grain yield.

Description of experimental sites

Thirty genotypes including three checks cultivars viz., Waadan-17, Khaista-17 and Paseena-17 were evaluated in nine environments during 2017/18. During 2017/18, the experimental materials were planted at multiple locations i.e., Mansehra, Cereal Crops Research Institute, Pirsabak Nowshera, Buner, Tarnab and DI Khan. Hereafter, these will be referred as E-01, E-02, E-03, E-04 and E-05 (Table 1).

Table 1. Agro-metrological features of tested environments including temperature, rainfall

Environments	Growing season	Geographical position		Altitude (m.a.s.l)	Average rainfall (mm)
		Latitude	Longitude		
Mansehra	2017/18	34.3313° N	73.1980° E	915	376
CCRI	2017/18	34.0159° N	71.9755° E	288	220
Buner	2017/18	34.4694° N	72.6333° E	944	248
Tarnab	2017/18	34.0162° N	71.7056° E	299	403.9
DI Khan	2017/18	31.8626° N	70.9019° E	165	268.8

Experimental design and procedure

Thirty genotypes including Waadan-17, Khaista-17 and Paseena-17 were field-tested in five environments during 2017/18. Experimental materials were planted in RCB design with two replicates at each environment. Standard dose of nitrogen (120 kg ha^{-1}) and phosphorous (80 kg ha^{-1}) was applied. Uniform cultural practices required for wheat crop were followed throughout the growing season.

Traits measurement

Data were recorded on days to heading, days to maturity, plant height and yield per hectare following the procedure described by [6].

Statistical analysis

Analysis of variance

Data recorded on various traits were statistically analyzed across five environments appropriate for RCBD design using SAS computer program [7]. Upon significant differences, means were separated using LSD test at 5% level of probability.

Results and Discussion

Analysis of variance

Significant differences were observed among genotypes, environments (locations) and G×E interaction (GEI) means for all the traits, which assured greater genetic variability among the genotypes which might be due to divergent genetic makeup of the genotypes, as well as environments (Table 2). These results are in conformity with the findings of [8, 9]. Contrarily, Khan *et al.* [10] reported non-significant differences among genotypes, environments and their interaction for days to heading and for grain yield in wheat. In this respect, contrary observations may be due to differences in genetic makeup of the genotypes being studied, environmental factors or even both. The presence of G×E interaction makes necessary the evaluation of stability for grain yield traits to obtain good efficiency in breeding programs focused on development of high yielding lines [11]. In present study,

the contribution to total sum of squares, regardless of trait, revealed that environments (11.51 to 96.27%) and genotypes (0.98 to 13.28%) play major role in managing the given traits. However, shares of genotype × environment and experimental error (replications) were 1.63 to 34.24% and 0.93 to 39.65%, respectively.

Genotypes contribution was maximum for plant height (13.28%), followed by grain yield per hectare (7.67%), days to heading (3.37%) and days to maturity (0.98%) (Table 2). The highest share of the environment in the total variation was observed for days to maturity (96.27%), followed by days to heading (90.27%), grain yield per hectare (62.29%) and plant height (11.51%). Accumulation of G×E effects was highest for plant height (34.24%), grain yield per hectare (13.93%), days to heading (3.02%), and days to maturity (1.63%).

Days to maturity(No.)

For days to maturity, genotypic and genotype × location interactions mean values ranged from 163 to 168 days and 142 to 188 days, respectively (Table 3). The genotype 25 TH SAWYT 307 and 25 TH SAWYT 305 revealed the minimum days to maturity with the mean value of 163 days each. The later genotype was again followed by three other genotypes viz., 38TH ESWYT 138, 38TH ESWYT 104 and 38TH ESWYT 103 with the mean value of 164 days each. However, the maximum days to maturity were taken by KT-17 and HYT 70 (N) E-1 with the mean value of 168 and 167 days, respectively. Considering locations means, on average the genotypes exhibited minimum days to maturity at DI Khan (142 days), followed by CCRI (161 days), Mansehra and Tarnab (162 days each) and Buner (182 days).

In case of genotype × environment interactions, it was evident that the genotype 25 TH SAWYT 305 and 25 TH SAWYT 307 revealed minimum days to maturity with a mean value of 142 days each at DI Khan

followed by 25 TH SAWYT 305 with the mean value of 161 days. While at Mansehra, 25 TH SAWYT 343 and 38TH ESWYT 116 exhibited minimum days to maturity with the mean value of 162 days to maturity each. The same days to maturity were taken by 25 TH SAWYT 307 and 38TH ESWYT 138 at Tarnab. However, the genotypes HYT 70 (N) E-40, 38TH ESWYT 138, 25 TH SAWYT 305 and 25 TH SAWYT 307 manifested maximum days to maturity, each with a mean value of 185 days.

Days to heading(No.)

For days to maturity, genotypic and genotype $\times$ location interactions mean values ranged from 123 to 130 days and 108 to 142 days, respectively (Table 4). The genotype 25 TH SAWYT and 25 TH SAWYT 305 307 took minimum days to heading with the mean value of 123 and 124 days, respectively. Whereas, the maximum days to heading were taken by the check cultivar viz., KT-17 and Paseena-17 with the mean value of 130 days each. Considering locations means, on average the genotypes exhibited minimum days to heading at DI Khan (108 days), followed by Manshera (108 days), Tarnab (124 days), CCRI (127 days) and Buner (138 days) (Table 4).

In case of genotype $\times$ environment interactions, the minimum days to heading (108 days) were taken by the genotype 38TH ESWYT 103 at DI Khan, followed by 38TH ESWYT 138 at Manshera with the mean value of 120 days. Similarly, two other genotypes viz., 25 TH SAWYT 307 and 38TH ESWYT 138 were earlier in heading at Tarnab with a mean value of 124 days. While at CCRI the genotypes i.e., 25 TH SAWYT 305, 25 TH SAWYT 307 and HYT 65 (S)E-9 took minimum days to heading (127 days) and Buner (138 days). Whereas, across all these tested located Buner took maximum days with a mean value of 138 days for majority of the genotypes (Table 4).

Plant height(cm)

For plant height, genotypic and genotype $\times$ location interactions mean values ranged from 88 to 100 cm and 71 to 115 cm, respectively (Table 5). The genotype WADAAN-17 obtained maximum plant height (100cm) followed by HYT 70 (N) E-40 (99cm) and 25 TH SAWYT 324 (97cm). Considering locations means, on average the genotypes exhibited maximum plant height at Buner (115cm), followed by Tarnab (108cm), Manshera (101cm), CCRI and DI Khan (99cm) each (Table 5).

In case of genotype $\times$ environment interactions, the maximum plant height was obtained by WADAAN-17 (115cm) followed by 38TH ESWYT 102 (106cm) at Buner. At Tarnab the maximum plant height was observed by the genotype KT-17 followed by 38TH ESWYT 116, HYT 70 (N) E-40 and WADAAN-17. These four genotypes exhibited a mean value of 108 cm. The genotypes HYT 70 (N) E-40, WADAAN-17 and KT-17 revealed maximum plant height at Mansehra with a mean value of 101cm. While at CCRI and DI Khan the genotypes 25 TH SAWYT 305 and 38TH ESWYT 140 revealed a maximum value of 99cm each (Table 5).

Grain yield per hectare

Yield improvement is one of the major objectives of every plant breeding program and is a complex quantitative trait that is controlled by genetic potential and also influenced greatly by environmental factors. Means for seed yield of 30 wheat genotypes across five environments are given in (Table 6). Overall means ranged from 2837.5 to 4330.8 kg ha⁻¹. Fifteen out of 30 genotypes produced higher seed yield than averaged seed yield over all environments. Minimum seed yield across five environments was produced by genotypes 25th SAWYT 305 (2837.5 kg ha⁻¹), followed by 25th SAWYT 343 (2980.8 kg ha⁻¹) and HYT 65 (S)E-34 (3000.8 kg ha⁻¹), whereas maximum seed

yield (4330.8 kg ha⁻¹) across all environments was obtained from genotype 38TH ESWYT 103, followed by HYT 65 (S) E-51 (4172.5 kg ha⁻¹) and KHAISTA-17 (4039.8 kg ha⁻¹). Among locations, the most productive environment for seed yield was Tarnab, produced an average seed yield of 4607.1 kg ha⁻¹, followed by Mansehra (4294.3 kg ha⁻¹), DI Khan (3716.3 kg ha⁻¹) and CCRI (3622.2 kg ha⁻¹), while least productive environment for seed yield was Buner (1503.6 kg ha⁻¹). Maximum desirable seed yield was produced by genotype WADAAN-17 (5666.7 kg ha⁻¹) at Mansehra, genotype HYT 65 (S) E-51 (5091.7 kg ha⁻¹) at CCRI, genotype HYT 70 (N) E-40 (2308.3 kg ha⁻¹) at Buner, genotype 38TH ESWYT 138 (5625.0 kg ha⁻¹) at Tarnab, and genotype HYT 70 (N) E-16 (4879.2 kg ha⁻¹) at DI Khan (Table 6).

Stability analysis

Eberhart and Russell analysis

Selection of desirable genotypes become difficult when evaluated across environments, because the presence of significant GEI reduce the relationship between genotypic and phenotypic values, thus preventing the expected genetic progression in breeding program. Therefore, stability study must be carried to identify genotypes with constant mean efficiency. Data of tested genotypes for grain yield were subjected to stability models that proposed by using [12]. According to this model, genotypes with high mean yield, having regression coefficient (bi) approximating unity and minimum deviation from regression (S²dj) will be stated as stable. Mean yield, coefficient of regression (bi) and deviation from regression (S²dj) of 30 wheat genotypes across five environments are given in (Table 7 & 8). None of the genotype were found to show ideal stability (S²di= 0). Even though, based on given mean grain yield, coefficient of regression near to unity and having minimum deviation from regression genotype HYT 65 (S) E-51 (bi= 0.92 and

S²dj= 39587.73) followed by KHAISTA-17 (bi= 1.06 and S²dj= -41653.94), 38TH ESWYT 110 (bi= 1.09 and S²dj= -31036.77) and HYT 70 (N) E-1 (bi= 1.07 and S²dj= 167932.65) were identified as relatively stable genotypes that rank 2nd, 3rd, 4th and 6th for grain yield in (Table 9). The first genotype had regression coefficient (bi) values less than unity, which indicates that this is specifically suited to unfavorable environments. However, the remaining three genotypes had regression coefficient (bi) values greater than unity implied the wide adaptability of these genotypes to favorable environments. Our results are in accordance of Eberhart and Russell [13] who reported stable genotype for grain yield plant⁻¹ in their study by using Eberhart and Russell model.

Wricke's ecovalence analysis

Wricke's ecovalence (Wi) is another model used as stability parameter. According to this model the genotypes with lowest Wi value will be consider more stable compared to other genotypes. Wricke's ecovalence was calculated for each of the 30 wheat genotypes evaluated across five diverse locations for one year in the major wheat growing regions of Khyber Pakhtunkhwa (Table 10). The genotypes with the lowest ecovalence contributed the least to the genotype by environment interaction and are therefore more stable. Accordingly, 38TH ESWYT 103, 38TH ESWYT 102, 38TH ESWYT 106, HYT 70 (N) E-1, 38TH ESWYT 140, PASEENA-17, 25th SAWYT 307 and KHAISTA-17 were the most stable genotypes that for grain yield ranked 14th, 10th, 12th, 06th, 20th, 13th, 25th and 3rd respectively. Although, the most unstable genotypes were HYT 70 (N) E-16, 38TH ESWYT 124, KT-17, HYT 65 (S) E-9, 38TH ESWYT 142, HYT 65 (S) E-8, HYT 65 (S) E-5 and 25th SAWYT 325; that for grain yield ranked 15th, 16th, 18th, 21st, 27th, 22nd, 27th and 23rd, respectively. The results indicate that some of the high yielding

genotypes have lowest ecovalence and therefore, could be recommended for general adaptability.

Table 2. Mean squares of different wheat genotypes tested across five environments of Khyber Pakhtunkhwa during 2018-19

Source	DF	Days to heading	Days to maturity	Plant height	Grain yield
Environments	4	5417.05** (90.27%)	11925.47** (96.27%)	499.81* (11.51%)	88378605.70** (62.29%)
Reps w/n Loc	5	41.01** (0.85%)	18.50** (0.19%)	45.65 ^{NS} (1.31%)	226532.67 ^{NS} (0.20%)
Genotypes	29	27.91** (3.37%)	16.75** (0.98%)	79.55* (13.28%)	1500989.88** (7.67%)
G × L	116	6.25* (3.02%)	6.96** (1.63%)	51.27** (34.24%)	681522.25** (13.93%)
Pooled Error	145	4.10 (2.48%)	3.19 (0.93%)	47.49 (39.65%)	622798.77 (15.91%)
CV (%)	-	1.59	1.08	7.35	22.24

*,** = Significant at 1% and 5% level of probability, N.S = Non-significant, DF = Degree of freedom, CV = coefficient of variation and () = values in parenthesis are percent sum squares

Table 3. Means for days to maturity of different genotypes evaluated across five environments during 2018-19

Genotypes	Days to maturity				DI Khan	Genotype means
	Mansehra	CCRI	Buner	Tarnab		
25 TH SAWYT 305	165	161	185	163	142	163
25 TH SAWYT 307	165	162	185	162	142	163
25 TH SAWYT 324	164	165	187	167	145	165
25 TH SAWYT 325	166	162	186	164	145	165
25 TH SAWYT 343	162	163	186	167	146	165
38 TH ESWYT 102	163	165	187	170	151	167
38 TH ESWYT 103	166	162	186	165	142	164
38 TH ESWYT 104	163	163	186	164	144	164
38 TH ESWYT 106	167	165	187	168	145	166
38 TH ESWYT 110	163	163	186	166	146	165
38 TH ESWYT 111	165	163	186	167	150	166
38 TH ESWYT 140	167	164	186	167	150	166
38 TH ESWYT 116	162	164	186	166	149	165
38 TH ESWYT 124	164	163	186	167	148	165
38 TH ESWYT 138	164	162	185	162	147	164
38 TH ESWYT 142	166	164	187	166	144	165
38 TH ESWYT 145	165	163	188	168	153	167
39 TH ESWYT 108	164	164	187	164	146	165
HYT 65 (S) E-5	169	162	186	165	144	165
HYT 65 (S)E-8	163	163	186	168	145	165
HYT 65 (S)E-9	165	163	186	169	148	166
HYT 65 (S)E-34	168	162	186	165	143	165

HYT 65 (S) E-51	164	162	188	170	152	167
HYT 70 (N) E-1	166	164	188	170	150	167
HYT 70 (N) E-16	167	162	186	167	146	165
HYT 70 (N) E-40	166	164	185	168	145	165
WADAAN-17	163	165	188	170	148	167
KHAISTA-17	165	164	185	170	151	167
PASEENA-17	164	163	188	169	153	167
KT-17	165	163	188	171	153	168
Loc means	165	163	186	167	147	165

LSD_{0.05} Genotypes = 1.58, Locations = 0.64, GLI = 3.53

Table 4. Means for days to heading of different genotypes evaluated across five environments during 2018-19

Genotypes	Days to heading				DI Khan	Genotype means
	Mansehra	CCRI	Buner	Tarnab		
25 TH SAWYT 305	121	127	138	125	108	124
25 TH SAWYT 307	121	127	138	124	108	123
25 TH SAWYT 324	126	129	139	129	111	127
25 TH SAWYT 325	128	129	138	126	111	126
25 TH SAWYT 343	126	129	138	129	112	127
38 TH ESWYT 102	128	128	142	132	117	129
38 TH ESWYT 103	125	128	138	127	108	125
38 TH ESWYT 104	128	129	139	126	110	126
38 TH ESWYT 106	129	128	142	130	111	128
38 TH ESWYT 110	128	129	140	128	112	127
38 TH ESWYT 111	127	129	138	129	116	128
38 TH ESWYT 140	126	128	138	129	116	127
38 TH ESWYT 116	124	130	139	128	115	127
38 TH ESWYT 124	127	128	140	129	114	127
38 TH ESWYT 138	120	130	138	124	113	125
38 TH ESWYT 142	126	130	141	128	110	127
38 TH ESWYT 145	128	129	142	130	119	129
39 TH ESWYT 108	130	129	141	126	112	127
HYT 65 (S) E-5	126	129	139	127	110	126
HYT 65 (S)E-8	127	128	140	130	111	127
HYT 65 (S)E-9	127	127	138	131	114	127
HYT 65 (S)E-34	127	128	138	127	109	126
HYT 65 (S) E-51	127	129	142	132	118	129
HYT 70 (N) E-1	127	130	142	132	116	129
HYT 70 (N) E-16	126	129	138	129	112	127
HYT 70 (N) E-40	126	129	138	130	111	126
WADAAN-17	128	129	141	132	114	128
KHAISTA-17	127	129	140	132	117	129
PASEENA-17	128	130	141	131	119	130
KT-17	128	128	142	133	119	130
Loc means	126	128	139	129	113	127

LSD_{0.05} Genotypes = 1.79, Locations = 0.73, GLI = 4.0

Table 5. Means for plant height of different genotypes evaluated across five environments during 2018-19

Genotypes	Plant height (cm)				DI Khan	Genotype means
	Mansehra	CCRI	Buner	Tarnab		
25 TH SAWYT 305	92	99	98	95	93	95
25 TH SAWYT 307	94	91	96	98	93	94
25 TH SAWYT 324	93	91	105	98	98	97
25 TH SAWYT 325	87	95	99	90	92	92
25 TH SAWYT 343	96	90	100	105	91	96
38 TH ESWYT 102	100	93	106	100	84	97
38 TH ESWYT 103	90	92	93	98	89	92
38 TH ESWYT 104	95	95	94	98	86	93
38 TH ESWYT 106	87	90	91	95	98	92
38 TH ESWYT 110	98	95	90	93	96	94
38 TH ESWYT 111	95	87	94	93	93	92
38 TH ESWYT 140	87	89	77	93	99	89
38 TH ESWYT 116	99	88	105	105	87	97
38 TH ESWYT 124	97	83	71	100	90	88
38 TH ESWYT 138	96	86	94	98	97	94
38 TH ESWYT 142	90	88	87	90	93	90
38 TH ESWYT 145	97	90	89	98	98	94
39 TH ESWYT 108	96	94	95	95	92	94
HYT 65 (S) E-5	89	91	88	95	91	91
HYT 65 (S)E-8	99	83	96	91	93	92
HYT 65 (S)E-9	94	84	96	100	88	92
HYT 65 (S)E-34	91	89	91	98	92	92
HYT 65 (S) E-51	91	86	87	103	90	91
HYT 70 (N) E-1	100	91	91	93	92	93
HYT 70 (N) E-16	93	91	103	95	93	95
HYT 70 (N) E-40	101	92	103	105	97	99
WADAAN-17	101	89	115	105	92	100
KHAISTA-17	95	91	101	103	91	96
PASEENA-17	95	93	93	100	97	95
KT-17	101	92	93	108	88	96
Loc means	94	90	95	98	92	94

LSD_{0.05} Genotypes = 6.09, Locations = 2.49, GLI = 13.62**Table 6. Means for grain yield of different genotypes evaluated across five environments during 2018-19**

Genotypes	Grain yield (kg hac ⁻¹)				DI Khan	Genotype means
	Mansehra	CCRI	Buner	Tarnab		
25 TH SAWYT 305	3708.3	2025.0	1425.0	4166.7	2862.5	2837.5
25 TH SAWYT 307	4032.1	2616.7	1550.0	3895.8	3233.3	3065.6
25 TH SAWYT 324	4083.3	3800.0	1216.7	4104.2	2500.0	3140.8
25 TH SAWYT 325	3875.0	2150.0	1354.2	4229.2	4179.2	3157.5
25 TH SAWYT 343	3583.3	2383.3	1541.7	4458.3	2937.5	2980.8
38 TH ESWYT 102	4791.7	3775.0	1620.8	4687.5	3920.8	3759.2
38 TH ESWYT 103	4666.7	3633.3	1566.7	4583.3	3833.3	3656.7

38 TH ESWYT 104	4666.7	3816.7	1470.8	3520.8	3933.3	3481.7
38 TH ESWYT 106	4458.3	3566.7	1350.0	5041.7	4195.8	3722.5
38 TH ESWYT 110	5025.0	4366.7	1816.7	5208.3	3333.3	3950.0
38 TH ESWYT 111	4916.7	3566.7	1800.0	5604.2	3425.0	3862.5
38 TH ESWYT 140	4229.2	3800.0	1250.0	4854.2	3083.3	3443.3
38 TH ESWYT 116	3937.5	4933.3	2079.2	4645.8	3829.2	3885.0
38 TH ESWYT 124	5500.0	2983.3	1129.2	4958.3	3145.8	3543.3
38 TH ESWYT 138	4083.3	4083.3	1579.2	5625.0	3879.2	3850.0
38 TH ESWYT 142	2833.3	3891.7	1579.2	3387.5	3412.5	3020.8
38 TH ESWYT 145	4437.5	3150.0	958.3	3991.7	4745.8	3456.7
39 TH ESWYT 108	5062.5	4100.0	962.5	4958.3	4208.3	3858.3
HYT 65 (S) E-5	2958.3	3758.3	1454.2	4583.3	2445.8	3040.0
HYT 65 (S)E-8	3437.5	2791.7	1191.7	5229.2	4325.0	3395.0
HYT 65 (S)E-9	3604.2	2983.3	1550.0	4104.2	4875.0	3423.3
HYT 65 (S)E-34	3583.3	2308.3	1150.0	4708.3	3254.2	3000.8
HYT 65 (S) E-51	4729.2	5091.7	2195.8	5062.5	3783.3	4172.5
HYT 70 (N) E-1	4208.3	4091.7	1583.3	5041.7	4483.3	3881.7
HYT 70 (N) E-16	3333.3	4291.7	1379.2	4125.0	4879.2	3601.7
HYT 70 (N) E-40	4375.0	4475.0	2308.3	4416.7	3212.5	3757.5
WADAAN-17	5666.7	4341.7	1404.2	5479.2	4762.5	4330.8
KHAISTA-17	5166.7	4658.3	1833.3	4895.8	3641.7	4039.2
PASEENA-17	4333.3	4433.3	1562.5	4354.2	3745.8	3685.8
KT-17	5541.7	2800.0	1245.8	4291.7	3420.8	3460.0
Loc means	4294.3	3622.2	1503.6	4607.1	3716.3	3548.7

LSD_{0.05} Genotypes = 697.55, Locations = 284.77, GLI = 1559.77

Table 7. Mean, regression coefficient (bi) and deviation from regression (s²di) values for plant height and seed yield of different wheat genotypes evaluated across five environments during 2018-19

Genotypes	Plant height			Grain yield per hectare		
	Mean	Bi	S ² di	Mean	Bi	S ² di
25th SAWYT 305	95.3	-0.29	-13.38	2837.50	0.83	63230.63
25th SAWYT 307	94.2	0.84	-22.86	3065.58	0.80	-174554.56
25th SAWYT 324	96.8	0.88	8.76	3140.82	0.95	36692.32
25th SAWYT 325	92.2	-0.43	1.75	3157.51	0.93	330297.92
25th SAWYT 343	96.4	2.08	-19.28	2980.84	0.83	-13844.48
38TH ESWYT 102	96.5	1.68	38.27	3759.16	1.04	-278176.82
38TH ESWYT 103	92.2	0.84	-16.73	3656.69	1.02	-279649.87
38TH ESWYT 104	93.1	0.75	-2.89	3481.67	0.87	117140.19
38TH ESWYT 106	92.2	0.19	0.78	3722.51	1.17	-257796.69
38TH ESWYT 110	94	-0.41	-12.95	3950.01	1.09	-31036.77
38TH ESWYT 111	92.1	0.70	-17.27	3862.51	1.15	1705.72
38TH ESWYT 140	88.7	-0.30	58.68	3443.33	1.11	-165715.58
38TH ESWYT 116	96.7	2.72	1.11	3884.99	0.78	137001.81
38TH ESWYT 124	88	1.68	124.63	3543.34	1.32	302588.92
38TH ESWYT 138	93.8	1.29	-11.36	3850.00	1.14	-59530.62
38TH ESWYT 142	89.5	0.07	-16.14	3020.84	0.56	115919.68
38TH ESWYT 145	94	0.68	-3.62	3456.68	1.12	305965.92

39TH ESWYT 108	94.3	0.26	-21.91	3858.34	1.37	-245040.91
HYT 65 (S) E-5	90.6	0.41	-15.40	3040.00	0.81	326083.42
HYT 65 (S)E-8	92.1	1.15	11.36	3395.00	1.12	381188.70
HYT 65 (S)E-9	92.2	2.19	-22.10	3423.34	0.83	433849.05
HYT 65 (S)E-34	92	0.94	-19.41	3000.84	1.02	47648.79
HYT 65 (S) E-51	91.3	1.88	-4.92	4172.49	0.92	39587.73
HYT 70 (N) E-1	93.2	0.28	-7.52	3881.68	1.07	-167932.65
HYT 70 (N) E-16	95	0.71	-0.02	3601.66	0.88	644503.73
HYT 70 (N) E-40	99.2	1.79	-21.81	3757.50	0.69	-12045.19
WADAAN-17	100.1	2.67	48.43	4330.83	1.40	-228819.26
KHAISTA-17	95.9	1.76	-15.07	4039.17	1.06	-41653.94
PASEENA-17	95.3	0.74	-16.80	3685.82	0.95	-105083.69
KT-17	96	2.24	3.73	3460.00	1.17	445809.19

Table 8. Mean, regression coefficient (bi) and deviation from regression (s^2di) values for days to heading and maturity of different wheat genotypes evaluated across five environments during 2018-19

Genotypes	Days to heading			Days to maturity		
	Mean	Bi	S ² di	Mean	Bi	S ² di
25 TH SAWYT 305	123.5	-0.52	1.11	163.1	1.08	2.79
25 TH SAWYT 307	123.3	0.71	1.13	162.7	1.09	1.78
25 TH SAWYT 324	126.5	-0.76	1.07	165.3	1.07	0.37
25 TH SAWYT 325	126.2	1.24	1.01	164.5	1.03	0.53
25 TH SAWYT 343	126.6	-0.46	0.99	164.5	1.03	0.63
38 TH ESWYT 102	129.1	2.43	0.93	167	0.92	3.16
38 TH ESWYT 103	125.1	-0.69	1.14	164.1	1.10	1.77
38 TH ESWYT 104	126.1	3.18	1.10	163.8	1.06	0.37
38TH ESWYT 106	127.7	1.09	1.13	166.2	1.05	1.09
38TH ESWYT 110	127.3	-0.40	1.04	164.7	1.01	-1.10
38TH ESWYT 111	127.6	-1.95	0.83	166	0.91	-0.60
38TH ESWYT 140	127.1	-1.67	0.84	166.4	0.92	-0.88
38TH ESWYT 116	126.7	0.88	0.91	165.2	0.95	1.51
38TH ESWYT 124	127.3	-1.75	0.99	165.3	0.97	-1.22
38TH ESWYT 138	124.6	10.41	0.95	163.8	0.97	1.80
38TH ESWYT 142	126.9	-0.88	1.17	165.1	1.08	0.13
38TH ESWYT 145	129.3	1.90	0.86	167.1	0.91	3.82
39TH ESWYT 108	127.4	4.28	1.07	164.9	1.03	0.35
HYT 65 (S) E-5	125.9	-0.55	1.11	164.9	1.06	7.41
HYT 65 (S)E-8	126.9	-0.71	1.11	164.6	1.05	0.22
HYT 65 (S)E-9	127.2	0.08	0.91	165.9	0.97	-0.36
HYT 65 (S)E-34	125.6	0.39	1.09	164.7	1.07	6.49
HYT 65 (S) E-51	129.3	2.50	0.89	167	0.93	6.46
HYT 70 (N) E-1	129	-0.30	1.00	167.3	0.98	-0.43
HYT 70 (N) E-16	126.6	-0.46	0.99	165.3	1.02	0.87
HYT 70 (N) E-40	126.4	0.61	1.03	165.3	1.01	1.76
WADAAN-17	128.4	-0.81	1.02	166.6	1.03	2.22
KHAISTA-17	128.8	-0.14	0.87	166.7	0.88	1.26
PASEENA-17	129.5	-0.35	0.84	167.3	0.91	4.42

KT-17	129.9	3.66	0.87	167.8	0.92	5.71
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Table 9. Mean, regression coefficient (bi) and deviation from regression (s^2di) values for Grain yield of different wheat genotypes evaluated across five environments during 2018-19

Genotypes	Grain yield (Kg hac ⁻¹)			
	Bi	S ² di	Mean	Rank
25th SAWYT 305	0.83	63230.63	2837.50	30
25th SAWYT 307	0.80	-174554.56	3065.58	25
25th SAWYT 324	0.95	36692.32	3140.82	24
25th SAWYT 325	0.93	330297.92	3157.51	23
25th SAWYT 343	0.83	-13844.48	2980.84	29
38TH ESWYT 102	1.04	-278176.82	3759.16	10
38TH ESWYT 103	1.02	-279649.87	3656.69	14
38TH ESWYT 104	0.87	117140.19	3481.67	17
38TH ESWYT 106	1.17	-257796.69	3722.51	12
38TH ESWYT 110	1.09	-31036.77	3950.01	04
38TH ESWYT 111	1.15	1705.72	3862.51	07
38TH ESWYT 140	1.11	-165715.58	3443.33	20
38TH ESWYT 116	0.78	137001.81	3884.99	05
38TH ESWYT 124	1.32	302588.92	3543.34	16
38TH ESWYT 138	1.14	-59530.62	3850.00	09
38TH ESWYT 142	0.56	115919.68	3020.84	27
38TH ESWYT 145	1.12	305965.92	3456.68	19
39TH ESWYT 108	1.37	-245040.91	3858.34	08
HYT 65 (S) E-5	0.81	326083.42	3040.00	26
HYT 65 (S)E-8	1.12	381188.70	3395.00	22
HYT 65 (S)E-9	0.83	433849.05	3423.34	21
HYT 65 (S)E-34	1.02	47648.79	3000.84	28
HYT 65 (S) E-51	0.92	39587.73	4172.49	02
HYT 70 (N) E-1	1.07	-167932.65	3881.68	06
HYT 70 (N) E-16	0.88	644503.73	3601.66	15
HYT 70 (N) E-40	0.69	-12045.19	3757.50	11
WADAAN-17	1.40	-228819.26	4330.83	01
KHAISTA-17	1.06	-41653.94	4039.17	03
PASEENA-17	0.95	-105083.69	3685.82	13
KT-17	1.17	445809.19	3460.00	18

Table 10. Wricke's covalence value for 30 wheat genotypes evaluated across five locations

Genotypes	Wi	Rank	Grain yield(kgha ⁻¹)	Rank
25th SAWYT 305	1294547.5	13	2837.5	30
25th SAWYT 307	654125.0	24	3065.6	25
25th SAWYT 324	1058890.6	18	3140.8	24
25th SAWYT 325	1957611.1	08	3157.5	23
25th SAWYT 343	1058005.2	19	2980.8	29
38TH ESWYT 102	111300.1	29	3759.2	10
38TH ESWYT 103	98765.6	30	3656.7	14

38TH ESWYT 104	1382161.3	12	3481.7	17
38TH ESWYT 106	321394.1	28	3722.5	12
38TH ESWYT 110	889049.6	21	3950.0	04
38TH ESWYT 111	1064945.5	17	3862.5	07
38TH ESWYT 140	506270.2	26	3443.3	20
38TH ESWYT 116	1626194.9	10	3885.0	05
38TH ESWYT 124	2450795.1	02	3543.3	16
38TH ESWYT 138	871597.8	22	3850.0	09
38TH ESWYT 142	2399120.1	05	3020.8	27
38TH ESWYT 145	1937261.5	09	3456.7	19
39TH ESWYT 108	997380.2	20	3858.3	08
HYT 65 (S) E-5	2126440.1	07	3040.0	26
HYT 65 (S)E-8	2160577.7	06	3395.0	22
HYT 65 (S)E-9	2403594.4	04	3423.3	21
HYT 65 (S)E-34	1079847.1	16	3000.8	28
HYT 65 (S) E-51	1093714.6	15	4172.5	02
HYT 70 (N) E-1	457005.1	27	3881.7	06
HYT 70 (N) E-16	2957669.6	01	3601.7	15
HYT 70 (N) E-40	1453364.1	11	3757.5	11
WADAAN-17	1207296.3	14	4330.8	01
KHAISTA-17	829483.1	23	4039.2	03
PASEENA-17	633655.6	25	3685.8	13
KT-17	2445908.2	03	3460.0	18

Conclusion and Recommendation

In case of genotype $\times$ environment interactions, maximum desirable seed yield was produced by genotype WADAAN-17 at Mansehra, genotype HYT 65 (S) E-51 at CCRI, genotype HYT 70 (N) E-40 at Buner, the genotype 38TH ESWYT 138 at Tarnab and genotype HYT 70 (N) E-16 at DI Khan. According to [13] stability model none of the genotype were found to show ideal stability ($S^2_{di}=0$). However, based on their conditions genotypes HYT 65 (S) E-51, KHAISTA-17, 38TH ESWYT 110 and HYT 70 (N) E-1 were identified as relatively stable for grain yield. Considering the Wricke's ecovalence (W_i) model genotypes 38 TH ESWYT 103, 38 TH ESWYT 102, 38TH ESWYT 106, HYT 70 (N) E-1, 38TH ESWYT 140, PASEENA-17, 25 TH SAWYT 307 and

KHAISTA-17 showed better stability across the locations. Both Eberhart and Russell and Wricke's ecovalence stability models similarly described the stability of 38TH ESWYT 110 and KHAISTA-17 for grain yield. Therefore, these genotypes could be used in wheat improvement program for enhancing stability.

Authors' contributions

Conceived and designed the experiments: I Ullah, Performed the experiments: S Ali & S Fahad, Analyzed the data: A Ahmad, Contributed materials/ analysis/ tools: S Mukhtiar & N Samad, Wrote the paper: H Raza & M Babar.

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