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The development of the first Sudanese grain sorghum hybrids (*Sorghum bicolor* L. Moench) for use under irrigation in central Sudan

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ABSTRACT

A field experiment was carried out during 2012 and 2014seasons at three irrigated locations, Wad Medani, New Halfa and Suki. The hybrids tested were NS-5655, NS-5511, A8xR2, A30xR4,A6xR10, A41xR8, and HD-1 used as a check. A8xR2, A30xR4, A6xR10 and A41xR8were developed by the Sorghum Research Program at the Agricultural Research Corporation, Sudan; while NS-5655, NS-5511 were supplied by Mahgoub sons Company. The land was prepared by disc plowing, disc harrowing, leveling and ridging. Each entry was sown to five rows of five meters length at 0.8m and 0.3m between ridges and within plants respectively. The design at each site and season was a randomized complete block with four replications. Sowing was on the first week of July and cultural practices pertaining to irrigation, weeding etc. were carried as recommended by the Agricultural Research Corporation. Data was measured on days to 50% flowering, panicle length, plant height; grain yield, stover yield and 100 grain mass. Data was analyzed by IRRISTAT for separate seasons and combined and stability analysis wasalso carried using the regression procedure of Eberhart and Russel (1966). The results showed that, the mean squares of hybrids, environments and hybrids x environments interaction were highly significant ($P<0.01$) for grain yield. The overall mean grain yield for irrigated environments for the hybrid A6xR10, NS-5511 and A30xR4 were 4.9, 4.1 and 3.9 t/ha, followed by the hybrid A8xR2 which was 3.8t/ha. These values were 44%, 21%, 15% and 12% more than the grain yield of HD-1 (3.4 t/ha) respectively. The results of grain yield and its stability showed that, the hybrids A6xR10, NS-5511, A30xR4 and A8xR2 were suitable for irrigated conditions.

KEYWORDS:

Introduction

Sorghum (*Sorghum bicolor* L.Moench) is an important cereal crop, ranks fifth worldwide after wheat (*Triticum* spp), rice (*Oryza* spp), maize (*Zea mays*) and barley (*Hordeum vulgare*) (FAO. 1995). It is grown over 42 countries (Belum VS Reddy *et al*. 2004 with developing countries growing 90% of the world sorghum area and 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 in particular, the region of Eastern Sudan and Ethiopia is considered a center of probable origin (Doggett and Prasada Rao, 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 of the country, and is used in different forms. The national average yield in the Sudan of 250 kg/fed is very low compared to that obtained at the research stations (3000 kg/fed). This may be due to the use of low yielding cultivars as well as poor cultural crop management practices.

During the last 15 years, the plant breeders of the Agricultural Research Corporation have successfully developed high yielding open pollinated varieties such as FW Ahmed, Ingaz (Osman and Mahmoud 1992) and Tabat (Osman et al. 1996). In addition, many other varieties suitable for both irrigated and rainfed sectors were also developed such as Butana and Bashayer (Ibrahim N. et al. 2007), and AG-8 (Mohamed et al. 2009). In Sudan, the plant breeders 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 in the Agricultural Research corporation succeeded in releasing three hybrids (DIA-07666, PAC-501 and HD-2) suitable for irrigation and high rain fall areas of the Sudan (Elasha et al. 2011). To raise the low national average sorghum grain yield of 250 kg/fed, hybrids could be among the most important technological packages for the irrigated sector. Therefore, the objective of this study was to assess the genotype x environment interaction and the stability of some local and introduced sorghum hybrids for their grain yield under irrigated environments.

Materials and Methods

The experiment was carried during 2012 and 2014 seasons at three irrigated locations, WadMedani, New Halfa and Suki. The hybrids tested were NS-5655, NS-5511, A8xR2, A30xR4, A6xR10, A41xR8, and HD-1 was used as a check. A8xR2, A30xR4, A6xR10 and A41xR8are hybrids from the Sorghum Research Program, the Agricultural Research Corporation, Gezira Research Station (ARC), Sudan, developed by Prof. Elasha A. Elasha, NS-5655, NS-5511 from Mahgoub sons Company. The breeding work on the local hybrids at the Sorghum Research program had started by Prof. Elasha A. Elashaon 2007 where various crosses involving different R lines were used. The various crosses had resulted in the generation of

various hybrids which were then tested through preliminary hybrids trials during the summer seasons of 2008 and 2009. The promising hybrids in terms of grain yield and desirable agronomic characters were advanced for various testing. The advanced trials for the promising hybrids were carried during the summer seasons of 2010 and 2011. From these advanced trials, three promising hybrids in terms of grain yield and desirable agronomic characters were selected for the national testing during 2012 and 2014. These were A8 x R2, A6xR10and A30x R4. The land was prepared by disc plowing, disc harrowing, leveling and ridging. The design used at each site and season was a randomized complete block with four replications. Sowing was at the first week of July and the entries were sown to five rows of 5 m length, on ridges of 0.8 m apart at 0.3 m intra row spacing and were thinned to three seedlings per hill. Urea at the rate of 80 kg urea was applied. Thinning to three seedlings per hill was done at two to three weeks after emergence at each site during each season. Other cultural practices pertaining to irrigation, weeding etc. were carried as recommended. The net harvested area at each site and season was 3 rows x 4 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. Data was analyzed by IRRISTAT (2005) statistical package for separate seasons. Also, the combined and the stability analysis were carried according to the procedure of Eberhart and Russel (1966) to know the stability and the adaptability of sorghum hybrids under irrigated environments.

Results and Discussion

Morphological traits

Days to 50% flowering

There were significant differences ($P< 0.01$) between the hybrids in their days to flower (Table 1). Days to 50% flowering at Wad Medani in season 2012 and 2014 ranged from 62-72 days and 57-69 days respectively. At Suki and New Halfa during 2012, it ranged from 69-79 days and from 62-69 days respectively. Across the three sites, there were highly significant differences among the entries for days to 50% flowering which ranged from 63-70 days with an overall mean of 67 days. The earliest entries were A8xR2 (Average of 63 days), A6xR10 (Average of 65 days), NS-5511 (Average of 66 days) and NS-5611 (Average of 69 days). The latest entries were A41xR8 and HD-1(Table 1).

Table 1. Mean of days to 50% flowering of sorghum hybrids evaluated over four irrigated environments during season 2012 and 2014

Hybrid name	Medani		Suki	New Halfa	Mean
	2012	2014	2012	2012	
NS-5655	70	66	71	69	69
NS-5511	62	69	69	66	66
A8xR2	62	57	70	62	63
A30xR4	70	61	73	66	67
A6xR10	66	60	70	66	65
A41xR8	72	61	79	67	70
HD-1	69	69	75	66	70
Mean	67	63	72	65.7	67.1
CV%	3.5	6.7	3.6	2.9	5.9
SE±	1.1	2.1	1.3	0.95	0.98
Sig. level	***	*	**	*	**

Plant height

There were significant differences between the entries in their plant height (Table 2). Plant height at Wad Medani during season 2012 and 2014 ranged from 139.2-201.4 cm and from 171.3-200.4 cm respectively. At Suki, the plant height ranged from 134.5-185 cm from 142.7-168.7 cm at New halfa. Across all sites, there were significant differences among the entries, with many entries showing a reasonable plant height (< 180 cm) (Table 2).

Table2. Mean of plant height (cm) of sorghum hybrids evaluated over four irrigated environments during season 2012 and 2014

Hybrid name	Medani		Suki	New Halfa	Mean
	2012	2014	2012	2012	
NS-5655	139.2	200.4	134.5	166.5	160.2
NS-5511	165.7	198.6	146.7	168.7	169.9
A8xR2	175.8	185.7	181	142.7	171.3
A30xR4	211.4	185.5	179.5	154.7	182.7
A6xR10	201.4	192.4	184.7	154.5	183.2
A41xR8	205.1	187.1	185	168.5	186.4
HD-1	150.4	171.3	156	155	158.6
Mean	178.4	188.7	167.1	158.7	173.2
CV%	13	5.7	7.5	7	11.8
SE±	11.6	5.4	6.3	5.5	5.1
Sig. level	*	*	**	*	*

Panicle length (cm)

At Wad Medani, during the first season there was a significant difference between the hybrids for panicle length. At Wad Medani, the panicle length ranged from 28-37.6 cm in the first season and from 28 to 32.2 cm in the second season (Table 3). At Suki and new halfa, it ranged from 24 to 29.6 cm and from 25 to 31 cm respectively. Across all sites there was a significant difference among the entries and the panicle length ranged from 27.1-30.6 cm. A41xR8 showed the longest (Table 3).

Table 3. Mean of panicle length (cm) of sorghum hybrids evaluated over fourirrigated environments during season 2012 and 2014

Hybrid name	Medani		Suki	New Halfa	Mean
	2012	2014	2012	2012	
NS-5655	30.7	29	26	28.7	28.6
NS-5511	28	28	26.5	28.5	27.7
A8xR2	30.8	28.1	23.7	26.5	27.3
A30xR4	30.5	28.7	24	25	27.1
A6xR10	32.1	28.4	26.7	26.7	28.5
A41xR8	37.6	32.2	28.7	31	32.5
HD-1	34.1	30.3	29.6	29.5	30.6
Mean	32	29.2	26.4	28	28.9
CV%	5.7	8.1	10.8	6.2	8.1
SE±	0.91	1.1	1.4	0.87	0.58
Sig. level	*	Ns	Ns	*	**

100 grain weight

There were significant differences among the entries for 100 grain weight except at Wad Medani during 2012 (Table 4).The grain weight ranged from 2.3-2.8 g at Wad Medani, from 2.4-3.4 g at Suki and from 2.2-3.1g at New halfa. Across the three sites, the 100 grain weight was found not significant (Table 4).

Table 4.Mean of 100 grain weight (g) of sorghum hybrids evaluated over fourirrigated environments during season 2012 and 2014

Hybrid name	Medani		Suki	New Halfa	Mean
	2012	2014	2012	2012	
NS-5655	1.8	2.3	2.7	3.1	2.5
NS-5511	2.0	2.4	2.4	2.7	2.4
A8xR2	2.0	2.3	2.6	2.3	2.3
A30xR4	2.1	2.8	3.1	2.4	2.6
A6xR10	2.4	2.6	3.4	2.9	2.8
A41xR8	2.0	2.3	2.5	2.2	2.2
HD-1	2.5	2.5	2.9	2.6	2.6
Mean	2.1	2.5	2.8	2.6	2.7
CV%	11.9	8.8	11.4	7.6	87.3
SE±	0.12	0.1	0.15	0.98	0.59
Sig. level	Ns	*	*	**	NS

Stover yield T/ha

There were significant differences among the hybrids for stover yield except at Wad Medani during 2014 (Table 5). The Stover yield at Wad Medani ranged from 8.1-13.5 t/ha, from 6.5-10.9 t/hduring 2012 and 2014 respectively. At Suki, it ranged from 6.5 to 10.9 t/ha, while at New halfa from 17.8 to 26.7 t/ha. Across the three sites, there were significant differences among the hybrids and the stover yield of all the tested hybrids was greater than HD-1 (Table 5).

Table 5. Mean of Stover yield (T/ha) of sorghum hybrids evaluated over four irrigated environments during season 2012 and 2014.

Hybrid name	Medani		Suki	New Halfa	Mean
	2012	2014	2012	2012	
NS-5655	8.1	6.4	6.5	26.7	11.8
NS-5511	8.7	8.5	7.3	24.1	12.2
A8xR2	8.6	7.1	9.4	21.3	11.6
A30xR4	13.5	8.8	10.9	19.1	13.1
A6xR10	10.2	7.2	8.3	20.8	11.6
A41xR8	11.2	7.2	8.7	25.2	13.1
HD-1	8.2	7.5	8.1	17.8	10.4
Mean	9.8	7.5	8.5	22.1	12
CV%	17.9	16.8	12.3	7.5	19.1
SE±	0.87	0.63	0.52	0.83	0.57
Sig. level	*	Ns	*	***	*

Grain yield (t/h)

There were significant differences between hybrids for grain yield at Wad Medani, Suki and New halfa sites (Table 6). The grain yield at Wad Medani during 2012 and 2014 seasons ranged from 2.3-5.1 t/ha and from 2.1-3.8 t/ha respectively. At Suki, it ranged from 2.5-6 t/ha and from 3.4-4.6 t/ha at New Halfa. The overall mean for grain yield across the three sites ranged between 2.7-4.9 t/ha (Table 6).All entries out-yielded HD-1 in the grain yield except A41xR8.

Table 6. Mean of grain yield (t/ha) of sorghum hybrids evaluated over four irrigated environments during season 2012 and 2014

Hybrid name	Medani		Suki	New Halfa	Mean
	2012	2014	2012	2012	
NS-5655	3.8	2.5	4.3	4.3	3.7
NS-5511	4.4	3.3	4.4	4.2	4.1
A8xR2	4.9	2.1	4.9	3.4	3.8
A30xR4	4.6	2.1	5.4	3.6	3.9
A6xR10	5.1	3.8	6	4.6	4.9
A41xR8	2.3	2.2	2.5	3.9	2.7
HD-1	3.4	3.3	3.1	3.7	3.4
Mean	4	2.7	4.4	4	3.8
CV%	14.7	30.1	15.7	8.5	16.9
SE±	0.30	0.42	0.34	0.17	0.16
Sig. level	**	*	*	***	**

Grain yield stability and adaptability

The combined analysis over seasons and locations, showed a significant genotype x environment interaction for grain yield (Table 7). Similar results were also reported by Abdalla et al. (2009), who found that the mean squares of genotypes, environments and genotypes x environments interactions were highly significant (P=0.01). Also, Elasha et al. (2011) found significant differences between environments, genotypes and genotype x environment interaction. Over the irrigated environments, the hybrid A6xR10,NS-5511 and A30xR4 gave higher grain yield (4.9, 4.1 and 3.9 t/ha respectively) followed by the hybrids A8xR2 (3.8t/h). This grain yield was more than the grain yield of HD-1 (3.4 t/ha) (Table 8). According to Eberhart and Russel (1966), the hybrids A6xR10, NS-5511, A30xR4 and A8xR2 showed slope of 1.19, 0.74, 1.92 and 1.74 respectively, and deviations from regression of 0.6, 0.09, 0.17 and 0.3 respectively. Their mean grain yield was higher than the general mean of the trials and accordingly these hybrids are more adaptable and stable under irrigated conditions (Table 8).Similar results were also reported by Elsiddig and Elasha (2015) in their study for the stability and the adaptability of some local and introduced sorghum hybrids and they found that, hybrids DIA-07666, PAC-501 and E-1 showed slopes of (bi) 2.67, 2.34 and 1.18 with Sd^2 of 0.08, 0.45 and 0.12 and a mean grain yield above than the general mean; meaning that these hybrids are better and responsive to favorable environment.

Table 7. Mean squares from combined analysis of variance of grain yield and its components measured over irrigated environments during 2012 and 2014

		Irrigated environments					
Source of var.	d.f	F	PH	PNL	100 Sw	Yi	St
Environments(E)	3	398.3**	4828.2**	155.3**	13ns	13.5**	1306.4**
Replication (R)	12	25.7	283.5	8.4	5.5	1.5	3.9
Hybrid (G)	6	99.5**	2039.7**	63.3**	7.5sn	7.1**	14.1**
G x E interaction	18	37.6**	1206.6**	6.1ns	5.7ns	1.9**	18.8**
Error	72	8.6	233.8	5.0	5.7	0.4	2.1

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

DF= days to 50% flowering, PH= plant height (cm), PNL= panicle length (cm).

100Sw= seed weight/g, yi= yield (t/ha), St= Stover yield (t/ha).

Table 8. Stability parameters across irrigated environments for sorghum grain yield evaluated during season 2012 and 2014

Hybrid	**Mean**	**Slope (bi)**	**Se± slop**	**S^2_{di}**
NS-5655	**3.7**	1.14	0.276	0.662
NS-5511	**4.1**	0.74	0.084	0.094
A8xR2	**3.8**	1.74	0.559	0.316
A30xR4	**3.9**	1.92	0.440	0.171
A6xR10	**4.9**	1.19	0.386	0.671
A41xR8	**2.7**	0.28	0.779	0.453
HD-1	**3.4**	-0.02	0.233	0.048
Mean	**3.8**			

Conclusions

- The hybrids A6xR10,NS-5511, A30xR4 and A8xR2 were early in flowering, with reasonable plant height, high stover and high grain yield compared to control HD-1.
- Their mean grain yield was higher than the general mean of the trial and accordingly they are stable and adaptable for the irrigation conditions of central Sudan.

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