ORIGINAL PAPER

EVALUATION OF GRAIN YIELD STABILITY, RELIABILITY AND CULTIVAR RECOMMENDATIONS IN SPRING WHEAT (TRITICUM AESTIVUM L.) FROM KAZAKHSTAN AND SIBERIA

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ABSTRACT

The investigation was carried out to determine the stability and adaptability patterns of a set of 40 promising spring wheat genotypes from Kazakhstan and Siberia evaluated in a multievironment yield trial across 22 environments. Some of the most widely known parametric stability parameters were used as well as the less frequently cited reliability index (I). Grain yield correlated significantly and positively with the stability parameters b and S^2 and the reliability index (I); but did not correlate with AMMI ASV. However, the stability parameters failed in detecting adaptability patterns. In contrast, the reliability index (I) was probed to be more useful in supporting practical decisions. With regard to the genotypes, cultivars Lutescens 54, Lutescens 30-94, Lutescens 29-94, Tertsia, Omskaya 35, and Shortandynskaya 95 showed to be the widest adapted and the most reliable cultivars.

KEYWORDS: spring bread wheat (Triticum aestivum L.), Kazakhstan, Siberia, parametric stability analysis, reliability index

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1. INTRODUCTION

Among the objectives of multienvironment yield trials are the establishment of adaptation strategies for breeding programs and definition of domains for cultivar recommendations. The adaptation strategy objectives focuses on responses of a set of genotypes to obtain indications and generate predictions relative to future breeding material that may be produced from the genetic bases of which the tested genotypes are assumed to be a representative sample, while, for cultivar recommendations the most important information concerns the response of, and comparison between, high-yielding genotypes [2].

High yield stability usually refers to a genotype's ability to perform consistently, whether at high or low yield levels, across a wide range of environments [2]. Several biometrical methods including univariate and multivariate ones have been developed to assess stability [1]. Between them the most widely used are the regression coefficient [4], the environmental variance [12], the Shukla's [16] stability variance and Wricke's ecovalence [17]. More recently, Purchase [14] developed the AMMI Stability Value (ASV) based on the AMMI (Additive Main Effects and Multiplicative Interaction) model's PCA1 and PCA2 (Principal Components Axis 1 and 2 respectively) scores for each cultivar. This AVS is in effect the distance from the coordinate point to the origin in a two dimensional scattergram of PCA1 scores against PCA2 scores [11].

The practical interest of combining high levels of mean yield and yield stability has led to the development of the yield reliability concept [3] [6], where a reliable genotype is characterized by consistently high yield across environments [2]. The use of a yield reliability index facilitates genotype selection or recommendation, as the mean yield and the yield stability are combined into a unique measure of genotype merit [2].

A few number of studies of genotype by environment interactions (GxE) and stability have been reported on wheat in Kazakhstan [8] [9] [10]. However, no stability and reliability studies have been performed for spring bread wheat developed by Kazakhstan and Siberian breeding programs and tested together in a multienvironment yield trial. The objectives of the present study were to evaluate the grain yield of promising spring wheat genotypes in different environments in Kazakhstan-Siberia and to determine their stability and reliability for cultivar recommendations.

2. MATERIALS AND METHODS

2.1 Plant material and locations

Forty spring wheat genotypes from Kazakhstan and Siberian breeding programs (Table 1) were evaluated at the 4th and 5th Kazakhstan Siberia Network Spring Bread Wheat Breeding Yield Trials (4th and 5th KASIB-SBWBYT) across 11 locations in Kazakhstan and the Siberian region of Russia. The locations in Kazakhstan were: Karabalyk, Karaganda, Pavlodar, Aktube, Shortandy, Petropavlovsk and Almaty; and in Siberia: Omsk, Kurgan, Barnaul (Altay region of Russia) and Chelyabinsk. The nursery was evaluated in 2003 and 2004 as a yield trial in a randomized complete block design with two replications.

2.2 Yield stability and reliability methods

2.2.1 The Finlay and Wilkinson' b regression coefficient

According to Finlay and Wilkinson [4], the modeled genotype response is represented by:

$$R_{ij} = a_i + b_i m_j \qquad (1)$$

where R_{ij} = modeled genotype yield response in environment j, a_i = intercept value, and m_j = the environmental mean yield. They showed that a regression coefficient approximating 1.0 indicated an average stability, and in association with high yield, the entry possesses general adaptability. However, entries with a low yield would be poorly adapted to the environment. Regression coefficient values increasing above 1.0 describe genotypes with increasing sensitivity to environmental change, thus below average stability. Regression coefficients decreasing below 1.0 provide a measure of greater resistance to environmental change, thus above average stability [15], where the greatest stability is b = 0.

2.2.2 The environmental variance (S²)

The environmental variance (S^2) is one of the major stability measures for the static stability concept (type 1 stability) [12], i.e. the variance of genotype yields recorded across test or selection environments (i.e. individual trials). For the genotype i:

$$S_i^2 = \sum (R_{ij} - m_i)^2/(e - 1) \qquad (2)$$

where R_{ij} = observed genotype yield response in the environment j, m_i = genotype mean yield across environments, and e = number of environments. Greatest stability is $S^2 = 0$.

2.2.3 AMMI model and the AMMI Stability Value (ASV)

The AMMI model postulates additive components for

Table 1. Mean yield and origin of wheat genotypes.

Code	Name of genotypes	Yield (t/ha)	Origin
1	Omskaya 34	2.52	Siberian Research Institute
2	Omskaya 35	2.86	Siberian Research Institute
3	Lutescens 148-97-16	2.38	Siberian Research Institute
4	Chernyava 13	2.60	Omsk State Agrarian University
5	Sonata	2.85	Omsk State Agrarian University
6	Niva 2	2.61	Omsk State Agrarian University
7	Golubkovskaya	2.71	Omsk State Agrarian University
8	Iren	2.34	Krasnoufimsk Breeding Station
9	Irgina	2.01	Krasnoufimsk Breeding Station
10	Krasnoufimskaya 90	2.26	Krasnoufimsk Breeding Station
11	Sibirskaya 12	2.64	Siberian Research Institute
12	Sibirskaya 123	2.57	Siberian Research Institute
13	Novosibirskaya 15	2.25	Siberian Research Institute
14	Novosibirskaya 29	2.44	Siberian Research Institute
15	Udacha	2.79	Siberian Research Institute
17	Lutescens 574	2.81	Altay Research Institute
18	Lutescens 424	2.65	Altay Research Institute
19	Altaiskaya 50	2.11	Altay Research Institute
20	Aria	2.85	Kurgan Agric Res Institute
21	Tertsia	2.97	Kurgan Agric Res Institute
22	Fora	2.04	Kurgan Agric Res Institute
23	Chelyaba	2.58	Chelyabinsk Agric Res Institute
24	Chebarkulskaya	2.68	Chelyabinsk Agric Res Institute
25	Astana	2.70	Scientific Prod Center of Grain Farming
26	Bayterek	2.73	Scientific Prod Center of Grain Farming
27	Shortandynskaya 95	2.85	Scientific Prod Center of Grain Farming
28	Lutescens 13	2.92	Karabalyk Experimental Res Station
29	Lutescens 54	3.16	Karabalyk Experimental Res Station
31	Nadezhda	2.18	Kazakh Res. Center of Farming
32	No. 18	2.15	Kazakh Res. Center of Farming
33	Eritrospermum 727	2.55	Kazakh Res.Center of Farming
34	Lutescens 29-94	3.01	Pavlodar Agric Research Institute
35	Lutescens 30-94	3.11	Pavlodar Agric Research Institute
36	Lutescens 53-95	2.78	Pavlodar Agric Research Institute
37	Stepnaya 1	2.82	Aktube Experimental Res Station
38	Aktubinka	2.62	Aktube Experimental Res Station
39	Aktube 32	2.76	Aktube Experimental Res Station
40	GVK 1860/8	2.58	East Kazakhstan Agric Res Institute
41	GVK 1369/2	2.85	East Kazakhstan Agric Res Institute
42	GVK 1857/9	2.77	East Kazakhstan Agric Res Institute
	max	3.16	
	min	2.01	
	mean	2.62	

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the main effects of genotypes (αi) and environments (βj) and multiplicative components for the effect of the interaction (φij). Thus, the mean response of genotype i in an environment j is modeled by:

$$\hat{Y} = \mu + \alpha i + \beta j + \sum_{k=1}^{m} \lambda k \gamma ik \delta jk + \rho ij + \varepsilon ij \qquad (3)$$

in which φij is represented by:

$$\sum_{k=1}^{m} \lambda k \gamma ik \delta jk$$

where λk is the size, γik is the normalized genotype vector of the genotype scores or sensitivities, δjk is the normalized environmental vector of the scores describing environments, ρij are the AMMI residuals , and εij is the error term.

As mentioned above, the AVS is the distance from the coordinate point to the origin in a two dimensional scattergram of PCA1 scores against PCA2 scores. Because the PCA1 score contributes more to the GxE sum of squares, a weighted value is needed. This weight is calculated according to the relative contribution of PCA1 to PCA2 to the interaction SS [11].

$$ASV = \{[(SS_{PCA1} / SS_{PCA2}) (GPCA1score)]^2 + (GPCA2score)\}^{1/2} \qquad (4)$$

where SS_{PCA1} / SS_{PCA2} is the weight given to the PCA1 value by dividing the PCA1 sum of squares by the PCA2 sum of squares, GPCA1score is the PCA1 score for that specific genotype, and GPCA2score is the PCA2 score for that specific genotype.

2.2.4 The reliability index (I)

The reliability index as proposed by Kataoka [7] for economic analysis can be used for estimating, on the basis of the distribution of yield values observed across test environments, the lowest yield expected for a given genotype and a specified probability of negative events [3]. It can be calculated by the following expression:

$$I_i = m_i - Z_{(P)} S_i \qquad (5)$$

where m_i = mean yield, S_i = square root of the environmental variance (S^2), and $Z_{(P)}$ = percentile from the standard normal distribution for which the cumulative distribution function reaches the value P. $Z_{(P)}$ can assume the following values depending on the chosen P level: 0.675 for P = 0.75; 0.840 for P = 0.80; 1.040 for P = 0.85; 1.280 for P = 0.90; and 1.645 for P = 0.95. P values may vary between 0.95 (for subsistence agriculture in unfavorable cropping regions) to 0.70 for modern agriculture in most favorable regions [2].

2.3 Computer program

Calculations were performed by IRRISTAT 4.3 software [5] using the cross site analysis procedure, which gives outputs of AMMI and joint regression models including analysis of variance, regression coefficients, as well as genotypes and environments means and Biplots graphics. For the rest of calculations as stability and reliability index an ordinary spread sheet program was used.

3. RESULTS AND DISCUSSION

3.1 Mean yield

The mean yield of the 40 genotypes across 22 environments (location x year) ranged from 2.01 t/ha to 3.16 t/ha (Table 1). The difference in the rank of the genotypes in the various environments indicated the presence of GxE interactions (Table 2), that was confirmed by the significant effect of the genotype x environment interaction (explaining 15.76% of the G + E + GE) in the AMMI analysis of variance (Table 3). From Table 2 and Figure 1 it is possible to see that genotype 29 (Lutescens 54) was present in the top 5 rank in 13 out of 22 environments (being identified as dominant cultivar in 6 environments); followed by genotype 34 (Lutescens 29-94) that appeared in the top 5 rank in 8 of 22 environments, being the dominant cultivar in 3 environments; genotype 35 (Lutescens 30-94) was the best in 2 environments and appeared in the top 5 rank in 7 of 22 environments; genotype 36 (Lutescens 53-95), was the dominant cultivar in 3 environments and was inside the top 5 rank in 6 environments; genotype 21 (Tertsia), was the dominant cultivar in 2 environments and in 6 environments appeared within the top 5 rank; genotype 15 (Udacha), was winner in 3 environments and was within the top 5 rank in 5 environments; and genotype 39 (Aktube 32), that was the dominant cultivar in 3 environments. Other genotypes that, although were not dominant cultivars in more than one environment, but appeared consistently in the top 5 rank across 22 environments were: genotype 27 (Shortandynskaya 95), genotype 2 (Omskaya 35), and genotype 5 (Sonata), (7, 7 and 5 times inside the top 5 rank respectively).

Table 4 serves to illustrate the importance of recommending the right genotype for each environment. In our case, an improvement of 0.893 t/ha could be achieved across the 22 environments if only the dominant cultivar for each environment had been sown.

Table 2. Environments grouped by their winning genotypes, including the first 5 recommended cultivars for each environment, based on the AMMI2 estimates.

Environments		Dominant cultivar		AMMI2 cultivar recommendations				
Code[a]	yield (t/ha)	Code	yield (t/ha)	1st	2nd	3rd	4th	5th
B	4.63	**36**	5.58	**36**	29	34	41	37
H	2.74	**36**	3.7	**36**	28	42	35	34
R	2.14	**36**	2.9	**36**	42	21	2	29
A	4.46	**35**	5.73	**35**	23	29	34	27
L	4.40	**35**	5.8	**35**	20	5	21	2
O	3.02	**29**	4.57	**29**	35	25	2	34
Q	2.67	**29**	4.19	**29**	17	2	24	25
G	2.54	**29**	3.42	26	**29**	34	11	36
U	1.48	**29**	2.29	**29**	18	21	27	28
T	0.75	**29**	1.03	28	7	**29**	27	6
V	1.99	**29**	2.47	11	5	27	**29**	2
S	2.99	**15**	4.5	**15**	5	21	8	9
J	1.85	**15**	2.4	27	26	17	**15**	25
N	2.29	**15**	3.12	**15**	35	2	42	36
M	2.43	**21**	3.2	**21**	27	2	29	15
P	2.07	**21**	3.15	**21**	5	24	15	29
F	1.87	**39**	2.27	**39**	29	37	38	7
K	1.86	**39**	2.29	**39**	25	18	35	27
E	1.85	**39**	2.32	24	**39**	18	37	17
C	3.86	**34**	4.59	37	38	20	**34**	41
D	3.46	**34**	5.22	41	**34**	35	40	29
I	2.44	**34**	2.69	8	31	36	5	**34**

[a]The full name of the environments are: A = Barnaul 2004, B = Chelyabinsk 2004, C = Kurgan 2004, D = Omsk 2004, E = Aktube 2004, F = Karabalyk 2004, G = Shortandy 2004, H = Almaty 2004, I = Pavlodar 2004, J = Petropavlovsk 2004, K = Karaganda 2004, L = Barnaul 2003, M = Chelyabinsk 2003, N = Kurgan 2003, O = Omsk 2003, P = Aktube 2003, Q = Karabalyk 2003, R = Shortandy 2003, S = Almaty 2003, T = Pavlodar 2003, U = Petropavlovsk 2003, V = Karaganda 2003.

Table 3. AMMI analysis of variance for the yield (t/ha) of 40 spring wheat genotypes in 22 environments.

Source	Df	SS	MS	Explained (%)
Environment	21	854.539	40.6923	77.76
Genotype	39	71.0508	1.82182	6.46
Genotype X Environment	819	173.217	0.211498	15.76
AMMI component 1	59	43.7750	0.741948	25.27
AMMI component 2	57	28.3835	0.497956	16.38
Total	879	1098.81		

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Table 4. Yield improvement on the trial if only the first AMMI2 recommendation
was planted at each environment.

Environment[a]	Environment yield (t/ha)	Dominant cultivar	Cultivar yield (t/ha)	improvement
B	4.63	**36**	5.58	0.953
H	2.74	**36**	3.7	0.960
R	2.14	**36**	2.9	0.759
A	4.46	**35**	5.73	1.272
L	4.40	**35**	5.8	1.397
O	3.02	**29**	4.57	1.551
Q	2.67	**29**	4.19	1.525
G	2.54	**29**	3.42	0.884
U	1.48	**29**	2.29	0.807
T	0.75	**29**	1.03	0.279
V	1.99	**29**	2.47	0.478
S	2.99	**15**	4.5	1.512
J	1.85	**15**	2.4	0.549
N	2.29	**15**	3.12	0.834
M	2.43	**21**	3.2	0.773
P	2.07	**21**	3.15	1.079
F	1.87	**39**	2.27	0.405
K	1.86	**39**	2.29	0.427
E	1.85	**39**	2.32	0.465
C	3.86	**34**	4.59	0.726
D	3.46	**34**	5.22	1.764
I	2.44	**34**	2.69	0.251
Average	**2.63**		**3.52**	**0.893**

[a]The full name of the environments are: A = Barnaul 2004, B = Chelyabinsk 2004, C = Kurgan 2004, D = Omsk 2004, E = Aktube 2004, F = Karabalyk 2004, G = Shortandy 2004, H = Almaty 2004, I = Pavlodar 2004, J = Petropavlovsk 2004, K = Karaganda 2004, L = Barnaul 2003, M = Chelyabinsk 2003, N = Kurgan 2003, O = Omsk 2003, P = Aktube 2003, Q = Karabalyk 2003, R = Shortandy 2003, S = Almaty 2003, T = Pavlodar 2003, U = Petropavlovsk 2003, V = Karaganda 2003.

3.2 The Finlay and Wilkinson' (b) regression coefficient

Table 5 showed genotypes 9 (Irgina), 31 (Nadezhda), 32 (No. 18), 19 (Altaiskaya 50), and 13 (Novosibirskaya 15) as the cultivars with the greatest stability because of their b value significantly lower than 1.0. However, as all of them were within the cultivars with the lowest yield mean, the conclusion is that they were poorly adapted to the test environments.

Genotypes 17 (Lutescens 574), 4 (Chernyava 13), 27 (Shortandynskaya 95), and 2 (Omskaya 35) possesses average stability due to their regression coefficient near to 1.0, and can be consider as well adapted cultivars across the environments because their good mean yield, except for cultivar 4 (Chernyava 13).

Genotypes 29 (Lutescens 54), 35 (Lutescens 30-94) and 34 (Lutescens 29-94) ranked as the three best yielding cultivars (the only three with mean yield over 3 t/ha), but genotype 29 (Lutescens 54) adapted better by having the best mean yield (rank 1) and lower regression coefficient (rank 33 versus 39 and 40 respectively).

3.3 The environmental variance (S²)

The environmental variance (S^2) gave almost the same rank of the cultivars as the regression coefficient. This near perfect correlation is confirmed by the Spearman correlation coefficient r = 0.97*** (Table 6). Genotypes 31(Nadezhda), 9 (Irgina), and 32 (No. 18) with the lowest (S^2) values (the most stable cultivars), were also within the lowest yielding, and thus performed as the least adapted

Table 5. Rank and estimation of stability and reliability measures, and grain yield for
40genotypes across environments.

Rank	ASV stability		S^2 stability		Regression coefficient		Reliability index		Mean yield	
	Genotype	ASV	Genotype	S^2	Genotype	b	genotype	I	Genotype	Yield
1	17	0.112	31	0.617	9	0.669*	29	2.115	29	3.16
2	21	0.189	9	0.669	31	0.685*	28	1.988	35	3.11
3	38	0.205	32	0.715	32	0.716*	35	1.967	34	3.01
4	20	0.232	13	0.756	19	0.740*	17	1.939	21	2.97
5	7	0.263	14	0.783	13	0.755*	21	1.935	28	2.92
6	3	0.289	22	0.818	8	0.785	27	1.931	2	2.86
7	28	0.294	19	0.848	24	0.805	25	1.888	41	2.85
8	1	0.308	10	0.919	14	0.808*	15	1.884	27	2.85
9	27	0.328	25	0.940	22	0.827*	24	1.862	20	2.85
10	14	0.380	8	0.949	10	0.862	5	1.854	5	2.85
11	33	0.388	24	0.950	25	0.893	34	1.847	37	2.82
12	25	0.399	1	0.988	11	0.948	26	1.843	17	2.81
13	39	0.405	11	1.033	18	0.948	2	1.842	15	2.79
14	26	0.409	18	1.049	15	0.954	20	1.809	36	2.78
15	11	0.450	6	1.065	6	0.956	11	1.788	42	2.77
16	15	0.464	17	1.086	1	0.970	18	1.785	39	2.76
17	6	0.490	26	1.119	26	0.976	39	1.784	26	2.73
18	18	0.494	15	1.175	23	0.983	6	1.739	7	2.71
19	23	0.533	23	1.198	17	0.996	37	1.730	25	2.70
20	12	0.585	33	1.199	4	1.006	36	1.729	24	2.68
21	22	0.597	27	1.201	27	1.007	41	1.725	18	2.65
22	4	0.622	28	1.223	2	1.010	14	1.692	11	2.64
23	37	0.724	4	1.240	33	1.028	42	1.686	38	2.62
24	2	0.738	3	1.274	3	1.037	1	1.682	6	2.61
25	13	0.767	38	1.318	28	1.050	4	1.666	4	2.60
26	32	0.791	12	1.328	5	1.051	23	1.664	23	2.58
27	40	0.841	39	1.346	38	1.082	7	1.657	40	2.58
28	36	0.842	5	1.404	12	1.104	38	1.654	12	2.57
29	29	0.853	2	1.466	39	1.120	33	1.633	33	2.55
30	31	0.891	21	1.529	20	1.129	12	1.602	1	2.52
31	5	0.910	20	1.535	36	1.137	31	1.525	14	2.44
32	10	0.910	29	1.545	21	1.142	8	1.519	3	2.38
33	35	0.978	7	1.561	29	1.145	13	1.517	8	2.34
34	24	0.997	36	1.568	7	1.164	40	1.505	10	2.26
35	8	1.040	40	1.623	42	1.174	10	1.453	13	2.25
36	19	1.113	42	1.659	40	1.181	32	1.440	31	2.18
37	42	1.188	37	1.694	41	1.248*	3	1.433	32	2.15
38	41	1.215	41	1.804	37	1.257*	19	1.332	19	2.11
39	34	1.262	35	1.858	35	1.291*	9	1.324	22	2.04
40	9	1.346	34	1.913	34	1.313*	22	1.275	9	2.01

*indicates coefficients significantly different from the overall regression coefficient which is 1.

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cultivars across the test environments. Between the top yielding genotypes, cultivar 29 (Lutescens 54) performed as the widest adapted by having a lower (S^2) value, and being the top one yielding genotype. Conversely, genotypes 35 (Lutescens 30-94) and 34 (Lutescens 29-94) were the two least stable cultivars and although wide adapted, they showed some specific adaptation to locations Barnaul and Omsk respectively (Table 2).

3.4 AMMI model and the AMMI Stability Value (ASV)

The PCA scores of a genotype in the AMMI analysis are an indicator of the stability of a genotype over environments. The greater the PCA scores, either negative or positive, the more specifically adapted a genotype is to certain environments. The more the PCA scores approximate zero (0), the more stable the genotype is

Table 6. Spearman correlation between yield, S^2, b, ASV and I ranks.

	S^2	b	ASV	I
Yield	0.75***	0.73***	-0.12	0.87***
S^2		0.97***	0.01	0.40**
b			-0.08	0.38*
ASV				-0.26

* Indicates significance at $P = 0.05$
** Indicates significance at $P = 0.01$
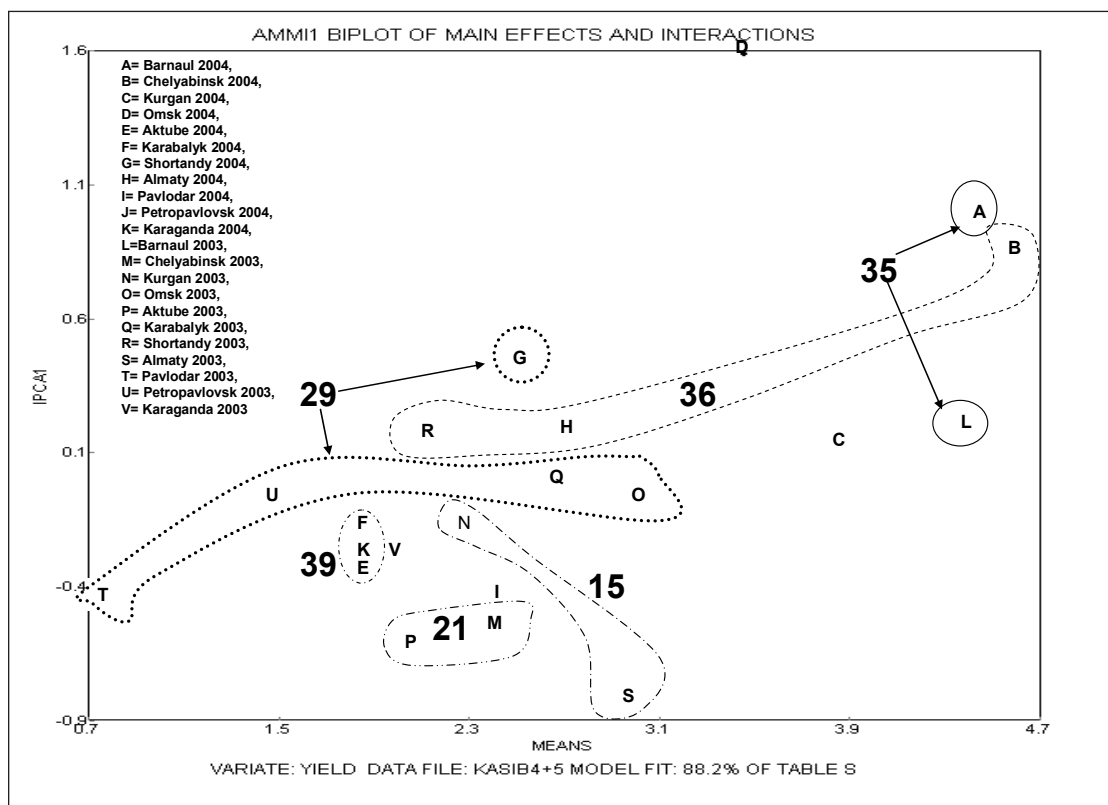*** Indicates significance at $P = 0.001$

Figure 1. Grouping of environments according to the superior cultivar as determined by theAMMI2 estimates at each environment. Note that according to the information provided in Table 2, environments I, C, and D and can join the genotype's 34 group; environment J, the genotype's 15 group; and environment V, the genotype's 29 group.
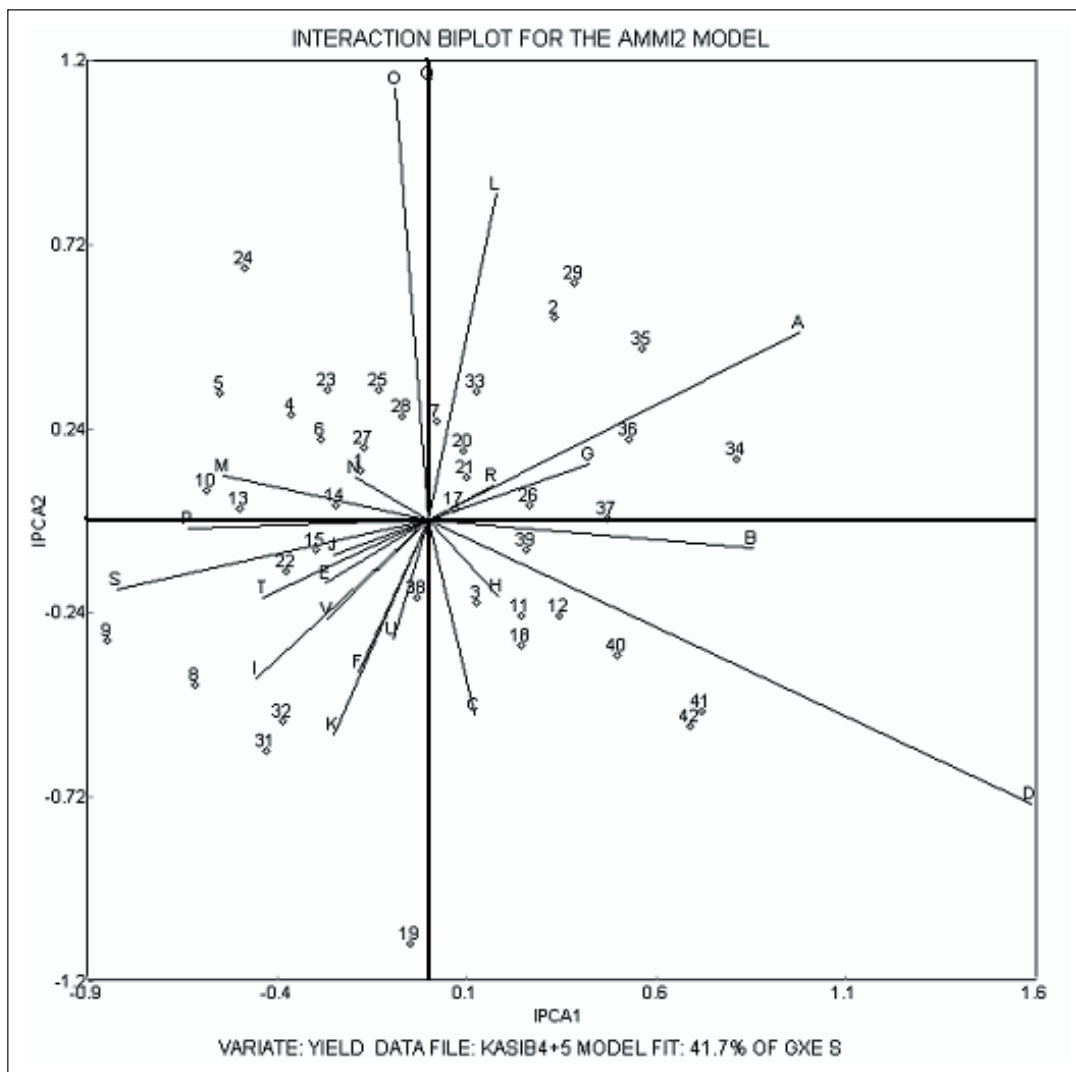
Figure 2. AMMI2 genotype x environment biplot for 40 genotypes and 22 environments. Genotypes and environments names correspond to those in Tables 1 and 2.

over all environments sampled [15].

From Figure 2, it is possible to visualize some interesting patterns. For genotypes, the GVK cultivars (genotypes 40, 41, and 42) were very in close relation to each other indicating similar germplasm. The same situation happens to genotypes 11 and 12 (Sibirskaya 12 and Sibirskaya 123) and some of the Lutescens cultivars (genotypes 29, 34, 35 and 36). This group of Lutescens cultivars (Lutescens 54, Lutescens 29-94, Lutescens 30-94, and Lutescens 53-95) fell into the upper-right side quadrant of the AMMI2 biplot, indicating their good yield potential, especially in high yielding environments as A, B and L (Barnaul 2004, Chelyabinsk 2004, and Barnaul 2003 respectively). Cultivars 17 (Lutescens 574)

and 21 (Tertsia) appeared as the most stable genotypes as they were located very close to the origin point (zero PCA scores), and genotype 19 as the most instable (and also the least adapted due to its low yield mean across the environments). However, when analyzed together the PCA scores with the mean yield, genotype 21 (Tertsia) emerges not only as very stable cultivar, but also as a cultivar with wide adaptation pattern. The AMMI ASV stability value confirms what it can be seen graphically in the biplot. However, the ASV ranked genotype 34 (Lutescens 29-94) as the second most instable cultivar, and genotype 9 (Irgina) as the most instable one (and one of the least adapted to the testing environments because of its low mean yield). The fact that one high yielding

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cultivar (genotype 34), and one low yielding cultivar (genotype 9) were the two most instable cultivars serves to demonstrate the importance of analyzing both stability and yield performance to determine also the adaptability patterns for cultivar recommendations.

3.5 The reliability index (I)

Making assumption that the technological level of agriculture in Kazakhstan and Siberia falls between the subsistence agriculture and modern agriculture, we took (P) = 0.8, which corresponds to a $Z_{(p)}$ = 0.84 to be inserted in equation 5 (see section 2.2.4). The reliability index (I) ranked the genotypes according to the lowest average yield one can expect for each cultivar across the test environments. Table 5 shows that the top 5 reliable genotypes were: genotype 29 (Lutescens 54), 28 (Lutescens 13), 35 (Lutescens 30-94), 17 (Lutescens 574) and 21 (Tertsia), which agrees in grand extent to the top 5 yielding genotypes (Spearman correlation coefficient r = 0.87***). It is not surprising that genotype 17 (Lutescens 574) appeared as one of the most reliable genotypes because from the regression coefficient analysis it was identified as one with average adaptation (b coefficient close to 1.0), and from the biplot graphic and AMMI ASV value, as the most stable cultivar; all this plus its good yield potential (although not being the best) placed it as 4th in the reliability rank.

3.6 Comparisons and concluding remarks

No one of the three stability parameters (b, S^2, and AMMI ASV) was sufficiently accurate in its own to be considered of practical interest for genotype selection and recommendation as it was manifested by the Spearman correlation coefficient between them and the mean yield rank (Table 6). For instance, b and S^2 values, although with a middle-high correlation coefficients (0.73*** and 0.74*** respectively) with respect to yield, failed in detecting more yielding and wider adapted genotypes as Lutescens 29-94 (genotype 34), and Lutescens 30-94 (genotype 35). Similarly, the AMMI ASV value did not correlate with the yield of the genotypes (r = -0.12). Only when they were combined with the yield data and assisted by a table of mean yield of environments and genotypes and cultivars ranks for each environment (as Table 2 in the present study), the use of these stability parameters take a more practical application for selection and recommendation. Conversely, the reliability index (I), due to its nature of combining a derived stability measure (the S_i value) and yield data, gave more useful information for selection and recommendation. It was confirmed by its correlation with yield (r = 0.87***).

In regard to the genotypes, cultivars 29, 35, 34, 21, 2, and 27 (Lutescens 54, Lutescens 30-94, Lutescens 29-94, Tertsia, Omskaya 35, and Shortandynskaya 95 respectively) showed to be the widest adapted and the most reliable cultivars. Many of the Lutescens cultivars (genotypes 29, 35, 34, 36) and cultivar Omskaya 35 (genotype 2) dominated the reliability and mean yield ranks. It can be explained by the fact that they possess in their pedigrees blood from the landrace Poltavka, a very broad adapted genotype due to its ability to tolerate abiotic stresses and present in more than 76% of the modern spring wheat varieties released in Kazakhstan [13].

In summary, the following cultivars were identified as promising for practical recommendations at the different spring wheat producing regions in Kazakhstan and Siberia, according to their performance across 22 environments:

- Cultivar 29 (Lutescens 54): Chelyabinsk, Shortandy, Barnaul, Omsk, Karabalyk, Petropavlosk, Pavlodar and Karaganda.
- Cultivar 35 (Lutescens 30-94): Barnaul, Karaganda, Omsk and Kurgan.
- Cultivar 27 (Shortandynskaya 95): Petropavlosk, Karaganda and Almaty.
- Cultivar 34 (Lutescens 29-94): Pavlodar, Omsk and Chelyabinsk
- Cultivar 36 (Lutescens 53-95): Pavlodar and Shortandy.
- Cultivar 21 (Tertsia): Almaty and Aktube.
- Cultivar 24 (Chebarkulskaya): Aktube.
- Cultivar 15 (Udacha): Almaty.

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