



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

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ABSTRACT

This experimental work was carried out during 2012 and 2014 seasons at three rainfed sites; Suki, Gedarif and Damazin. The hybrids tested were NS-5655, NS-5511, A8xR2, A30xR4, A6xR10, A41xR8 and HD-1 used as a check. The A8xR2, A30xR4, A6xR10 and A41xR8 are local Sudanese hybrids developed by Prof. Elasha A. Elasha at the Sorghum Research Program of the Agricultural Research Corporation (ARC), Sudan. NS - 5655, NS-5511 are foreign hybrids introduced from outside and supplied by Mahgoub sons Company. Land was prepared by disc harrowing followed by ridging at the three rain-fed sites. The design was a randomized complete block with four replications. Sowing was done at the first week of July and all other cultural practices were carried as recommended by ARC. The agronomic traits measured were days to 50% flowering, panicle length, plant height, grain yield, stover yield and 100 grain weights. Data was analyzed by IRRISTAT (2005 software) for separate seasons and both combined and stability analyses were carried according to the 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 over rainfed environments showed that, hybrids NS-5511 obtained 1.8 t/ha, A6xR10 1.8 t/ha, A30xR4 1.6 t/ha and A8xR2 1.5 t/ha higher than the grain yield of HD-1 which was 1.2 t/ha. The results showed that, these hybrids were also more adaptable and stable across the rainfed environments; in addition to their higher grain and stover yields compared to the check HD-1. Also, they were earlier in flowering with suitable plant height.

KEYWORDS:

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is one of the five most important cereal crops in the world (Doggett, 1988). It is mainly grown in the Semi-Arid Tropic of the world, particularly under rain fed conditions and considered the most staple food for millions of people in these areas. Sorghum is a major source of food in Africa and India with adaptive features that favor its growth in areas where other staple cereals such as wheat (*Triticum aestivum* L.), maize (*Zea mays* L.) and rice (*Oryza sativa* L.) would not be suitable (Hausmann *et al.* 2000; Rami *et al.* 1998). In the Sudan, Sorghum is grown under both irrigated and rainfed areas. The rainfed sorghum constitutes about 90% of the area. Sorghum plays a significant role in both, the small and large scale farmers as it is the leading cereal in term of production, consumption as well as the area cultivated. It is the chief source of food and income for the majority of people The cultivated area yearly varied due to biotic and a biotic factors and is annually estimated to be 7-8 million/ha. Both sorghum productivity and production were low. The national average sorghum productivity is about 0.6 t/ha and the production rarely exceeds 4 million tons per annum. The objective of the sorghum breeding program in Sudan, since its inception in the early mid-fifties has been the development of high yielding and combinable varieties for both irrigated and mechanized crop production (Mahmoud, 1966) as well as, the development of varieties that are adapted to a wide range of environments. Recently, the plant breeders in the Agricultural Research Corporation succeeded in releasing three hybrids (DIA-07666,PAC-501 and E-1 suitable for irrigated and high rain fall areas of the Sudan (Elasha *et al.* 2011).To raise the low national average sorghum grain yield of 0.6 t/ha, hybrids could be important candidates to be introduced for rainfed sites compared to the open pollinated varieties. Therefore, the objectives of this study was to evaluate the agronomic performance, grain yield and stability and adaptability of selected Sudanese and introduced sorghum hybrids under rainfed areas of the Sudan.

Materials and Methods

The experiment was carried out during 2012 and 2014 seasons at the rainfed locations; Suki, Gedarif, and Damazin. The hybrids tested were NS-5655, NS-5511, A8xR2, A30xR4, A6xR10, A41xR8 and HD-1 was used as a check. A8xR2, A30xR4, A6xR10 and A41xR8 are local Sudanese hybrids developed by Prof. Elasha A. Elasha at Sorghum Research Program of the Agricultural Research Corporation (ARC), Sudan. The introduced hybrids NS -5655, NS-5511 are supplied by Mahgoub sons Company. The breeding work on the local hybrids at the Sorghum Research program had started by Prof. Elasha A. Elasha on 2007 where various crosses involving different R lines were used. These 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, A6xR10 and A30x R4. During both seasons of 2012 and 2014, the land was prepared by disc harrowing and then ridging. Randomized Complete Block Design with four replications was used. Sowing was taken at the first to the third week of July depending on the onset of rainfall. The hybrids were sown to five rows 5 m length, on flat of 0.8 m apart at 0.2 m intra row spacing and thinned to two seedlings per hill., thinning to two seedlings per hill was

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carried at two to three weeks after emergence, followed by urea application at the rate of 40 kg /fed a week later. Other cultural practices were carried as recommended by the ARC. At each site and season, the net harvested area was three 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 collected at each site and season was; days to 50% flowering, panicle length, plant height, grain yield, stover yield and 100 grain weight. Data was analyzed by IRRISTAT (2005) software for separate seasons and both combined and stability analyses were carried according to the procedure of Eberhart and Russel (1966).

Results and Discussions

Agronomic traits

Days to 50% flowering

At the three rainfed sites, there were significant differences among hybrids for days to 50% flowering (Table1). The overall mean of days to 50% flowering ranged from 65 to 73 days with a general mean of 68 days. The results showed that, all hybrids were earlier than HD-1 a character that is important under rainfed conditions.

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

Hybrid name	Suki		Gedarif		Damazin		Mean
	2014	2012	2014	2012	2014	2012	
NS-5655	80	60	71	63	72	69	
NS-5511	80	57	71	60	66	66	
A8xR2	75	50	70	60	70	65	
A30xR4	80	55	74	63	72	69	
A6xR10	80	49	71	59	72	67	
A41xR8	85	57	78	61	78	72	
HD-1	84	61	77	62	81	73	
Mean	80.5	55.3	73	60.9	72.9	68.5	
CV%	4.6	5.5	1.8	1.4	4.7	4.9	
SE±	1.8	1.5	0.65	0.41	1.17	0.63	
Sig. level	*	***	*	*	*	**	

Plant height

There were significant differences between hybrids at the three rainfed sites (Table 2). The overall mean of plant height of the hybrids at the three rainfed sites ranged from 132.1cm for HD-1 to 150.4 cm for A30xR4. All the tested hybrids showed a reasonable plant height, a trait that is important for resistant to lodging and for machine harvest.

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

Hybrid name	Suki	Gedarif		Damazin		Mean
	2014	2012	2014	2012	2014	
NS-5655	116	159.2	102.7	177	111.3	133.2
NS-5511	121.5	147	107.7	169	118.8	132.8
A8xR2	148.7	143.7	123.5	145.3	135	139.2
A30xR4	150.5	141.2	140	164	156.3	150.4
A6xR10	134.7	129	121	161.5	127.5	134.7
A41xR8	143.5	140.7	120.5	173.5	143.7	144.4
HD-1	127.5	126.2	116.5	157.7	132.5	132.1
Mean	134.5	141	118.8	164	132.1	138.1
CV%	7.6	6.8	6.3	5.6	2.8	9.2
SE±	5.1	4.8	3.7	4.6	1.87	2.3
Sig. level	**	*	*	*	*	**

Panicle length

There were significant differences among hybrids for panicle length except for Gedarif at season 2012. Across the five environments, mean panicle length ranged from 23 cm to 30.7 cm with all hybrids showing a reasonable panicle length compared to HD-1 (Table 3).

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

Hybrid name	Suki	Gedarif		Damazin		Mean
	2014	2012	2014	2012	2014	
NS-5655	26.5	29.5	22	22.2	26.7	25.4
NS-5511	25.2	30	21.7	28.2	26.7	26.4
A8xR2	24.5	26.7	21.7	15.7	26.2	23
A30xR4	24.5	29.7	24.7	18.7	28.5	25.2
A6xR10	25.5	27	23.5	24.2	26.3	25.3
A41xR8	34.2	31.2	28.2	27.5	32.5	30.7
HD-1	28.7	27.7	25.2	33.7	29	28.9
Mean	27	28.8	23.89	24.3	28	26.4
CV%	8.1	9.7	6.3	12.1	6.7	12
SE±	1.1	1.3	0.75	1.4	0.93	0.59
Sig. level	*	Ns	*	*	*	**

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100 grain weight/g

Over the five environments, there were no significant differences between hybrids for 100 grain weight, except at Damazin during 2012 season (Table 4). The mean 100 grain weight for the hybrids across the three rainfed sites ranged from 2.3 to 2.5g.

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

Hybrid name	Suki		Gedarif		Damazin	
	2014	2012	2014	2012	2014	Mean
NS-5655	2.6	2.6	2.5	2.7	1.6	2.4
NS-5511	2.5	2.5	3.0	2.4	1.8	2.4
A8xR2	2.6	2.5	2.9	1.9	1.7	2.3
A30xR4	3.1	2.5	2.7	2.3	1.6	2.4
A6xR10	2.9	2.6	2.9	2.1	1.5	2.4
A41xR8	2.3	2.5	2.7	2.2	1.5	2.3
HD-1	2.5	2.6	2.9	2.8	1.5	2.5
Mean	2.6	2.5	2.83	2.3	1.6	2.3
CV%	11.8	6.4	8.8	6.6	8.1	10.9
SE±	0.15	0.81	0.12	0.76	0.64	0.49
Sig. level	Ns	Ns	Ns	*	Ns	NS

Stover yield (T/h)

Development of hybrids with high stover and grain yield is important for both growers and farmers. There were significant differences among entries for stover yield except at Suki during 2014 (Table5). Across the three sites, the stover yield of the hybrids ranged from 3.7 for A8xR2 to 4.6 t/ha for A41xR8 compared to 4.4 t/ha for HD-1.

Table 5. Mean of stover yield (t/ha) of sorghum hybrids evaluated over five rainfed environments during season 2012 and 2014.

Hybrid name	Suki		Gedarif		Damazin		Mean
	2014	2012	2014	2012	2014	2012	
NS-5655	3.5	4.7	2.5	5.9	5.4	4.4	4.4
NS-5511	2.8	3.7	4.1	4.9	5.5	4.2	4.2
A8xR2	3.2	2.6	2.3	5.1	5.4	3.7	3.7
A30xR4	3.9	3.1	3.1	5.8	5.1	4.2	4.2
A6xR10	3.7	2.6	3.3	4.5	5.3	3.9	3.9
A41xR8	4.1	4.5	3.4	5.7	5.4	4.6	4.6
HD-1	3.5	2.9	3.5	5.9	6	4.4	4.4
Mean	3.5	3.4	3.1	5.4	5.4	4.1	4.1
CV%	21	18.5	8.3	2.8	3.4	15.1	15.1
SE±	0.37	0.32	0.13	0.77	0.91	0.12	0.12
Sig. level	Ns	*	*	*	*	*	*

Grain yield

Across all rainfed sites, there were highly significant differences between the hybrids. Mean grain yield of the hybrids ranged from 1.2 t/ha for HD-1 to 1.8 t/ha for NS-5511 and A41xR8 (Table 6). Greater mean grain yield values were obtained by NS-5511 (1.8 t/h), A6xR10 (1.8 t/h), NS-5655 (1.7 t/h) and A8xR2 (1.5 t/h) compared to a mean grain yield of 1.2 t/ha for HD-1 (Table 6).

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

Hybrid name	Suki		Gedarif		Damazin		Mean
	2014	2012	2014	2012	2014	2012	
NS-5655	1.5	1.9	1.22	1.72	2.10	1.7	1.7
NS-5511	2.3	1.6	1.25	1.33	2.42	1.8	1.8
A8xR2	2	0.99	1	1.62	1.97	1.5	1.5
A30xR4	2	1.1	1.22	1.72	1.85	1.6	1.6
A6xR10	2.6	1.5	1.15	1.53	1.95	1.7	1.7
A41xR8	0.51	1.7	0.95	1.89	1.20	1.8	1.8
HD-1	1	1.1	1.1	1.69	1.12	1.2	1.2
Mean	1.7	1.4	1.13	1.64	1.80	1.5	1.5
CV%	30.3	13	8.4	6.7	25.5	21.3	21.3
SE±	0.26	0.092	0.47	0.55	0.23	0.07	0.07
Sig. level	**	**	*	*	Ns	**	**

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Adaptability and grain yield stability

The combined analysis of variance showed highly significant differences in grain yield over the five rainfed environments, for the genotypes and for environment x genotype interaction (Table 7). Similar results were also reported by Elsiddig and Elasha (2015) who studied the adaptability and the grain yield stability for some local and introduced sorghum hybrids. They found significant differences in grain yield for environments, genotypes and environment x genotypes interaction.

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

Irrigated environments							
Source of var.	d.f	F	PH	PNL	100 Sw	Yi	St
Environments (E)	4	2895.17**	7680.04**	136.20**	6.71**	2.07**	34.84**
Replication (R)	15	9.87	59.86	7.28	0.05	0.08	0.11
Hybrid (G)	6	181.44**	970.43**	134.20**	0.13**	1.12**	1.94**
G x E interaction	24	25.06**	548.31**	29.70	0.17**	0.69**	1.25**
Error	90	7.466	70.98	5.38	0.05	0.11	0.22

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

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

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

Many stability statistical methods have been used to determine whether or not cultivars evaluated in multi-environment trials were stable or not. Among these, are those that are based on linear regression which are described by Eberhart and Russel (1966). They defined the stable variety as one with slope $b = 1$, a deviation from regression $S^2_d = 0$ and with a grain yield higher than the overall mean grain yield of the trial. According to them, the hybrids NS-5511, A6xR10, A30xR4 and A8xR2 showed slopes of 1.5, 1.5, 1.2 and 1.6 respectively with deviations from regression of 0.1, 0.1, 0.06 and 0.06 respectively. Their mean grain yield is more than the control HD-1 and above the general mean of the trial of 1.5. These findings indicated that, these hybrids are more stable and adaptable under rainfed environments. Similar findings were also reported by Elzeinet *al.* (2008).

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

Hybrid	Mean	Slope(bi)	Se± slop	S ² _{di}
NS-5655	1.7	0.83	0.540	0.087
NS-5511	1.8	1.59	0.779	0.180
A8xR2	1.5	1.67	0.460	0.063
A30xR4	1.6	1.24	0.454	0.061
A6xR10	1.8	1.54	0.735	0.160
A41xR8	1.3	-0.07	1.207	0.433
HD-1	1.2	0.17	0.576	0.098
Mean	1.5			

Conclusions

- The hybrids A6xR10,NS-5511, A30xR4 and A8xR2 were earlier in flowering have reasonable plant height, high grain and stover yield compared to the control HD-1.
- Across the five rainfed environments, these hybrids out yielded the control HD-1 and had a mean grain yield higher than the general mean of the trial.
- The hybrids are more adaptable, stable and are suitable for high rainfall environments (650 mm and above).

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