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Genotype, Environment Interaction and Yield Stability Estimates of Some Sorghum (*Sorghum bicolor L. Moench*) Traits in Sudan

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Abstract

This research work was carried out during two seasons of 2016 and 2017 at four locations. Two of them are under irrigation and two under rain-fed conditions. The irrigated sites were Wad Medani and Suki, while the rain-fed sites were Gedarf and Damazin. The experiments at the four locations were testing7 sorghum genotypes against three checks (Tabat, Wad-Ahmed and HD-2) for their grain yield, yield stability and some important agronomic characters. The design at each site and season was a randomized complete block design (RCBD) with four replicates. Sowing was in the first week of July under irrigation and in the first to the third week of July under rainfed conditions depending on the rainfall. All other recommended cultural practices suitable to irrigation and rain fed conditions were adopted as recommended. Combined analysis showed that there were significant differences among tested genotypes. The results of AMMI analysis of variance showed that, the mean squares of genotypes, environments and genotypes environments interaction were highly significant (p<0.01) for grain yield. Genotype W638 recorded the highest grain yield (3.6 t/ha) followed by genotype Mena (3.2 t/ha) while the three checks HD-2, Tabat and W.Ahmed showed a mean grain yield of 2.9, 2.8, and 3.1 t/ha respectively. From these results, it was found that, the genotypes W638 and Mena out yielded all the checks and had a mean grain yield greater than the general mean of the irrigated environments (2.9 t/ha),while Maroa scored a grain yield comparable to Wad Ahmed (2.0 t/ha), but greater than Tabat (1.7 t/ha) and HD-2 (1.3 t/ha) and above the general mean of the rain fed environments (1.7 t/ha) .These results indicated that, genotypes W638 and Mena were stable and adaptable under irrigated conditions, while genotype Maroa was considered as stable and adaptable under rain fed conditions.

Keywords: environments, genotypes, sorghum, yield stability

تفاعل النمط الجيني والبيئي وتقديراستقرارالمحصول في بعض الطرزالوراثية للذرة الرفيعة في السودان

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المستخلص

تم إجراء هذا البحث في موسمين خلال عامي 2016 و 2017 في أربعة مواقع.اثنان منهم تحت الري واثنان تحت ظروف الأمطار. المواقع المروية كانت في ود مدني والسوكي، أما المواقع المطرية فكانت القضارف والدمازين. كانت التجربة في المواقع الأربعة تختبر 7 طرز وراثية للذرة مقابل ثلاثة استخدمت كشاهد (طابت، ود أحمد وHD-2) من أجل محصول الحبوب وثباتها وبعض الصفات الزراعية المهمة.كان التصميم في كل موقع ومواسم الزراعة عبارة عن تصميم القطاعات الكاملة العشوائية (RCBD) بأربعة مكررات.تم البذر في الأسبوع الأول من يوليو تحت الري وفي الأسبوع الأول إلى الأسبوع الثالث من يوليو في ظروف الامطار اعتمادًا على هطولها .تم اعتماد جميع الممارسات الزراعية الأخرى الموصى بها المناسبة للري والظروف المطرية على النحو الموصى به.أظهر التحليل المشترك وجود فروق ذات دلالة إحصائية بين الطرز الوراثية المختبرة.أظهرت نتائج تحليل التباين AMMI أن متوسط المربعات لتفاعل الطرز الوراثية والبيئات والطرز الوراثية كانت ذات دلالة إحصائية عالية (p <0.01) في محصول الحبوب.سجل النمط الوراثي W638 أعلى محصول حبوب (3.6 طن / هكتار) يليه النمط الوراثي مينا (3.2 طن / هكتار) بينما أظهرت الشواهد الثلاثة HD-2 وطابتوود احمد متوسط محصول حبوب قدره 2.9 و 2.8 و 3.1 طن / هكتار على التوالي.من هذه النتائج ، وجد أن الطرز الوراثية W638 و مينا اكبر من جميع الشواهد وكان متوسط محصول الحبوب أكبر من المتوسط العام للبيئات المروية (2.9 طن / هكتار) ، بينما سجل مروةمحصول حبوب مماثل لودأحمد (2.0 طن / هكتار) ولكن أكبر من طابت (1.7 طن / هكتار) و HD-2 (1.3طن / هكتار) وأعلى من المتوسط العام للبيئات المطرية (1.7 طن / هكتار) وقد أشارت هذه النتائج إلى أن الطرز الوراثية W638 وميناستقرة وقابلة للتكيف في ظل الظروف المروية ، بينما اعتبر التركيب الوراثي مروةمستقرًا وقابلًا للتكيف تحت ظروف الزراعة المطرية .

كلمات مفتاحية: الذرة الرفيعة، النمط الجيني، البيئة، استقرار المحصول

Introduction

Sorghum (*Sorghum bicolor* (L. Moench) is an important cereal crop and ranks fifth worldwide after wheat (*Triticumspp*), rice (*Oryzaspp*), maize (*Zea mays*) and barley (*Hordeum vulgre*) (FAO. 1995). It is grown over 42 countries (Belum *et al*., 2004). Developing countries are growing 90% of the world sorghum area and are producing 70% of the total sorghum production. Semi-arid tropical Asia and semi-arid tropical Sub-Saharan Africa grow about 60% of the world area (ICRISAT and FAO, 1996), while Sudan grows about 24% of Africa area and produces 17% of its production. Sorghum was first domesticated in the region of North East Africa and consists of cultivated and wild species. The region of Eastern Sudan and Ethiopia is considered a center of probable origin (Doggett and PrasadaRao, 1995). Doggett (1988) reported that, the greatest genetic diversity of cultivated and wild sorghum is present in East Africa. In Sudan, sorghum is the main staple food especially in rural areas and is used in different forms. Itplays a significant role for small and large scale farmers, it is the leading cereal crop by production, consumption as well as area cultivated. The national averages yield in Sudan was250 kg/fed (4200 m^2) which is very low compared to that obtained at research stations. This is due to the use of low yielding poor grain quality cultivars and poor crop management practices.

During the last 15 years, plant breeders in the Agricultural Research Corporation have successfully developed high yielding open pollinated varieties such as FW Ahmed, Ingaz (Ibrahim and Mahmoud 1992) and Tabat (Ibrahim *et al*., 1996). In addition, many other varieties suitable for both irrigated and rainfed sectors were also developed such as Butana and Bashayer (Elzein *et al.,* 2007) and AG-8 (Mohamed *et al.,* 2009). In the Sudan, the first hybrid developed is through the INTSORMIL collaborative program which started in 1979. That program succeeded in releasing the first hybrid in 1983 (HD-1) and since then, very few hybrids were released such as Hageen Rabih and Sheikan. Still, very few hybrids are famous to the farmers such as HD-1 and PAN 606. Recently, the plant breeders at the Agricultural Research Corporation succeeded in releasing three hybrids (DIA-07666, PAC-501 and E-1) suitable for irrigation and high rain fall areas of the Sudan (Elasha *et al.* 2011). Also, (Mohammed *et al.,* 2018) had released new sorghum hybrids for both irrigated and rain fed sectors. To increase the low national average sorghum grain yield of 250 kg/fed, hybrids could be among the most important technological packages for both irrigated and rain fed sectors. This study was carried out with an objective to evaluate some genotypes under irrigated and rain fed environments and to select among them the most stable under irrigated and rain fed environments

Materials and Methods

The experiment was carried during two seasons of 2016 and 2017 at four locations. Two locations were under irrigation and two under rain fed conditions. The irrigated sites were Wad Medaniand Suki, while the rain fed sites were Gedarif and Damazin. The genotypes tested under both irrigation and rain fed environments were W625,Maroa,Pro 4450,W 02W,Mena, W638 and Muzdalifa while Tabat, Wad Ahmed and HD-2 were used as checks.Land was prepared by disc ploughing, disc harrowing, leveling and ridging at the irrigated sites and by the wide level disc and ridging at the rain-fed sites. The design used at each site and season was a randomized complete block with four replications. Sowing was at the first week of July under irrigation and the first to the third week of July under rain fed conditions depending on the onset of the rainfall.

Under irrigation, the entries were sown to five rows, 5 m length on ridges of 0.8 m apart at 0.3 m intra row spacing and thinned to three seedlings per hill. Under rain fed conditions, they were also sown to five rows 5 m length, on flat at 0.8 m apart at 0.2 m intra row spacing and thinned to two seedlings per hill. In either season, urea at a rate of 80 kg and 40 kg /fed was applied under irrigation and rain fed sites respectively. Thinning to three and two seedlings per hill (for irrigated and rain fed sites respectively) was carried two to three weeks after emergence at each site during each season. Other cultural practices such as irrigation, weeding etc. were carried as recommended. The net harvested area at each site and season was three rows x 5 m length x 0.8 m for grain yield and 1 m length x 0.8 m x 3 rows for Stover. The data recorded at each site and season was; days to 50% flowering, panicle length, plant height; grain yield, Stover yield and 100 grain mass. The experiments for studying the distinction, uniformity and stability were run at the Gezira research station in season 2016-2017 to study the distinguished characters, the stability and the uniformity of the most promising genotypes. The Chemical analysis and the kisra (baking) quality tests were carried for the most promising genotypes. Samples of different genotypes were subjected to physical and proximate chemical analyses. Data were analyzed by IRRISTAT 2005 for separate seasons. Combined and stability analysis were also carried for both irrigated and rain-fed environments according to AMMI model (Gauch and Zobel, 1988 and Nachit *et al.*, 1992).

Results and Discussion

Stability and adaptability

Grain yield at the irrigated sites showed significant differences among the tested genotypes except at Medani in the first season (Table 1).This trait at Wad Medani ranged from (2.0-3.3 t/ha) in first season, from (2.4-4.17 t/ha) in the second season, while at Suki it ranged from (3.8-5.9 t/ha) to (1.1-2.6 t/ha) for the first and second seasons respectively (Table1). From the combined analysis, there were also significant differences between the tested genotypes for grain yield. Genotypes W638 showed the highest grain yield (3.6 t/ha) followed by Mena (3.2t/ha). From these results, it was found that, both W638 and Mena out yielded all other genotypes including the three checks. They also had a mean grain yield greater than the general mean of the irrigated sites (2.9 t/ha) (Table 1). At the rain fed sites, in both seasons there were significant differences among the tested genotypes ($P \leq 0.01$) as presented in (Table 1). The combined analysis showed that, there were significant differences among genotypes for grain yield. Similar results were reported by Elasha and Mohammed (2022), they found significant differences among sorghum hybrids over all environments. The genotypes Maroa and W. Ahmed had highest grain yield which was 2 t/ha. Maroa out yielded the two checks, HD-2 and Tabat and was comparable in grain yield to W. Ahmed and have a mean yield greater than the general mean of the rain fed sites which is 1.7 t/ha (Table 1).

Table 1.Mean of grain yield (t/ha) of ten sorghum genotypes evaluated over eight environments during season 2016 and 2017.

Site	Irrigated environments					Rain fed environments				
	Medani		Suki			Gedarif		Damazin		
	2016	2017	2016	2017	Mean	2016	2017	2016	2017	Mean
1. W625	2.65	2.00	3.8	1.7	2.5	1.05	1.95	1.9	1.14	1.5
2.Maroa	2.65	1.90	4.8	1.8	2.8	1.7	1.73	2.9	1.54	2.0
3.Pro 4450	2.67	2.43	4.3	1.2	2.7	1.8	1.82	3.0	0.83	1.9
4.W02W	2.87	1.49	4.9	2.3	2.9	1.5	2.04	2.3	1.46	1.8
5.Mena	2.95	2.89	4.3	2.6	3.2	1.3	2.01	2.9	0.85	1.8
6.W638	2.0	4.17	5.9	2.4	3.6	0.94	2.05	2.5	1.05	1.6
7.Muzdalifa	2.52	2.34	5.0	1.8	2.9	1.4	1.50	2.4	0.88	1.5
8.HD-2	2.8	2.46	5.2	1.1	2.9	1.5	0.0	3.0	0.61	1.3
9.TABAT	2.8	1.83	4.3	2.1	2.8	0.46	1.97	2.7	1.70	1.7
10.WAhmed	3.32	1.56	5.0	2.5	3.1	1.6	1.73	2.7	2.03	2.0
Mean	2.73	2.31	4.76	1.97	2.9	1.33	1.68	2.64	1.21	1.7
SE±	0.32ns	0.38*	0.36*	0.18*	0.27*	0.09**	0.06**	0.19**	0.09*	0.22**
CV%	23.8	32.9	15.0	17.8	18.3	9.6	6.8	14.5	14.1	23.9

*, **,*** significant at 0.05, 0.01 and 0.001 probability level, respectively

The combined analysis of variance according to the AMMI model is presented in (Table 2). Highly significant differences were observed for environments (E), genotypes (G) and their interactions GEI ($P\leq 0.01$), Same results were reported by (Mohamed *et al.*, 2022),who studied grain yield stability in sorghum. From total sum of squares due to treatments (G+ E+GEI), 83.3% of the variance was due to (E), the GEI accounted for 14.3%, while the genotypes explained only 2.3%. The partitioning of GE interaction through AMMI model analysis revealed that, the three terms (PCA1, PCA2 and PCA3) were significant and explained 49.7 %, 23.7% and 14.3% of variation due to GE interaction sum of squares, respectively (Table 7). Together, they accounted for 99.9% of GEI sum of squares and most of variation was explained by the first two principal component axes (PCA1 and PCA2).

Table 2. AMMI analysis of variance of the significant effects of genotypes (G), environments (E) and genotype-environments interaction (GE) on grain yield (t/h) and the partitioning of GE into AMMI scores.

Source	df	SS	MS	F	Efficiency%
Total	319	477.5	1.497		
Treatments	79	420.1	5.317	0.00000	
Genotypes	9	9.7	1.076***	0.00001	2.3
Environments	7	350.3	50.044***	0.00000	83.3
Block	24	7.7	0.322	0.10819	
Interactions	63	60.1	0.954***	0.00000	14.3
IPCA	15	29.9	1.996***	0.00000	49.7
IPCA	13	14.3	1.099***	0.00000	23.7
IPCA	11	8.6	0.779***	0.00024	14.3
Residuals	24	7.3	.303	0.15506	
Error	216	49.7	0.230		

*, **,*** significant at 0.05, 0.01 and 0.001 probability level, respectively

AMMI bi-plot of the first two principal components axes (PCA1 and PCA2) which usually showed stability of the genotypes across environments in term of principal component analysis and is used to identify adapted genotypes having stable performance across sites or under specific location. In this study, the first two principal components axes (PCA1 and PCA2) explained 73.4% of the total GE sum of squares (Fig.1and Table3). The genotypes Mena (2.5 t/ha) and W638 (2.6 t/ha) had mean grain yield more than the two checks HD-2 and Tabat and comparable to the check W. Ahmed (2.5 t/ha). Both genotypes (Mena and W638) were stable.

Table 3. PCA1 And PCA2 scores for yield of ten selected sorghum genotypes evaluated in eight environment

Genotype	NG	Gm	IPCAg[1]	IPCAg[2]	IPCAg[3]
G1	1	2.016	0.23857	0.19195	-0.48680
G2	2	2.386	0.27573	-0.23562	0.21494
G3	3	2.269	-0.06248	-0.75677	-0.37415
G4	4	2.362	0.45859	0.17243	0.36555
G5	5	2.494	-0.17701	0.17810	-0.67428
G6	6	2.653	-1.26924	0.53261	0.25057
G7	7	2.238	-0.21398	-0.08096	0.30644
G8	8	2.309	-0.31354	-0.74174	0.20692
G9	9	2.236	0.39510	0.52736	-0.24702
G10	10	2.558	0.66825	0.21264	0.43784

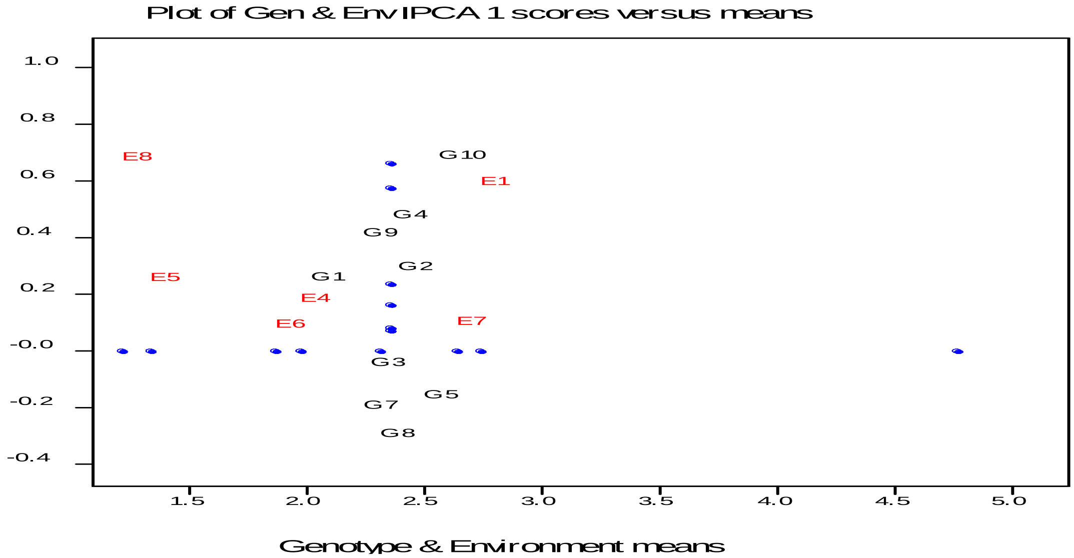

Fig.1. The AMMI bi plot of the main and PCA1 effects of both genotypes and environments on grain yield Of eight sorghum genotypes grown at eight environments during 2016 and 2017.

The best four genotypes selected according to AMMI estimate among all environments were genotypes Mena as was selected 5 times out of eight environments, genotype W638 as was selected 3 times out of four irrigated environments and genotype Maroa as was selected three times in four rain fed environments (Table 4). From the above results, the stable genotypes for grain yield were genotypes Mena and W63under irrigated conditions, also they had a mean grain yield of (3.2 t/ha) and (3.6 t/ha) compared to the general mean of the irrigated environments (2 t/ha), and genotype Maroa also had a mean grain yield of 2 t/ha higher than the two checks Tabat (1.7 t/ha) and HD-2 (1.3 t/ha) and comparable to W. Ahmed (2 t/ha) and had mean grain yield higher than the general mean of the rain fed environments.

Table 4.The best four genotypes in each environment for grin yield according to AMMI selections.

Number	Environment	Mean	Score	1	2	3	4
8	E8	1.211	0.6628	G10	G4	G9	G2
1	E1	2.735	0.5757	G10	G2	G4	G5
5	E5	1.332	0.2369	G8	G3	G2	G10
4	E4	1.971	0.1632	G6	G10	G9	G5
7	E7	2.635	0.0818	G3	G8	G5	G2
6	E6	1.863	0.0724	G5	G6	G10	G9
3	E3	4.761	-0.5333	G6	G8	G7	G10
2	E2	2.308	-1.2595	G6	G5	G8	G3

Conclusion

Seven sorghum genotypes were evaluated across four locations for two year (eight environments) to study Genotype x Environment interaction and yield stability. Genotypes W638 and Mena gave higher grain yield (3.6 t/ha) and (3.2 t/ha) compared to all checks and had mean grain yield higher than the overall mean (2.9 t/ha) and performed consistently well across the irrigated environments indicating good stability and adaptability under irrigated conditions. Genotype Maroa had higher grain yield (2 t/ha) compared to the two checks Tabat and HD-2 and had mean yield above than the general mean (1.7 t/ha) of the rain fed environments, indicating its stability under rain fed conditions.

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