Stability Analysis for Grain Yield and Micronutrients in Bread Wheat Genotypes

**Ramandeep Kaur Jhinjer[1*], Gurvinder Singh Mavi[1], Akhil Malhotra[1],
Neerja Sood[1], Baldeep Singh[1], Binder Kaur[1], Vineet Kumar[2],
Indoo Bhagat[3] and Virinder Singh Sohu[1]**

[1]*Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana, Punjab, India.*
[2]*Regional Reaserch Station (PAU), Bathinda, Punjab, India.*
[3]*Regional Reaserch Station (PAU), Gurdaspur, Punjab, India.*

Authors' contributions

This work was carried out in collaboration between all authors. All authors contributed in analyzing and interpreting and preparing the manuscript. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

This study was carried out in order to determine stability of some traits like plant height, days to heading, 1000-grain weight, grain Zinc and Iron concentrations and grain yield of fifty bread wheat genotypes. The experiment was conducted at three environmental conditions during 2015-2016 using randomized block design with two replicates. For all the traits investigated in this study, component of variation due to environment was larger than the component of variation due to genotype and G x E interaction. Different traits like plant height, days to heading, thousand grain weight, grain iron and zinc concentrations and grain yield showed range from 92.8 to 107.1 cm, from 91 to 101 days, from 32.0 to 46.1 g, from 37.5 to 45.7 ppm, from 30.2 to 41.9 ppm and from 2.1 to 3.3 kg, respectively in three environments. Two stability parameters were used to develop and evaluation of stable genotypes. The study of genotypic stability showed that the adaptation ability of the 8 genotypes (403, 413, 416, 428, 430, 435, 440 and 449) for grain Fe concentration and 2 genotypes (410 and 431) for grain Zn concentration are relatively high and they are more stable

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Corresponding author: E-mail: ramandeepkaur175@pau.edu;

than the other genotypes. Also, genotype number 440 for grain Fe concentration, genotypes 410 and 431 for grain Zn concentration and genotypes 420 and 425 for grain yield had high mean value compared with mean value of check genotype 401 as well as high stability.

1. INTRODUCTION

For humans, cereals are the main source of micronutrient minerals. Biofortification, which aims to improve micronutrient concentrations and bioavailability in plant based foods through genetic enhancement, is a cost effective way of solving the micronutrient deficiency problem [1-2]. Knowledge of the difference in the trait among the available germplasm is required for breeding of cereal crops with improved micronutrient concentration [3-4].

For zinc (Zn) and iron (Fe) concentrations, significant genotype x environment (G × E) interactions have been observed in wild and improved wheat cultivars [5-8]. Particularly, in case of grain Zn concentration, environmental conditions complicate the breeding, specially the soil composition [7]. Thus, despite advances in breeding for uptake efficiency or mobilization to the grain, grain Zn concentration is restricted by Zn availability in the soil [6,9-10].

The high Zn lines developed at CIMMYT, Mexico, and evaluated in a multilocation trial in India's Eastern Gangetic Plains (EGP), revealed that wheat grain Zn concentrations were highly unstable [11] as the performance of the elite lines varied across locations and years. Cause for greater G × E interaction for grain Zn concentration may be its quantitative inheritance, as reported in maize [12], rice [13] and wheat [7]. One more study tested biofortified wheat lines at multiple locations in South Asia and revealed high heritability and high genetic correlation between locations for grain Zn, suggesting that G × E may not be a serious issue in breeding high Zn wheat genotypes [14-15].

For breeders, stability of micronutrients is important in terms of changing ranks of genotypes across environments and affects selection efficiency [16]. A genotype is therefore considered to be stable if its contribution to the G × E interaction is low. Several stability measures including univariate and multivariate ones have been developed to assess the stability and adaptability of varieties. The most widely used is the joint regression including regression coefficient (b_i) [17] and variance of deviations from regression (S^2_{di}) [18].

Thus, in present investigation, 50 bread wheat genotypes developed by CIMMYT, Mexico were used to evaluate their stability in plant height, days to heading, 1000-grain weight, grain Zinc and Iron concentrations and grain yield across three environments in NWPZ (Northern Western Plains Zone).

2. MATERIALS AND METHODS

2.1 Plant Material

Fifty lines of bread wheat (*Triticum aestivum* var. aestivum) including one check cultivar HD 3086 (401) were grown at three sites in NWPZ (Ludhiana, Bathinda, Gurdaspur) during 2015-16 crop season. Each line was sown in two replicate plots of 5 metre long with six rows spaced at a distance of 20 cm. Recommended package of practices was followed to raise a good crop. Observations were recorded on plant height (cm), days to heading (days), 1000-grain weight, grain yield (kg/plot), grain Zn concentration (ppm) and grain Fe concentration (ppm).

2.2 Grain Analysis

The concentration of elements Fe and Zn in wheat grains was determined using a bench-top, non-destructive, energy-dispersive X-ray fluorescence spectrometry (EDXRF) instrument (model X-Supreme 8000, Oxford Instruments plc, Abingdon, UK), previously standardized for high throughput screening of Zn and Fe in whole wheat grain [19].

2.3 Statistical Analysis

Combined analysis of variance on data from trials in three environments was computed according to the method given by [20]. Two stability parameters were applied to assess stability performance of genotypes and to identify superior genotypes; b_i, the linear regression of the phenotypic values on environmental index [17] and S^2_{di}, the deviation mean square from

regression [18]. Analysis was performed using the statistical software OPSTAT for ANOVA and for stability statistics. To predict stability, a genotype was considered stable for grain Zn and Fe concentrations if it appeared stable in two stability analyses. Genotypes that proved to be stable for both stability parameters were then selected as the best.

3. RESULTS AND DISCUSSION

This study aimed to define environmental adaptation and stability features and the relationships between stability parameters using 50 bread wheat genotypes that were grown in the ecological conditions of three locations of NWPZ.

The combined analysis of variance for plant height, days to heading, 1000-grain weight, grain Zn and Fe concentration and grain yield across environments is given in Table 1. The difference in environments and genotypes for most of the traits investigated were statistically significant (p<0.01). Analysis of variance showed significant G × E interaction. For all the traits investigated in this study, components of variation due to genotype and G x E interaction were smaller than the component of variation due to environment. These results are similar with the results of earlier studies [10,16,21,22].

Values of the mean, regression coefficient (b_i) and deviation from regression (S^2_{di}) are given in Table 2. The mean values of total 47 genotypes (from 32.3 to 41.9 ppm) for grain Zn concentration had better performance than check HD 3086 (genotype 1, 31.2 ppm). Twenty two genotypes had better performance for grain Fe concentration (from 41.2 to 45.7 ppm) in terms of mean values than genotype 401 (41.1 ppm). For grain yield per plot, four genotypes had better performance (from 3.3 to 3.1 kg) than check (3.1 kg).

In general, genotypes with high yield, regression coefficient (bi) close to 1, and non-significant deviation from the regression line are considered as the most desirable [18,23,24]. Value of regression coefficient less than 1 indicates that the genotype can adapt to poor environmental conditions, whereas a *bi* value greater than 1 indicates that the plant can adapt to favourable environmental conditions [25,26].

The value of b_i of five genotypes (413, 424, 408, 448, 437) for plant height; eight genotypes (425, 444, 414, 448, 450, 439, 421, 445) for days to heading; four genotypes (426, 409, 445, 439) for 1000-grain weight; three genotypes (426, 424, 412) for grain Zn concentration and ten genotypes (435, 416, 441, 436, 449, 403, 439, 440, 448, 428) grain Fe concentration was unit. These genotypes showed a good stability for corresponding traits.

The value of b_i of six genotypes (421, 445, 410, 426, 422, 420) for grain yield per plot were also unit. Based on the methods of [17], these genotypes can adapt well to all environmental conditions even if the conditions improve or worsen. It is further understood that their yields remain stable. Additionally, four genotypes (420, 425, 435, 437) which had better or same performance with check (genotype 1) for yield, also showed b_i as unit or near to unit (from 0.9 to 1.3) indicated that grain yield of these genotypes is expected to increase if the conditions improve and to remain stable if the conditions deteriorate. Some were able to adapt to favourable conditions, and their yields were stable only under favourable conditions as their b_i values more than unity (b_i>1). Three of these genotypes (402, 438, 444) were able to adapt well to favourable conditions, and their yields are expected to increase as the conditions improve.

Additionally, genotypes 407, 413 and 450 did not remain stable for grain yield under favorable or unfavorable conditions as their b_i values less than unity (b_i<1). Similarly, eight genotypes (414, 442, 436, 418, 419, 450, 407, 420) for grain Zn concentration and eight genotypes (442, 414, 433, 432, 419, 437, 417, 407) for grain Fe concentration had b_i values more than unity (b_i>1) and were able to adapt to favorable conditions. In case of b_i values less than unity (b_i<1), eight genotypes (405, 406, 408, 425, 415, 413, 447, 428) for grain Zn concentration and seven genotypes (446, 425, 445, 405, 450, 447, 443) for grain Fe concentration included in this category.

S^2_{di} serves as another stability parameter. For stable genotypes, this value should be low and close to zero [24,18,27-30]. In the present study, the twenty six genotypes (from -3.3 to 0.0) for plant height, ten genotypes (from -0.4 to -0.2) for days to heading, nine genotypes (from -0.9 to -0.1) for 1000-grain weight, eighteen genotypes (from -2.2 to 0.0) for grain Zn concentration, twenty four genotypes (from -2.1 to -0.3) for grain Fe concentration and thirty five genotypes (0.0) for grain yield had greatest stability according to

this criterion as all with values less than or equal to 0 (Table 2).

Results revealed that high yielding genotypes can also be stable. Genotypes 437, 420, 425 and 435 had better performance than check HD 3086 and desired performance for grain yield per plot in term of high mean, unit b_i and least deviation from regression (S^2_{di}), indicating the role of linear portion of G x E interaction in the performance of these genotypes (437, 420, 425 and 435).

In view of the stability and adaptation parameters values determined in this study, it can be concluded on basis of two stability analyses that adaptation ability of two genotypes (410 and 431) for grain Zn concentration, eight genotypes (403, 413, 416, 428, 430, 435, 440 and 449) for grain Fe concentration and seventeen genotypes (406, 408, 410, 414, 420, 421, 422, 424, 425, 426, 427, 428, 430, 442, 443, 445 and 447) for grain yield are relatively higher and they are more stable than the other genotypes. Genotypes number 410 and 431 for grain Zn concentration, genotype number 440 for grain Fe concentration and genotypes numbers 420 and 425 for grain yield, also had high mean values compared with mean value of check genotype number 401. Genotypes numbers 410 and 427 are stable for both grain Zn concentration and grain yield. Similarly genotypes numbers 428 and 430 were stable for both grain Fe concentration and grain yield. Any genotype which is highly stable for three desired traits like grain Zn and Fe concentration and grain yield, was not found in this study. As compared to number of genotypes which are stable for grain Zn concentration and Fe concentration, more

genotypes showed stability for grain yield in three environments.

Robert and Dennis, 1996 [31] have explained that the breeder must keep in mind that the evaluation of stability depends on the sets of genotypes and environments studied. In stability analysis, various statistics should be applied to characterize the genotypes for responsiveness to environments as much as possible and to be sure of the G x E interaction effects.

Our results suggest that almost all traits measured, changed substantially with environments (Table 2). Therefore, production of a cultivar with improved grain Zinc and Fe concentrations and grain yield may need a growing environment that favors expression of this genetic potential. This directs to the production of high yielding biofortified grains. Thus, some genotypes were stable for some traits and unstable for another, suggesting that the genetic factors involved in the G x E differed between traits [16,22,32,33]. The cultivation of more unstable cultivars should be recommended only for specific regions where they can attain a high performance with regard to quality traits independent of seasonal effects.

Genotypes selected according to stability of grain micronutrients and grain yield in present study verified the possibility of combining both stable and high performances. Though, breeders must be aware of the difficulties in selection. The important goal for breeders is to find genotypes with stable traits, not only to provide good raw material for end users, but also to provide parents in the future breeding programmes.

Table 1. Combined Analysis of Variance for Stability (Eberhert and Russel Model) of 50 genotypes across three environments

Source of variation	d.f.	M S					
		Plant Height	Days to heading	Thousand grain weight	Zn	Fe	GY
Variety	49	29.98**	24.10**	35.21**	19.79**	11.95	0.15**
Environment	2	1,374.70**	491.30**	71.95**	457.56**	955.12**	18.21**
Var. X Envion.	98	12.57**	3.38**	9.66**	8.68**	9.55**	0.06*
Env+Var X Env	100	39.82	13.14	10.90	17.66	28.46	0.43
Env (Linear)	1	2,749.39**	982.60**	143.90**	915.13**	1,910.24**	36.42**
Env X Var(Lin)	49	11.09	1.81	7.79	9.68	13.44**	0.06
Pooled Deviation	50	13.77**	4.86**	11.29**	7.53**	5.54**	0.06**
Pooled Error	147	6.56	0.75	1.75	4.45	4.27	0.04

*Figures with * and ** are significant at 5% and 1% level, respectively*

Table 2. Mean (M), regression coefficient (b_i) and deviation from regression (S^2_{di}) for plant height (PH), days to heading (DTH), 1000-grain weight (TGW), grain Zinc concentration (Zn), grain Iron concentration (Fe) and grain yield (GY) for each genotype (G) tested in three environments

G	PH			DTH			TGW			Zn			Fe			GY		
	M	b_i	S^2_{di}	M	b_i	S^2_{di}	M	b_i	S^2_{di}	M	b_i	S^2_{di}	M	b_i	S^2_{di}	M	b_i	S^2_{di}
401	101	0.6	64.6	96	0.8	-0.4	38.0	0.0	6.8	31.2	1.3	12.8	41.1	0.5	-1.9	3.1	1.2	0.1
402	103	0.6	-2.7	93	0.8	2.0	34.0	-0.1	33.3	30.8	1.4	9.6	39.5	1.6	17.3	2.8	1.6	0.0
403	101	1.2	-1.0	101	1.3	-0.2	33.0	2.2	2.9	30.2	0.9	2.6	37.5	1.0	-1.4	2.9	1.4	0.0
404	101	1.3	-2.4	91	0.8	1.5	42.0	1.4	5.5	38.0	0.6	7.9	45.7	1.2	-1.7	2.6	1.3	0.0
405	100	1.3	4.3	101	1.1	-0.3	36.9	2.5	2.8	41.9	-1.0	0.7	41.6	0.2	-1.2	2.1	0.7	0.0
406	99	0.9	-2.4	99	0.9	7.2	43.9	-0.1	17.1	32.7	-0.5	0.0	44.6	0.8	-2.0	2.9	1.1	0.0
407	105	0.6	8.4	94	0.8	0.6	40.1	-1.3	14.7	33.6	2.3	-0.1	43.3	2.4	1.3	2.9	0.5	0.0
408	107	1.0	19.2	95	0.6	11.7	41.0	-0.3	7.2	37.3	-0.4	2.3	40.8	1.1	21.8	2.9	1.1	0.0
409	93	1.4	12.2	100	0.5	2.1	34.5	1.0	19.7	39.7	0.4	12.8	42.5	1.6	-1.8	2.7	0.7	0.0
410	107	1.5	31.9	98	1.1	3.2	40.2	0.5	17.2	38.0	1.2	-1.8	41.1	0.6	3.6	2.7	1.0	0.0
411	100	0.8	1.1	98	1.1	4.2	39.3	1.6	5.1	34.9	1.3	1.1	39.8	0.5	23.7	2.6	0.7	0.2
412	100	1.2	-3.3	98	0.6	1.1	37.6	-1.8	39.7	33.1	1.0	1.5	39.5	1.6	1.9	2.6	0.6	0.0
413	101	1.0	29.6	95	0.8	0.4	32.0	1.6	15.6	32.3	0.3	4.1	37.9	0.9	-1.2	2.5	0.5	0.1
414	97	1.2	-0.8	98	1.0	8.1	34.0	0.3	2.1	32.9	1.8	1.2	37.7	1.7	3.4	2.8	0.9	0.0
415	102	1.3	-2.7	92	0.6	3.6	43.4	-0.9	-0.1	33.8	0.2	9.7	42.2	0.5	12.5	2.8	0.7	0.0
416	101	0.7	24.0	96	1.2	3.6	37.5	2.4	42.4	35.1	1.2	10.6	38.2	1.0	-2.0	2.5	1.2	0.0
417	97	1.9	12.8	98	1.2	4.3	41.5	2.4	1.8	33.6	0.8	7.1	43.0	2.0	-1.8	2.9	1.2	0.0
418	95	1.1	-2.0	96	0.9	5.1	35.5	-1.1	29.9	34.6	1.9	20.5	39.4	1.6	-0.3	2.5	0.6	0.0
419	97	1.4	-3.1	101	1.1	-0.3	34.7	2.0	3.7	37.7	2.1	-0.8	40.6	1.7	-0.7	2.8	1.2	0.0
420	99	0.7	-0.3	101	0.7	-0.3	43.7	3.0	13.3	36.8	2.6	2.4	41.9	1.1	2.9	3.2	1.0	0.1
421	98	1.4	-2.3	100	1.0	1.7	39.7	3.4	1.2	34.2	0.5	4.6	42.9	0.5	-2.1	2.8	1.0	0.0
422	101	1.5	-0.2	100	0.9	5.1	40.6	3.3	-0.8	33.4	0.9	1.5	39.8	1.4	3.3	2.8	1.0	0.3
423	102	0.2	-1.0	93	0.5	4.3	39.2	0.5	-0.5	33.5	0.4	9.4	38.5	0.6	-1.5	2.7	1.2	0.0
424	106	1.0	-0.6	94	0.7	20.1	40.1	3.5	42.3	38.0	1.0	29.9	41.2	1.2	1.3	2.8	1.1	0.0
425	102	1.7	-2.2	98	1.0	-0.3	42.6	1.4	8.8	36.0	0.0	2.4	43.8	-0.3	4.3	3.2	0.9	0.1
426	93	1.4	1.0	93	0.4	1.9	35.5	1.0	-0.3	32.9	1.0	9.4	39.2	0.8	-1.9	2.9	1.0	0.0
427	100	2.1	1.6	100	1.2	1.4	39.3	1.4	-0.1	34.6	1.3	-2.1	42.4	1.3	39.0	2.5	0.9	0.0
428	100	0.4	33.2	96	0.4	1.9	36.6	-2.1	1.5	34.1	0.3	-1.3	38.9	1.0	-2.1	2.9	1.1	0.0
429	99	0.8	-3.1	101	1.5	-0.3	38.9	0.4	2.3	33.3	0.4	9.1	42.1	1.4	-0.8	2.8	1.2	0.1
430	101	-0.1	51.5	98	1.3	1.7	40.5	3.4	-0.8	33.4	1.7	-2.2	38.5	0.9	-1.8	2.9	0.9	0.1

G	PH			DTH			TGW			Zn			Fe			GY		
	M	b_i	S^2_{di}	M	b_i	S^2_{di}	M	b_i	S^2_{di}	M	b_i	S^2_{di}	M	b_i	S^2_{di}	M	b_i	S^2_{di}
431	101	0.6	-2.3	101	1.3	-0.4	42.7	2.4	23.3	35.8	0.8	-2.1	38.7	0.6	-2.1	3.0	1.3	0.0
432	99	0.9	-1.2	97	1.1	8.3	39.6	2.4	-0.6	36.1	0.7	27.2	40.2	1.7	5.4	2.8	1.2	0.0
433	104	0.8	-3.2	100	1.1	5.4	42.7	0.8	1.1	33.5	1.4	30.3	40.7	1.7	0.7	2.8	0.8	0.0
434	103	0.9	62.1	101	1.4	0.6	33.7	1.7	8.5	36.8	1.4	11.2	39.9	0.8	-1.9	2.5	0.6	0.3
435	103	0.0	6.6	94	0.9	10.2	40.4	3.1	3.8	37.6	0.8	18.9	39.6	1.0	-1.0	3.1	1.3	0.0
436	99	0.7	2.0	100	1.9	0.9	36.2	2.2	22.4	37.5	1.8	-2.2	38.8	1.0	0.5	2.8	1.3	0.0
437	99	1.0	3.1	96	0.8	7.2	41.6	2.9	6.3	32.9	0.6	-1.7	41.2	1.8	2.4	3.3	1.2	0.1
438	103	1.3	-1.5	98	1.3	1.7	38.7	-0.3	2.0	35.6	1.4	1.2	42.3	0.9	7.6	2.8	1.5	0.0
439	100	0.6	-1.6	96	1.0	1.2	35.7	1.0	22.8	37.5	1.6	-0.3	43.4	1.0	6.7	2.4	0.8	0.3
440	98	1.7	-1.9	97	1.7	-0.2	41.8	3.5	6.6	41.8	1.6	10.1	41.6	1.0	-2.1	2.9	1.3	0.0
441	107	1.1	0.0	99	1.2	4.3	35.4	1.5	3.6	34.0	0.7	-0.4	37.6	1.0	2.7	2.8	1.2	0.0
442	102	1.5	7.4	93	1.1	0.2	45.5	1.2	19.7	36.5	1.8	5.6	42.2	1.7	-2.1	2.5	0.9	0.0
443	99	0.8	-3.2	99	1.1	42.4	37.1	-4.0	1.5	32.4	1.5	-2.1	39.6	0.4	6.7	2.7	0.9	0.1
444	101	0.8	-3.0	94	1.0	-0.3	46.1	-0.8	-0.9	36.0	1.4	-2.2	42.7	0.8	-2.1	2.9	1.6	0.0
445	100	0.8	-1.7	98	1.0	16.6	44.1	1.0	7.6	39.1	0.5	-1.3	42.1	-0.2	18.4	2.8	1.0	0.0
446	97	0.9	107.4	100	1.3	1.9	42.2	-0.3	14.1	34.6	1.2	9.9	42.7	-0.7	15.4	3.0	0.6	0.1
447	98	1.1	39.9	95	1.1	24.4	38.2	-0.6	3.1	36.9	0.3	-0.4	43.1	0.4	2.9	2.9	1.1	0.0
448	97	1.0	5.1	100	1.0	0.7	39.4	-1.0	30.2	35.0	1.1	1.5	37.9	1.0	3.0	3.0	0.8	0.1
449	104	0.7	26.3	98	1.1	3.6	40.2	0.6	-0.6	37.3	0.5	-1.7	39.5	1.0	0.4	3.0	1.3	0.1
450	104	0.5	19.0	100	1.0	0.7	43.1	1.2	11.9	35.6	2.2	-0.9	39.3	0.3	-1.5	2.7	0.4	0.0

4. CONCLUSION

In view of the high mean, stability and adaptation parameters values determined in this study, it can be concluded that genotype 440 for grain Fe concentration, genotypes 410 and 431 for grain Zn concentration and genotypes 420, 425, 435 and 437 for grain yield have relatively high adaptation ability, more stable and high mean values than check as well as other genotypes.

ACKNOWLEDGEMENTS

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Bouis HE. Plant breeding: A new tool for fighting micronutrient malnutrition. Journal of Nutrition. 2002;132:491S–494S.
2. Nestel P, Bouis HE, Meenakshi JV, Pfeiffer W. Biofortification of staple food crops. Journal of Nutrition. 2006;136:1064–1067.
3. Liu ZH, Wang HY, Wang XE, Zhang GP, Chen PD, Liu DJ. Genotypic and spike positional difference in grain phytase activity, phytate, inorganic phosphorus, iron, and zinc contents in wheat (*Triticum aestivum* L.). Journal of Cereal Sciences. 2006;44:212–219.
4. Morgounov A, Gomez-Becerra HF, Abugalieva A, Dzhunusova M, Yessimbekova M, Muminjanov H, Zelenskiy Y, Ozturk L, Cakmak I. Iron and zinc grain density in common wheat grown in central Asia. Euphytica. 2007;155:193–203.
5. Oury FX, Leenhardt F, Remesy C, Chanliaud E, Duperrier B, Balfouriera F, Charmet G. Genetic variability and stability of grain magnesium, zinc and iron concentration in bread wheat. European Journal of Agronomy. 2006;25:177-185.
6. Ortiz-Monasterio I, Palacios-Rojas N, Meng E, Pixley K, Trethowan R, Pena RJ. Enhancing the mineral and vitamin content of wheat and maize through plant breeding. Journal of Cereal Science. 2007; 46:293-307.
7. Trethowan RM. Breeding wheat for high iron and zinc at CIMMYT: State of the art, challenges and future prospects. In: Proceeding of the 7th International Wheat Conference. Mar del Plata, Argentina; 2007.
8. Gomez-Becerra HF, Yazici A, Ozturk L, Budak H, Peleg Z, Morgounov A, Fahima T, Saranga Y, Cakmak I. Genetic variation and environmental stability of grain mineral nutrient concentrations in *Triticum dicoccoides* under five environments. Euphytica. 2010;171:39-52.
9. Ortiz-Monasterio I, Trethowan R, Holm PB, Cakmak I, Borg S, Tauris BEB, Brinch-Pedersen H. Breeding, transformation, and physiological strategies for the development of wheat with high zinc and iron grain concentration. In: Bonjean AP, Angus WJ, Van Ginkel M. (Eds.). The World Wheat Book, A History of Wheat Breeding. 2011;2:951-977.
10. Garg A, Sohu VS, Mavi GS, Bhagat I, Kumar N, Malhotra A, Kaur R. Genotype environment interaction for grain micronutrient concentration in biofortified wheat lines. Crop Improvement. 2014; 41(2):177-181.
11. Joshi AK, Crossa I, Arun B, Chand R, Trethowan R, Vargas M, Ortiz-Monasterio I. Genotype x environment interaction for zinc and iron concentration of wheat grain in eastern Gangetic plains of India. Field Crops Research. 2010;116:268-277.
12. Long JK, Banziger M, Smith ME. Diallel analysis of grain iron and zinc density in southern African-adapted maize inbreds. Crop Science. 2004;44:2019-2026.
13. Gregorio GB, Senadhira D, Htut T, Graham RD. Breeding for trace mineral density in rice. Food Nutrition Bulletin. 2000;21:382-386.
14. Velu G, Singh RP, Huerta-Espino J, Pena RJ, Arun B, Mahendru-Singh A, Mujahid MY, Sohu VS, Mavi GS, Crossa J, Alvarado G, Joshi AK, Pfeiffer WH. Performance of biofortified spring wheat genotypes in target environments for grain zinc and iron concentrations. Field Crops Research. 2012;137:261–267.

15. Velu G, Ortiz-Monasterio I, Cakmak I, HaoY, Singh RP. Biofortification strategies to increase grain zinc and iron concentrations in wheat. Journal of Cereal Science. 2013;30:1-8

16. Mut Z, Aydin N, Orhan Bayramoglu H, Ozcan H. Stability of some quality traits in bread wheat (*Triticum aesivum*) genotypes. Journal of Environmental Biology. 2010;31:489-495.

17. Finlay KW, Wilkinson GN. The analysis of adaptation in a plant breeding programme. Australian Journal of Agricultural Research. 1963;14:742-754.

18. Eberhart SA, Russel WA. Stability parameters for comparing varieties. Crop Science. 1966;6:36-40.

19. Paltridge NG, Milham PJ, Ortiz-Monasterio JI, Velu G, Yasmin Z, Palmer LJ, Guild GE, Stangoulis JCR. Energy-dispersive X-ray fluorescence spectrometry as a tool for zinc, iron and selenium analysis in whole grain wheat. Plant and Soil. 2012;361:261-269.

20. Comstock RE, Moll R. Genotype x Environment Interactions. In: Statistical genetics and plant breeding (Eds: Hanson WD, Robinson HF). NASNRC Pub. Washington, D.C. 1963;164-196.

21. Robert N. Comparison on stability statistics for yield and quality traits in bread wheat. Euphytica. 2002;128:333-341.

22. Rharrabti Y, Carcia Del Moral LF, Villegas D, Royo C. Durum wheat quality in Mediterranean environments. III. Stability and comparative methods in analysing G x E interaction. Field Crops Research. 2003; 80:141-146.

23. Becker HC, Leon J. Stability analysis in plant breeding. Plant Breeding. 1988;101: 1-23.

24. Kurt Polat PO, Cifci EA, Yagdi K. Stability performance of bread wheat (*Triticum aesivum* L.) lines. Journal of Agricultural Science and Technology. 2016;18:553-560.

25. Yildırım MB, Ozturk A, Ikiz F, Puskulcu H. Bitki Islahında Istatistik-Genetik Yontemler. Ege Bolge Zirai Arastırma Enstitusu Yayınlari. 1979;20:217-251.

26. Akgun I, Altindag D. Stability analysis and grain yield in some triticale genotypes. Suleyman Demirel University Journal of the Faculty of Agriculture. 2011;6(1):7-14.

27. Yagdi K. A research on determination of stability parameters of bread wheat (*Triticum aestivum* L.) cultivars and lines grown in Bursa Province. Journal of the Agricultural Faculty of Uludag University. 2002;16:51-57.

28. Amin MT, Mohammad AJK, Irfaq MA, Tahir GR. Yield Stability of Spring Wheat (*Triticium aestivum* L.) in the North West Frontier Province, Pakistan. Songklanakarin Journal of Science and Technology. 2005;27(6):1147-1150.

29. Aycicek M, Yildirim T. Adaptability performances of some bread wheat (*Triticum aestivum* L.) genotypes in the Eastern region of Turkey. The International Journal of Science & Technology. 2006; 1(2):83-89.

30. Hassan MS, Mohamed GIA, El-Said RAR. Stability analysis for grain yield and it's components of some durum wheat Genotypes (*Triticum durum* L.) under different environment. Asian Journal of Crop Science. 2013;5(2):179-189.

31. Robert N, Denis JB. Stability of baking quality in bread wheat using several statistical parameters. Theoretical Applied Genetics. 1996;93:172-178.

32. Grausgruber H, Oberforster M, Werteker M, Ruckenbauer P, Vollmann J. Stability of quality traits in Austrian-grown winter wheats. Field Crops Research. 2000;66: 257-267.

33. Baric M, Pecina M, Sarcevic H, Keresa S. Stability of four Croation bread winter wheat (*T. aestivum* L.) cultivars for quality traits. Plant Soil and Environment. 2004; 50:402-408.