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Concurrent Improvement of Stem Sugar, Stover and Grain Yield in Sudanese and Exotic Sorghums I: Identification of Materials

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Authors' contributions

This work was carried out in collaboration between the two authors. Author SIA conducted the field experiments, carried out laboratory work, collected and prepared the data for analysis. Author MIM provided the plant materials, designed and supervised the study, performed the statistical analysis and wrote the protocol. Both authors approved the final manuscript.

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ABSTRACT

Aims: To identify materials combining high levels of stem sugar, grain and stover yields in local and exotic sorghum (*Sorghum bicolor* (L.) Moench) genotypes.

Methodology: 28 genotypes arranged in three replicated Alpha lattice design and evaluated for stem juice, grain and stover yields and related traits.

Results: The exotic materials showed high potential for sugar yield than the local ones. Blue-ribbon and Red-x demonstrated the best joint performance for brix, extractability, grain, and stover yields. Ank.36 (Ankolib selection) and S.158 (Abu Sabin selection) were the best among local materials in joint performance for extractability and brix showing moderate potential for sugar yield during the summer season. Kambal (Abu Sabin selection) showed the best juice yield among the local materials but suffered from low brix and juice extractability. Some of the local genotypes

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performed better than the exotic materials during summer in grain, stover and cane yields whereas the opposite is true during the winter season.

Conclusion: The local Ankolib population needs to be improved for juice extractability and cane yield before being used for bioenergy production. The future research work should focus on improving the local materials by hybridization with the exotic ones to transfer traits related to high sugar yield.

Keywords: Stover; millable cane; extractability; brix; stem juice; Ankolib.

1. INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is a crop of world-wide importance, ranking fifth among the important cereal crops [1]. It is a C4 species with greater resource-use photosynthetic efficiency employed to support the multipurpose-usability of the crop. Much of the agricultural history of sorghum has been for food, beverage, feed and building material [2]. Recently, sorghum also appeared to have great potential as an annual energy crop. Depending on the feedstock, the known three types of sorghum (grain, juice and fodder) could be utilized in energy production [3]. Forage sorghum is an energy sorghum bred for high biomass production for cellulosic ethanol conversion processes. Grain types can be used in starch to ethanol conversion processes. The juice in sweet sorghum types is directly fermented to produce ethanol. Considering the unique genetic variability in sorghum, such versatile nature may support the possibility of developing a “three in one” (grain, forage and energy) sorghum varieties, yet sorghum received little attention as a multi-purpose crop and was widely investigated as single–commodity crop. Such mono-commodity breeding strategy of sorghum has been questioned by some workers [4,5]. Tapping the full potential of sorghum as feed, food, and biofuel feedstock has become a necessity under the increased population pressures and depleting fossil energy. Concurrent evaluation of multi-purpose traits in sorghum will provide valuable information on how various economic traits of this crop are interrelated; hence improving our knowledge of sorghum as a multi-purpose crop.

The present study aims at the parallel investigation of stem-juice, grain and stover attributes in some local and exotic sorghum genotypes. The objectives were to identify materials showing the best compromise between multi-economic traits of sorghum and assessing the possibility of selecting sorghum cultivars combining high levels of stem sugars, grain and stover yields.

2. MATERIALS AND METHODS

2.1 The Experimental Site

The study was conducted in Sudan in the Experimental Farm of Shambat Research Station (lat.15° 39 N; long.32° 31 E) during summer of 2012 and winter of 2012/2013 seasons. The soil is heavy clay with pH of 8.5. The climate is hot and dry. Average Min and Max were 26.8°C and 38.2°C, respectively. The rainy season is short extending from July to October with scant and fluctuating precipitation.

2.2 Plant Materials

28 genotypes representing 4 groups as depicted in Table 1 were used in this study. The first 14 genotypes comprised the exotic sweet sorghum group. The other 14 genotypes are local genotypes representing 3 groups with major uses as dual forage /grain (Abu Sabin), forage (Sudan grass) and sweet sorghum (Ankolib). All of the local materials except ‘Anknyala’ undergone improvement for juiciness and/or forage production.

2.3 Management, Experimental Design and Layout

Sowing dates were on 22/ July/2012 and 6/ Dec/2012 for the summer and winter sowings, respectively. Planting was done on 5m long ridges by placing 5 seeds in holes spaced 0.7m x 0.2m. The seedlings were later thinned to approximately three plant /hole. The trials were watered at 7 to 10 days interval and nitrogen fertilizer (urea) was added at the second irrigation at a rate of 55 kg n / ha. The insecticide Sevin (Carbaryl 85 WP) was sprayed against stem borers one month after sowing. Weed population was kept to a minimum by `hand removal. The 28 genotypes were arranged in α lattice design [6] with

Table 1. The 28 sorghum genotypes used in the study (Shambat, 2012-2013)

No	Genotypes	Source	Group / Type
1	N98	USDA (U. of Nebraska)	Sweet sorghum
2	N99	”	Sweet sorghum
3	Kansas Collies	”	Sweet sorghum
4	Blue-ribbon	”	Sweet sorghum
5	Hastings	”	Sweet sorghum
6	Red-x	”	Sweet sorghum
7	Waconia-I	”	Sweet sorghum
8	Fremont	”	Sweet sorghum
9	Brawley	”	Sweet sorghum
10	Sugar Drip	”	Sweet sorghum
11	N110	”	Sweet sorghum
12	N100	”	Sweet sorghum
13	Colman	”	Sweet sorghum
14	E-35-1	”	Sweet sorghum
15	Kambal	FIP-Shambat*	Abu Sabin
16	Ank.18	FIP-Shambat*	Ankolib
17	Ank.43	”	Ankolib
18	Ank.36	”	Ankolib
19	Anknyala	Niyala Research Station	Ankolib
20	SG.32-2A	FIP-Shambat*	Sudan grass
21	SG.54	”	Sudan grass
22	SG.33	”	Sudan grass
23	SG.12-1	”	Sudan grass
24	S.70	”	Abu Sabin
25	S.158	”	Abu Sabin
26	S.154	”	Abu Sabin
27	S.126	”	Abu Sabin
28	S.134	”	Abu Sabin

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14 incomplete (iblock) and 3 complete blocks. The iblock composed of two plots each having two ridges. The iblocks were separated by 1m from each other. The blocks were separated by a 2m alley and watered by a separate canal.

2.4 Data Taken

Grain yield/plant (g): Estimated from 5 heads of randomly sampled plants. The heads were dried, threshed, weighed and averaged to obtain grain yield per plant.

Stover yield (t/ha): Taken at grain maturity after panicle removal by harvesting the whole plot at 5-7 cm above ground level and the weight was determined in the field using sprig balance.

Millable cane yield (t/ha): Determined from the harvested stover in each plot after striping the leaves (blade + sheath) and removing the peduncles. The fresh cane in each plot was weighed in the field, labeled and taken immediately to the lab to determine the juice attributes.

Juice yield (l/ha): Juice yield was determined from the first press of the cane produced in the whole plot. The cane was washed, left to dry for a while and then passed through a two-roller sugarcane mill. The juice received was filtered using muslin cloth. The volume of juice per plot was determined using measuring cylinder and transformed to l / ha.

Juice extractability: Calculated as the volume of juice produced by one kg of cane, by dividing the volume of juice in each plot by the corresponding cane yield (kg).

Brix value (%): Measured immediately after determining the juice yield from the entire volume of the extracted juice using a hand refractometer. The juice was then kept in tightly closed plastic bottles, labeled and frozen for future investigations.

Other traits: pH of the juice; 1000 seed weight; number of seeds/panicle; plant height; stem diameter and days to flowering were measured but will not be highlighted in this paper.

2.5 Statistical Analysis

The data were subjected to analysis of variance (ANOVA) following the procedure of alpha lattice design [6]. Bartlett's test [7] indicated non-homogeneous error variance for most of the characters studied (specially productive traits) hence, the results of each season are separately reported. The statistical packages Agrobase Gen II [8] was used to run alpha lattice analysis.

3. RESULTS

Analysis of variance revealed highly significant differences among genotypes for all studied traits (Table 2).

3.1 Juice Yield

As shown by Table 3, the overall mean for juice yield obtained in the summer season (1489 l/ha) was higher than that obtained during winter (890 l/ha). The highest juice yields were shown by Kambal (2770 l/ha) and Red-X (1548 l/ha) at summer and winter seasons, respectively. Anknyala showed the lowest juice yields in both summer and winter seasons, averaging 580 and 302 l/ha, respectively. Most of the exotic materials were leading in juice yield in the winter season whereas the opposite is true during summer. However, three exotic varieties namely: N98, N99 and Waconia-I performed well in both seasons.

3.2 Extractability

The overall means for extractability in summer and winter seasons were 137 and 120 ml/kg, respectively (Table 3). In the summer season, the extractability shown by Waconia-I (206 ml/kg) and Red-x (198 ml/kg) were significantly the highest among the whole material tested, followed by N110 (175 ml/kg). In the winter season, the best performance in extractability was shown by N98 (165 ml/kg) and Brawley (158 ml/kg) followed by Sugar Drip and N110 (151 ml/kg). Most of the local materials exhibited low extractability levels in both seasons; however, S.158 was among the best five performing genotypes in summer (160 ml/kg) and yielded above average extractability in winter (122 ml/kg). The Ankolib genotypes were among those exhibiting the lowest extractability ranging 74.6 - 99.7 ml/kg.

3.3 Brix

The grand means obtained for brix were 16.8% and 17.2% in the summer and winter seasons, respectively (Table 3). Most of the exotic materials excelled the local ones in brix specially Brawley, Blue-ribbon, N100, Kansas Collies and Hastings where values ranging from 19.8% to 21.6% have been obtained in both season. Apart from Ank.18 in the winter season, the Ankolib genotypes were the best performing among the local material exhibiting brix values comparable to exotic materials ranging from 18.5% to 20.7%. Abu Sabin and Sudan grass groups showed below average brix value with Kambal showing the highest value (16.3%).

3.4 Cane, Grain and Stover Yields

Table 4 indicated that the millable cane yield shown by Kambal during summer (20.4 t/ha) was significantly higher than all exotic cultivars and most of the local ones. In the winter season, Sugar Drip gave the highest cane yield (21.4 t/ha). Generally, exotic cultivars performed well in cane yield during winter season. The lowest cane yields were displayed by Kansas Collies in summer (5.29 t/ha) and Anknyala (5.82 and 7.54 t/ha) in summer and winter seasons, respectively. The highest grain yields per plant were exhibited by S.70 (56.3g) and Hastings (19.5g) at summer and winter seasons, respectively (Table 4). In the summer season, the grain yield shown by S.70 was significantly higher than that of most varieties other than S.134 and Kambal. The grain yield shown by Hastings in the winter season was significantly higher than that of many varieties. In contrast Hastings gave below average yield in the summer season. Generally, apart from Ankolib types, the local genotypes were better than the exotic ones in grain yield during summer. The overall means for stover yield were 18.8 and 14.3 t/ha at summer and winter seasons, respectively (Table 4). In the summer season, the local materials displayed the highest stover yield e.g. SG.54, SG.33 and Kambal that gave 31.5, 30.1, 29.6 t/ha, respectively. Among exotic materials, N99 and N98 were the best performing in the summer season, displaying above average stover yield. In the winter season the highest stover yields was shown by Sugar Drip (21.3 t/ha). It's stover yield was significantly higher than all materials other than N 100, Blue-ribbon, Red-x, N110 and N98 that gave 19.9,18.5, 18.4, 17.2 and 16.8 t/ha, respectively.

Table 2. Mean squares for different characters studied in 28 sorghum genotypes (Shambat, 2012-2013)

Source of variation	D.f	Juice yield (l/ha)		Stover yield (t/ha)		Millable cane yield (t/ha)		Grain yield /plant (g)		Extractability (ml/kg)		Brix (%)	
		Summer	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**
Block	2	653410	425801	178	22	798	1470	798	1470	798	1470	15.7	0.512
Entry	27	1194281**	421312**	126**	32**	2432**	1813**	2432**	1813**	2432**	1813**	19.1**	32.1**
Residual†	54	194259	83592	21.1	6.34	274	319	274	319	274	319	2.38	0.833
iBlock ♣	39	202629	97419	25.5	7.20	286	—	286	—	286	—	2.59	—
Error ‡	15	172498	47643	9.83	4.10	241	—	241	—	241	—	1.82	—

*** = Significant at 0.01 probability level, † = RCBD residual, ♣ = Incomplete block, ‡ = Intra block error*

Table 3. Juice yield and some related attributes in sorghum as concurrently measured with other productive traits (Shambat, 2012-2013)

Genotype	Juice yield (l/ha)		Extractability (ml/kg)		Brix (%)	
	Summer	Winter	Summer	Winter	Summer	Winter
N98	1886	1487	165	165	16.4	17.6
N99	1712	1211	148	133	17.6	16.6
Kansas Collies	760	1229	141	139	20.0	21.6
Blue-ribbon	997	1500	149	141	20.6	21.3
Hastings	893	893	122	122	19.8	20.0
Red –x	1116	1548	198	141	16.8	21.0
Waconia-I	1504	1195	206	149	15.8	20.6
Fremont	723	616	127	112	15.8	17.3
Brawley	1256	1325	153	158	21.2	21.6
Sugar Drip	1019	977	149	151	17.5	18.3
N110	1045	1298	175	151	17.2	21.3
N100	857	1373	91.5	127	20.4	21.3
Colman	834	759	138	140	16.1	20.0
E-35-1	594	386	89.7	98	16.1	18.0
Kambal	2770	968	134	113	14.2	16.3
Ank.18	1319	362	99.7	85.3	20.7	11.3
Ank.43	1955	449	117	80	14.9	13.0
Ank.36	1843	764	131	117	18.5	18.6
Anknyala	580	302	92.4	74.6	20.0	16.3
SG.32-2A	1873	618	140	90.7	13.0	15.0
SG.54	2644	560	140	93	15.1	15.0
SG.33	2375	602	134	97	14.6	13.6
SG.12-1	1227	500	123	113	12.5	16.0
S.70	1811	781	106	112	13.9	12.3
S.158	1982	1004	160	122	14.1	15.3
S.154	2118	934	125	124	16	12.0
S.126	2328	610	142	110	15.1	15.0
S.134	1679	669	118	105	16.1	13.3
Mean	1489	890.61	137	120	16.8	17.2
SE±	253.3	154.66	9.51	10.3	0.872	0.527
CV (%)	29.5	30.08	12.1	14.8	8.98	5.30

4. DISCUSSION

4.1 Potential for Sugar Yield

Sugar yield is a function of juice yield and concentration of sugar in the juice (brix). Juice yield is further dependent on juiciness (extractability) and the millable cane yield. Most of the exotic materials exhibited high extractability coupled with high brix values in both seasons. Some of these, namely: Blue-ribbon, Red-x N110 and Brawley were among the best in millable cane yield (and consequently the best in juice yield) in the winter season, therefore, are expected to show high potential for sugar production in the winter season. On the other hand, most if not all of the local materials were expected to show low potential for sugar yield in the winter season as they failed to combine good performance in extractability, brix and cane yield. Although most of the local cultivars were better in juice yield than the exotic ones in the summer season they were, however, inferior in extractability and brix. Therefore, their comparatively high juice yield could be attributed to their high cane yield. The cultivars Ank.36 (Ankolib selection) and S.158 (Abu Sabin selection) could be regarded as having moderate potential for sugar yield during summer season. Ankolib is the general term used for sweet sorghum in Sudan. In this study 3 out of 4 Ankolib genotypes showed high brix values. Having high brix value is not enough for achieving high sugar yield unless being coupled with high juice yield. The study showed that the Ankolib genotypes were low juice yielders. Extractability and/or cane yield seem to pose a negative impact on the potential of Ankolib population for sugar yield through reduced juice yield. Murray et al. [5] emphasized the importance of juice yield over sugar concentration (brix) arguing that brix value has limited room for further improvement, as it has already reached the ceiling of 20% to 25% in many elite sweet sorghum cultivars. However, they noted that high sugar concentration (brix) would be very valuable in reducing processing and transportation costs via increased energy density.

4.2 Grain, Stover and Sugar Attributes

The possibility of harvesting three products (grain, stem sugar, and stover) from one sorghum crop attracted the attention of plant breeders to the potential of sorghum as a dedicated energy crop [5,9]. However, in the developing countries like Sudan, emphasis should be placed on grain for food rather than for energy. Reddy et al. [10] stated that the bioenergy revolution should not marginalize the poor and raise food prices. The present study revealed that some exotic cultivars like Blue-ribbon and Red-x kept top performance in sugar yield attributes as well as grain and stover yields. Some of the local cultivars (i.e. Kambal, S.158 and S.154) showed moderate performance in one attribute while keeping top performance in the others. Such results point to the possibility of selecting varieties having potentials of concurrently combining high yields of grain, stover and stem sugars. Concurrent improvement of grain and sugar yields in sorghum was also sought feasible by some workers [11,5,12]. The developing grain is not a significant sink for whole –plant carbohydrates. Sugar accumulation occurs before anthesis [11] thus largely escaping competition with grain filling.

Table 4. Performance of sorghum genotypes for concurrently measured productive traits (Shambat, 2012-2013)

Genotype	Stover yield (t/ha)		Millable cane yield (t/ha)		Grain yield /plant (g)	
	Summer	Winter	Summer	Winter	Summer	Winter
N98	19.5	16.8	11.2	16.8	23	17
N99	19.7	15.2	11.7	15.2	15	9.77
Kansas Collies	10.2	15	5.29	15	6.1	14.1
Blue-ribbon	11.9	18.5	6.91	18.5	16	19
Hastings	13.7	15.8	7.15	15.9	19.3	19.5
Red –x	11.4	18.4	5.66	18.4	17.6	17.7
Waconia-I	14 .0	14.9	7 .00	14.9	17.3	16.7
Fremont	12.6	10.7	5.63	10.8	8.27	8.94
Brawley	14.4	14.4	8.14	14.4	6.83	15.5
Sugar Drip	11.6	21.3	6.87	21.4	23.3	8.77
N110	11.5	17.2	6.04	17.3	15.6	13.1
N100	16.6	19.9	9.7	20	12.1	16.9
Colman	13	12.6	5.93	12.6	8.07	13.1
E-35-1	13.6	10.2	6.95	10.3	20.3	12.6
Kambal	29.6	15.4	20.4	15.4	45.3	19.4
Ank.18	21.2	11.2	14.4	11.2	14.5	5.2
Ank.43	22 .0	11.7	16.6	11.8	31.3	9.16
Ank.36	26	13.9	14.6	14	14.4	5.41
Anknyala	10.4	7.5	5.82	7.54	13.3	8.01
SG.32-2A	26.5	13.7	13.4	13.8	10.1	6.94
SG.54	31.5	13.8	18.8	13.9	24	13.2
SG.33	30.1	13.8	17.4	13.9	26.6	5.42
SG.12-1	17.6	8.8	9.8	8.86	22.6	9.54
S.70	25.5	14.9	16.9	14.9	56.3	12.3
S.158	18.3	13.7	12.4	13.7	38.3	18.4
S.154	24.8	12.9	16.8	12.9	38.6	18.8
S.126	25	11.4	16.2	11.4	22	9.41
S.134	24.1	14.3	14.3	14.3	50.6	13.4
Mean	18.8	14.3	11.15	7.05	22.1	12.8
SE±	2.34	1.38	1.89	0.859	3.79	2.15
CV (%)	21.5	16.8	29.4	21.1	29.7	29.1

The study revealed that the local materials suffer from reduced juiciness, and also (apart from Ankolib) reduced-sugar concentration (brix value). On the other hand, the grain characteristics of the exotic materials might be unsuitable for food consumptions (most have brown seed coat and might also have pigmented testa). Future research is needed to improve the local materials for high juice content and brix value. This can be attained by crossing followed by selection for sugar attributes while maintaining high yield and quality grain of the local materials.

5. CONCLUSION

The study indicated the feasibility for direct concurrent selection of sorghum genotypes combining top performance in stem sugar, grain and stover attributes. The exotic materials were mostly juicier (high in juice extractability) with higher sugar concentration (brix) than the local ones which were in contrast, superior in grain and stover attributes. The present Ankolib population (local sweet sorghum) is not suitable for direct use as biofuel feedstock unless being improved for juice yield attributes (extractability and cane yield). Future research work should focus on improving the local materials for the pertinent traits by hybridization and selection in the filial generation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Haussmann BIG, Mahalakshmi V, Reddy BVS, Seetharama N, Hash C, Geiger H. QTL mapping of stay-green in two sorghum recombinant inbreed populations. Theor. Appl. Genet. 2002;106:133-142.
2. Dowling LF, Amdt C, Hamaker BR. Economic viability of high digestibility sorghum as feed for market broilers. Agron, J. 2002;94:1050-1058.
3. Turhollow AF, Webb EG, Downing ME. Review of Sorghum Production Practices: Applications for Bioenergy, 28.03.11; 2010. Available:http://info.ornl.gov/sites/publications/files/Pub22854.pdf
4. Kelley TG, Rao PP, Walker TS. The relative value of cereal-straw fodder in the semi-arid tropics of India: Implications for cereal breeding programs at ICRISAT. Progress Report No. 105, ICRISAT, India. 1991;33.
5. Murray SC, Sharma A, Rooney WL, Klein PE, Mullet JE, Mitchell SE, Kresovich S. In Crop genetic improvement of sorghum as a biofuel feedstock: I. QTL for stem sugar and grain nonstructural carbohydrates. Crop Sci. 2008a;48:2165–2179.
6. Patterson HD, Williams ER. A new class of resolvable incomplete block designs. Biometrika. 1976;63:83-92.
7. Snedecor GW, Cochran WG. Statistical Methods. 6th Ed. Ames: Lowa State University Press; 1989.
8. Agrobase Gen II. Agronomix software, inc. Canada. Version. 2008;18.5.1.
9. Murray SC, Rooney WL, Mitchell SE, Sharma A, Klein PE, Mullet JE, Kresovich S. Genetic improvement of sorghum as a biofuel feedstock: II. QTL for stem and leaf structural carbohydrates. Crop Sci. 2008b; 48:2180–2193.
10. Reddy VSB, Ramesh S, Ashok KA, Wani SP, Ortiz R, Ceballos H, Sreedevi TK. Biofuel crops research for energy security and rural development in developing countries. Bioenergy Research. 2008;1: 248–258.
11. Gutjahr S, Vaksmann M, Dingkuhn M, Thera K, Trouche G, Braconnier S, Luquet D. Grain, sugar and biomass accumulation in tropical sorghums. I. Trade-offs and effects of phonological plasticity. Functional Plant Biology. 2013;40:342-354.
12. Lingle SE. Sucrose metabolism in the primary culm of sweet sorghum during development. Crop Sci. 1987;27:1214-1219.

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