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STABILITY ANALYSIS AND TOLERANT TO WATER DEFICIT IN BARLEY AND WHEAT GENOTYPES

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Abstract

To evaluation of several wild wheat and barley genotypes in response to water deficit stress, experiments were laid out in randomized complete block design with three replicates in optimal and stress condition environment for three years. Data analysis showed a significant genetic diversity within genotypes in terms of grain yield, and the existence of significant genotype × environment interaction, made it possible to analyze data for genotypes stability to environment in this study. The stability analysis showed that Garni (an emmer variety) was recognized as the most stable genotype to water deficit stress with a high grain yield. The stress tolerance tests also found that the Garni genotype is more tolerant to water deficit stress than other genotypes. Based on the results obtained, Garni genotype was recognized as a stable genotype and the most tolerant genotype to water deficit stress that has a high grain yield, and it can be used as a crossbreeding parent in wheat breeding.

Keywords: tolerant genotypes, stable wheat lines, wild wheat, wild barley, Water deficiency.

Introduction

To meet the growing demand of the population, for the preparation of food and meat, it is necessary to introduce new varieties of plants. Plants in addition to having high yields under normal conditions are also resistant to environmental stresses. Growing plants under changing climatic conditions, and exposed to a variety of water and heat stresses, causes plants to not be able to show their yield potential well. The promotion of yield quantity, and quality improvement in the field crops particularly in the cereal crops, is the main strategic direction of the modern agriculture in the Republic of Armenia. Assessing the adaptability and stability of crop production in various environmental conditions is important in crop breeding programs. By evaluating the adaptability and stability of cultivar yield in various environments, it is possible to identify genotypes that have acceptable yield in every environment [17].

In this regard, the role of plant breeders with the participation of wild parent breeds, which are endowed with high resistance to diseases and pests, as well as resistant to various stressful situations, is especially important. Similar valuable traits are found in the varieties of cereals we have inherited that have inheriting those traits from their wild parent breeds. Crop wild relatives (CWRs) are a reservoir of genetic variation providing an important source of novel alleles for the genetic improvement of cultivated species. The crosses between cultivars and CWRs have been carried out in several crop species to unlock this favorable genetic diversity [10]. It should be noted that the Republic of Armenia is rich in wild species of cereals, in particular, it should be noted that three of the four wild species of wheat as well as eight of the 12 species of wild barley were found in Armenia. They are a valuable selection material, distinguished by such properties as high frost resistance, drought resistance, high protein content in the grain, etc.

Emmer wheat (*Triticum dicoccoides* Korn.) is an allo-polyploid with genome constitution AABB (2n = 4x = 28). It is an annual, self-pollinated grass that is detected in the transition zone between Mediterranean and steppe phytogeographic provinces. Emmer wheat grows from 200 m below to 1500 m above sea level. Also *Hordeum bulbosum* L. (2n = 4x = 28), a wild relative of barley (*Hordeum vulgar* L.), has been considered as a valuable source of genetic diversity for barley improvement [29].

It is worth mentioning that Armenia is rich in the wild cereal crop varieties, which come forth as a valuable selection source material distinguished by such characteristic traits as tolerant to high rate of frost, drought-resistance, high protein content in grain, etc. Two emmer wheat varieties called Garni and Zvartnots as well as a *H. bulbosum* variety called Araratyan were used in this study. Stresses of heat, drought, cold, diseases and pests are major factors limiting crop cultivation and development [19]. Stable genotypes have similar reactions in different environments and their identification using different stability parameters is one of the important breeding goals. Researchers have used various methods to analyze the stability of crops, such as the environmental coefficient of variation (C.V.) of Francis and Kannenberg (1978), the *Shukla's stability variance parameter* (1972), the *Wricke's equivalence* (1962), of Roemer's environmental variance (1917), the *deviation mean square* from regression line by Eberhart and Russell (1966), coefficient of determination by Becker and Leon (1988), regression coefficient by Finaly and Wilkinson (1963) and the simultaneous selection for *Stability* of Kang (1993). Most stability parameters are correlated with each other. The results of Pinthus (1974) research showed a significant correlation between environmental variance and regression coefficient. In addition, Wricke's equivalence and coefficient of determination showed a high correlation with the mean squares of deviations from the regression line. In view of the above, sustainability is considered as an important aspect of performance comparison tests, because the genotype × environment interaction can reduce the progress of selection in plant breeding program. For this reason, researchers often use one of the methods or a combination of them to find high-yielding and stable genotypes.

The aim of this study was the evaluation of some Armenian wild genotypes of barley and wheat with high yielding in terms of stability and tolerance to water deficit stress for recommending use in plant breeding programs.

Materials and methods

Scientific investigations have been conducted on the mentioned genotypes to disclose whether those valuable properties are fixed and sustainable in the plants' genotypes. The mentioned investigations were aimed at the disclosure of the resistance rate of those genotypes samples to the water deficit stress. The experiments were performed as a randomized complete block design with three replications and three types of genotypes, in two zones, in the normal condition of the Ejmiatsin province at the Armavir region and in the pre-mountainous under water deficit condition (dry lands) of the Abovyan province at the Kotayk region of Armenia, for three cropping years (2017 - 2020). Because of in rainfed cultivation, the distribution of rainfall time and amount of rainfall was unpredictable, so the three-year experiment was repeated.

The land was plowed in the fall of last year and sowing of the barley variety "Araratyan" and emmer varieties Garni and Zvartnots were sown in the third and first ten days of March respectively. Sowing with 500 seeds per square meter was considered for both experiments. Before sowing the amount of 25 $t.ha^{-1}$ manure and phosphoric-potash fertilizers per $P_{90}K_{60}$ active agent were used under the deep plowing as the main fertilizers. The plants were provided with N70 nitrogen during plant growing period in spring. Planting was implemented with the 500 seed in m^2 for every genotype. The planting dose has been chosen with relatively lower indices, so as the plants could have the best conditions for air and soil nutrition, which would promote the increase of potential yield capacity. Similar conditions for all genotypes have been created and the treatment activities have been implemented at the same time upon the same principle.

Table 1

Geographical characteristic and rainfall of experiment sites

Location	Elevation ASL (m)	Latitude	Longitude	Average annual rainfall (mm)
Armavir (Optimal condition)	850	40° 16' N	44° 29' E	750
Kotayk (water deficit stress)	1450	40° 27' N	44° 63' E	350

At the time of physiological ripening, the crop of each variety was harvested in four middle rows by removing half a meter from the beginning and end of each planting line. The geographical characteristics and rainfall of the experimental location and the names of the genotypes are presented in table 1 and table 2, respectively.

Table 2

Description of genotyped used in experiment

Genotypes	Type	Origin
Garni (Triticum dicoccum Schuebl)	Emmer	Armenia
Zvartnots (Triticum dicoccum Schuebl)	Emmer	Armenia
Araratyan (*Hordeum vulgar* × Hordeum bulbosum)	Barley	Armenia

After analyzing the variance of the data obtained from every experiment, the combined analysis has been performed based on Steel et al. (1997) method after the homogeneity of error variances test [27]. In these experiment, the combination of year and zone (Location) (Y, L) were considered as the main factor and genotype (G) as a secondary factor, so that the year factor was considered as random, also zone as well as genotype were considered fix [31]. The means of treatments were compared by using Least Significant Difference test in a probability level of five and one percent [28]. The data were subjected to analysis of variance (ANOVA) using statically analysis system [24] version 8.

Results

The genotypes data analysis of variance for grain yield (one year) under optimal and water deficit stress conditions showed that the genotype effect for grain yield was significant for both optimal and stress conditions as well as years (table 3). In the other hand the combined analysis of variance results in year showed the environment effects and genotypes effects were significant in both conditions and genotype × year interaction effect was significant in optimal condition at the level of one percent probability (table 4). It means the genotypes show similar effects for reduction of grain yield in water deficit condition.

Table 3

Analysis of variance (one year) for grain yield genotypes under optimal and water deficit stress conditions

Source of variation	Degrees of freedom	Mean Square					
		Optimal			Stress		
		2017-18	2018-19	2019-20	2017-18	2018-19	2019-20
Replication	2	2033.33ns	544.44ns	477.78ns	4433.33ns	7144.44ns	3144.44ns
Genotype	2	974033.3**	958544.4**	1271244**	1073633**	958744.4**	929911.1**
Error	4	2716.67	2227.78	2744.44	3216.67	4394.44	627.78
C.V %		2.1	1.86	2.08	2.78	3.17	1.23

ns and **: Non significant and significant at 1% probability level, respectively

Table 4

Combined analysis of variance for grain yield genotypes under optimal and water deficit stress conditions

Source of variation	Degrees of freedom	Mean Square	
		Optimal condition	Stress condition
Year	2	8477.78ns	9448.148ns
Rep. / Exp. ($Error_a$)	6	1018.52ns	4907.407ns
Genotype	2	3181633.3**	2948903.70**
Year × Genotype	4	11094.44*	6692.59ns
Error	12	2567.96	2746.29
C.V %		2.015	2.55

ns and **: Non significant and significant at 1% probability level, respectively

Table 5

Mathematical expectations of mean squares for combined analysis based on randomized complete block design in several locations,where the treatment factor and the location factor are considered as fixed and the year factor as random model (Yazdi samadi et al., 2010)

Sours of variation	Degrees of freedom	Mean square
Year (Y)	2	16168.52**
Locations/Environment (L)	1	2824490.74**
Genotypes (G)	2	6120146.30**
Genotype × Environment (G × L)	2	10390.74*
Genotype × Year (G × Y)	4	9087.96*
Genotype × Year × Environment (G × Y × L)	4	8699.07*
C.V % = 2.29		

ns: Non-significant, *: Significant in 5 %, **: Significant in 1 %

Also the complete combined analysis showed significant effect for genotypes, environment, Genotype × Environment interaction, Genotype × Year interaction and Genotype × Year × Environment interaction (table 5). The results showed that the environment (region) and genotype × environment interaction were effective in demonstrating the performance of genotypes (table 5). Similar results have been reported by other researchers for grain yield [17]. The three-way interaction in combined analysis is showed the need for stability analysis to identify the desired genotypes. Similar results have been reported by other researchers for grain yield [13, 14]. Average grain yield comparable results within three years of study are shown in table 6 and table 7. As can be seen, the Garni genotype had the highest grain yield. Eberhart and Russell (1966) regression method was used in order to determine the stability of genotypes. Accordingly, a genotype will have relative stability that while having a higher average yield than other genotypes, also has a regression coefficient equal to one (or non-significant with one) and deviations from regression are insignificant and minimal.

Table 6

Mean comparison of grain yield (kg ha^{-1})
of genotypes in "Armavir" with optimal condition and "Kotayk" with water deficit condition (2017 - 2019)

Genotype	2017-18		2018-19		2019-20	
	Optimal condition	Stress condition	Optimal condition	Stress condition	Optimal condition	Stress condition
Garni	3131.0[a]	2703.3[a]	3193.3[a]	2736.7[a]	3260.0[a]	2673.3[a]
Zvartnots	2243.0[b]	1860.0[b]	2236.7[b]	1860.0[b]	2233.3[b]	1786.7[b]
Araratyan	2066.0[c]	1546.7[c]	2193.3[b]	1680.0[c]	2053.3[c]	1946.7[c]

Table 7

Mean comparison of grain yield (kg ha^{-1}) of genotypes in two conditions (2017 - 2019)

Genotypes	Optimal condition	Water deficit condition	Total mean
Garni	3194a	2704a	2949a
Zvartnots	2238b	1836b	2037b
Araratyan	2104c	1624c	1864c
SE= 1.8			SE= 1.2

Means with a common letter are not significantly different (p > 0.5)

Deviations from regression are equivalent to the maximum coefficient of explanation [15]. Therefore, first, the significance of the Genotype × Environment interaction was investigated; then, to determine the significance of the difference between each of the regression coefficients of one value, the t-student test was used separately. Also, to investigate the existence of nonlinear Genotype × Environment interaction, this component was studied through regression analysis. The stability analysis for grain yield of genotypes in different environments is shown in table 8.

Table 8

Stability analysis for grain yield of genotypes in different environments

S.O.V.	D.F.	Sum of Square	Mean Square
Total	17	510.185	---
Genotype (Gen.)	2	360.981	180.490**
Env. + (Gen. × Env.)	15	149.203	9.94
Env. (Linear)	1	135.922	135.92**
Gen. × Env. (Linear)	2	2.515	1.257*
Pooled deviation	12	9.765	0.813ns
Garni	4	2.526	0.631ns
Zvartnots	4	1.668	0.417ns
Araratyan	4	5.570	1.392*

M.S. pooled= 0.41

*, **and ns: Significant at 5% and 1% probability levels, and non-significant respectively

In general, it can be stated that the results of this type of stability statistics are based on biological stability and the genotypes selected in this method can be recommended for adverse environments.

The results of stability analysis of variance by Eberhart and Russell (1966) method showed (table 8) that there was a significant difference between genotypes in terms of productivity. The significance of (linear) variance related to the environment indicates that there is linear relationship with the environmental index between the performances of genotypes in each environment. That increase of environmental index (improvement of cultivation conditions) will necessarily lead to an increase in the yield of genotypes. The significance of the mean squares of the genotype × environment interaction showed that there was a significant difference between the genotypes in terms of compatibility and yield stability.

The non-significance of the mean squares of deviations from the regression line (pooled deviation) indicates that the points related to the performance of the genotypes are completely around the regression line and the response of a genotype is not wide during linear variation. Such results have also been reported in many crops [1, 11, 12].

Based on the coefficient of stability presented by Eberhart and Russell (1966), Zvartnots genotype showed the lowest value of this coefficient (S^2_{di} = 0.002) and was more stable than other genotypes. Based on the coefficient of explanation (R^2) presented by Becker and Leon (1988) to determine the stable genotypet, the genotypes with the highest coefficient of determination are known as stable genotypes. The Garni and Zvartnots genotypes are more stable than the Araratyan genotype because their coefficient of explanation (R^2) is high and close to one ($R^2 = 0.96$).

Also, according to Wrick (1962) stability coefficient, the lowest value of this index was related to Zvartnots genotype with a value of $W^2_i = 1.66$, which shows the stability of this genotype compared to two other genotypes (Table 5). Based on *Shukla's stability variance parameter (1972*), the lowest value of this index was related to Zvartnots genotype with a value of $\sigma^2_i = 0.32$, which indicates the stability of this genotype compared to the other two genotypes (Table 9).

Table 9

Stability parameters for grain yield of genotypes in two regions (2017 to 2020)

Genotypes	Grain yield	C.V.	Environmental index	Interception for each genotype	S^2_{di}	W_i^2	σ^2_i	b_i	R^2_i
Garni	2949	4.68	1.39(-2.60)	-8.32	0.21	4.32	1.26	1.19	0.96
Zvartnots	2037	4.49	2.92(-1.67)	-4.21	0.00	1.67	0.32	0.99	0.96
Araratyan	1864	3.73	3.52(-3.57)	12.54	0.97	7.29	3.04	0.80	0.84

Table 10

Tolerance indices used for evaluation of the reaction of genotypes to water deficit conditions

Dry tolerance indices	Equation[1]	Reference
Stress susceptibility index	$SSI = [1 - (Y_{si} / Y_{pi})] / [1 - (Y_s / Y_p)]$	Fischer and Maurer (1978)
Mean productivity	$MP = (Y_p + Y_s) / 2$	Rosielle and Hambling (1981)
Tolerance index	$TOL = Y_{pi} – Y_{si}$	Rosielle and Hambling (1981)
Yield stability index	$YSI = Y_{si} / Y_{pi}$	Bouslama and Schapaugh(1984)
Geometric mean productivity	$GMP = \sqrt{(Y_{pi} \times Y_{si})}$	Fernandez (1992)
Stress tolerance index	$STI = (Y_{si} \times Y_{pi}) / Y^2_p$	Fernandez (1992)

[1] Y_{si} , Y_{pi} , Y_s and Y_p were grains yield of each genotype under stress conditions, grain yield of each cultivar under optimal condition, mean of grain yield in all genotypes in stress and average of grain yield for all genotypes under optimal condition.

n and X_{ij}, respectively, show the number of environment and measure of the desired trait in the i^{th} genotype in the j^{th} environment, and M_j is the maximum desired trait in the j^{th} environment.

The indices were obtained based on grain yield of different genotypes under optimal condition and stress condition and have shown in table 11. Fernandez (1992) believes that the best index for screening water deficit tolerant genotypes is an index has a relatively high correlation with the grain yield in both optimal and stress conditions. Stress susceptibility index (SSI) is a proportion of genotypic performance under optimal and stress conditions, which is adjusted for the severity of each test [7]. It is known that this index is correlated with grain yield of wheat [21]. Khanna-Chopra and Viswanathan (1999) proposed using this index to be classifying three groups of genotypes tolerant ($SSI \leq 0.5$), moderately tolerant ($0.5 < SSI \leq 1$) and sensitive ($SSI > 1$).

Table 11

Grain yield in optimal condition (Y_p) and stress condition (Y_s), and stress tolerance indices estimated for genotypes over three years (2017 to 2019)

Genotype	Mean grain yield (kg ha^{-1})		Stress indices					
	Y_p	Y_s	TOL	MP	GMP	SSI	STI	YSI
Garni	3194.4	2704.4	490.0	2949.4	2939.2	0.84	1.37	0.85
Zvartnots	2237.7	1835.5	402.2	2036.6	2026.7	0.99	0.65	0.82
Araratyan	2104.4	1624.4	480.0	1864.4	1848.9	1.25	0.54	0.77

In study on durum wheat reported [19], that to identify genotypes tolerant, indices STI and GMP have more diagnostic power in compared with TOL, SSI and MP. Results of this study indicated that, the highest STI (1.37) and GMP (2939.2) belonged to Garni genotype with most tolerance to water deficit stress compared to other genotypes.

The SSI index for Garni genotype (SSI = 0.84) and after that for Zvartnots (SSI = 0.99) are moderating, as well as Araratyan genotype is sensitive. The MP, TOL and some other indices are using to tolerant distinct genotypes based on the performance in both the optimal and stress conditions [9]. The highest TOL value for a genotype shows maximum reduction in yield under stress condition, and its greatest sensitivity to stress [26]. By this reason the Zvartnots genotype because of high TOL is not consider as a tolerant genotype against the Garni genotype. So the Garni genotype is most tolerant to water deficit with high grain yield.

Conclusions

Due to the significant effect of genotype, there was significant genetic diversity between genotypes in terms of grain yield, and the existence of significant genotype × environment interaction, made it possible to analyze the stability of this study. Based on the results of this study, Garni genotype was recognized as a stable genotype with a high grain yield and it can be used as a crossbreeding parent in crop breeding.

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