The Analysis of Genotype-Environment Interactions: Comparison of Parametric and Non-Parametric Tests for Interactions in Bread Wheat Genotypes in Cold Regions of Iran

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Abstract: In order to evaluate adaptability and stability of wheat genotypes grain yield and also to select and introduce the most productive genotype, regional tests were conducted in the form of randomized complete block design with three replicates and 18 genotypes in eleven different regions were evaluated during two cropping season years (2009-2011). The grain yield data were combined variance analyzed. Given the significance of trilateral interaction, stability analysis was performed with parametric and non-parametric statistics and different methods including environmental variance, coefficient of environmental variations, Wrickeequivalence, Shukla stability variance, rank test, simultaneous selection and Eberhart and Russell methods in roder to conduct more precise investigation on the interactions and stable lines. Results obtained using different methods were to some extent similar. In most methods, the lines no 8, 16, 18, and 10 with average yields of 6.778, 6.671, 6.046, and 6.601 ton/ha were reported to be the most stable lines.

Keywords: Wheat, stability parameters, adaptability, cold zone, genotype x environment interaction.

1. Introduction

To examine grain yield in multi-regional tests, if the genotype relative yield is different from other genotypes in other regions, it indicates the presence of interaction between genotype and environment (24). The varieties should be evaluated within a wide range of environmental changes (different locations and years) so that a more accurate measure presented in the recommendation of the varieties(16) and recommended varieties are recommendable in different regions in a way that the varietieswould have acceptable yield, stability, and compatibility with various environments in all areas of similar climate orfairly in most them. Given that the analysis of conventional methods, such as using variance analysis tables, only provide information on the interaction of genotype and environment, different criteria are used to examine the varieties' stability and introducing them. One of the parameters is environmental variance (S_i^2), which is not desired when the diversity of test environments are high. While it is an effective method in geographical region with low diversity. According to this method, a genotype is stable if it has lowerenvironmental variance. In 1959, the use of mean has been considered as pair variance in varieties, and genotypes were presented to identify the adaptability of varieties with various environments. The method similar to the previous one was also proposed by Pelstid in 1960 where the greater is the value of this index, the genotype will be more stable. According to Perkins and Jinks (1963), genotype isconsideredstable with zero regression line. The coefficient of determination (R^2) was proposed instead of the mean squares deviation from the regression line to estimate the stability of genotypes (18). Francis and Kannenbergintroduced the coefficient of variations (CV) in the case of the coefficient of variations is less than and theyield is greater than mean in the detection of stable varieties. In 1962, equivalenceparameter was proposed by Rick based on the sum of squares of the interactionsbetween genotype and environment in experimental environments (25). The stability variance parameter for each genotype was proposed in 1972 by Shukla (22). This parameter is a linear combination of equivalence, so the two parameters mentioned for stability and stability variance are equal to one another for ranking purposes (26). Genotypes are considered stable by these methods if their parameter value is minimum. Many researchers, including Eberhart and Russell (1966), Finlay and Wilkinson (1963), and Freeman and Perkins (1971) explained the relationship between genotypes' yield and average yieldof the environments or environmental index by a linear regression equation. Accordingly, if the slope of the regression line is equal to one, general or stable adaptation will be

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medium. The deviations from regression line was used by Eberhart and Russell (1966) as a new parameter to diagnose stable varieties, in addition to average yield and regression coefficient. So, ideal varieties will have regression coefficient of one and regression deviation of zero. Ranking statistic proposed by Kang (1998) considered the genotypes that have the lowest average in ranking and regions with lowest standard deviation as stable genotypes and line. Also in 1993, this researcher suggested the stability-yield statistic (Ysi) as the simultaneous selection method for grain yield and stability (10). Mean squares estimation was proposed by Lynn and Baines (1988) as a parameter in assessing stability. This study aims to investigate the effects of year and location on varieties and also examine different statistical methods for selecting adaptable and stable genotypes in different environments.

Materials and methods

The experiment was carried out with 18 lines of wheat from breeding programs (Table 1) in agricultural research and natural resources stations of cold regions of the country by winter and facultative growth habit and also by passing tests for comparingbasic and advanced yield, in companion with Shahriar figure as the control one in the form of randomized complete block design (RCBD) with three replications and 11 agricultural research stations of Karaj, Tehran, Mashhad, Arak, RokhPlain, Tabriz, Eghlid, Zanjan, Ardebil, Miandoab and Qazvin within 2 cropping season years (90-1388). The land was cultivated under 2-year cereal-fallow periodicity, and each genotype was cultivated in the plots with the area of 7.2m^2 where the harvesting area was 6m^2 by removing half meter from both ends of each plot as the margin effect. After collecting the information of all stations within 2 years, statistical calculationswere performed. First, simple variance analysis of each year and station was performed, thenBartlet test was carried out to test the congruency of the variance of test errors. Combined variance was also carried out to determine the interaction. Finally, different methods of stability analysis including Roemer environemtnal variance, variation coefficient of Kannbrg and Francis (1978), Wrickeequivalence (1962), stability variance of Shukla (1972), ranking and simultaneous selection of yield and stability by Kang (1993, 1998) were also used.

Table1. Genotypes Tree

Plot no.	Pedigress	Origin
C-88-1	Shahriyar(check)	___
C-88-2	Alvand	___
C-88-3	C-80-4	___
C-88-4	Gascogne/Col.no.3625//Alamoot	Karadj
C-88-5	Spb"s"//K134(60)/Vee"s"/3/Gascogne/4/Alamoot	Karadj
C-88-6	Alvd//Aldan/Ias58/3/MV17/5/Kal/Bb//Cj"s"/3/Hork"s"/4/MV17	Karadj
C-88-7	Rsh*2/10120//Zagros	Karadj
C-88-8	1-72-92/Vratza//Almt	Karadj
C-88-9	Bez/90Zhong87/3/Alvd//Aldan/Ias58	Miandoab
C-88-10	Ow1/4/Gv/D630//Ald"s"/3/Azd	Ardebil
C-88-11	Agri/Bjy//Vee/6/Sn64//Ske/2*Ane/3/Sx/4/Bez/5/Seri/7/F10S-1	WON-IR(10th)
C-88-12	1-72-92/Gascogne//Almt	Karadj
C-88-13	Qds/4/Anza/3/Pi/Nar//Hys/5/Vee/Nac/6/Gascogne/7/Zarrin	Karadj
C-88-14	Qds/4/Anza/3/Pi/Nar//Hys/5/Vee/Nac/6/Gascogne	Karadj
C-88-15	1-72-92/Col.no.3617//Ow1	Miandoab
C-88-16	Agri/Bjy//Vee/3/Tnmu/4/Ks82142/Cupe	WON-IR(10th)
C-88-17	Madsen/Tam 202//Tx89V4138	FAWWON(14th)
C-88-18	Sardari/HD83//Linfen 875072/Kauz	Iran-ICARDA

Conclusion and Discussion

The genotypes status and interactions in different locations and years was investigated for grain yield attribute using the data from different stations during 2 years through the combined variance analysis assuming that the fixed genotype effect and randomized effect of year and location. The results of the combined analysis (Table 2) showed that the trilateral interaction were significant at one percent, indicating significant differences between the means oflocations and years from one year to another, while the main effects of location, year and dualgenotype interaction were not significant.

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Comparing the mean grain yield showed that the most grain yield is related to the genotypes 13 and 14 and then genotypes 4 and 11 with 7057, 7065, 6964, 6797 tons per hectare, respectively. Regarding the significance of interaction between genotype-year-location, the use of mean genotype yield is not effective to identify better genotypes. Therefore, stability analysis was used in order to achieve genotypes with high adaptability and desired yield in the grain yield.

According to the results from environmental variance, the least variance is related to genotype 18, then 13 and 14 due to the yield higher than control value and total mean, so they have higher stability and suitable. Finally, a relatively similar results were obtained using coefficient of variation where genotypes 9 and 18 have the least CV and thus the highest stability. As with the previous method, the genotypes 14 and 13 that had a yield higher than control and higher than total mean of genotypes and lower CV were suitable. Genotypic stability of this criterion cannot be extended unless the genotypes available in the experiment are the representative of genotypes under cultivation in the environment. Means that, a genotype seems to be stable with a group of genotypes might be unstable with another group.Habibi et al. (2007) in the stability analysis of water and dryland farming of wheat by the coefficient of variation, have identified two varieties of Zarrin and Alvand to be similar and twice greater than Alamoutvarieties. According toWrickeequivalence parameter values (W_i), which directly depends on the interaction of genotype and environment, it was observed that genotypes 11 and 12 have the least equivalence and genotype 11 hasayieldhigher than the average of all genotypes. Therefore, the most stable genotype was identified based on this criteria. Genotype 13 had the highestgeneraladaptability and genotype 1 was estimated to the most unstable genotype due to the highest equivalence. Genotype 3 had also private adaptability in favorable environmentsbecause of a yield higher than total average. With respect to the Shuklastability parameter (δi2), genotype 12 was insignificant, indicating the stability of this genotype that has a yield higher than the total average. Therefore it had a general adaptability. Genotype 3 has also a yield close to the total average and is suitable forfavorable conditions.

Plastid method ($\theta_{(i)}$) also introduced genotypes 18, 16 and 10 as stable varieties with a large variance of the residual interaction, because they showed less contributions in the interaction. Therefore, the results from four above methods indicate the stability of these four genotypes. It can be concluded that the varieties introduced by these methods have less contributions in the interaction of genotype-environment and the emphasis will be put on the interaction in these methods. The results are in line with the results of a study conducted in 2006 by Majbodini and colleagues (15). The results of stability analysis using nonparametric rank method showed that the lowest level of R belongs to the genotypes 13 and 14. This parameter indicates the high yielding of genotype. The results obtained by calculating the standard deviation assigned the lowest value rank to the genotypes 18 and 13 (Table 2). According to the results of this method, genotype 13 is introduced as the most stable figure (Table 4). Khaje Ahmed Attari and Akbari (1996) investigated the adaptability and stability of wheat varietiesusing ranking method, and introduced the varietiesof Alamut, Zarrin and Alvand as adaptable and stable varieties.

In another research performed to determine the genotype ranks and stability of maizehybrids, the hybrid 8 with an average rank of2.909 and standard deviation of 1.92 was found to be the most stable hybrid. The results from type-4 parameter (Lynn and Binz method) showed that the least inter-location variance is related to the genotypes 17 and 8 with 0.733 and then to the genotype 10; so it is considered as the most stable genotype. In addition, genotype 8 has a yieldhigher than total average. In a research by this method, the varieties of Zarrin and Alvand had similar stability and in respect to the varieties of dryland farming, Sardari and Azar2 had no difference.

Based on thesimultaneous selection of the yield and stability (YS) in accordance with Kang method (1993) and also varieties 4 and 12with an average yield of 6764 and 6964 kg/ha and YS of 16, they were identifiedthe best genotypes in terms of stability and yield. The genotypes 14 and 13, respectively, with an average yield of 7065 and 7075 and YS of 15 and 14 were in the next positions. The genotype 18 was identified as the weakest genotypes (table was introduced as stable varieties). The research conducted by Mekbib(2002) in experimental sites in Ethiopia during three years and using this statistic, the genotypes GLP x92 and G-2816 of Beanwere selected as the genotypes suitable for future works.

Causality analysis and Correlation analysis

Investigation of correlation coefficients between physiological attributes and grain yield indicated that total weight and cluster weight at the time of flowering and maturity, grain weight and grain number had significant correlation with the yield, meaning that the yield increases with the increase in any of these attributes and vice versa. According to Tables 6 and 7, the highest direct effect and

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correlation coefficientis related to the grain weight the equal value of these correlation coefficients indicates a strong relationship between the two variables, grain yield and grain weight thus the direct selection through this attribute would be useful. The most positive indirect effects are createdthrough cluster weight at the time of maturity whenit is equal to0.873. Thus, the greater correlation between grain weight and grain yield is mainly due to the indirect effects through cluster weight at the time of maturity. Direct effects of the proportion of the cluster weight to the stem length and total weight were negative at the time of maturity, while they have positive correlation coefficient. Hence, when there is not consistency between direct effect and total effect, it is better to use indirect effect instead of direct effects for the selection of attributes. Direct effects of cluster weight during flowering and its indirect effects were positive in terms of other of the other attributesand the most positive effect was created indirectly through grain weight.

Conclusion

Finally, it can be said that the two attributes of grain weight and cluster weight have the most effect on the yield at the time of maturity and significantly influenced the yield. Therefore, they have the highest importance in modification programs.

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Table2. combined variance analysis during 2 years in 11 stations

Source of changes	df	EMS
(Llocation)	10	580219431ns
(Y)year	1	1441751.7ns
Y*L	10	50826082**
Rep (L*Y)	44	1412924.2
(G)Genotype	17	7616064.8**
G* L	170	1739736.9ns
G* Y	17	897770.6ns
G*Y*L	170	1534207.1**
(G*R)error	748	598867
CV%	11.74%	

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Table4. stability statistics value of wheat genotypes

Gen	Yield	Si2	CVi	Wi	δi2	$\overline{R}$	SDR
1	6118	2138128	23/90	26542806	4691960**	11/68	5/23
2	6163	2124574	23/65	14413428	2274325**	12/00	4/88
3	6456	2269140	23/33	17909506	2741821**	9/14	4/86
4	6964	1429117	17/17	7064641	1069936*	6/82	3/80
5	6348	2013690	22/36	14027003	1810023**	11/55	5/14
6	6231	1326531	18/48	10291209	1664803**	12/00	5/22
7	6615	1400323	17/89	7071818	1063043*	9/32	4/93
8	6844	1532535	18/09	7598922	1130826**	8/23	5/08
9	6681	1095831	15/67	9793931	1106804**	8/91	4/53
10	6399	1089577	16/31	6713454	1077956**	11/59	4/55
11	6797	1183684	16/01	4831801	1184112**	7/95	3/31
12	6764	1353398	17/20	5898253	656512/8^{ns}	8/32	4/08
13	7075	1451757	17/07	9130661	1519868**	6/27	4/57
14	7065	1419925	16/87	12142678	2085383**	6/77	5/24
15	6866	1357533	16/97	11036521	2009624**	8/05	5/17
16	6625	1339620	17/47	6508041	1029648*	9/59	4/90
17	6759	1158467	15/92	12431401	1547628**	8/14	5/04
18	5897	685041/2	14/03	7033904	1104204**	14/64	3/30

Table3. the comparison of mean grain yield during 2 years in the least significant difference test

Hamedan		Zanjan		Arak		Ghazvin		Mashhad		Jolge rokh		Ardebil		Tabriz		Eghlim		Miandoab		Mean
6856	c	6939	c	6725	c	4551	c	6954	c	7285	c	4219	c	7080	c	5170	c	5424	c	6118
5970	c	6493	c	5484	e	4589	c	6669	c	7464	c	5769	b	6697	c	4911	c	6402	c	6163
6047	c	6868	c	6355	c	5455	b	7182	c	7775	c	5044	c	7846	c	5049	c	6176	c	6456
6717	c	7658	c	6173	c	6195	a	6976	c	8206	a	6653	a	8028	c	5271	c	7349	a	6964
5340	d	6951	c	5564	d	5516	b	6908	c	8813	a	6581	a	5743	c	4640	c	6054	c	6348
6126	c	6524	c	5178	e	5440	b	7610	b	6646	d	5528	b	6278	c	4732	c	6646	b	6231
6357	c	7231	c	6437	c	6062	a	7445	c	7542	c	5881	a	6735	c	4583	c	6998	a	6615
7079	c	7393	c	6345	c	5923	a	7163	c	7483	c	6625	a	8000	c	4598	c	7629	a	6844
6990	c	7224	c	6180	c	6359	a	6697	c	7034	c	7206	a	7066	c	5205	c	6268	c	6681
6276	c	6050	c	6171	c	6591	a	6151	e	7336	c	5964	a	7293	c	4748	c	7193	a	6399
7478	c	7346	c	5776	d	6312	a	6974	c	7519	c	6656	a	7092	c	5418	c	6844	a	6797
6055	c	6933	c	6512	c	5662	a	6757	c	8223	a	7081	a	7904	c	5042	c	7246	a	6764
7050	c	6846	c	7476	c	6086	a	7583	b	8224	a	6536	a	8385	c	4504	d	7086	a	7057
7230	c	6947	c	6993	c	6731	a	6574	c	8259	a	7756	a	8131	c	5500	c	6218	c	7065
7213	c	7650	c	6469	c	5972	a	6353	d	7173	c	7550	a	8291	c	4727	c	0671	a	6866
6489	c	7204	c	6313	c	5783	a	7333	c	7317	c	5222	b	7494	c	5535	c	6734	b	6625
5760	c	7708	c	5585	d	6413	a	7136	c	7641	c	7164	a	6668	c	6205	a	6391	c	6759
5742	c	5782	c	5077	e	5708	a	6200	d	6922	c	5956	b	5787	c	5053	c	5870	c	5897
6488	c	6926	c	6156	c	5853	a	6926	c	7603	c	6299	a	7251	c	5049	c	6646	b	6592

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Table5. stability analysis of grain yield for simultaneous selection of yield and stability

Gen	Yield	Yield rank	Modification to the rank	Modified rank	Stability variance	Stability value	**Simultaneous effect**
1	6118	3	0	3	4691960**	-8	-5
2	6163	4	1	5	2274325**	-8	-3
3	6456	9	2	11	2741821**	-8	3
4	6964	16	4	20	1069936*	-4	16
5	6348	7	2	9	1810023**	-8	1
6	6231	6	1	7	1664803**	-8	-1
7	6615	10	3	13	1063043*	-4	9
8	6844	5	1	6	1130826**	-8	-2
9	6681	2	-1	1	1106804**	-8	-7
10	6399	8	2	10	1077956**	-8	2
11	6797	14	4	18	1184112**	-8	10
12	6764	13	3	16	656512/8^{ns}	0	16
13	7075	17	5	22	1519868**	-8	14
14	7065	18	5	23	2085383**	-8	15
15	6866	15	4	19	2009624**	-8	11
16	6625	11	3	14	1029648*	-4	10
17	6759	12	3	15	1547628**	-8	7
18	5897	1	-1	5	1104204**	-8	-8

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Attributes	Direct effects	Indirect effects				Correlation with yield
		GWS	SPWSTA	BWM	SPWM	
GWS	1	---	0/424	0/626	0/873	1
SPWSTA	-0/005	-0/002	---	-0/001	-0/002	0/422
BWM	-0/005	-0/003	-0/001	---	-0/004	0/625
SPWM	0/004	0/003	0/004	0/002	---	0/873

Table7. Correlation coefficients of different attributes with the yield

	BWA	SPWA	BWM	SPWM	TKW	GWS	KNSP-1	HI	PAPCG	PTRR	SPWSTA	Y
BWA	1											
SPWA	0/714**	1										
BWM	0/653**	0/666**	1									
SPWM	0/562*	0/920**	688**	1								
TKW	0/123ns	0/044ns	-0/135ns	0/048ns	1							
GWS	0/504*	0/782**	0/626**	0/873**	0/102ns	1						
KNSP-1	0/379ns	0/711**	0/652**	0/768**	-0/424ns	0/814**	1					
HI	-0/415ns	-0/188ns	-0/657**	-0/111ns	0/267ns	0/122ns	-0/072ns	1				
PAPCG	0/333ns	0/108ns	-0/429ns	-0/034ns	0/391ns	0/079ns	0/187ns	0/556*	1			
PTRR	0/277ns	-0/091ns	-0/074ns	-0/106ns	0/489*	-0/020ns	-0/408ns	0/112ns	0/434ns	1		
SPWSTA	-0/318ns	0/376ns	0/016ns	0/462ns	-0/127ns	0/424ns	470*	0/296ns	0/244ns	-0/464ns	1	
Y	0/506*	0/782**	0/625**	873**	103ns	1**	0/814**	0/124ns	0/082ns	-0/018ns	0/422ns	1

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