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Stability of wheat entries across seasons and nitrogen rates by AMMI analysis

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Key words: Environment, performance, stability, years, wide adaptation.

Abstract

To study the stability of spring bread wheat entries across years and nitrogen rates, yield trials were conducted from 2010 to 2013 preceding by screening trail in 2009-2010 at farm of college of Baghdad agriculture. Randomized complete block design (RCBD) with split plots arrangement was followed. Across years, nitrogen rates occupied main plots whereas, genotypes were in subplots. Five promising genotypes of CIMMYT entries viz: 106s, 107s, 108s, 109s, 110s and local variety (abugraib-3) that were symbolized by letters G1, G2 to G6, respectively. Nitrogen rates were 25, 100, 175kg.N.ha^{-1}. Each nitrogen rate within year was considered as an environment, so that, nine environments were generated. Statistical analysis results revealed that the percentage of genotypes variation from total was 65.6%, also, the percentage of environments and interaction sum of square from total variation was 26.1% and 8.3%, respectively. Sum of square of investigated variation of PCA1, PCA2 and PCA3 was 60.54%, 25.1% and 10.6%, respectively. The total of interaction variation investigated was 96.3%. Grain yield of environments ranged from 3.739 t.ha^{-1} that ranked the first to 2.801t.ha^{-1} that ranked the lowest. In addition, the grain yield of genotypes ranged from 3.783 t.ha^{-1} for G5 that ranked the first to 2.267 t.ha^{-1} for G1 that ranked the lowest. G4 was more stable than other genotypes; consequently, it was wide adapted and high yield over years. However, this statistical technique was a powerful tool for diagnosing the stable genotypes in grain yield across years of research. We can recommend cultivating G4 for its wide adapted and high stability.

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Introduction

Wheat is grown on 200mha worldwide annually with productivity reached 2.7t.ha^{-1}. This productivity has varied largely across countries and regions. Western Europe such as France was the highest grain yield per hectare (8t.ha^{-1}) compared to one t.ha^{-1} in middle and West of Asia and North Africa (Rajaram and Braun, 2009). It is necessary to achieve potential yield and increasing genetic gain to face a raising demand of wheat grain supply. Generally, Mediterranean region was the largest importer of wheat grain during the last decades. To achieve a sufficient, big efforts are required for creating or improving superior genotypes with high yield ability, adapted for specific environment to reduce the gap between production and consumption.

Genetic improvement for high yield has been a major goal of breeding program. The cooperation with CIMMYT led to get sets of spring wheat entries. Some genotypes have high response under specific environment but the performance of other genotypes are indifferent across wide range of environments. Genetic environment interaction (GEI) refers to the differential response between genotypes for various environments. The aim was to evaluate some of these sets in Iraqi environment and then selecting the best entries depending on their yield and stability. The potential yield for any genotype is an outcome of interaction with different environments factors such as years, soil fertility, moisture, planting dates, temperature and day length that vary across locations. These factors have big effects on different plant stages (Crossa, 1990, Johansson *et al.* 2003). The climate change may cause fluctuation in precipitation, temperature and drought cycles that requires adapted genotypes for wide variations in environment. GEI plays essential role in proportional expression on maximum yield of various genotypes (Reza *et al.*, 2007). Stability refers to stable performance of genotypes across sets of environments (Romagosa *et al.*, 1993). Optimum genotype must achieve high yield and at the same time has low degree of fluctuation in productivity across years and locations (Tarakanovas and Ruzgas, 2006) and low GEI, high response of maximum yield and low aberrations of expected response in target environment (Mohammadi *et al.*, 2011).

Generally, the variation in yield is large because the yield is quantitative trait with low heritability. Therefore, grain yield may be affected not by genotypes but also with environment and GEI. Depending on the magnitude of the interactions or the differential genotypic responses to environments, the varietal ranking can differ greatly across environments (Kaya *et al.*, 2002). Many approaches are used to investigate GEI. Additive main effects and multiplicative interaction (AMMI) is the most active way because it investigates the large portion of mean square variation of GEI in addition to isolating of main effects and interaction (Ebdon and Gauch, 2002). The results of AMMI analysis are very useful in determining specific adaptation and choice the best environment (Gauch and Zobel, 1997). Developing high yield cultivars with wide adaptability is the final target of plant breeders in spite of the difficulty of this goal because of GEI. AMMI model proven as an effective tool in diagnosing GEI fashion (Crossa, 1990). According to Line *et al.*(1986); Becker and Leon (1988) there are two controversy perceptions about stability. The first type is the static and the second is the dynamic. The first type includes the inclination of best genotypes to persist on stable yield across environments, while, the second type includes the stable and responsive genotype for yield in each environment (Annicchiarico, 2002).

The determining and analysis of GEI lead to reduce errors in breeding process in addition to the selection at one environmental condition will not give the same advantage in another condition. This will make the diagnosing of superior genotypes across environments and selecting the best genotypes is more complicated. The undesirable effects of GEI are the result of poor correlation between phenotypic value and genotypic value alongside reducing the response of selection leading to bias in estimates of heritability and prediction of selection progress (Farshadfar *et al.*, 2000, Alghamdi, 2004). The objective of this research was to estimate the yield stability of some spring bread wheat entries introduced from CIMMYT across range of years and nitrogen rates and choice the genotypes that have high stable performance yield.

Material and methods

Trials were conducted at farm of Agric.-College in Baghdad located in the middle of Iraq for four winter seasons 2009-2010, 2010-2011, 2011-2012 and 2012-2013. The aim was to screen advanced entries of spring wheat introduced from CIMMYT. Fourteen entries of spring wheat besides the check variety (Abugraib-3) were planted. Entries with poor performance were discarded at the end of 2009-2010 season. Five entries were selected depending on their superiority on local variety in grain yield. Five entries and local variety were planted for three successive winter seasons to determine grain yield stability under three levels of nitrogen were 25, 100, 175kgN.ha^{-1}. Letters from G1 to G6 as shown in table1 symbolized the entries. Randomized complete block design (RCBD) according to split plots arrangement with three replicates was used. Nitrogen levels were occupied the main plots whereas the sub plots were assigned for genotypes. The plot dimension was 3m x 2m. Each entry was in a small package that contained about 300 grains planted with two rows. The length of row was 2.5m and the distance between rows was 0.4m to allow maximum gene expression of genotypes and reducing the competition among plants to minimum. Seeding rate was 100kg.ha^{-1}. Phosphorous fertilizer as a rate of 100kg.P_2O_5 per hectare was added to the soil at tillage. Nitrogen fertilizer was added as urea form (46%N) according to required level with two applications; the first application was at planting and the second was at anthesis. Soil and crop managements were performed as recommended. At maturity, samples represented 1m^2 were taken to estimate grain yield and then converted to total grain yield t.ha^{-1} after adjusting the moisture content of grain to 14%.

Statistical analysis

Data primarily were analyzed according to RCBD of combined analysis of treatments planted in one area across years. If the interaction between genotypes and years is a significant, the next step will include estimating of interaction components by AMMI on the basis that each nitrogen within the year is considered as environment to form nine environments as shown in table1.

AMMI analysis includes the additive components of single main effects of genotypes and environments in addition to multiplicative components of interaction effects (Yan and Kang 2003). Therefore, the mean of genotype response i in environment j will be as following formula:

$Y_{ij} = \mu + G_i + E_j + GE_{ij} + \square_{ij}$

Where: μ is the general mean, G_i is the genotype effects, E_j is the environment effects, GE_{ij} is the interaction effects that adjusted to $\Sigma_{k=1}\lambda k\ y_{ik}\ \alpha_j k + p_{ij}$ and the final model will be as following:

$Y_{ij} = \mu + G_i + E_j + \Sigma_{k=1}\lambda_k\ \gamma ik\ \alpha jk + p_{ij} + \square_{ij}$ where λ_k is the eigenvalue value associated with kth of main components, γik is eigenvector of λ_k associated with genotypes, αjk is the elements of ^{jth} eigenvector of λ_k that associated with environments, pij is the additive residual and $\square_{ij}$ is the error ijth that associated with mathematical model.

Table 1. Environments and genotypes.

Environments	Nitrogen rates x year	
E1	N_{25} kg.ha^{-1} x year(2010-2011)	
E2	N_{100} kg.ha^{-1} x year(2010-2011)	
E3	N_{175} kg.ha^{-1} x year(2010-2011)	
E4	N_{25} kg.ha^{-1} x year(2011-2012)	
E5	N_{100} kg.ha^{-1} x year(2011-2012)	
E6	N_{175} kg.ha^{-1} x year(2011-2012)	
E7	N_{25} kg.ha^{-1} x year(2012-2013)	
E8	N_{100} kg.ha^{-1} x year(2012-2013)	
E9	N_{175} kg.ha^{-1} x year(2012-2013)	
Genotypes used, their symbols and origin		
Genotypes	symbol	origin
106S	G1	CIMMYT
107S	G2	CIMMYT
108S	G3	CIMMYT
109S	G4	CIMMYT
110S	G5	CIMMYT
Abugraib-3	G6	Iraq

AMMI was used to analysis of variance of main effects (additive portion) and analysis of main components (PCA) and analysis the residue non-additive across ANOVA. In analysis, each combination of nitrogen level and year is considered as an environment (table 1). The AMMI stability value (ASV) described by Purchase *et al*., (2000) was calculated as follows:

$$AVS = \sqrt{\left[\frac{IPCA1\ Sum\ of\ square}{IPCA2\ Sum\ of\ square}(IPCA1_{SCORE})\right]^2 + (IPCA2_{score})^2}$$

The higher the IPCA score, either negative or positive, the more specifically adapted a genotype is to certain environments. Lower ASV scores indicate a more stable genotype across environments.

Results and discussion

Results of combined analysis of variance for treatments planted in one location across years revealed significant differences of all sources of variation (table 2). The interaction between genotypes and years was significant; this indicator to a different behavior of genotypes across years and GEI had a role in performance of genotypes yield across years. Significant environmental effects stated the differential performance of genotypes across environments as results of fluctuation of weather conditions, soil fertility and other environmental variations from year to year. Yan and Kang (2003) stated the genotypic makeup of any individual remains constant from environment to another if the mutation will not occur. Therefore, the phenotypic variation for any genotype is a reflection to genotypic factors under environmental conditions in spite of there are wide ranges to produce number of phenotypes depending on the kinds of genotypic composition and their interaction with growth factors. Mostly, the highest grain yield of genotypes is correlated with low stability (Padi, 2007).

Results in Table 3 (AMMI analysis) revealed the percent of genotypes variance out of treatments variance was 65.6% that refers to ability of improving grain yield efficiently. The percent of environmental variance from treatments variance was 26.1% whereas the percent of interaction between genotypes and environments from treatments variance was 8.3%. All these effects were significant that refers to the importance of these sources in analysis. Genotypes effect had the major source of variance because of its high contribution in treatments variance indicating different response of genotypes across environments. PCA1 explained 60.54% from interaction variance out of degree of freedom 30.5% whereas PCA2 and PCA3 explained 25.1% and 10.6%, respectively, that account for 96.3% of interaction explained.

Table 2. Combined analysis of variance with RCBD for nitrogen rates, genotypes and years.

S.O.V	D.f	S.S	M.S	V.R	F. pr
Replicates	2	0.16386	0.08193	6.91	
years	2	1.91874	0.95937	80.87	<.001
Error(1)	4	0.04745	0.01186	1.46	
nitrogen	2	12.90092	6.45046	791.20	<.001
Nitrogen x Years	4	0.12928	0.03232	3.96	0.028
Error(2)	12	0.09783	0.00815	0.64	
genotypes	5	37.55189	7.51038	591.17	<.001
Genotypes x Years	10	3.60707	0.36071	28.39	<.001
Genotypes x Nitrogen	10	0.26118	0.02612	2.06	0.036
Genotypes x Years x Nitrogen	20	0.87060	0.04353	3.43	<.001
Error(3)	90	1.14339	0.01270		
Total	161	58.69222			

Table 3. AMMI analysis of grain yield of six genotypes of spring wheat planted at nine environments.

Sources	D.f	S.S	M.S	V.R	F.pr
Treats	53	57.24	1.080	85.01	0.00000
Genotypes	5	37.55	7.510	591.17*	0.00000
Environ.	8	14.95	1.869	108.80*	0.00000
Interaction	40	4.74	0.118	9.33*	0.00000
IPCA1	12	2.87	0.239	18.84*	0.00000
IPCA2	10	1.19	0.119	9.36*	0.00000
IPCA3	8	0.50	0.0628	4.94?*	0.00004
IPCA4	6	0.12	0.0205	1.62	0.15163
Residual	4	0.05	0.0131	1.03	0.39754
Block	18	0.31	0.0172	1.35	0.17634
Error	90	1.14	0.013		
Total	161	58.69	0.365		

Sivaplan *et al.* (2000) recommended a predictive AMMI model with the first four PCAs while Yan and Rajcan (2002) reported that the most accurate for AMMI could be predicted by using the first two PCAs.

AMMI has a valuable and effective tool to diagnose genotypes according to their adaptation if it is wide or specific. Genotype is defined as ideal depending on its performance and stability across environments (Aina *et al*., 2009). Genotypes that located near to horizontal axes have wide adaptation and stable whereas genotypes that located apart from the horizontal axes have specific adaptation for some environments so they have high GEI (Ebdon and Gauch, 2002). Grain yield of environments was the lowest in first environment reached 2.801t.ha^{-1} to 3.739 t.ha^{-1} in the ninth environment that had the first rank and it was the highest grain yield. This indicating that the environments had high variability (table 5). Grain yield of genotypes ranged from 3.783t.ha^{-1} in G5 that occupied the first rank to 2.276 t.ha^{-1} in G1 that occupied the latest rank (table 4). G1 and G2 had the highest scores of PCA1, therefore, they were more adapted to specific environments such as environment 3 for G2 and environment 4 for G1. Specific adaptation can be described as synchronizing of growth stages developments of plant with environ-mental conditions that reduce risks to extreme factors such as drought, coldness and nutrients deficiency. Therefore, in specific area that well characterized, the specific adaptation is considered the key to improve yield (Najafian *et al*., 2010). The genotype can be considered more favorable if it has high yield and stable performance across a wide range of environments. Depending on that, G4 was more adapted, stable and high grain yield because it has low scores of PCA1 and high grain yield whereas G6 was low stability because it has low yield and high scores of PCA1 that is, adapted to specific environment. Kang (2002) reported the importance of GEI depending on the target by plant breeder. If the plant breeder aims to produce cultivars with high yield across many environments, he must look for cultivars selected based on low GEI. Otherwise, if the plant breeder is interested to get a cultivar with specific adaptation, the contribution of genotype in GEI will be important. AMMI can be used through biplot diagram for main effects and scores of 1PCA1 between genotypes and environments. The differences among genotypes are related to their direction and magnitude along the X-axes (yield) and Y-axes (1PCA1 scores) (Kadhem 2014). Genotypes that locate on vertical line have the same grain yield while those locate on the horizontal line have the same GEI (Crossa 1990). Genotypes or environments that locate on the right side from the zero point of vertical line (yield mean) have high grain yield compared to that locate on the left side. PCA scores of genotype in AMMI are considered as an indicator to genotype stability or adapted across environ-ments. There are two types of drawing; the first is used to investigate AMMI-1 biplot that showed if any genotypes or environments scores are close to zero that is, contributing little to the interaction (stable). The greater the PCA scores, either negative or positive the more specific adapted (Gauch and Zobel, 1996). In AMMI-2, the scores of PCA1 and PCA2 are plotted to diagnose the best genotypes in which environment is.

Variation produced by genotypes was greater than variation of environmental differences. G5 gave the highest yield while G1 gave the lowest yield (Fig. 2). The environments 9, 6 and 3 were the favorable but environment 9 was the best whereas the environment 1 was the lowest. Genotypes or environments with high scores negative or positive of IPCA1 had high interaction, whereas those had IPCA1 scores close to zero (near to horizontal line) possess low interaction across environments therefore, they were more stable than those located far from horizontal line. Stone and Savin (2000) stated that grain yield and quality of wheat are considered a complex trait as a result of interaction between biochemical processes and large number of genes that control it. Fig. 1 showed that G5 was the best in grain yield followed by G4 and G2 while the lowest was G1 and G6. E9 gave the highest mean in grain yield followed by E6 and E3 while E1 gave the lowest grain yield. G4 was more stable because it had low scores of PCA1 and was the closet to horizontal line. That is, G4 is more favorable for wide adaptation. Piepho (1996) reported that the deep knowledge of GEI and exploiting it in plant breeding can be contributed in improving genotypes yield. If the genotype is selected across many locations, the stability and yield mean across environments will be the most important than grain yield in specific environments. Fig. 2 of AMMI-2 biplot model includes IPCA1 and IPCA2 that captured 85.64% from GEI of grain yield. G4 was the closet to the center of origin, that is, it had low variation in GEI, and therefore, it was more stable than other genotypes. G5 was more stable in PCA2 because it located on horizontal line that means it had low PCA2 scores. G2, G6, G1 were far from center of origin that made them less stable and they were adapted for specific environments. In respect to total environment, G1 was more adapted to E6, E4 and E5 while G3 was more adapted to E7, E8 and E9. G2 was more adapted to E1, E2 and E3. The environments E1, E2 and E3 were closest from zero in respect to PCA2; this indicates less contribution of these environments in IPCA2 variation.

Data in table 5 showed the rank of three first superior genotypes in each environment. G5 captured the first rank in six environments (E4, E5, E6, E7, E8 and E9). Further, G5 recorded the second rank in E1, E2 and E3. G5 was the best in grain yield followed by G2 that captured the first rank in three environments (E1, E2 and E3) and the second rank in E4. High yield criteria must not be taken the only ones when doing selection because genotypes with high yield may be unstable. (Kadhem, 2014). Therefore, stability and high yield must be considered together at selection.

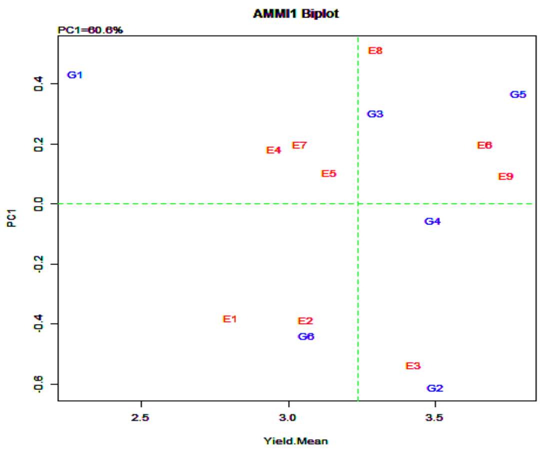

Fig. 1. Biplot of grain yield of six genotypes planted at nine environments.

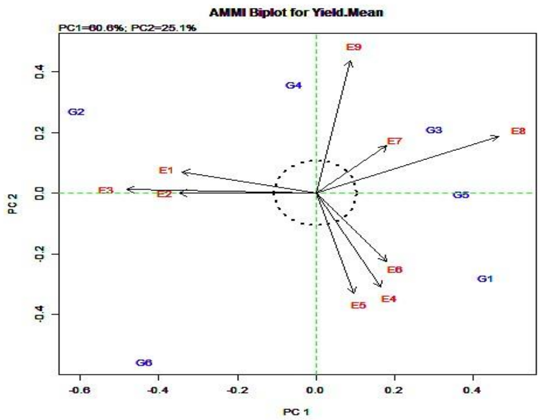

Fig. 2. Biplot of AMMI-2 shown PCA1 against PCA2 of six genotypes planted at nine environments.

Table 4. Grain yield mean and IPCA1, IPCA2 scores of six genotypes planted at nine environments.

Envi. / Geno.	E1	E2	E3	E4	E5	E6	E7	E8	E9	Geno. Mean	IPCA1 score	IPCA2 score
G1	1.656	1.931	2.231	2.167	2.326	2.864	2.117	2.504	2.687	2.276	0.431	-0.279
G2	3.319	3.558	4.019	3.011	3.240	3.744	3.230	3.307	4.078	3.501	-0.609	0.270
G3	2.763	3.000	3.326	2.994	3.153	3.735	3.195	3.558	3.930	3.295	0.302	0.208
G4	3.107	3.336	3.716	3.075	3.258	3.824	3.347	3.602	4.165	3.492	-0.055	0.357
G5	3.209	3.463	3.776	3.567	3.726	4.289	3.660	4.036	4.322	3.783	0.368	-0.003
G6	2.749	3.052	3.476	2.886	3.120	3.544	2.681	2.783	3.255	3.061	-0.438	-0.554
Envi. mean	2.801	3.057	3.424	2.950	3.137	3.667	3.038	3.298	3.739			
IPCA1	-0.379	-0.386	-0.534	0.183	0.105	0.199	0.199	0.515	0.096			
IPCA2	0.078	0.001	0.013	-0.343	-0.366	-0.249	0.173	0.208	0.484			

AVS values of genotypes

G1	G2	G3	G4	G5	G6
0.6702	0.9032	0.4757	0.3650	0.5210	0.8319

Table 5. Shown AMMI-2 for the first three genotypes for each environment.

Environments	Yield mean	IPCA1 Score	IPCA2 Score	First	Second	Third
E1	2.801	-0.37959	0.07865	G2	G5	G4
E2	3.057	-0.38662	0.00086	G2	G5	G4
E3	3.424	-0.53418	0.01358	G2	G5	G4
E4	2.950	0.18369	-0.34375	G5	G4	G2
E5	3.137	0.10556	-0.36639	G5	G4	G2
E6	3.667	0.19920	-0.24958	G5	G4	G2
E7	3.038	0.19969	0.17340	G5	G4	G2
E8	3.298	0.51549	0.20841	G5	G4	G3
E9	3.739	0.09676	0.48483	G5	G4	G2

Conclusion

Base on that, we can conclude G4 was better than other genotypes because it had high stability as shown from the AVS value that was the lowest reached 0.3560 that is, its yield is more stable across environments studied.

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