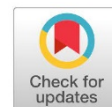


Research Article

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Genotype-Environment Interaction and Phenotypic Stability Analysis for Grain Yield of Durum Wheat in the Misurata Region

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Abstract: The objectives of this study were to assess genotype-environment (GE) interaction and determine stable durum wheat (*Triticum turgidum* var. durum Desf.) genotypes for grain yield in Misurata in the central Libyan region. Fifteen durum wheat genotypes were evaluated under supplementary irrigation using a randomized complete block design with 3 replications. The study was repeated for 5 years. GE interaction was analyzed using linear regression techniques. There was considerable variation in grain yield among the different genotypes. Stability was estimated using the Eberhart and Russell method. According to the stability analysis, genotype G9 was the most stable for grain yield. The regression coefficient (b_i) for genotype G9 was almost one and had the lowest deviations from regressions (S^2_{di}). In contrast, genotypes G10 and G3 showed regression coefficients greater than 1.0, indicating sensitivity to environmental changes for grain yield. Among the genotypes, the highest average grain yield was obtained from genotypes G9 and G10 (3.19 and 3.65-ton ha⁻¹, respectively) across environments. Genotype G10 had the highest grain yield as well as a regression coefficient greater than one, suggesting that G10 was sensitive to changing environments and could be recommended for more favorable environments.

Keywords: Durum wheat; Grain yield; Stability; Libya.

التفاعل بين التراكيب الوراثية والبيئة وتحليل الثبات الوراثي لمحصول القمح الصلب في منطقة مصراتة

المستخلص: تهدف هذه الدراسة إلى تقييم التداخل بين التركيب الوراثي (GE)، والبيئة، وتحديد سلالات القمح الصلب (*Triticum turgidum* var. durum) المناسبة لإنتاج الحبوب في منطقة مصراتة - ليبيا. تم تقييم خمس عشرة سلالة، وصنف من القمح الصلب تحت الري التكميلي باستخدام تصميم القطاعات الكاملة العشوائية بثلاث مكررات. نفذت الدراسة لمدة 5 سنوات. وتم تحليل التداخل GE باستخدام تقنيات الانحدار الخطي. أوضحت النتائج وجود فروق معنوية عالية في صفة إنتاج الحبوب بين التراكيب الوراثية. أجري تقدير الثباتية وفقاً لتحليل الثبات باستخدام طريقة Eberhart، و Russell، كان التركيب الوراثي G9 هو الأكثر استقراراً في صفة إنتاج محصول الحبوب. معامل الانحدار للسلالة G9 كان وحدة تقريباً ($b_i = 1$) وسجل أدنى انحراف عن معامل الانحدار (S^2_{di}). في المقابل، أظهرت السلالات G10، و G3 معامل انحدار أكبر من 1.0، مما يشير إلى تأثيرهما الكبير بالتغيرات البيئية لصفة محصول الحبوب. سجل أعلى محصول للسلالات G9، و G10، و G3.65، و 3.19 طن/هكتار على التوالي متوسطاً لكل البيئات. أظهرت السلالة G10 أعلى محصول للحبوب، ومعامل انحدار أكبر من الواحد، مما يشير إلى أنها حساسة للتغير البيئي، ويمكن التوصية بها تحت ظروف الزراعة المروية.

الكلمات المفتاحية: القمح الصلب؛ محصول الحبوب؛ الثبات؛ ليبيا.



INTRODUCTION

Wheat, after barley, is the second most important cereal crop in Libya. Libya's production of wheat for the year 2018 was 138,770 tons, and the quantity imported for the same year was 1,461,816 tons, meaning that the contribution of the local production of wheat was 8.7% (FAO. 2020). During the periods from 1961-2013, wheat production in the Central and West Asia and North Africa (CWANA) region has increased from 22 to 126 million tons, mainly due to the adoption of modern wheat varieties of CIMMYT/ICARDA origin (Tadesse et al. 2019). Wheat is grown on a fairly wide range of soil conditions. Climate changes from year to year, such as rain amount and distribution, cause inconsistent yield production (Ceccarelli et al. 2010).

Information about phenotypic stability is useful for the selection of crop varieties as well as for breeding programs. Agricultural outputs, just as the livelihoods of people who rely upon them, are threatened by climate change, resulting in additional food insecurities (ORKING et al. 2008). It is important that we evaluate adaptation mechanisms to decrease these vulnerabilities (Kurukulasuriya et al. 2013). The yield production of a genotype is not necessarily the same under diverse agro-ecological conditions (Ali, Javidfar et al. 2003). Some genotypes may perform well in certain years but fail in several others. Genotype environment interactions (GE) are very important in the evaluation and selection of varieties because they reduce genotypic stability values under varied environments (Casadebaig et al. 2016; Hébert et al. 1995). The concept of stability has been defined in several ways. The Lin and Binns procedure showed the greatest deviation from the other procedures. The procedure defines stability as the deviation of a specific genotype's performance from the performance of the best-performing cultivar in an experiment. This implies that a stable cultivar is one that performs in tandem with the environment. Therefore, in most cases, a close correlation will be found between such a genotype and the environment. In other words, a genotype with an inherently high yield would be classified as stable as its yields over environments will always be close to that of the top performer over the respective environments (Purchase et al. & van Deventer, 2013). The most widely used procedure is the regression method, based on regressing the mean value of each genotype on the environmental index or marginal means of environments (Romagosa et al. 1993; Tesemma et al. 1998). A good method to measure stability has been previously proposed (Eberhart et al. 1966). The stability of varieties was defined by high mean yield and regression coefficient ($b_i = 1.0$) and deviations from regression as small as possible ($S^2_{di} = 0$). However, no stability study has been performed for durum wheat in Libya. The objectives of this study were to evaluate the grain yield of promising durum wheat genotypes in different environments and to determine their stabilities using stability parameters.

MATERIALS AND METHODS

Plant material and field condition: Fifteen durum wheat genotypes (1 cultivar (Karim) and 14 advanced lines) were introduced from the 39th International Durum Observation Nursery (ICARDA). The nursery includes genotypes that responded well when exposed to terminal drought, cold, heat, rusts, *Septoria tritici*, dryland root rots, tan spot, wheat stem sawfly, and Hessian fly (Bassi & Natchit, 2019). The experiments were designed as a randomized complete block design with 3 replications. The pedigrees and other information related to the durum wheat genotypes are given in Table 2. The experiment was performed under supplementary irrigation conditions in the five years starting in the 2015-2016 growing seasons at Misurata Agriculture Research Station – Libya Table 2. The seeds were sown using an experimental planter in 1.8 x 4 m plots consisting of 6 rows with a 25 cm row space. The seeding rates were about 200 seeds/m². The plots were fertilized with 200 kg N ha⁻¹ and 150 kg P₂O₅ ha⁻¹. Plots 2 m² in size were harvested by a combined harvester. The

yield was determined and expressed in tons per hectare. Climatic elements data at Misurata Agricultural Research Station are summarized in Table 1. All statistical analyses were performed using IWIN-DAP: An Excel Add-In offered by CIMMYT (Kehel & Thomas, 2016). Broad sense heritability (H^2) and variance components for grain yield were computed as proposed by (Akinwale et al. 2011; Arslan, 2007) using the following formula: $H^2 = \frac{Q2g}{Q2g + Q2ph + Q2gy + Q2e}$, where $Q2g$ is the genotypic variance; $Q2ph$ is the phenotypic variance; $Q2gy$ is the variance for genotypes with years; and $Q2e$ is the variance for error.

The IWIN-DAP: An Excel Add-In was used to describe genotypic stability. The stability test runs the Eberhart and Russel 1966 stability indices (regression coefficient, B , and deviation mean squares, SD^2) and draws a scatter plot of average trait versus SD^2 . The trait values of a genotype in each year are regressed on the mean of the year. The deviation means squares measure describes the contribution of a genotype to the genotype by environment interaction (G.E). (SD^2_{di}) is considered a stability parameter, as it is highly related to the remaining unpredictable part of the variability of a genotype across years. A genotype is stable when its deviation from regression on the environmental index is small. Differences in the genotype and year means were tested using Duncan's Multiple Range Test at a 0.05 level of probability.

Table:(1). Climatic data at Misurata Agricultural Research Station

YEAR	Mean C°	Mini C°	Max C°	Rain mm	Rainy day
2016	17.12	6.48	39.81	203.00	36.00
2017	17.06	4.73	43.50	215.00	35.00
2018	17.77	6.80	36.50	212.00	39.00
2019	16.05	6.33	38.79	233.00	57.00
2020	18.06	7.80	45.10	226.00	40.00
Average	17.21	4.73	45.10	217.80	41.40

Table:(2). Pedigrees and other information related to genotypes used in 6 environments.

Code	Pedigree	Sel. history
G1	Mrf1/Stj2//Gdr2/Mgn1/3/Bcrch1	ICD07-326-BLMSD-0AP-0T-2AP-0T-3AP-0APT-2AP-0AP-0AN-0MCH[TIMSJGAA]-0AUB[MTrJT]
G2	Ter1//Mrf1/Stj2/3/Icasyr1	ICD07-349-BLMSD-0AP-0T-4AP-0T-3AP-0APT-2AP-0AP-0AN-0MCH[TIMSJGAA]-0AUB[MTrJT]
G3	Ter1//Mrf1/Stj2/3/Icasyr1	ICD07-349-BLMSD-0AP-0T-6AP-0T-8AP-0APT-1AP-0AP-0AN-0MCH[TIMSJGAA]-0AUB[MTrJT]
G4	Mrb3/Tdicoccoides601116//IcamorTA0463/Zna4/4/Stj3//Bcr/Lks4/3/Ter3/6/Ossl1/5/tj5/5/Bicredera1/4/BezaizSHF//SD19539/Waha/3/Stj/Mrb3	ICD07-822-BLMSD-0AP-0T-5AP-0T-5AP-0APT-2AP-0AP-0AN-0MCH[TIMSJGAA]-0AUB[MTrJT]
G5	Geromtel1/IRANYT053//Mgn1/3/Ainzen1	ICD06-0048-BLMSD-0AP-6AP-0T-6AP-0T-2AP-0APT-2BR-0AP-0AN-0MCH[TIMSJGAA]-0AUB[MTrJT]
G6	Icamor-TA0471//IcamorTA0459/Arislahn10/3/Mgn1/3/Ainzen1	ICD06-0176-BLMSD-0AP-8AP-0T-3AP-0T-6AP-0APT-1BR-0AP-0AN-0MCH[TIMSJGAA]-0AUB[MTrJT]
G7	Quabrach1/4/IcamorTA0462/3/Maamouri3//Vitron/Bidra1/5/Murlagost2	ICD06-0303-BLMSD-0AP-1AP-0T-3AP-0T-4AP-0APT-1AP-0AP-0AN-0MCH[TIMSJGAA]-0AUB[MTrJT]
G8	Aghrass1/3/HFN94N8/Mrb5//Zna1/4/IcamorTA0458	ICD04-0178-BLMSD-0AP-8AP-0T-4AP-0T-1AP-0T-3AP-0T-3AP-0APT-1AP-0AP-0AN-0MCH[TIMSJGAA]-0AUB[MTrJT]
G9	Korifla/AegSpeltoidesSyr//Mrb5	ICDJMC04-032-BThL(Bulksel)-0sTh-0wTh-0sTh-1wTh-0sTh-0MCH-0MCH[MtAJDSZ]-0AUB[MMkJT]
G10	Korifla/AegSpeltoidesSyr//Lahn	ICDJMC04-031-BThL(Bulksel)-0sTh-0wTh-0sTh-10wTh-0sTh-0MCH-0MCH[MtAJDSZ]-0AUB[MMkJT]
G11	Saadi/Adnan2	ICD10-003-BLMSD-0AP-4AP-0TR-8STR-0TR-0AUB
G12	CandocrossH25/Ouasbar2//Berghouata1	ICD10-142-BLMSD-0AP-2AP-0TR-3STR-0TR-0AUB
G13	Quamal/Gbch2/3/Mrf2/NormalHamari//Bcr/Lks4/4/IcaKader2	ICD10-305-BLMSD-0AP-2AP-0TR-5STR-0TR-0AUB
G14	Maamouri3/Sebatel2	ICD09-1314-BLMSD-0AP-4AP-0AP-2AP-0TR-10STR-0TR-0AUB
G15	KARIM	Local verity

RESULTS AND DISCUSSION

Mean grain yield varied among years and ranged from 0.9-ton ha⁻¹ for 2016 to 3.9-ton ha⁻¹ for 2019 (Table 3). Estimates for pertinent variance components are given in Table 4. The Genotype Year and Rep variance were significant ($P < 0.05$). The remaining parameters were not significant for grain yield. The small 'genotype x year interaction' indicates a small effect of the years on relative productivity (Table 4).

Table:(3). The range of grain yield (ton ha⁻¹) in environments.

Code	Growing seasons	Mean	Maxi	Min	Range
Y1	2015-2016	2.95	5.07	0.97	4.10
Y2	2016-2017	2.63	3.71	1.86	1.85
Y3	2017-2018	0.93	1.24	0.48	0.76
Y4	2018-2019	3.92	4.61	3.31	1.30
Y5	2019-2020	2.87	4.34	2.22	2.12

Table:(4). Analysis of variance and variance components for grain yield among 15 durum wheat genotypes (Var).

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Var	14	20.84	1.49	3.13	0.0010
REP	2	3.22	1.61	3.39	0.0401
YAER	4	86.89	21.72	45.63	<.0001
YAER*Var	56	33.15	0.59	1.24	0.2000
REP*Var	28	12.84	0.46	0.96	0.5295
REP*YAER	5	9.83	1.97	4.13	0.0026
Error	63	29.99	0.48		
Total	172	196.77			

The broad sense heritability (H %) was 74% for grain yield, indicating that grain yield has a complex character and yet not affected by a range of years (Table 5).

$$H = 0.08592 / (0.08592 + (-0.03294/5) + (0.55368/15)) * 100 = 74\%$$

Table:(5). Expected mean square of variance components.

MIVQUE (0) Estimates	
Variance Component	GW
Var (Var)	0.08592
Var (REP)	-0.0031769
Var (YAER)	0.75753
Var (YAER*Var)	-0.03294
Var (REP*Var)	-0.0035265
Var (REP*YAER)	-0.04976
Var (Error)	0.55368

The results of the combined analysis of stability are given in (Table 6). An analysis of variance for stability revealed significant differences in grain yield among genotypes and environments. This reveals not only the amount of variability that existed among environments but also the presence of genetic variability among the genotypes. The mean square for GE interaction was not significant for grain yield ($P > 0.05$), indicating that the 15 durum wheat genotypes interact semi-nary at 5 environments (Table 5 & Table 8). The mean grain yield of the 15 genotypes ranged from 2.14 t ha⁻¹ to 3.65-ton ha⁻¹, and the highest grain yield was obtained from genotypes G10 and G9 2.14, 3.65-ton ha⁻¹ respectively, and local variety Karim (G15) yield 2.14-ton ha⁻¹ (Table 6 & Table 7). It was emphasized that both linear (bi) and non-linear (S^2_{di}) components of GE in-

teractions are necessary for evaluating the stability of a genotype (Eberhart et al. 1966; Hébert et al. 1995). A regression coefficient (b_i) approximating 1.0 coupled with an $(S^2di) = 0$ indicates average stability. Regression values above 1.0 describe genotypes with higher sensitivity to environmental change and greater specificity of adaptability to high-yielding environments. A regression coefficient below 1.0 is indicative of more adaptability to environmental changes, and thus increases the specificity of adaptability to low-input environments (Carneiro et al. 2019; Eberhart et al. 1966; Hébert et al. 1995; Purchase et al. 2013).

Table:(6). Estimates of stability and adaptability parameters of grain yield (ton ha^{-1}) for 15 durum wheat genotypes at 5 environments.

code	Grain yield	(b_i)	(S^2di)	T test	P value
G1	2.42	0.92	5.26	1.491	0.157
G2	2.62	1.05	8.93	1.843	0.085
G3	2.74	1.19	14.63	2.216	0.043
G4	2.58	1.07	9.71	1.903	0.076
G5	2.18	0.89	4.60	1.408	0.180
G6	2.75	0.98	6.73	1.649	0.120
G7	2.42	0.98	6.87	1.662	0.117
G8	2.65	1.01	7.49	1.721	0.106
G9	3.19	0.99	7.01	1.676	0.115
G10	3.65	1.34	23.56	2.623	0.019
G11	2.62	0.98	6.78	1.654	0.119
G12	2.66	1.06	9.15	1.861	0.083
G13	2.76	0.92	5.31	1.497	0.155
G14	2.50	0.79	2.89	1.145	0.270
G15	2.14	0.82	3.38	1.230	0.238
Average	2.66	1.00		1.491	0.157
SD	0.37	0.14		1.843	0.085

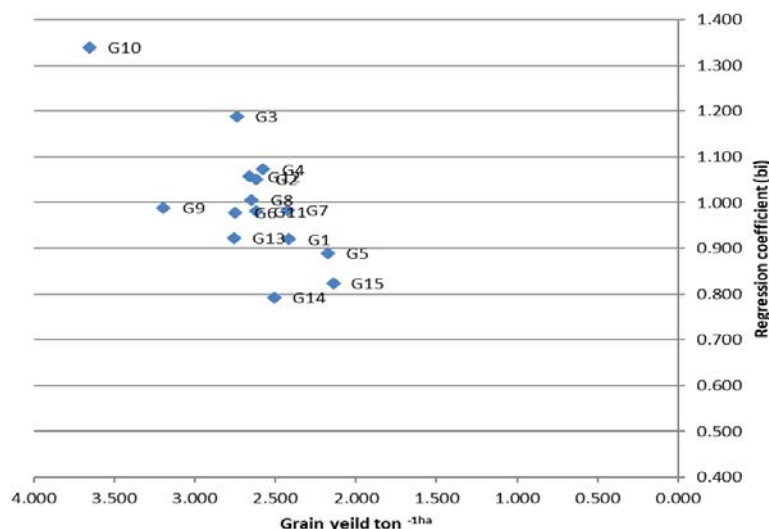


Figure:(1). The relationship between the regression coefficients and mean grain yield (ton ha^{-1}) for 15 durum wheat genotypes.

Linear regression for the average grain yield of a single genotype on the average yield of all genotypes in each environment resulted in regression coefficient values (b_i) ranging from 0.79 to 1.34 for grain yield. The great variation in regression coefficients indicates different responses of

genotypes to different years (Table 6, Figure 1). The regression coefficients of most genotypes were non-significant compared with $b_i = 1.0$ and had a small deviation from regression (S^2_{di}) and thus possessed high stability. However, genotypes G10 and G3 were significant for regression coefficient value and had a large deviation from regression (S^2_{di}), and thus possessed fair stability and sensitivity to environmental changes. Accordingly, genotype G9 (Korifla/ AegSpel-toidesSyr//Mrb5) was the most stable for grain yield because its regression coefficient was almost equal to unity, and it had lower deviations from regression. Genotype G9 had a mean yield as high as 197% compared to the local variety G15 (Karim). In contrast, genotype G10 had the highest grain yield and regression coefficients greater than one, and so was regarded as sensitive to environmental changes and can be recommended for cultivation under favorable conditions. Genotypes G1, G2, G4, G5, G6, G7, G8, G9, G11, G12, G13, G14, and G15 had insignificant regression coefficients. These genotypes could be considered widely adapted. Among these lines, genotype G9 could be considered the most stable genotype.

Table:(7). Means and Duncan's multiple range tests for grain yield (ton ha⁻¹) over 15 genotypes.

Genotype (Duncan ^{a,b,c})	N	Subset	
		1	2
G15	12	2.14 ^a	
G5	11	2.18 ^a	
G1	12	2.42 ^a	
G7	12	2.42 ^a	
G14	11	2.50 ^a	
G4	12	2.58 ^a	
G11	12	2.62 ^a	
G2	11	2.62 ^a	
G8	12	2.65 ^a	
G12	11	2.66 ^a	
G3	11	2.74 ^a	
G6	12	2.75 ^a	
G13	11	2.76 ^a	
G9	12	3.19 ^a	
G10	11		3.65 ^b
Sig.		0.050	1.000

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square (Error) = .412.

a. Uses Harmonic Mean Sample Size = 11.512.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

c. Alpha = 0.05.

Table:(7). Means and Duncan's multiple range tests for grain yield (ton ha⁻¹) over five years in Misurata.

Growing seasons (Duncan ^{a,b,c})	N	Subset		
		1	2	3
2017-2018	39	0.93 ^a		
2016-2017	30		2.63 ^b	
2019-2020	45		2.87 ^b	
2015-2016	15		2.95 ^b	
2018-2019	44			3.92 ^c
Sig.		1.00	0.07	1.00

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square (Error) = .412.

a. Uses Harmonic Mean Sample Size = 29.310.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

c. Alpha = 0.05.

CONCLUSION

Genotype G9 showed higher grain yields than the mean of the local variety (Karim), and its regression coefficient was close to unity ($b_i = 1.0$). This genotype was considered the best in terms of adaptation to all environments. Genotype G10 was suitable for favorable environments due to its regression coefficients being greater than unity ($b_i = 1.0$), as well as having the highest mean grain yield and low deviations from regression values ($S^2 d_i$). Most genotypes were semi-adapted because they had gone over 5 years of yield experiments. We recommend testing those genotypes in a different location and different Libyan regions.

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