Assessment of phenotypic performance, association and path analysis of upland cotton (*Gossypium hirsutum* L.) yield and fiber quality traits in central Sudan

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ABSTRACT

Fifteen upland cotton inbred lines and the check (commercial cultivar *Hamid*) were evaluated during 2013/14 and 2014/15 seasons at the Rahad Research Station Farm, Gezira Research Station Farm and Sennar Research Station Farm of the Agricultural Research Corporation, Sudan. The objective was to estimate seed cotton yield potential and carry out interrelationships and path coefficient analysis. Treatments were arranged in a randomized complete block design with four replicates. Data were collected on days to 50% flowering, number of sympodia/plant, number of bolls / plant, plant height, ginning out-trun, boll weight, seed cotton yield (kg/ha) and fiber characteristics . The study showed significant differences among the genotypes for all characters. Seed cotton yield over environments ranged between 1907 and 2380kg/ha. The genotypes R-6, R-40, R-231 and R-43 showed the best seed cotton yield ranging from 2310 to 2380 kg/ha over environments. At the same time, these genotypes had good number of sympodia / plant, GOT%, lint index, seed index and number of bolls / plant. Over environments, line R-231 revealed high fiber length (28.9 (2.5% SL)) and bundle strength (30 g⁄tex). The simple linear correlation and path coefficient analysis showed that seed cotton yield was highly significantly and positively correlated with most traits. In conclusion, genotypes R-6, R-40, R-231, and R-43 are recommended for further testing over a range of environments to examine their yield and fiber quality for large field production.

INTRODUCTION

Cotton is the natural source of fiber and secondly most important oil seed crop after soybean in the world. Upland cotton dominates the world's cotton fiber production accounting for approximately 90% of the total production. Cotton in the Sudan had been grown since 1867 by flood irrigation in Toker Delta in eastern Sudan.

Progress in plant breeding depends on the extent of genetic variability present in a population that permits effective selection procedures, based on locally adapted land races (Swarp and Chaugale, 1962). Therefore, the first step in any plant breeding program is the study of genetic variability, which cannot easily be measured. Correlation studies are important in breeding program, as they give information on direction and magnitude of association between different traits. This could be utilized to select for one character indirectly by selection for another one (Sharaan and Ghallab, 1997). The objectives of cotton breeding programs in the Agricultural Research Corporation of the Sudan is to increase productivity and sustainability of cotton production in the country and thereby making better use of national resources.

Therefore, the cotton breeders are looking for traits used as potential selection criteria with yield to develop high and stable genotypes. The objective of this study was to evaluate the performance of yield potential, the extent of genetic variability and interrelationships of 16 upland cotton genotypes at six growing environments of cotton in the Sudan.

MATERIALS AND METHODS

The experiments were conducted over two consecutive seasons (2013/14 and 2014/15) in three locations, which were: (1) Rahad Research Station (RRS) Farm in the clay plains of east Sudan between latitude 13º 31'– 14 º 25' N, longitude 33 º 31' - 34 º 32' E and 570 masl. The soil is vertisol with 78% clay content, pH 7.8, 0.74% O. C. and N% of 0.04%, the area has a semi-arid climate with a summer rainfall of 300 - 600 mm (Hammed, 2001); (2) Gezira Research Station Farm (GRSF), located in the central clay plain of the Sudan latitude 14º 24' N,33º 29' E, longitude 33º 32'E and 407 masl with a soil characterized by cracking heavy clay (vertisols), very low water permeability, pH of 8.3 organic matter (0.4%), nitrogen (0.04% ppm), and phosphorus (ESP, 4 ppm) and (3) Sennar Research Station (SRS) Farm with a soil characterized by cracking heavy clay (vertisols), with a pH of 7.8, nitrogen of 0.025-0.07%, organic matter (0.6%) and latitude 13 º 12' N, longitude 33 º 32' E and 417 msal.

Fifteen inbred lines were selected from a certain genetic material (Ahmed, 2007). The entries were R-6, R-1, R-43, R-42, R-93, R-114, R-200, R-43-1, R-187, R-96, R-231, R-240, RS-5,RS-2, RS-10 and the variety *Hamid* was used as a check. Continuous selfing up to F9 was used in the designated material.

Table1. Designation and description of the genotypes used in the study.

Genotype	Pedigree
1- R-6	Wagar x Barac(67)B
2- R-1	Wagar x Barac(67)B
3- R-43	Wagar x Barac(67)B
4- R-42	Wagar x Barac(67)B
5- R-93	Wagar x Shambat-B
6- R-114	Barac(67)B x Shambat-B
7- R-200	Barac(67)B x Acala(93)H
8- R-43-1	Wagar x Barac(67)B
9- R-187	Barac(67)B x Acala(93)H
10- R-96	Wagar x Shambat-B
11- R-231	Barac(67)B x Acala(93)H
12- R-240	Acala(93)H x Chandri
13- RS-5	Niab78 x BA1303
14- RS-2	Barac(67)B x Brycot
15- RS-10	Niab78 x BA1303
16- Hamid	Commercial variety

The standard cultural practices adopted for cotton production at ARC were followed. Experiments were conducted using a randomized complete block design with four replicates. *Effective* sowing dates were the first week of July at the three locations and during the two growing seasons. Hand harvesting was done after boll opening. Five random plants were selected from each plot to score the days to 50% flowering, number of bolls / plant, number of sympodia / plant and plant height. Thirty random bolls were picked from each plot to measure boll weight, ginning out-turn (GOT), seed cotton yield (kg/ha) and lint quality characteristics (length of fiber (2.5 span lengths, micronair value and fiber bundle strength).

Analysis of variance was performed for each season; location and combined to test for significant differences among genotypes. Means for seasons were used to compute simple linear correlation coefficients between all possible combinations. The path coefficients procedure was used to partition correlation coefficients between seed cotton yield and its components into direct and indirect effects.

RESULTS AND DISCUSSION

Although the separate effects of season, location and genotype on most characters were significant (Tables 2 and 3), but their second degree interaction effects (S x L x G) were significant only for number of sympodia/plant, plant height and seed cotton yield. Final results are difficult to explain because the first degree interaction effects of genotype with location (G x L) were significant for all characters while that of (G x S) were significant for only four characters (seed cotton yield was one of them) out of a total of nine characters (Tables 2 and 3).

Table 2. Mean squares of different cotton yield parameters of 16 genotypes grown at Rahad, Gezira and Sennar Research Stations for season, 2013/14.

SOV	DF	NSP	NBP	PH	YI	GOT	BW
Location(L)	2	104.1***	729.6***	9410***	54633758***	12.11***	3.14***
Genotype (G)	15	8.02**	12.77	1273***	371220**	40.21***	2.28***
LxG	30	6.08*	18.68	316*	257979*	2.13*	0.32*
Error	141	3.31	13.59	159.7	147545	1.6	0.19

*, **, *** Significant at P = 0.05, 0.01 and 0.001 levels, respectively. NSP = number of sympodia per plant, NBP= number of bolls per plant, PH = plant height (cm), YI = Seed cotton yield (kg ha^{-1}),
GOT = Ginning out-turn and BW = boll weight (g).

Table 3. Mean squares of different cotton yield parameters of 16 genotypes grown at Rahad, Gezira and Sennar Research Stations for season, 2014/15.

SOV	DF	NSP	NBP	PH	YI	GOT	BW
Location(L)	2	965.9***	7267***	52607***	6056636***	2327***	2.05***
Genotype (G)	15	23.7***	32.1***	874	301372	32.08***	0.9***
LxG	30	13.7***	13.9*	206	376628	1.96**	0.16
Error	141	5.66	8.47	149.38	316168	1.03	0.13

*, **, *** Significant at P = 0.05, 0.01 and 0.001 levels, respectively. NSP = number of sympodia per plant,
NBP= number of bolls per plant, PH = plant height (cm), YI = Seed cotton yield (kg ha^{-1}),
GOT = Ginning out-turn and BW = boll weight (g).

In general, the genotypes showed significant differences in days to 50 % flowering. Lines R-43, R-114, and R-231as well as cultivar *Hamid* showed mean days to 50% flowering of 55, 54, 54 and 55, respectively, while lines R-93, Rs-2 and Rs-10 showed mean days of 59, 57 and 58, for this character, respectively. The members of the first group were early flowering genotypes while the members of the second group were late flowering (Table 4).

The analyses of variance (Table 4) *revealed* significant differences in mean number of sympodia/plant of the 16 genotypes under study at Rahad, Gezira and Sennar Research farms for seasons 2013/14 and 2014/15. Line R-6, R-43, R-114 and RS-5 showed the highest number of sympodia/plant while R-1 and R-240 showed the lowest (Table 4). R-43 and R-114 are early flowering genotypes.

The genotypes showed significant differences in mean number of bolls /plant at the three locations and in the two seasons (Tables 2 and 3). Lines R-43 and R-114 showed the highest number of bolls/plant (17.7 and 17.0 bolls /plant over environments, respectively) (Table 4). These lines gave high seed cotton yield. Similar results were obtained by Singh *et al.* (1968), Kalwar and Shabani (1983) and Tyagi (1987) who reported positive correlation between number of bolls/plant and seed cotton yield. Lines R-187, R-96 and *Hamid* (the check) showed the lowest values for this trait.

Table 4. Means across locations of 50% days to flowering, number of sympodia / plant and number of bolls / plant of 16 cotton genotypes grown in Rahad, Gezira and Sennar Research Station Farms during seasons 2013/14 and 2014/15.

Genotype	Season 2013/14			Season 2014/15			Mean over seasons		
	50% F	NS P	NB P	50% F	NSP	NB P	50% F	NSP	NBP
1-R-6	56	9	8	55	11	16	55	10	15
2-R-1	55	8	8	56	7	15	55	8	14
3-R-43	54	9	13	55	12	19	55	11	18
4-R-40	55	10	10	57	9	15	56	10	16
5-R-93	60	9	7	57	8	15	59	9	15
6-R-114	54	10	10	54	10	17	54	10	17
7-R-200	55	9	8	56	9	16	56	9	15
8-R-43-1	54	10	11	56	10	18	55	10	17
9-R-187	57	8	8	57	10	15	57	9	14
10-R-96	54	8	8	58	9	13	56	9	13
11-R-231	55	10	6	55	9	15	55	9	15
12-R-240	55	9	7	56	7	13	55	8	14
13-RS-5	54	9	11	57	11	17	56	10	16
14-RS-2	58	8	11	56	10	15	57	9	15
15-RS-10	60	8	9	56	9	15	58	8	14
16-Hamid	55	8	8	55	9	14	55	9	14
Mean	56	9	8	56	9	16	56	9	15
CV(%)	2.0	19.4	18.1	3.0	21.2	18.8	2.5	20.3	22.2
SE(±)	0.3	0.2	0.3	0.2	0.3	0.7	0.3	0.2	0.4

Across the different environments, the tallest genotypes were R-187, R-96 and R-231 (more than 123 cm tall) over mean seasons. The shortest genotypes were R-40 and R-114 (less than one meter) over mean seasons (Table 5).

Heaviest boll weight was scored by line R 1 and R-240 (4.9 gm), whereas the lowest one was given by Line R-114 and R-43-1 (4.1 gm) (Table 5).

The highest GOT value over locations and seasons was given by Line R-43 (41.0%) followed by Line R- 1, R-40 and RS-2 (40.0%), while line R-96 and the check Hamid recorded the lowest GOT (35.0%). Significant differences were detected among the 16 genotypes for GOT, revealing the presence of sufficient genetic variability. The magnitude and the significance of the interactions necessitate the evaluation of the genotypes for GOT at different locations and in more than one season (Table 5).

Table 5. Means across locations of plant height, boll weight and ginning out-turn (GOT) of 16 cotton genotypes grown in Rahad, Gezira and Sennar Research Station Farms during seasons 2013/14 and 2014/15.

Genotype	Season 2013/14			Season 2014/15			Mean over seasons		
	PH	BW	GOT %	PH	BW	GOT %	PH	BW	GOT %
1-R-6	106.1	4.8	38	122.3	4.3	39	114.2	4.6	39
2-R-1	97.1	5.2	40	118.3	4.7	40	107.7	4.9	40
3-R-43	100	4.5	41	110.4	4.3	41	105.2	4.4	41
4-R-40	88.7	4.6	40	109	4.2	40	98.9	4.4	40
5-R-93	107.2	4.8	37	116.6	4.2	39	111.9	4.5	38
6-R-114	94.3	4.4	38	104.7	3.9	38	99.5	4.1	38
7-R-200	107.9	4.6	39	126.1	4.1	39	117	4.4	39
8-R-43-1	91.5	4.1	36	117.6	4.0	36	104.5	4.1	36
9-R-187	118.8	4.6	37	133.1	4.1	38	126	4.4	38
10-R-96	117.5	4.8	35	134.2	4.3	36	125.8	4.6	35
11-R-231	119.6	5.2	36	126.9	4.4	36	123.3	4.8	36
12-R-240	100	5.3	38	111.7	4.5	39	105.8	4.9	38
13-RS-5	89.7	4.6	38	113.5	4.4	38	101.6	4.5	38
14-RS-2	104.1	5.0	39	118.1	4.6	40	111.1	4.8	40
15-RS-10	96.6	4.5	37	115	4.2	38	105.8	4.3	37
16-Hamid	114.1	5.1	34	126.5	4.5	35	120.3	4.8	35
Mean	103	4.8	38	119	4.3	38	111	4.5	38
CV(%)	011.3	8.4	03.0	009.2	6.9	03.0	010.2	7.6	03.0
SE(±)	001.4	0.1	00.2	000.1	0.1	00.1	001.3	0.1	00.1

Lines R-6, R- 40, R-231, and R-43-1 gave the highest seed cotton yield over all locations and seasons (2380 kg/ha, 2350 kg/ha, 2339 kg/ha, 2334 kg/ha, and 2310 kg/ha, respectively) (Table 6). On the other hand, the two genotypes RS-10 and the check *Hamid* showed the lowest mean seed cotton yield across locations and seasons (1907 kg/ha, and 1987 kg/ha), respectively. Season 2014/15 was better than season 2013/14 for seed cotton yield because the rainfall of 2014/15 was higher and uniformly distributed compared to the 2013/14 season. The high yield potential of lines R-6, R- 40, R-231, and R-43-1 could be attributed mainly to number of bolls / plant and number of sympodia/plant. Lines R-43 and R-40 recorded the highest GOT (41% and 40% respectively).

Across genotypes and environments, lines R-96 and R-231 recorded the longst fiber length (29.6 mm and 28.9mm, respectively). Similar results were reported by Behery (1993). The uniformity ratio for all genotypes over environments was more than 80% UI (Table 6). Micronair (fiber fineness) varied from location to another, season and irrigation (Chewning, 1995). They reported that, in USA, the acceptable upland micronaire range for which no price penalty is assessed is 3.5 to 4.9, with a premium range of 3.7 to 4.2. Empirical relationships have been developed between micronaire and cotton-fiber processing properties and bale-average micronaire readings which are used by mills in bale selection and blending. Over environments line R-231 revealed high fiber 25 % SL ((28.9) 2,5% SL) and bundle strength (30 g⁄tex) (Table 6) .

Table 6. Mean of seed cotton yield (kg/ha) and fiber quality of 16 cotton genotypes grown in Rahad, Gezira and Sennar Research Station Farms during seasons 2013/14 and 2014 / 15.

	Seed yield	cotton		Fiber test			
Genotype	Season 2013/14	Season 2014/15	Over seasons	UHM	UI %	Mic	HVI
1-R-6	2188	2573	2380	26.3	82.8	5.2	28.4
2-R-1	1999	2531	2265	25.2	80.8	4.4	26.4
3-R-43	2259	2361	2310	27.0	84.0	4.8	28.6
4-R-40	2235	2464	2350	27.1	83.6	5.1	28.0
5-R-93	2203	2274	2239	27.9	83.8	4.7	28.7
6-R-114	2184	2352	2268	25.7	82.4	5.2	27.5
7-R-200	2204	2135	2169	27.8	83.1	4.5	28.2
8-R-43-1	2118	2549	2334	26.6	83.3	4.6	28.1

9-R-187	1922	2171	2047	28.4	84.6	4.4	28.9
10-R-96	1864	2258	2061	29.6	84.4	3.6	29.1
11-R-231	2274	2403	2339	28.9	85.1	5.1	30.5
12-R-240	2334	2236	2285	28.6	83.7	4.3	28.9
13-RS-5	2067	2407	2237	27.1	83.1	4.7	28.4
14-RS-2	2099	2228	2164	25.6	82.0	4.3	27.0
15-RS-10	1706	2107	1907	27.3	84	4.9	28.2
16-Hamid	1888	2086	1987	27.6	82.5	4.7	28.6
Mean	2096	2321	2209	27.3	83.3	4.7	28.3
CV(%)	18.1	18.5	18.3	-	-	-	-
SE(±)	62.8	45.8	39.2	-	-	-	-

UHM = Upper half mean length, UI% = Uniformity ratio, FM = Fiber Maturity, Mic = Micronair (fiber fineness) and HVI = high volume instrumeter.

Simple linear correlation coefficients

Seed cotton yield showed highly significant, positive correlation coefficients with most traits with the exception of GOT (Table 7). Its positive correlation coefficient with (GOT) was small and non-significant. The current findings are in agreement with those of Dedaniya and Pethani (1994) and Carvalho who observed that seed cotton yield per plant was positively correlated with number of bolls/plant, plant height, boll weight, lint weight per plant and bundle strength tenacity.

Number of sympodia/plant showed positive and non-significant correlation coefficient with boll weight, but highly significant negative correlation coefficient with number of bolls/plant. Number of bolls / plant showed positive and non-significant correlation coefficients with boll weight, but negative and significant correlation coefficients with plant height and GOT.

Table 7. Simple linear correlation coefficients among seed cotton yield and its components of 16 cotton genotypes grown in Rahad, Medani and Sennar Research Farms during seasons 2013/2014 and 2014/15.

Traits	NSP	NBP	PH	GOT%	BLWT	YI
NSP	-	-0.637***	- 0.011	-0.008	0.049	0.437***
NBP		-	-0.437***	-0.099*	0.139**	0.214***
PH			-	-0.037	-0.076	0.136**
GOT%				-	- 0.046	0.094
LI					0.492***	0.242***
SI					0.545***	0.321***
BLWT					-	0.311***

*, **, *** Significant at P = 0.05, 0.01 and 0.001 levels, respectively.NSP = number of sympodia per plant, NBP = number of bolls per plant, PH = plant height (cm), GOT% = ginning out-turn, BLWT = boll weight (g) and YI = seed cotton yield (kg ha^{-1}) .

Path coefficient analysis

All measured agronomic traits were analyzed by path coefficient analysis model to determine the direct and indirect effects on seed cotton yield and results are presented in Table (8).

The highly significant association of number of sympodia/plant (0.437***) with seed cotton yield was due to its direct effect (0.425) while the indirect effects are negligible. This suggested the direct use of number of sympodia/plant as a selection criterion for high seed cotton yield. Also, the association of boll weight (0.311***) with seed cotton yield was due to its direct effect (0.189) while the indirect effects are small. The results are in accordance with the findings of Do-Tha-Ha-An *et al.* (2008) and Venkateshwarlu *et al*. (2010) who reported that number of bolls per plant exerted maximum direct effect on seed cotton yield per plant followed by boll weight, number of sympodia per plant and lint index. 2.5% span length and uniformity ratio also had positive direct effect, but the association of number of bolls /plant (0.214) with seed cotton yield was not due to its direct effect (0.007) but due to its indirect effect, mainly through number of sympodia/plant (0.271). This suggested the use of this character as an indirect selection criterion *via* number of sympodia / plant.

The path analysis identified number of sympodia/plant and boll weight as the most important characters which require breeder's attention in deciding appropriate selection strategies and could be used as potential selection criteria for developing high yielding cotton varieties in central Sudan. This agreed with the correlation analysis and, in conclusion, number of sympodia/plant could be used as potential selection criteria in breeding programs for developing high yielding cotton genotypes.

Table 8. Path coefficient analysis of direct and indirect effects of agronomic characters of seed cotton yield of 16 genotypes grown in seasons 2013/14 and 2014/15 (average across locations).

Traits	NSP	NBP	PH	GOT	BLWT	rj
NSP	**0.425**	-0.0045	-0.0019	-0.001	0.0093	0.437***
NBP	0.271	**-0.007**	-0.0704	-0.0135	0.0263	0.214***
PH	-0.0051	0.0031	**0.161**	-0.005	-0.0144	0.136**
GOT	-0.0034	0.001	-0.006	**0.136**	-0.0088	0.094
BLWT	0.0208	-0.001	-0.0122	-0.0064	**0.189**	0.311***

, * Significant at P = 0.01 and 0.001 levels, respectively. Direct effects are in bold.NSP = number of sympodia per plant, NBP = number of bolls per plant, PH = plant height (cm), GOT% = ginning out-turn, BLWT = boll weight (g) and YI = seed cotton yield (kg ha^{-1}), rj = simple linear correlation coefficients.

CONCLUSION

Based on the results of this study, it could be concluded that the highest yielding genotypes were lines R-6, R- 40, R-231, and R-43. Also, the number of sympodia/plant, number of bolls / plant, and boll weight could be used as potential selection criteria in breeding programs for developing high yielding cotton genotypes under Sudan irrigated sector.

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تقييم الأداء الظاهري والاختلافات الور اثية والارتباطات وتحليل المسار لصفات الانتاجية وجودة شعرة القطن الامريكي (.*Gossypium hirsutum* L) للانتاج و صفات جودة الشعرة في وسط السودان

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الخلاصة

تم اختبار 15 سلالة نقية من القطن الأكالا (.*Gossypium hirsutum* L) بالأضافة الي الصنف حامد المنزرع تجاريا بالسودان في موسمي 2013/14 و 2014/15 في محطة بحوث الرهد و محطة بحوث الجزيرة و محطة بحوث سنار, هيئة البحوث الزراعية , السودان. الهدف من هذه التجربة هو تقدير الاداء والعلاقات المتداخلة للانتاجية ومكوناتها. استخدم تصميم القطاعات العشوائية الكاملة بأربعة مكررات. الصفات التي تم قياسها هي 50% ازهار و عدد الأفرع الثمرية بالنبات و عدد اللوز بالنبات و طول النبات و تصافي الحليج و وزن اللوزة والانتاجية بالهكتار وخصائص الشعرة. نتائج التحليل أظهرت فروقات معنوية بين الطرز الوراثية في جميع الصفات. متوسط الانتاجية تراوح ما بين 1907 و 2380 كيلو جرام للهكتار. أظهرت الطرز الوراثية التالية: R-6 و R-40 و R-231 و R-43 انتاجية عالية تراوحت ما بين 2310 الي 2380 كيلوجرام للهكتار كمتوسط لكل البيئات. امتازت هذه الطرز بأفرع ثمرية كثيرة و بتصافي حليج عالي و عدد كبير للوز بالنبات. أظهرت السلالة R-231 طول شعرة (28,9 2,5% SL ومتانة الفتلة (30 g/tex) في البيئات المختلفة. كما أظهر تحليل المسار والارتباط الجيني أن كل الصفات ارتبطت ايجابا بانتاجية القطن زهرة مع تصافي حليج عالي. خلاصة البحث واستناداً علي متوسط الأداء يوصى باختبار انتاجية الطرز الوراثية R-6 وR-40 وR-231 وR-43 في عدة مواقع ومواسم للتأكد من نتائج هذه الدراسة والاستفادة منها في توصية باجازة بعض هذه الطرز لتناسب الظروف البيئية في السودان.