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Genotype X Environment Interaction in Bread Wheat in Northern Sudan Using AMMI Analysis

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Abstract: Eight wheat lines developed in Central Sudan were tested under arid conditions of Northern Sudan against four commercial checks across five testing environments during 1992-96. The AMMI method of analysis was employed to assess the phenotypic stability of these genotypes and to investigate the validity of the policy of recommending wheat genotypes developed in Central Sudan for cultivation in the Northern part of Sudan. None of the studied lines outperformed the commercial checks recommended for Northern Sudan. The check El Nielain exhibited high yield associated with good stability and would be expected to perform well in a wide range of environments. The check Wadi Elniel ranked first in grain yield but tend to be unstable, favoring high yielding environments. The check Condor proved to be a valuable source for yield stability in wheat breeding programs. DebiraX21PHS the best yielding among the studied lines showed moderate stability. Pavon76XCondor was moderately yielding high stable genotype. Selaim environment was the best for testing wheat genotypes. Meroe appeared to be a different target environment with low yield potential. Unless a full wheat breeding programs has been established in the Northern State, the relative advantage in wheat production of Northern over Central Sudan will not be fully utilized.

Key words: AMMI · GEI · Meroe · Stability · Sudan · Wheat

INTRODUCTION

Wheat (*Triticum asetivum* L.) has become an important stable food in the Sudan. Being a temperate crop, it is not indigenous to Sudan; yet it was traditionally grown since early times in the Northern State (Lat. 18-22° N) that enjoys a relatively cooler and longer winter season than in Central Sudan (Lat. 18-22° N). However, owing to increasing demand for wheat coupled with the limited resources in Northern Sudan, the expansion in wheat cultivation took place in warmer but comparatively less expensive production systems of the central plains. Enormous efforts to attain wheat-self sufficiency have been exerted during 1985-95. The gap between consumption and production was about to be bridged in 1991/92 when it was again widened, specially from 2000 onwards, due to increased consumption levels accompanied by successive drop in wheat production (Fig 1). Revival of wheat production in its traditional areas was, therefore, thought crucial and the Government lunched a program to rehabilitate wheat production in Northern State. The policy of self-reliance in wheat that had been raised two decades ago is now becoming inevitable in view of food vs fuel concerns.

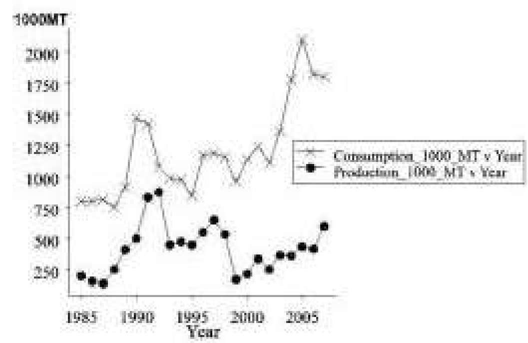

Fig. 1: Wheat production and consumption in Sudan (1985-2005)

The wheat breeding program is currently situated in the Gizera Research Station (GRS) that represents environments prevailing in central plains of Sudan. Wheat germplasm usually undergo preliminary and advanced testing in GRS before being transferred to Northern Sudan for further evaluation. Breeding programs targeting specific environments in the Northern State are yet to start. However, some research efforts (1985-95) has resulted in only two cultivars being specifically released for cultivation in Northern Sudan, namely, Wadi Elniel [1] and El Neilain [2].

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The development of high yielding cultivars with wide adaptability is the ultimate aim of plant breeders. However, attaining this goal is more complicated by genotype-environment interaction (GEI). Additive main effects and multiplicative interaction (AMMI) model proved to be a powerful tool in diagnosing GEI patterns [3]. The results can be graphed in a very informative bi-plot that shows both main and interaction effects for both genotype and environment.

The objectives of this study were to evaluate the agronomic performance and stability of some wheat genotypes developed at Central Sudan under conditions of Northern Sudan and to employ AMMI method of analysis to investigate the validity of recommending these genotypes for wheat cultivation in the Northern part of the Sudan.

MATERIALS AND METHODS

Plant Materials: Twelve genotypes (Table 1) were used in this study 8 of which were lines developed by the national wheat program based at GRS, Wad Medani, namely: F7L.2159, KAUZ'S', GRS229X75-14PYTV, 12300X14PYTV, Pavon76XCondor, DebiraX21PHS, CondorXBaladi, and 145F679-80X14PYTV. The other 4 were commercial cultivars, used as checks, comprising Wadi Elniel, El Neilain, Condor and Debira. Wadi Elniel is Egyptian cultivar (Giza 160) recommended for Upper Egypt in 1982 [4] before being released for cultivation in Northern Sudan in 1987 [1]. El Neilain was released for Central Sudan in 1990 and was later recommended for Northern Sudan [2]. Condor and Debira were released for Central Sudan in 1979 and 1982, respectively.

Environments: The wheat genotypes were evaluated at five Location-year testing environments in the Northern State viz.; Sortot 1992/93, Selaim 1993/94, Burgaig 1994/95, Karowat 1995/96 and Meroe 1995/96. The Soil analysis revealed that the soils at Karowat, Meroe and Burgaig are sandy clay with the later two being comparatively poor in nitrogen content. The soils of Sortot and Selaim are silty clay. The pH ranged from 7.1 to 8.2. Temperature degrees during the growing season showed that the environment at Meroe was characterized by comparatively higher winter temperatures, specially, those of the mean maximum, which ranged from 29.6 to 35.4°C. Sowing dates at Burgaig, Selaim and Sortot were on the 1^{st}, 3^{rd} and 4^{th} week of December, respectively, whereas for Karowat and Meroe the materials were sown on the 29^{th} of Nov.

Field Methods and Data Collected: The experimental design was RCB with 3 replicates. Planting method was on rows 30 cm apart at a seed rate of 120 kg/ha. The plot area ranged from 10 to 15 m^2. Nitrogen fertilizer was applied at tillering at a rate of 55 kg n./ha in all sites other than Meroe and Selaim where 109 kg n./ha was applied. The trials were irrigated every 10 to 15 days and kept weed free by hand weeding. The data collected include grain yield, number of days to heading, plant height, number of grains per spike and 1000 grains weight. The whole plot was harvested to estimate grain yields. Plant height and number of grains per spike were estimated from 10 plants randomly selected from each plot. Seed weight was estimated from a random sample taken from the bulked grains of each plot.

Statistical Analysis: Separate analysis of variance for grain yield was performed prior to combined analysis. Combined ANOVA was performed for grain yield and yield components. The mean squares of genotype-environment interaction (GEI) for grain yield was used to test the effect of genotypes. The genotypes (G) and environments (E) were subjected to AMMI method of analysis [5]. The AMMI model combines the

Table 1: The wheat germplasm used in the study

Entry	Name	Description/Pedigree
1	Debira (check)	HD 2172 (Recommended for Central Sudan)
2	Condor (check)	Recommended for Central Sudan
3	F7L.2159	Adv.11(12)91/92F7L.2159
4	El Nielain (check)	S948-A-Se7 (Recommended for Northern and central Sudan)
5	KAUZ	Adv.1(14)91/92KAUZCM67458-4Y-1M-3Y-1M-0Y
6	GRS229X75-14PYTV	NH.ANT(1)91/92GRS229X75-14PYTV(NH281)
7	12300X14PYTV	NH.ANT(5)91/9212300X14PYTV(NH243)
8	Pavon76XCondor	VYT(11)Pavon 'S' XCondor 'S'
9	DebiraX21PHS	VYT(12)DeberiaX21PHS(NH270)
10	CondorXBaladi	NHAYT(7)Condor 'S' X Baladi No18
11	145F679-80X14PYTV	NHAYT(10)145F679-80X14PYTV(NH248)
12	Wadi Elniel (check)	Chenab 70 / Giza155 (Recommended for Northern Sudan)

analysis of variance for main effects of G and E with principal components analysis of GEI. It has proven useful in understanding complex GEI. The results were graphed in bi-plot showing the main and interaction effects for both genotypes and environments. The bi-plot main effect of means vs the first Interaction Principal Component Analysis Axis (IPCA1) from AMMI analysis was used to study the pattern of response of G, E, and GEI. It was also used to identify genotypes with broad or specific adaptation to target environments for grain yield. The model equation [5] is:

$$Y_{ij} = \mu + G_i + E_j + \sum_{\kappa=1}^{n} \lambda_\kappa \alpha_{ik} \gamma_{jk} + e_{ij}$$

Where Y_{ij} is the yield of the i^{th} genotype in the j^{th} environment; μ is the grand mean; G_i and E_i are the genotype and environment deviations from the grand mean, respectively; $\lambda\kappa$ is the eigenvalue of the PCA analysis axis κ; a_{ik} and γ_{jk} are the genotype and environment principal component scores for axis κ; n is the number of principal components retained in the model and e_{ij} is the error term..

The AMMI stability value was used to quantify and rank genotypes according to their yield stability. It was computed as suggested by Purchase [6] as follows

$$AVS = \sqrt{\left[\frac{IPCA1SumofSquares}{IPCA2SumofSquares}\right]^2 + [IPCA2score]^2}$$

Agrobase statistical package [7] was used to run the ANOVA and AMMI analysis.

RESULTS

Agronomic Performance: The AMMI model combines the analysis of variance for main effects of genotypes (G) and environment (E) with principal components analysis of genotype x environment interaction (GEI). The mean squares from AMMI analysis of variance (Table 2) indicated significant variations among the genotypes, the environments and their interaction for grain yield. The GEI is highly significant (P<0.01) accounting for 16.6 % of the sum of squares (nearly twice of that of the genotypes) implying the need for investigating the nature of differential response of the genotypes to environments. The genotype x environment interaction (GEI) was partitioned into four interaction principal component analysis axis (IPCA). The IPCA 1 score is highly significant explaining 65.32 % of the variability relating to GEI. The IPCA 2 was significant at p=0.0504, accounting for 16.9 % of the variability. The other two IPCAs captured insignificant portion of variability which could be regarded as noise.

Table 3 shows the performance of the 12 genotypes for grain yield in each environment and their average performance across five environments. Significant (P<0.01) differences between genotypes were encountered at Selaim Karowat and Sortot but not at Burgaig and Meroe. The check Wadi Elniel which was leading at Sortot, Selaim and Burgaig was among the lowest yielding in the other two sites, specially at Meroe. In contrast, the check El Nielain consistently showed high yield in all sites and was leading at Meroe. DebiraX21PHS was among the best 5 top yielding genotypes in most environments.

Table 2: Mean squares from AMMI and the percentage of G x E explained by each IPCA♣ for grain yield (kg/ha) of 12 wheat genotypes grown at 5 environments (1992-95) in Northern State of Sudan

Source	df	Sum of squares	Mean of squares	F-value	Prob.> F	Variations explained (%)
Total	179	230943272				100.00
Environments (E)	4	131598550	32899637**	41.28	0.0000	57.00
Reps within E	10	7970211	797021			3.45
Genotype (G)	11	20610283	1873662*	2.15	0.0225	8.92
G x E	44	38401494	872761**	2.97	0.0000	16.63
IPCA 1	14	25082598	1791614	6.09	0.0000	(65.32)
IPCA 2	12	6491516	540960	1.84	0.0504	(16.90)
IPCA 3	10	3953884	395388	1.34	0.2164	(10.30)
IPCA 4	8	2873496	359187	1.22	0.2936	(7.48)
Residual	110	32362735	294207			14.00

♣ : IPCA = Interaction principal component analysis axes. Figures between brackets denote percentage explained by IPCAs from that explained by GxE (16.63).

*, **: Significant at 0.05 and 0.01 probability level, respectively.

Table 3: Wheat grain yield (kg/ha) obtained by 12 genotypes in different location-year testing environments and their average performance in the Northern State of Sudan

	Environments					Average performance	
Genotype	Sortot 92/93	Selaim 93/94	Burgaig 94/95	Karowat 95/96	Meroe 95/96		Rank
Debira (check)	4472	5675	4815	5913	2528	4680	4
Condor (check)	5000	5159	4101	4762	2972	4399	9
F7L.2159	5250	4861	4132	5000	2139	4276	11
El Nielain (check)	6000	5496	5106	5794	3444	5168	2
KAUZ'S'	4111	4782	4206	5635	3305	4408	8
GRS229X75-14PYTV	4250	5060	3730	4564	2722	4065	12
12300X14PYTV	3639	5476	4550	5198	3211	4415	7
Pavon76XCondor	5039	5496	4735	5040	2805	4623	5
DebiraX21PHS	5889	5357	4471	5238	3139	4819	3
CondorXBaladi	4806	4504	4973	4960	3084	4465	6
145F679-80X14PYTV	3722	5357	4262	4921	3194	4291	10
Wadi Elniel (check)	6778	6480	5640	4564	2667	5226	1
Sig.L	**	**	ns	**	ns	*	
SE±	323.53	221.28	453.651	231.347	278.18	241.214	
LSD (0.05)	948.88	649.00	-	678.5183	-	687.498	
CV (%)	11.4	7.22	17.23	7.81	16.42	11.9	

*, **: Significant at 0.05 and 0.01probability level, respectively.
ns: Not significant at 0.05 probability level.

Considering the average performance combined over environments, the genotypes differed significantly ($P<0.05$) in grain yield. Wadi Elniel and El Nielain gave the highest yields averaging 5226 and 5168 kg/ha, respectively. The lines DebiraX21PHS, and Pavon76XCondor gave comparable yields to the check Deberia, averaging 4819 and 4623 kg/ha, respectively. They outyielded the check Condor (4399 kg/ha); however, the difference in yield was not statistically significant. The line GRS229X75-14PYTV showed the lowest yield level averaging 4065 kg/ha.

Highly significant differences were detected between genotypes for yield components and related traits. The CV ranged from 1.9 % for days to heading to 8.9 % for grains per spike. Days to heading ranged from 66.9 for the check El Nielain up to 73.1 day for the line 145F679-80X14PYTV. Plant height ranged from 77.5 for KAUZ'S' up to 97.9 cm for El Nielain. The line GRS229X75-14PYTV showed the highest value for number of grains per spike (47.1) whereas 12300X14PYTV gave the lowest value (36.6). El Nielain gave the highest value for 1000 grains weight (47.8 gm) whereas the lowest value was shown by KAUZ'S' (37.7 gm).

Stability Performance: Table 4 reflects IPCA scores and AMMI stability values (ASV). The lines CondorXBaladi, Condor, Pavon76XCondor, showed the lowest scores in the IPCA 1, followed by GRS229X75-14PYTV and El Nielain. The check Debira and the lines F7L.2159; DebiraX21PHS showed medium scores in the IPCA 1. Wadi Elniel scored the highest IPCA 1 value. Considering the AMMI stability value (ASV) that take into account the scores of the IPCA 2, the line F7L.2159 appeared to be among those showing low ASV. The line GRS229X75-14PYTV became the second lowest in ASV. On the other hand, the line CondorXBaladi that showed the lowest IPCA1 score ranked fourth in ASV. With regard to environments, Selaim 93/94 and Burgaig 94/95 gave the lowest IPCA 1 scores whereas the other environments, specially Sortot 92/93 scored high values.

Figure 2 depicts AMMI bi-plot based on IPCA 1 scores. The bi-plot was used to study the pattern of response of G, E, and GEI using main effect of means vs the first Interaction Principal Component Analysis Axis (IPCA1). It was also used to identify genotypes with broad or specific adaptation to target environments for grain yield. The dotted vertical line shows the grand means of all genotypes whereas the dotted horizontal line shows the zero point for the IPCA scores. Accordingly, the IPCA scores range from up to 23.889 down to-42.275 and means from 2934 up to 5309 kg/ha. Some patterns could be detected, for example; the lines KAUZ'S', 12300X14PYTV and 145F679-80X14PYTV showed distinct aggregate, indicating similar germplasm.

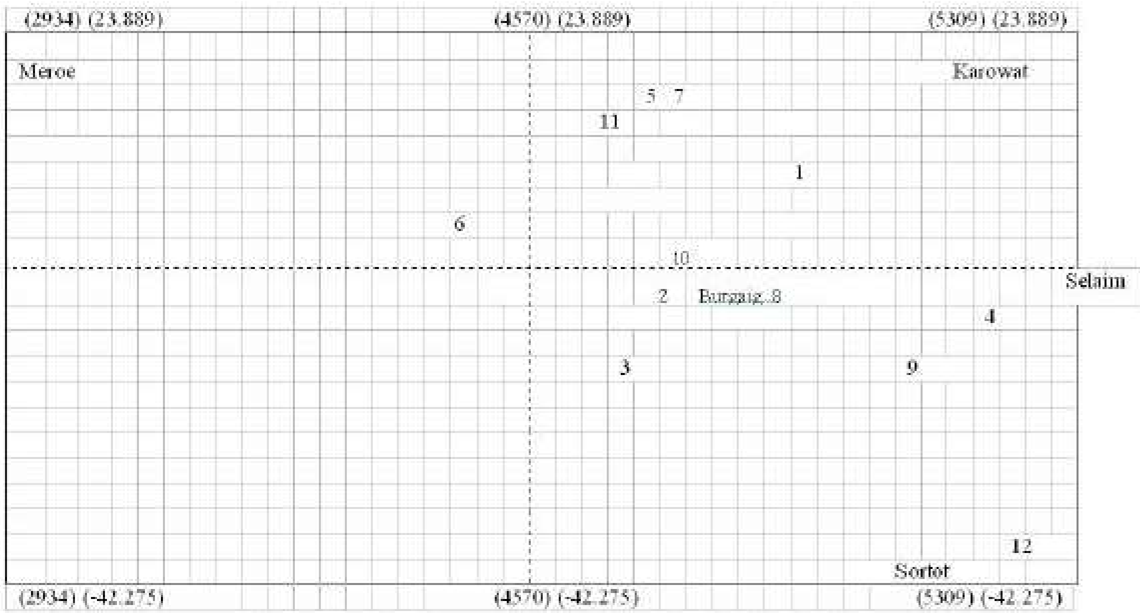

Fig. 2: AMMI bi-plot for grain yield (kg/ha) of 12 wheat genotypes♣ and 5 location-year testing environments@ with X-axis plotting means from 2934 to 5309 kg/ha and Y-axis plotting IPCA1 from,-42.275 to 23.889.
♣ : 1 =Deberia, 2 = Condor, 3 = F7L.2159, 4 = El Neilain, 5 = KAUZ'S', 6 = GRS229X75-14PYTV, 7 = 12300X14PYTV, 8 = Pavon76XCondor, 9 = DebiraX21PHS, 10= CondorXBaladi, 11 = 145F679-80X14PYTV and 12 = Wadi Elniel
@ : Sortot 92/93, Selaim 93/94, Burgaig 94/95, Karowat 95/96 and Meroe 95/96.

Table 4: IPCA axes scores for genotypes and environments, AMMI stability value (AVS) and mean performance for grain yield (kg/ha) of 12 wheat genotype grown at 5 environments in the Northern State of Sudan (1992-95)

Genotype code	Grain yield	Rank	IPCA1 Scores	IPCA2 Scores	ASV	Rank	Environment	IPCA1 Scores
Debira	4681	4	9.2454	7.7389	19.753	7	Sortot 92/93	-42.2752
Condor	4399	9	-3.4623	-3.1349	7.493	1	Selaim 93/94	-1.2780
F7L.2159	4276	11	-11.6346	-8.9453	16.547	5	Burgaig 94/95	-3.1806
El Nielain	5168	2	-7.0819	-13.5869	19.452	6	Karowat 95/96	23.8895
KAUZ'S'	4408	8	19.4299	-12.0089	40.036	10	Meroe 95/96	22.8444
GRS229X75-14PYTV	4065	12	4.3439	3.6315	9.279	2		
12300X14PYTV	4415	7	21.2925	13.7884	44.067	11		
Pavon76XCondor	4623	5	-3.9014	5.2763	9.309	3		
DebiraX21PHS	4819	3	-11.7023	-11.6831	25.800	8		
CondorXBaladi	4465	6	1.2251	-11.5907	11.838	4		
145F679-80X14PYTV	4291	10	18.0255	11.7302	37.324	9		
Wadi Elniel	5226	1	-35.7797	18.7846	72.797	12		

The check Condor and its progenies CondorXBaladi and Pavon76XCondor were close to each other, pointing to their common genetic background. The environments Karowat 95/96, Sortot 92/93 and Meroe 95/96-unlike those of Selaim 93/94 and Burgaig 94/95-represent the outliers and tend to diverge considerably from the stability zone. Selaim and Sortot displayed similar interaction effects as they fell within the lower right quadrant with negative interaction scores and above average wheat yield. On the other hand, Karowat and Meroe environments displayed similar interaction effects as they fell within the upper half with positive scores; however, Meroe fell in the left quadrant with below average yield, hence, could be regarded as low yielding environment.

The check Condor and its progenies (CondorXBaladi and Pavon76XCondor) were very close to the horizontal line (zero interaction effect) and situated on the right hand of the plot, hence, would be the most stable with above average yield. They form a group around Burgaig site indicating their specific adaptation to that environment. El Neilain, was the only genotype combining high yield with good stability. It showed specific adaptation to Selaim environment. DebiraX21PHS was good yielding genotype with medium stability. It was adapted to certain high potential areas relating to Selaim environment. The line F7L.2159 was moderately yielding and has good stability. It showed some adaptability to Burgaig environment. The check Wadi Elniel, the best yielding genotype tend to be the most unstable. Its proximity to Sortot environment suggests specific adaptability to that environment. The check Deberia is good yielding with medium stability. It was adapted to certain high potential areas relating to Burgaig environment. The lines 12300X14PYTV, KAUZ'S' and 145F679-80X14PYTV were unstable and seemed to relate to none of the studied environments; however, as they showed above average yield, they were adapted to certain high yielding environments. The line GRS229X75-14PYTV has good stability, but was the only one with below average yield.

DISCUSSIONS

This study demonstrates the importance of applying AMMI analysis to investigate the main effects of genotypes and environment and the complex patterns of their interaction. The GEI accounted for sizable and significant portion of variability almost as twice as that of genotypes. Using AMMI model, the variability relating to GEI has been partitioned into pattern rich model represented by IPCA 1 and IPCA 2 (accounted for 82 % of the variation caused by GEI) and noise rich residual (IPCA 3 and IPCA 4).

Wheat growing season in Sudan is very short with high temperatures experienced at both extremes; hence, developing genotypes tolerant to heat stress is crucial towards improving productivity. Earliness (days to heading) and plant height are major selection criteria used to develop heat tolerant genotype in Sudan [8]. The present study indicated that El Neilain was unique in combining high yield with good stability. It was the earliest and the tallest cultivar in the whole material tested, pointing to its improved tolerance to heat stress. Wadi Elniel, though ranking first in grain yield, appeared to be unstable, favoring high yielding environments. The check Condor and its progenies (CondorXBaladi and Pavon76XCondor) displayed the best satiability pointing to the reliability of using Condor as a source for yield stability in wheat breeding program.

Due to the limited number of environments being tackled here, the present study may not provide the ideal framework for identifying target testing environments for wheat breeding in Northern State. However, it does provide some initial information on the studied environments. Selaim appeared to be the best environment for testing wheat genotypes, displaying the lowest interaction effect (IPCA scores) coupled with the highest yield potential. Such environments allow expression of the real differences between genotypes. Meroe appeared to be a different target environment with low yield potential.

As pointed earlier, the wheat breeding program is based in Central Sudan where the germplasm undergo preliminary and advanced testing before being verified in Northern State. This seems to be behind the fact that none of the tested lines outperformed the commercial checks recommended for the Northern Sudan viz,. Wadi Elniel and El Nielain. However, under conditions of Central Sudan, the performance of some of these lines had been good enough to justify their release. For example, KAUZ'S' which ranked eighth and exhibited low stability in this study was released in 2008 under the name Nabeta. Pavon76XCondor was released in 1997 under the name Argine. It appeared in this study as moderately yielding-high stable cultivar. The line DebiraX21PHS, appeared as good yielding but moderately stable genotype. It was released in 1997 under the name Bohaine.

CONCLUSION

Our results suggest that a wheat breeding program based in Northern State seems to be a necessity to fully utilize the relative advantage of wheat production in Northern Sudan and to surpass the present maxima imposed by the recommended cultivars Wadi Elniel and El Nielain. The basic features of this program should include, in addition to introductions, hybridization and selection to bring together the good stability of Condor with the high productivity of Wadi Elniel and El Nielain. Furthermore, verification of elite materials developed at Central Sudan should be continued to avoid release of cultivars not adapted to the environment of Northern Sudan or to identify promising materials that might have been discarded if proved inferior under conditions of central Sudan. Selaim represents a good environment to implement preliminary and advanced testing stages.

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REFERENCES

1. Mohamedali, G.H., 1987. Wadi-El-Neel, a new bread wheat variety for the arid regions of Northern Sudan-merits and packages. In Transfer of technology for agricultural development in the Northern Region of Sudan, Eds., Habib Ibrahim M.E. and M.S. Shayya. NRARP, Khartoum, pp: 71-71.
2. Sheikh Mohamed, A.I., J.E. Mohamed and I.M. Maarouf, 1998. Evaluation of bread-wheat genotypes under semiarid tropical conditions of Northern Sudan. Rachis, 17(1and2), 62-63.
3. Crossa, J., 1990. Statistical analysis of multilocation trials. Advances in Agronomy, 44: 55-86.
4. AbdElShafi, A.A.M. and O.A.A. Ageeb, 1994. Breeding strategy for developing heat-tolerant wheat varieties adapted to Upper Egypt and Sudan. In Wheat in heat-stressed environments: Irrigated, dry areas and rice-wheat farming systems, Eds., Saunders, D.A. and G.P. Hettel. CIMMYT, Mexico, D.F., pp: 33-39.
5. Gauch, H.G. and R.W. Zobel, 1996. AMMI analysis of yield trials. In Genotype-by-Environment Interaction, Eds., Kang, M.S. and H.G.Jr. Gauch. CRC Press, Boca Raton, Florida, pp: 85-122.
6. Purchase, R.L., 1997. Parametric analysis to describe genotype by environment interaction and yield stability in winter wheat. Ph.D. Thesis, Department of Agronomy, Faculty of Agriculture of the University of the Free State, Bloemfontein, South Africa.
7. Agrobase, 2005. Gen II version 14.4.1., Agronomix Software Inc., Winnipeg, Canada.
8. Elahmadi, A.B., 1994. Development of wheat germplasm tolerant to heat stress in Sudan. In Wheat in heat-stressed environments: Irrigated, dry areas and rice-wheat farming systems, Eds., Saunders, D.A. and G.P. Hettel. CIMMYT, Mexico, D.F., pp: 48-54