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Analysis of Grain Yield Stability in Hexaploid Wheat Genotypes Grown in Temperate Regions of Iran Using Additive Main Effects and Multiplicative Interaction

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ABSTRACT

Eighteen wheat breeding lines were evaluated along with two check cultivars across nine locations of temperate zone of Iran during two crop seasons (2003-2004 and 2004-2005). Field records were taken for some important traits especially grain yield. Combined ANOVA for nine locations in the first season and for seven locations in both seasons was undertaken. In each case, additive main effects and multiplicative interaction analysis (AMMI) was employed and the biplot of the Interaction Principal Components (IPC) were evaluated for stability and adaptation relationships among genotypes and locations. IPC1, IPC2 and IPC3 accumulatively defining 78.4% of genotype×environment (G×E) interaction variation were found out as significant in the first crop season. Biplot of first two IPCs identified at least two sub-regions among the locations. Some genotypes (M-82-7 and M-82-17) showed specific adaptation toward one of the drought-prone sub-regions. For the combined data of both seasons, only IPC1 was significant defining 41.5% of G×E interaction variation. Thus, plot of IPC1 along with grain yield means were employed for an interpretation of adaptation relationships. Entries M-82-8, M-82-9, M-82-11 and M-82-15 showed specific adaptation to Mashhad station which was interactive and particular in behavior. The results indicated that AMMI is an informative method of stability and adaptation analysis to be employed in practical plant breeding and subsequent variety recommendations.

Keywords: Adaptation, AMMI, Bread wheat, Grain yield, Stability.

INTRODUCTION

It is estimated that out of 12 million hectares of arable lands in Iran, about 50% are allocated to wheat production. Wheat production in Iran reached 13.4 million tons in 2002-2003 growing season. This was harvested from 6.4 million hectares of area under wheat from which 2.4 million hectares were under irrigation producing 8.7 million tons. The rest of the area (4 million hectares), being rain fed and produced 4.7 million tons (Anonymous, 2003).

Severe drought and moisture stresses are the major factors for low wheat productivity under rain fed conditions with an average of 1.2 t ha^{-1} as compared to 3.6 t ha^{-1} under irrigation. However, still large areas under irrigation farms are also affected by different levels of moisture stress. This might be one of the major factors for the difference between the attained and the potential yield

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of more than 6 t ha^{-1}. In temperate zones of the country, which account for about 28 percent of the total irrigated wheat area, records of up to 12 t ha^{-1} have been reported. Due to the existence of favorable environmental conditions for rusts in spring when grain filling also takes place, the resistances in new released varieties is very frequently broken down by new races of stripe rust disease. It is a challenge to plant breeder to contribute to a dynamic production system in this climatic zone, through continuous release of new wheat varieties of high yield potential, acceptable stability, resistance to diseases and tolerant against abiotic stresses.

The main task in access to a stable variety is to account for environmental effects and a definition of G×E interaction. Many methods have been established to measure stability and the genotype×environment interaction (Comstack and Robinson, 1952; Finllay and Wilkinson, 1963; Eberhart and Russell, 1966; Perkins and Jinks, 1968; Hanson, 1970; Freeman and Perkins, 1971; Tai, 1971). However, the parameters introduced through the above-mentioned reports have been criticized as to be inefficient in G×E interpretation and in their defining of specific and wide adaptation. The Additive Main effect and Multiplicative Interaction (AMMI) method proposed by Gauch (1992) was a significant advance in the analysis and interpretation of G×E interaction. With this method main effects (genotypes and environments) are initialy accounted for by a regular analysis of variance, and then the interaction (G×E) is analyzed through a principal component analysis which leads to identification of stable genotypes as well as to widely or specifically adapted genotypes in an easier manner. AMMI has been successfully employed to estimate stability and its heritability, adaptation and G×E elucidation in different crops. Ortiz *et al.* (2001) using a complete diallel cross among eight bread wheat lines studied for several seasons over two locations estimated heritability of some stability parameters including interaction principal component axes (IPCA). Their result showed a considerable narrow sense heritability for IPCA1 of the AMMI method (h^2 = 0.461) followed to coefficient of phenotypic variation. AMMI analysis of root yield was used by Manrique and Hermann (2001) in sweet potato clones studied over 4 different locations. Their results showed that, non of the high-yielding cultivars had satisfactory stability for total root yield. The biplot for beta-carotene content in roots showed stability for 5 of the investigated cultivars. Najafian (2005) used AMMI analysis of grain yield to determine stability and adaptation status of 20 hexaploid wheat genotypes grown over 4 locations under late season moisture stress conditions. The results of that study showed specific adaptation for several genotypes toward one of the stations which was affected by frost damage. The reason of that behavior was mentioned to be the facultative/winter growth habit of those genotypes.

The main purpose of this study was to examine grain yield stability and to characterize the adaptability of 20 hexaploid wheat genotypes grown at 9 stations from temperate areas of Iran over two years, using the AMMI method.

MATERIALS AND METHODS

The study was conducted for two growing seasons over nine research stations: Karaj, Kermanshah, Zarghan, Neishabour, Broujerd, Varamin, Mashhad, Isfahan and Yazd, which are located in the temperate climatic zones of Iran. Locations were depicted with S_1-S_9 codes in the same order as above. These areas are characterized by an altitude range of 500 to 1,500 m above sea level, cold to moderately cold winters with 30 to 60 freezing days during which the absolute minimum temperature reaches -14 °C. Plant materials consisted of 18 hexaploid wheat genotypes (coded M-82-3 to M-82-20) which have been forwarded from advanced regional yield trials for adaptation evaluations. Two widely grown cultivars

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Table 1. Pedigree of evaluated genotypes.

Genotype	Parentage
M-82-1	Shiraz
M-82-2	Pishtaz
M-82-3	Ald"s"/Snb"s"//Tjn
M-82-4	Azd/HD2172//Kayson/Glenson/3/1-70-28/Ning8201
M-82-5	Dove"s"/Buc"s"//Darab
M-82-6	Karawan 1//Sun640/M2512
M-82-7	Kayson/Glenson//shiroodi(DH)
M-82-8	Ures81//HD2206/Hork"s"/3/F12-71/Coc//Cho79
M-82-9	M-70-4/5/Alborz/4/K 6290914/Cno//K58/Tob/3/Wa
M-82-10	Sannine/Ald"S"//90-Zhong 87
M-82-11	KASYON/GENARO.81//TEVEE-1
M-82-12	Ald"s"/Snb"s"//Tjn
M-82-13	CHAM-6/MAYON"S" ICW93-0031-1AP-OL-OBR-2AP-1AP-OAP
M-82-14	Ww33G/Vee"S"//Mrn/3/Attila/Tjn
M-82-15	Azd/HD2172//Attila
M-82-16	Kayson/Glenson//shiroodi(DH)
M-82-17	Maroon/90-Zhong 87
M-82-18	KASYON/GENARO.81//TEVEE-1 ICW92-0281-1AP-OL-2AP-…
M-82-19	Emu"s"/Tjb84//Inia
M-82-20	Shi#4414/Crow"S"//Attila

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"*Shiraz*" and "*Pishtaz*" (coded M-82-1 and M-82-2, respectively) were included in the study. Pedigree of the investigated genotypes has been shown in Table 1. Trials were planted in November and harvested in July of the next year. Planting was done in experimental plots of 6 m length and 1.2 m width each. The experiments were carried out using randomized complete block design (RCBD) of 3 replications each. All cultural practices were carried out as recommended. At harvest, grain yield of whole experimental plots were mechanically harvested. The data from all the nine stations were analyzed in the first season. However, due to poor experimental conditions of two stations (Isfahan and Yazd), their data were excluded from the second season and from the combined analyses. Combined analysis of variance was done for the first crop season data for grain yield across nine locations and further for both crop seasons over 2 years and for 7 locations using SAS (SAS, 1990) software.

AMMI analysis of G×E interaction was done using grain yield data of the first and of both the crop seasons. Means of locations for the two seasons were employed in AMMI plotting eliminating the effect of year, since data of locations can be repeated over time but that of year can not. The adaptability relationships of genotypes and stations was assessed using, biplot of IPC1 and IPC2 (for the first crop season), and IPC1 and grain yield means (for two crop seasons).

RESULTS

Crop Season 2003-2004

Analysis of variance for data collected from 9 stations showed that the effects of location, genotype and location×genotype were highly significant (Table 2). Genotype M-82-9 was the highest performer in terms of grain yield with 8.73 t ha^{-1} followed by M-82-6, M-82-17 and M-82-4, which showed higher grain yields than the two checks M-82-1 and M-82-2 (Table 3). Lowest grain yield (7.581 t ha^{-1}) was obtained from M-82-13. Table 2 also shows the results of AMMI analysis of G×E interaction. The IPC1, IPC2 and IPC3 axes accumulatively defining 78.4% of G×E interaction variations were significant.

Table 2. Results of combined ANOVA and AMMI analysis of grain yield for 9 locations in the first crop season.

Sources of variation	Degrees of freedom	Mean squares	*F* test	Percentage	Cumulative %
Combined ANOVA					
Location (E)	8	42.97	25.70**	-	-
Blocks (E)	18	1.67	2.92**	-	-
Genotypes (G)	19	3.14	2.01**	-	-
G×E	152	1.56	2.73**	-	-
Error	342	0.572	-	-	-
AMMI analysis				-	-
Location (E)	8	42.97	75.14**	-	-
Genotypes (G)	19	3.14	5.49**	-	-
G×E	152	1.56	2.73**	-	-
Error	342	0.572	-	-	-
IPC1	26	3.95	6.91**	43.2776	43.278
IPC2	24	1.90	3.33**	19.2320	62.510
IPC3	22	1.71	2.99**	15.8433	78.353
IPC4	20	0.88	1.54^{ns}	7.3978	85.751

**, Significant at probability level of less than 0.01

From AMMI results only the first four IPC 's have been presented.

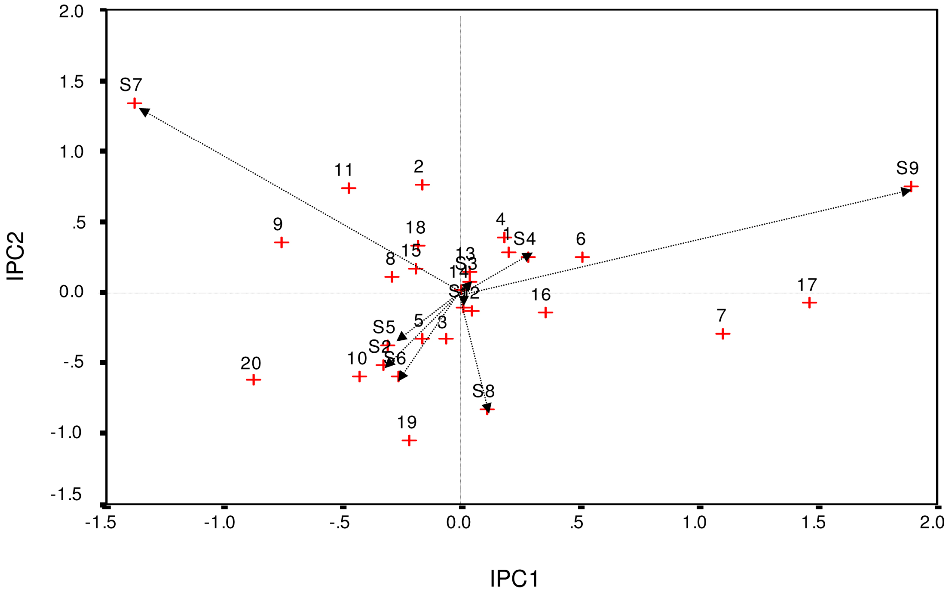

Figure 1. Biplot of G×E interaction for 20 genotypes and 9 locations as per their IPC1 and IPC2 in first crop season, S1= Karaj; S2= Kermanshah; S3= Zarghan; S4= Neishabour; S5= Broujerd; S6= Varamin; S7= Mashhad; S8= Isfahan, S9= Yazd.

However, the first two IPC's were more descriptive and accounted for 62.5% of G×E interaction variations.

For simplicity and ease of interpretation, the plot of first IPC as against IPC2 was used in first season (Figure 1) instead of three dimensional presentation using the third IPC. Results showed that the two typical temperate climate stations Karaj (S1) and Zarghan (S3) made little or no contribution to G×E interaction. Kermanshah (S2), Neishabour (S4), Broujerd (S5), Varamin (S6) and

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Table 3. Means of grain yield for evaluated genotypes.

Genotype	First crop season (t ha^{-1})	Genotype	Two crop seasons (t ha^{-1})
M-82-9	8.725 a*	M-82-9	8.257 a
M-82-6	8.522 ab	M-82-1 (Shiraz)	8.145 ab
M-82-17	8.473 ab	M-82-14	8.106 abc
M-82-4	8.457 ab	M-82-2 (Pishtaz)	8.014 abcd
M-82-2 (Pishtaz)	8.415 abc	M-82-18	7.826 abcde
M-82-1 (Shiraz)	8.384 abcd	M-82-6	7.824 abcde
M-82-5	8.259 abcd	M-82-11	7.689 bcdef
M-82-11	8.253 abcd	M-82-4	7.676 bcdef
M-82-14	8.237 abcd	M-82-5	7.635 bcdef
M-82-18	8.169 abcd	M-82-8	7.610 bcdef
M-82-7	8.163 abcd	M-82-15	7.564 cdef
M-82-8	8.157 abcd	M-82-17	7.556 cdef
M-82-3	8.031 abcd	M-82-16	7.543 cdef
M-82-15	7.863 bcd	M-82-3	7.488 def
M-82-20	7.852 bcd	M-82-20	7.421 ef
M-82-16	7.780 bcd	M-82-19	7.419 ef
M-82-19	7.732 bcd	M-82-10	7.400 ef
M-82-12	7.610 cd	M-82-13	7.395 ef
M-82-10	7.602 cd	M-82-12	7.374 ef
M-82-13	7.581 d	M-82-7	7.184 f

* Means with same letters indicated no significant difference at 5% probability level.

Isfahan (S8) stations showed partial contributions to G×E formation. Mashhad (S7) and Yazd (S9) stations showed considerable contributions to G×E interaction. Mashhad is climatically a temperate to mildly cold location, while Yazd, located near the deserts of Iran, is a temperate location of short springs, low rainfall and warm winds during the grain-filling period. Neishabour and Yazd, which are prone to terminal drought, showed similarity in behavior, but a strong G×E effect was observed for Yazd station, as its IPC1 value was high. Mashhad station was different from all the other stations with high values for both IPC's depicting its strong role in G×E formation.

M-82-14, M-82-12, and M-82-13 were the most stable genotypes as located in attachment to the cross section of IPC1 and IPC2 zero points (Figure 1). These genotypes presented no specific adaptation to any location. M-82-14 with grain yield of 8.2 t/ha could be regarded as a widely adapted genotype. M-82-3, M-82-5, M-82-8, M-82-15, M-82-18 M-82-4, M-82-1, and M-82-16 showed a degree of stability, having low contributions to G×E interaction. M-82-6, M-82-7, M-82-16, and M-82-17 showed specific adaptation to Yazd station. The contribution of entries M-82-7 and M-82-17 to G×E interaction was more than that of M-82-6 and M-82-16 as their IPC1 values were high. Kermanshah, Varamin, and Broujerd stations exhibited similar adaptation status with each other, while M-82-3, M-82-5, M-82-10, M-82-19, and M-82-20 showed a better adaptation to these sites. M-82-20 could be regarded as contributing significantly to G×E formation as its IPC1 value was a considerable one. Genotypes M-82-9, M-82-11 and M-82-2 showed higher specific adaptation to Mashhad as compared to genotypes M-82-8, M-82-15 and M-82-18.

Two Crop Seasons 2003-2005

The combined analysis of variance of the data of either season over seven locations revealed that the effects of year and location were not significant but year×location, genotype,genotype×location, genotype×year and genotype×location×year were significant

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Table 4. Results of combined ANOVA and AMMI analysis of grain yield means for 7 stations over two crop seasons.

Sources of Variation	Degrees of freedom	Mean squares	*F* test	Percentage	Cummulative %
Combined ANOVA					
Year (Y)	1	231.1	4.25^{ns}		
Location (E)	6	196.7	3.61^{ns}	-	-
Y×E	6	54.4	45.04**		
Blocks (Y×E)	28	1.21	2.65**	-	-
Genotypes (G)	19	3.54	2.94**	-	-
G×E	144	1.20	1.35*	-	-
G×Y	19	1.59	1.79*	-	-
G×E×Y	114	0.889	1.95**	-	-
Error	532	0.455	-	-	-
AMMI analysis				-	-
Location (E)	6	98.35	215.90**	-	-
Genotypes (G)	19	1.77	3.88**	-	-
G×E	114	0.60	1.32*	-	-
Error	532	0.455	-	-	-
IPC1	24	1.19	2.60**	41.48	41.48
IPC2	22	0.69	1.50^{ns}	21.96	63.44

** and *, Significant at probability levels of less than 0.01 and 0.05, respectively.
From AMMI results only the first two IPC 's have been presented.

(Table 4). M-82-9 with grain yield of 8.26 t ha^{-1} ranked first followed by M-82-1, M-82-14, and M-82-2 with grain yields of above 8 t ha^{-1}. However, no significant differences were found out among these genotypes. On the other hand, the lowest grain yield (7.2 t/ha) was obtained from genotype M-82-7 (Table 3).

AMMI analysis of mean grain yield for the two seasons showed a significant effect for environment, genotype and G×E interaction. Among the interaction principal components, only IPC1 was significant, defining 41.5% of G×E interaction

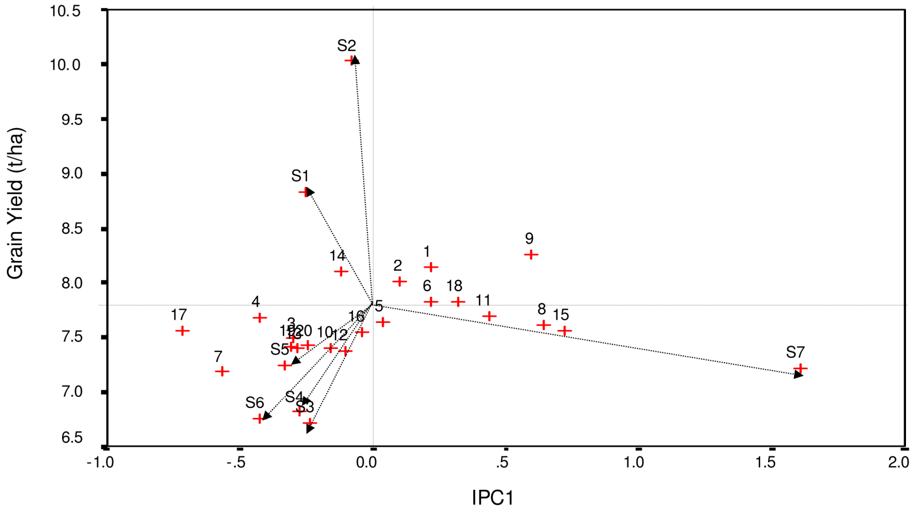

Figure 2. Biplot of G×E interaction for 20 genotypes and 7 locations as per their IPC1 and grain yield (t ha^{-1}) over two crop seasons, S1= Karaj; S2= Kermanshah; S3= Zarghan; S4= Neishabour; S5= Broujerd; S6= Varamin, S7= Mashhad.

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variations (Table 4). Therefore, grain yield was plotted against IPC1 to evaluate yield potential as well as adaptation relationship among stations and genotypes. Among stations, Mashhad showed the highest value for IPC1 (> 1.5) depicting its strong contribution to G×E interaction. The other six stations had IPC1 values between 0.0 and -0.5 showing partial stability in terms of contribution to G×E interaction. In terms of grain yield potential, Kermanshah (S2) and Karaj (S1) Stations showed the highest grain yields of above 10 and 8 t ha^{-1}, respectively (Figure 2). The most stable genotypes were M-82-5, M-82-16, M-82-2, M-82-12, M-82-14, and M-82-10 as their IPC1 values were near zero. M-82-3, M-82-19, M-82-13, M-82-20, M-82-1, M-82-6, M-82-18, M-82-4, and M-82-11 were partially stable. M-82-9, M-82-8, M-82-15, M-82-7, and M-82-17 had higher values of IPC1 showing their greater contribution to G×E interaction. Entries M-82-9, M-82-8, M-82-11, M-82-18 and M-82-15 showed specific adaptation to Mashhad station. The most desirable genotypes in terms of yield potential and general adaptation were M-82-14, M-82-1 ("*Shiraz*" check cultivar), M-82-2 (*"Pishtaz"* check cultivar), M-82-6 and M-82-18. M-82-9 was the best yield performer but its stability was moderate.

DISCUSSION

AMMI plotting of the data from the first season shows the heterogeneity of the nine tested stations in terms of contribution to G×E interaction. This plotting divided these nine stations to at least two subregions, the first one including Neishabour, Isfahan, and Yazd. These stations are drought-prone regions, water deficit being one of their characteristics especially in terminal stages of wheat growth. The second subregion included the rest of the stations. M-82-1, M-82-6, M-82-7, M-82-16, and M-82-17 being fitted to this group of stations may be due to their earliness and their adjusting performance under the circumstances. In fact, specific adaptation could be characterized as positive coincidence of plant phenology with such environmental reducing events as frost damage in winter and/or terminal drought. For example, in case of a dry season, during terminal stages of crop growth, early maturing drought tolerant genotypes may bring about a good performance which is detectable as specific adaptation in the AMMI plotting. In case of winter freezing damage, genotypes with winter growth habit or late maturity style (leading a later enter into the reproductive phase and consequently escaping frost damage) bear the trait which is further detected as specific adaptation to locations with freezing hazard during winter. Therefore, it is concluded that specific adaptation could be defined as positive harmony of plant phenology events with environmental-reducing factors which in most cases may be of temperature fluctuations nature. This phenomenon supports the conclusion that in a particular area with well characterized environment, specific adaptation is the key point for yield improvement (Ceccarelli, 2006; personal communications). In adaptation trials when such locations are assembled with a set of other contrasting locations, dividing of whole region into sub-regions is beneficial for variety recommendation to get gain of specific adaptation (Annicchiarico *et al.,* 2005).

In Figure 1, there is a particular point about Mashhad station as it was very interactive and showed a high absolute value for both plotted IPCs. This is a temperate to cold location with the risk of frost damage, especially to spring genotypes. Entries M-82-15, M-82-8, M-82-18, M-82-2, M-82-11, and M-82-9 showing specific adaptation to this station were either late maturing ones or of winter habit types. Plotting of both crop seasons' AMMI results for 7 stations (Figure 2) showed only one significant dimension of G×E plotting, that is the particular behavior of Mashhad Station as opposed to that in

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the other stations. M-82-9, M-82-8, M-82-15, M-82-11, and M-82-18 showed adaptation to this station due to their winter habit or late maturity style. Karaj and Kermanshah, the most suitable stations in terms of trial management demonstrated ever present consistency with each other. The highest grain yield records were observed in these two stations with the highest performer genotypes M-82-14, M-82-2, and M-82-1 adapted to them both.

CONCLUSIONS

In general, it could be concluded that getting a clear resulting view of adaptation interpretation, using AMMI method for a set of genotypes tested across several locations, is dependent on precision and accuracy of trial management so that the environmental effects could be clearly detectable and genotypes could express their genetic potential. Deficit in some determining factors such as irrigation may lead to a particular station as drought prone in relationship to drought tolerant genotypes. Otherwise, AMMI analysis is a very successful tool in identifying genotypes with either specific and wide adaptation. The clear adaptation relationships among the investigated genotypes and locations, which are extracted from biplot of AMMI analysis, could be an important advantage of this method compared to other methods e.g. Eberhart and Russell (1966). It is stressed that specific adaptation is mostly based on environmental hazards and in a limited scale, may follow soil properties. In this research M-82-5, M-82-16, M-82-2, M-82-14, and M-82-1 were identified as genotypes with general stability. Genotypes M-82-1, M-82-14, and M-82-2 exhibited general adaptation. M-82-15, M-82-8, M-82-17, and M-82-7 were interactive genotypes, showing specific adaptation toward some of the locations.

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تجزیه پایداری عملکرد دانه در ژنوتیپ های گندم هگزاپلویید کشت شده در مناطق معتدل ایران با استفاده از روش امی (AMMI)

گ. نجفیان، ا. ك. كفاشی و ا. جعفرنژاد

چکیده

با هدف تعیین روابط سازگاری بین ۲۰ ژنوتیپ گندم هگزاپلویید و ۹ منطقه مورد بررسی این تحقیق انجام گرفت.در این تحقیق تعداد ۱۸ لاین بهنژادی در یك آزمایش ۲۰ شماره ای در ۹ ایستگاه کرج، کرمانشاه، زرقان، نیشابور، اصفهان، بروجرد ، ورامین، مشهد و یزد در کنار ۲ رقم شاهد (شیراز و پیشتاز) به مدت دو سال زراعی ۸۴-۱۳۸۲ بررسی شدند. در کلیه مناطق کشت آزمایش ها در نیمه اول آبانماه صورت گرفت. در همه ایستگاهها آزمایش در قالب طرح بلوکهای کامل تصادفی با ۳ تکرار اجرا شد. پس از برداشت عملکرد دانه در هر کرت مشخص و ثبت گردید. نتایج بدست آمده در ایستگاههای اصفهان و یزد در سال دوم آزمایش یعنی سال زراعی ۸۴-۱۳۸۳ بدلیل مشکل در اجرای آزمایش در این مناطق در محاسبات و تجزیه و تحلیل ها وارد نگردیدند. تجزیه واریانس مرکب نتایج آزمایش در ۹ ایستگاه ذکر شده برای سال زراعی ۸۳-۱۳۸۲ و در ۷ ایستگاه برای داده های دو ساله آزمایش انجام شد. تجزیه پایداری و بررسی سازگاری با استفاده از روش AMMI و رسم نمودار بر اساس مولفه های معنی دار در مدل انجام گردید. نتایج سال اول نشان داد که مولفه های IPC1 ، IPC2 و IPC3 مجموعاً ۷۸/۴ درصد از تغییرات اثر متقابل ژنوتیپ با محیط را تعریف نمودند. بای پلات دو مولفه اول دو زیر منطقه در میان ایستگاههای مورد بررسی مشخص ساخت. برخی ژنوتیپ ها نسبت به یکی از زیر منطقه ها که در معرض تنش رطوبتی و مشکل خشکی بود ، سازگاری خصوصی نشان دادند. در مورد داده های دو ساله تنها مولفه اول معنی دار گردید که به تنهایی ۴۱/۵ درصد تغییرات اثر متقابل ژنوتیپ × محیط را تعریف نمود. در این مورد بای پلات مولفه اول در کنار میانگین عملکرد ژنوتیپ ها برای بررسی روابط سازگاری مورد استفاده قرار

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گرفت. در مورد هر دو سال ایستگاه مشهد رفتار خاصی نشان داد و نقش قابل توجهی در ایجاد اثر متقابل داشت. ژنوتیپهای M-82-8 ، M-82-9 ، M-82-11 و M-82-15 نسبت به ایستگاه مشهد سازگاری خصوصی نشان دادند. نتایج نشان داد که روش تجزیه AMMI روشی مفید برای تجزیه پایداری و تعیین سازگاری است که می تواند در اصلاح محصولات زراعی مورد استفاده قرار گیرد.

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