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EVALUATION OF GRAIN YIELD STABILITY AND SELECTION OF BREAD WHEAT (*Triticum aestivum* L.) GENOTYPES UNDER DIFFERENT IRRIGATION REGIMES

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Drought stress is one of the most important limiting factors for the production of crop plants in the arid and semi-arid regions of the world. Water deficiency during different developmental stages can change the values of yield components. The yield stability of wheat cultivars at different irrigation regimes is one of the important goals of breeders and agronomists. To determine which cultivar can be categorized as high yielding and stable at different irrigation regime, 10 bread wheat cultivars (C1-C10) were evaluated for grain yield under five levels of irrigation in two years. The significant genotype by environment (GE) interaction for yield confirms the differential response of cultivars to drought stress in different stages of plant development. Additive main effect and multiplicative interaction (AMMI) analysis were used to understand the GE interaction pattern. Based on AMMI parameters, genotypes C3, C6, and C7 exhibit the most stability in different moisture conditions. All three cultivars have been improved for rainfed conditions. Based on AMMI2 mega-environment analysis, Irrigation regimes were categorized into three groups. The first group contained E1 (rainfed) and E2 (interruption of irrigation at the tillering stage), the second group contained environments E3 (at booting stage) and E4 (after anthesis), and the tertiary group contained E5 (optimal irrigation). The results shown that AMMI stability statistics would be useful when static concept of stability is emphasized. But if the time of occurrence of drought stress in a given region is constant, then AMMI mega-environment analysis will be more appropriate.

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INTRODUCTION

Drought is a severe abiotic stress and the major constraint on wheat (*Triticum aestivum* L.) productivity worldwide. Wheat usually performs adequately in the semiarid environment when sufficient irrigation water is available. However, droughts often occur, and the development of urbanization has created increased demands on world water supplies. This makes the dependability of irrigation water often erratic, especially later in the growing season or during drought years. Even the most productive agricultural regions experience short periods of drought within almost any year and occasional years with severe droughts (BARNABAS *et al.*, 2008). The effects of drought on wheat have been extensively reported, including morphological changes of the plant and the reduction in grain quantity and quality. Deciphering the mechanisms of drought tolerance is a challenging task because of the complexity of drought responses, environmental factors, and their interactions. Severity and duration of drought determine physiological stress responses in plants (CHAVES *et al*., 2003). The negative impact of drought depends on the developmental stage of plants, tissue and organ specificity, soil types and experimental conditions of stress application (KRCˇEK *et al*., 2008). The use of tolerant cultivar is one of the main strategies that can reduce the yield losses caused by water stress. In the other words, the risk of producing wheat in irrigated fields can be reduced by choosing cultivars that have a high average yield and are more stable when less than optimum irrigation conditions exist.

The susceptibility of plants to drought varies in dependence of stress degree, different accompanying stress factors, plant species, and their developmental stages (DEMIREVSKA *et al*., 2009). Water deficiency during different developmental stages can change the values of yield components (HOSSAIN *et al*., 2012; FRANCIA *et al*., 2013). Drought stress reduces grain yield of wheat through negative affecting the yield components i.e. the number of plants per unit area, number of spikes and grains per plant or unit area and single grain weight, which are determined at different stages of plant development (FAROOQ *et al*., 2009; FRANCIA *et al*., 2013; HOSSAIN *et al*., 2012). In the other words, water deficiency in different stages of plant growth can have different effects on physiological and morphological traits. Usually, the stage of plant growth that it will confront with drought stress is unclear. Therefore, the cultivars are suitable that it has stable performance in the confrontation with drought stress in different stages of plant development.

Crop yield stability is an important issue for farmers, breeders, geneticists, and production agronomists. Differential response of cultivars from one environment to another is called a genotype × environment (GE) interaction. GE interactions are an important issue facing plant breeders and agronomists. A significant GE interaction for a quantitative trial such as grain yield can seriously limit progress in selection. Several methods have been proposed to study yield stability and GE interaction with the aim of explaining the information contained in the GE interaction data matrix. They each reflected different aspects of stability and no single method can adequately explain cultivar performance across environments. An alternative and complementary method of evaluating cultivars is through multivariate analysis of G × E interactions (CROSSA, 1990; LIN *et al*., 1986). A comprehensive description of G × E interaction requires more sophisticated statistical methods than ANOVA. A popular extension of ANOVA for studying G × E interaction is the additive main effects and multiplicative interaction (AMMI) model (GAUCH, 1992). This method extracts genotype and environment main effects and uses principal component (PC) axes to explain patterns in the G × E interaction or residual matrix, which provides a multiplicative model (DEHGHANI *et al*., 2010). The univariate parametric and nonparametric analyses attempt to define G × E interaction by one or two parameters, but the objective of the multivariate procedures such as AMMI is to explore multi-directionality aspects of the G × E interaction and to attempt to extract additional information out of this component (GAUCH, 2006; SABAGHNIA *et al*., 2008). The use of AMMI stability parameters permits evaluation of yield stability after reduction of the noise from effects of the G×E interaction and, thus, enables better understanding of genotypes yield over different environments for selection of stable and high yielding genotypes (HEIDARI *et al*., 2017)

There are few studies on the stability of grain yield under drought stress at different growth stages of wheat. In this study, ten wheat cultivars were evaluated for grain yield under five levels of irrigation in two years. The overall objective was to determine which cultivar can be categorized as high yielding and stable, and therefore, should be recommended to farmers for use in areas where irrigation may be limited.

MATERIALS AND METHODS

Experimental site and treatments

A field experiment was conducted through subjecting the bread wheat cultivar to five levels of drought stress in 2013–2015 years at the experimental farm of the University of Mohaghegh Ardabili, located at Moghan, Iran (39° 39′ N, 48° 16′ E and 32 m above sea level). Agro-climatic characteristics of testing environments are given in Table 1. The field experimental design was a split plot experiment based on randomized complete block design with three replications under five contrasting irrigation regimes. The cultivars used in the research are developed by various breeders at different research institutes/stations of Iran and the International Maize and Wheat Improvement Center (CIMMYT). The information about the cultivars are givenin Table 2. Drought stresses introduced: rainfed conditions (E1, E6), interruption of irrigation at the tillering stage (35 days after sowings; E2, E7), at booting stage (60 days after sowings; E3, E8), after anthesis (E4, E9). At the control treatment (E9, E10), soil moisture was maintained at the optimal level (full irrigation regime was applied).

The experimental plot consisted of 6 rows 6 m long with 0.2 m spacing between rows, which resulted in a plot area of 7.2 m^2 and the seed rate was 350 seeds m^{-2} for each treatment. Planting date was 15 November each year and preceding crop was wheat. Based on a soil test before planting, 50 and 100 kg ha^{-1} of urea and P_2O_5 were applied, respectively. Weed control was conducted with an application of the herbicides 2.4-D at 1.0 L ha^{-1}. At the end of the experiment, data on grain yield were taken from the middle four rows of each plot, leaving aside the guard rows on either side of a plot.

Table 1. Agro-climatic characteristics of testing environment

Month	Year	Temp (˚C)			Rainfall (mm)	Average Humidity (%)	Evaporation (mm)	Soil Condition	
		Min	Max	Mean					
Sep.	2013-14	15.5	30.0	22.7	19.0	68.2	165.8	Texture	Sandy-Loam-Silt
	2014-15	17.7	29.1	23.4	25.4	64.9	160.5		
Oct.	2013-14	9.7	20.6	15.15	29.7	75.0	67.2		
	2014-15	10.5	18.7	14.6	1.6	78.0	42.0		
Nov.	2013-14	6.3	15.7	11.1	75.0	80.0	21.1	%Silt	14
	2014-15	5.4	12.9	9.2	46.8	79.1	12.3		
Dec.	2013-14	-0.9	6.7	2.9	18.3	74.0	0		
	2014-15	2.6	10.5	6.5	5.3	81.3	0	%Loam	57
Jan.	2013-14	-0.6	10.7	5.0	7.8	70.0	0		
	2014-15	0.6	8.2	4.4	5.8	80.3	0		
Feb.	2013-14	-0.7	9.5	4.4	89.0	74.0	0	%Sandy	29
	2014-15	1.9	10.6	6.3	21.9	79.2	0		
Mar.	2013-14	4.7	15.7	20.4	51.3	70.0	0	pH	7.9
	2014-15	4.4	12.7	8.5	14.9	79.8	2.6		
Apr.	2013-14	8.0	20.9	14.4	22.9	68.0	72.0	%N	0.01
	2014-15	7.7	19.1	13.4	11.9	71.5	86.3		
May	2013-14	15.5	29.4	22.4	31.1	66.0	170.0		
	2014-15	14.0	26.7	20.3	11.6	68.2	121.5	%C	0.98
Jun	2013-14	18.4	33.1	25.7	37.2	52.0	232.9		
	2014-15	17.5	32.6	25.0	37.2	59.6	338.3		

Table 2. Cultivars code and name of 10 bread wheat cultivars

Cultivars codes	Name	Origin	growth type	Height (cm)	TKW	LGP (day)
C1	Zagros	Iran	Spring	100-110	38	120-130
C2	Karim	Iran	Spring	80-90	34	110-120
C3	Kohdasht	CIMMYT	Spring	90-100	37	120-130
C4	Seymareh	CIMMYT	Spring	70-80	32	130-140
C5	Dehdasht	Iran	Spring	70-80	40	130-140
C6	Niknejad	CIMMYT	Spring	80-90	32	120-130
C7	Aftab	Iran	Spring	70-85	36	120-130
C8	Shirodi	CIMMYT	Spring	100-90	39	160-180
C9	Chmran	CIMMYT	Spring	90-100	39	180-200
C10	Gaboss	Iran	Spring	80-90	40	120-130

CIMMYT, International Maize and Wheat Improvement Center

Statistical analysis

The additive main effects and multiplicative interactions (AMMI) model, which combines standard analysis of variance with principal component analysis (ZOBEL *et al*., 1988), was used to investigate of genotype × environment interaction. This method extracts genotype and environment main effects and uses principal component axes (PCA) to explain patterns in the GE interaction or residual matrix, which provides a multiplicative model, is applied to analyse the interaction effect from the additive ANOVA model (ROMAGOSA and FOX, 1993).

MATMODEL software (GAUCH, 2007) and the associated program, AMMIWINS, include mega-environment analysis for the AMMI model. AMMIWINS identifies each mega-environment by its winning genotype, counts its number of wins, and calculates the average expected yield over those environments included in that mega-environment.

statistics ($SIPC_1$, $SIPC_v$) are sums of the absolute value of the IPC scores $\sum_{n=1}^{N} \lambda_n^{0.5} \gamma_{in}$ for the *i*th genotype for $SIPC_1$, N was one; for $SIPC_v$, N was the number of IPC that were retained in the AMMI model via cross-validation. The SIPC of a genotype in the AMMI analysis were reported (GAUCH and ZOBEL, 1996; PURCHASE, 1997) an indication of the stability of a genotype across environments. The closer the SIPC scores are to zero, the more stable the genotypes are across their testing environments (YAU, 1995; PURCHASE, 1997).

The next two AMMI stability statistics (EV_1, EV_v) were suggested by ZOBEL (1994) and are averages of the squared eigenvector values, $\sum_{n=1}^{N} \frac{\gamma_{in}^2}{N}$ for the *j*th cultivar: for EV_1, N was one; for EV_v, N was the number of IPC that were retained in the AMMI model via cross-validation.

The other better option is, to calculate AMMI stability values (ASV), using a principle of the Pythagoras theorem and to get estimated values between IPCA1 and IPCA2 scores. ASV was reported to produce a balanced measurement between the two IPCA scores (PURCHASE, 1997). The AMMI stability values were calculated using the following formula, as suggested by PURCHASE (1997).

$$ASV = \sqrt{\frac{SS_{IPCA1}}{SS_{IPCA2}}(IPCA1)^2 + (IPCA2)^2}$$

Where, SS_{IPCA1} and SS_{IPCA2} are the sums of squares interaction of first and second PC analysis, respectively.

RESULTS AND DISCUSSION

Relative yield performance and yield stability are the two important growth attributes which help in the identification of drought tolerant genotypes under unpredictable rainfall conditions. Farmers in water-limited environments would prefer to use high-yielding cultivars that perform consistently from year to year, respond to favourable irrigation levels, and it has stable performance in a confrontation with drought stress in different stages of plant development.

An annual mean yield of 10 bread wheat cultivars grown under five irrigation regimes in two years are shown in Table 3. It can be seen that the difference in yield is from 1343 kg in rainfed conditions to 5088 kg in complete irrigation treatment. The highest wheat yield was observed in the full irrigation regime in both years. Also, Genotypes C8, C9 and C10 had the highest performance in experiments. The ANOVA for grain yield indicated that genotype (G), environments (E) and GE interaction were all highly significant (Table 4). The significant GE interaction for yield confirms the differential response of cultivars to drought stress in different stages of plant development (environments). The AMMI analysis of variance of grain yield of the 10 cultivars tested in 10 environments (5 irrigation regime at 2 years) showed that 91.5% of the total sum of squares was attributable to environmental effects, only 0.89% to genotypic effects, and 7.58% to GE interaction effects (Table 4). A large sum of squares for environments indicated that the environments were diverse, with large differences among environmental means causing most of the variation in grain yield. In other words, stress at different stages of growth has caused severe changes in the performance of cultivars.

Table 3 Annual mean yield of 10 bread wheat cultivars grown under five irrigation regime in 2013/2014 and 2014/2015 season.

Cultivar[1] codes	Irrigation regimes[2] (2013-2014)					Irrigation regimes (2014-2015)					
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Average
C1	1763^{b}	1643^{d}	1910^{d}	3647^{ab}	3647^{c}	1527^{d}	2030^{c}	2927^{bc}	3147^{f}	3785^{e}	2696^{D}
C2	1803^{ab}	1843^{cd}	2220^{bc}	3613^{ab}	3907^{cb}	2374^{a}	2437^{a}	2434f^{g}	3552de	3860^{e}	2804^{BC}
C3	1553^{d}	1633^{d}	2177^{bc}	3760^{ab}	3890^{cb}	1992^{abc}	1751^{d}	2345^{g}	4077^{a}	4419^{cd}	2760^{C}
C4	1853^{a}	2290^{bc}	2393^{ab}	3457^{b}	3810^{cb}	2169^{ab}	2368^{ab}	2994^{b}	3358^{e}	3758^{e}	2845^{C}
C5	1437^{e}	2367^{a}	2283^{ab}	3327^{b}	4207^{ab}	1644^{cd}	1630^{d}	3226^{a}	3851^{b}	4065de	2804^{BC}
C6	1343^{f}	2027^{bc}	2018^{cd}	4057^{a}	4280^{ab}	2100^{ab}	1998^{c}	2365^{g}	3642^{cd}	4382^{cd}	2821^{BC}
C7	1563^{d}	2387^{a}	2027^{cd}	3293^{b}	3403^{c}	1984^{abc}	2213^{b}	2615^{def}	3445d^{e}	4599^{bc}	2753^{C}
C8	1693^{c}	2123^{b}	2553^{a}	3297^{b}	4627^{a}	1661^{cd}	2332^{ab}	2460^{efg}	3536d^{e}	5088^{a}	2937^{A}
C9	1490^{ed}	2070^{bc}	2200^{bc}	3640^{ab}	4697^{a}	1839^{bcd}	2316^{ab}	2694^{cde}	3771^{bc}	4880^{ab}	2960^{A}
C10	1490^{ed}	1730^{d}	2503^{a}	3643^{ab}	4570^{a}	1641^{abc}	1719^{d}	2712^{cd}	3642^{cd}	4892^{ab}	2854^{AB}
Average	1581^{H}	2011F^{G}	2228^{E}	3573^{C}	4104^{B}	1893^{G}	2079^{F}	2677^{D}	3602^{C}	4373^{A}	2812

Abbreviations: [1] C1-C10 wheat genotypes; [2] E1 - ; E2-…E10 five irrigation regime; rainfed (E1 and E6), the tillering stage (E2 and E7), at booting stage (E3 and E8), after anthesis (E4 and E9) and control treatment (E5 and E10).

Table 4. Additive main effects and multiplicative interactions (AMMI) analysis of ariance for grain yield (kg ha^{-1}) of the 10 cultivars across 10 environments

S.O.V.	Df	Mean Square	RMSPD†	Explained (%)
Environment (E)	9	30808207**		91.53
Genotype (G)	9	299134**		0.89
G × E	81	283407**	549.1	7.58
IPCA 1	17	564630	533.7	47.49
IPCA 2	15	292865	509.3††	19.14
Residual	49	182944		
Pooled error	200	32852447		

^{ns} and **, non-significant and significant at the 0.01 probability level, respectively.

†RMSPD, the root mean square prediction differences, Predicted by MATMODEL software with repeating 1000 times splitting data.

†† The selected model with a minimum root mean square predictive difference.

Partitioning of GE interaction indicated the AMMI-2 model described the GE interaction patterns for yield using the first two IPCA scores based on cross-validation. Results from AMMI analysis also showed that the first PC axis (IPCA1) of the interaction captured 47.49% of the interaction sum of squares in 8.6% of the interaction degrees of freedom. Similarly, the second PC axis (IPCA2) explained a further 19.14% of the GE interaction sum of squares. The two IPCAs accounted for 66.63% of the total interaction.

The biplot in Figure 1 of IPCA1 plotted against IPCA2 compares relative magnitude and sign of the GE interaction controlled by each cultivar and each environment. Cultivars with large IPCA1 or IPCA2, or both have high interactions, whereas cultivars with IPCA1 or IPCA2 scores near zero have small interactions for the corresponding axis. This is exemplified by C7 which was close to the center of both axes.

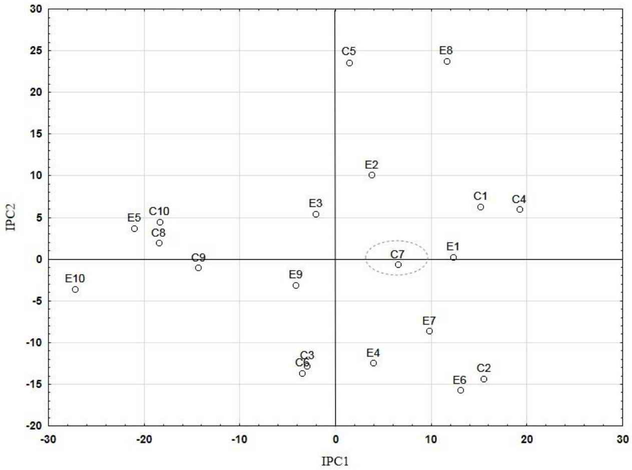

Fig. 1 Biplot of interaction principal component axis IPCA1 against IPCA 2 for yield of 10 wheat cultivar genotypes in 10 environments

Whether the cultivars and environments have similar or opposite GE interaction patterns are indicated by their same or opposite horizontal and/or vertical direction from the center. Simultaneous assessment of IPCA scores for cultivars and environments facilitates the interpretation and identification of specific interactions among them. For example, cultivars with a positive IPCA would be particularly adapted to environments with a positive IPCA and poorly adapted to environments with a negative IPCA. The C8, C9 and C10 have the best performer (due to large positive GE interaction) in E5 and E10 (normal irrigation) environments that these environments had the favourable environmental conditions, but these are the worst performer (due to large negative GE interaction) in others environments in the opposite sector of the biplot such as E1 and E6 (rainfed condition).

The six stability statistics derived from AMMI are shown in Table 5. According to the $SIPC_1$ scores, C5 was the most stable cultivar, followed by C3, C6 and C7. According to the $SIPC_V$ stability parameter cultivars C7, C9 and C3 which had lower values of $SIPC_V$ were stable but cultivars C2 and C4 were unstable. In accordance with the EV_1, C5 and C3 with lower value were considered to be stable, but C4, C8 and C10 were unstable cultivars. The lowest EV_V values for cultivars were for C7 and C9, therefore these cultivars were stable.

Table 5. Mean yields and AMMI stability parameter estimates for yields of 10 cultivars ested in 10 environments

Cultivars	Mean	$SIPC_1$	$SIPC_v$	EV_1	EV_v	ASV
C1	2602.5	15.15	21.46	0.128	0.161	23.51
C2	2804.4	15.46	29.76	0.134	0.303	27.19
C3	2759.8	2.99	15.76	0.005	0.140	13.53
C4	2795.0	19.20	25.19	0.206	0.236	29.33
C5	2803.6	1.40	24.96	0.001	0.460	23.66
C6	2821.3	3.50	17.14	0.007	0.160	14.61
C7	2752.9	6.51	7.11	0.024	0.024	9.76
C8	2937.0	18.50	20.47	0.191	0.194	27.73
C9	2959.7	14.33	15.37	0.115	0.116	21.45
C10	2854.3	18.40	22.90	0.189	0.206	27.88

ASV is the distance from zero in a two dimensional scattergram of IPCA1 scores against IPCA2 scores. Since the IPCA1 score contributes more to the GE sum of square, it has to be weighted by the proportional difference between IPCA1 and IPCA2 scores to compensate for the relative contribution of IPCA1 and IPCA2 to the total GE interaction sum of squares. (PURCHASE *et al*., 2000) The distance from zero is then determined using the theorem of Pythagoras. In proportion to better option ASV, the cultivars C7, C3 and C6 with lower value were stable. The AMMI procedure used in this study indicated a more complex interaction which required two PC axes to account for a considerable amount of variation in the G × E interaction. Therefore, it is clear those parameters which use the number of IPC that were retained in the AMMI model via cross-validation ($SIPC_v$, EV_v) are better than those parameters which use the first of IPC. In general, based on these parameters, it can be concluded that genotypes C3, C6, and C7 exhibit the most stability in different irrigation conditions. DEHGHANI *et al.* (2010) reported that these parameters are associated with static (biological) concept of stability and could be used as compromise methods that select genotypes with the moderate yield and high stability (EBADI *et al*., 2008). In other words, this genotype has a relative tolerance to drought stress at all stages of growth, and it is possible to introduce these genotypes for areas where the exact time of drought stress is not known.

Yield stability in cultivars C3, C6 and C7 can be attributed to the growth characteristics of these cultivars, which are among the dryland varieties. The characteristics that researchers in research centers and agricultural institutions consider to select drought tolerant wheat plants are: seed size, coleoptiles elongation, thickness and spread of leaves, rapid growth, high biomass before pollination, good capacity to store remobilization in the stem, high photosynthetic capacity in spike, high relative humidity of leaf water, high stomatal conduction during the formation of grain, osmotic regulation, acidic acid accumulation, leaf anatomy, greenness durability, stem height, number and durability of tillers, which can have an stable yield in drought conditions compared with drought-sensitive cultivars. However, these cultivars have limited of yield potential in full irrigated and non-stress condition (SANJARI *et al*., 2006). Rapid early growth is an important feature of these cultivars. As these cultivars can save more assimilate in their organs before stress conditions. In the case of high remobilization, these cultivars, in the last drought stress conditions, can fill the seeds with more ability and tolerate the drought (HAGHPARAST *et al*., 2008).

AMMI mega-environment analysis

The high yield cultivars under irrigation conditions would not necessarily be high in drought stress and vice versa. It seems that these AMMI parameters did not provide an overall picture of the individual cultivar responses to environments. If researchers' main goal is to identify cultivars tolerant to stress in a particular growth stage, then it is not necessary to introduce a cultivar for all environments. One method of getting over this problem is AMMI mega-environment analysis. Visualization of the “which-won-where” pattern of MET data is important for studying the possible existence of different mega-environments in a region (GAUCH and ZOBEL, 1997). In this study, environments are typically year-irrigation regime combinations, but mega-environment analysis focused on growth stage.

The AMMI2 mega-environment analysis identified three groups (mega-environments) for different growth stages (Table 6). The first group contained E1 and E2, where cultivar C4 was the winner. C4 (Seymareh) with pedigree (Orambi-5), is selected from the materials of the International Maize and Wheat Improvement Centre (CYMMIT). It is suitable for dryland areas of the country and has high yield capacity for tropical rainfed conditions.

The second group contained environments E3 and E4, where cultivar C9 was the winner (Table 6). C9 (Chamran), with the pedigree Attila (YO-M3-YO-MO-YO5-63858MC), has been selected from the genotypes received from the CIMMYT. Studies carried out at Maragheh Agricultural Research Station indicate that varieties that have an acceptable yield potential in dryland conditions, showed a high yield potential in some years and areas with good rainfall. Considering the low potential of these cultivars under full irrigation conditions, especially lodging in these cultivars and drought stress sensitivity in irrigated cultivars, it is possible to select appropriate lines for supplementary irrigation conditions to increase the wheat production efficiency in dryland areas (ROOSTAEI, 2010).

Table 6. AMMI2 mega-environment and their winning genotypes for the 10 bread wheat cultivars grown in 5 irrigation regime

AMMI2 Mega-environment	Winner genotypes	Expected values for Yield (kg ha^{-1})
Mega-environment 1		
E1	C4	1974.75
E2	C4	2148.97
Mega-environment 2		
E3	C9	2535.03
E4	C9	3744.10
Mega-environment 3		
E5	C8	4778.38

Drought stresses (no irrigation) introduced: rainfed (E1), the tillering stage (E2), at booting stage (E3), after anthesis (E4) and control treatment (E5).

The third group contained E5, where cultivar C8 was the winner. A cultivar that shows high yield under dry conditions may not be suitable for optimal irrigate conditions. C8 (Shirodi), with the pedigree Attila (ZPO-YO-M8-YO-MO -Y4-63858MC), has been selected from the genotypes received from the CIMMYT. The average yield of this cultivar of 6.5 t ha-^{1} was reported at research stations.

Despite having a more advanced water management system than most Middle Eastern countries, similar to the other countries in the region, Iran is currently experiencing serious water problems. Frequent droughts coupled with over-abstraction of surface and groundwater through a large network of hydraulic infrastructure and deep wells have escalated the nation's water situation to a critical level. This is evidenced by drying lakes, rivers and wetlands, declining groundwater levels, land subsidence, water quality degradation, soil erosion, desertification and more frequent dust storms. Drought conditions are predominant over the years and wet years are infrequent in most areas of Iran. Rainfall distribution also varies in different regions, and in each region, drought stress may affect distinctive stages of plant growth. Therefore selection should be based on the yield in the target regions and growth stages.

Our observations of irrigated levels have indicated that wheat yield usually declines along with increasing the level of drought. We found that AMMI stability statistics and AMMI mega-environment analysis were practical, informative, and useful. Decisions using AMMI stability statistics should be based knowing that selected genotypes has a relative tolerance to drought stress at all stages of growth, and it is possible to introduce these genotypes for areas where the exact time of drought stress is not known. The performance of the selected cultivars with these statistics may be very low, therefore the performance of the selected cultivars should be considered. In contrast, "AMMI mega-environment analysis" has the ability to select suitable cultivars for any environmental conditions separately. If the time of occurrence of drought stress in a given region is constant, then AMMI mega-environment analysis will be more appropriate and genotypes will be recommend that, in addition to stability, will have a high performance in those areas. Therefore, we recommend that the meteorological information of the area be studied before the selection of suitable tolerant cultivars.

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EVALUACIJA STABILNOSTI PRINOSA ZRNA I SELEKCIJA GENOTIPOVA HLEBNE PŠENICE (*Triticum aestivum* L.) U RAZLIČITIM REŽIMIMA NAVODNJAVANJA

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Izvod

Stres suše jedan je od najvažnijih ograničavajućih faktora za proizvodnju useva u sušnim i polusušnim regionima sveta. Manjak vode tokom različitih razvojnih faza može da promeni vrednosti komponenata prinosa. Stabilnost prinosa sorti pšenice u različitim režimima navodnjavanja jedan je od važnih ciljeva oplemenjivača i agronoma. Da bi se utvrdilo koji kultivar može da se klasifikuje kao prinosan i stabilan pri različitim režimima navodnjavanja, ocenjeno je 10 sorti hleba pšenice (C1-C10) na prinos zrna, u pet režima navodnjavanja u toku dve godine. Značajna interakcija genotipa i životne sredine (GE) za prinos potvrđuje različitu reakciju kultivara na stres suše u različitim fazama razvoja biljke. Analiza aditivnog glavnog efekta i multiplikativne interakcije (AMMI) korišćena je za razumevanje interakcije GE. Na osnovu AMMI parametara, genotipovi C3, C6 i C7 pokazuju najveću stabilnost u različitim uslovima vlage. Sva tri kultivara poboljšana su za sušne uslove. Na osnovu analize većeg broja spoljašnjih sredina AMMI2, režimi navodnjavanja su svrstani u tri grupe. Prva grupa je sadržavala E1 (suvo) i E2 (prekid navodnjavanja u fazi klasanja), druga grupa je sadržavala okruženja E3 (u fazi izduživanja) i E4 (nakon polinacije), a tercijarna grupa je sadržavala E5 (optimalno navodnjavanje). Rezultati su pokazali da bi AMMI analiza stabilnosti bila korisna kada se naglašava statički koncept stabilnosti. Ali ako je vreme pojave stresa suše u datom regionu konstantno, tada će AMMI analiza za mega-spoljašnje sredine biti pogodnija.

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