Stalk-Juice Quality Traits of Sweet Sorghum as Affected by Season in Sudan

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Abstract: An experiment was conducted in Shambat (2012-2013) during the summer and winter seasons to study the stalk-juice quality parameters of 29 exotic and local sweet sorghum varieties as affected by season. The objectives were to provide basic data attributing to syrup and sugar (jaggery) production in the Sudan. The materials were arranged in RCB design. Data were collected on brix, pol (sucrose %), reducing sugars, total sugars, purity and pH. The single and combined analysis of variance revealed highly significant differences among varieties for all traits studied. The variety x season interaction was significant for all traits other than total sugars %, implying the need for considering the variety choice in each season. The results of juice quality parameters were mostly within the range reported in the literature. The exotic materials excelled the local ones in brix, pol%, total sugars% and purity. The exotic varieties: N100, Red-X, Hastings and N110 as well as the local Ankolib selections: AnkNyala and Ank36 were identified as having juice quality traits suitable for syrup production. The exotic varieties: BlueRibbon, KansasCollies and Brawley were identified for sugar (jaggery) production. It was concluded that interaction of variety x season and yield parameters for juice, grain and stover should be considered when determining the choice of the variety. Future research should focus on developing multi-purpose varieties capable for concurrent production of syrup/sugar, grain and stover.

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is a crop of world-wide importance. It ranks fifth in importance as a grain cereal. It is the most qualified crop in meeting the demand for large quantities of high-quality fodders, especially in the drier parts of the world [1] with unique ability to produce under a wide array of harsh environmental conditions [2]. Sweet sorghum is a type of sorghum characterized by ability to accumulate sweet juice in the stalk. It was first introduced to USA more than a century ago with the primary aim of manufacturing crystalized sugar, but due to some technical difficulties the emphasis switched to syrup production before being further shifted to forage production. Recently, sweet sorghum also appeared to have great potential as an annual energy crop.

The agro-industrial potentials of sweet sorghums have been discussed by many workers. The crop offers great potential for multi-purpose uses mainly for syrup, forage and ethanol production [3]. Plant breeders in the United States, India and China have developed high-brix cultivars to increase the potential of this crop for syrup production. Excellent syrup can be made from sweet sorghum when brix of raw juice is greater than 15% [4]. Syrup yields ranging 800-1900 L/ha have been reported depending on weather conditions [3]. Sweet sorghum provides options for concurrent food, feed and sugar production and is suitable for smallholder farmer cultivation on less-favored lands. Although sugar content declines by about 25% at grain maturity, this is, however, compensated for by the added gain from grain-income [5].

In Sudan, sorghum is the most important crop grown for food and feed. Sudan is believed to be one of the major centers of sorghum domestication and diversification [6, 7]. ‘Ankolib’ is the vernacular name for sweet sorghum. It is a highly diverse population belongs to race durra-bicolor characterized by sweet stalk just like sugar cane [8]. Developing improved grain or forage types have

been the main focus of research efforts in Sudan. Attempts to investigate traits attributing to syrup production from sweet sorghum are specifically lacking. Mohammed and Mohamed [9] evaluated exotic and locally developed genotypes for forage attributes. Concurrent improvement of stem-sugar, stover and grain yield was also studied in Sudanese and exotic sorghums [10, 11].

The present study aimed to evaluate stalk-juice quality parameters of sweet sorghum as affected by season in Sudan. The ultimate objectives were to provide some basic data that may contribute to syrup and/or sugar (jaggery) production in Sudan.

Materials and Methods

The experimental site

The study was conducted in the Experimental Farm of the Agriculture Research Corporation (ARC) at Shambat (latitude 15° 39' N; longitude 32°31'E; altitude 380m above sea level) during the summer of 2012 and winter of 2012/2013. The soil is heavy clay, non-saline, non-sodic with pH of 7.9-8.5.

The growing seasons

The major features of the climatic conditions prevailed during the growing seasons are depicted in Fig. 1. The winter season is drier than the summer with no precipitations.

Fig. 1. The major features of climatic conditions of the growing seasons

The plant materials

The plant materials consisted of 29 sorghum genotypes representing 4 groups (Table 1). The genotypes 1-15 are exotic sweet sorghum materials. The genotypes 16-29 were locally developed by selection within local populations of Ankolib, Sudan grass and Abu Sabin. Selection was practiced for juiciness (green mid-rib) and other forage attributes.

Management and experimental design

Sowing dates were on 22/July/2012 and 6/Dec/2012 for the summer and winter sowings, respectively. The materials were arranged in RCB design with 3 replicates. The plot was composed of two ridges 5 m long. Planting was done by placing 5 seeds in holes spaced 0.7m x 0.2m. The trials were watered at 7 to 10 days interval. 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 minimum by hand removal.

Table 1. Sorghum genotypes used in the study

Entry	Genotypes	Source	Group / Type
1	N98	USDA / U.of Nebraska	Sweet sorghum
2	N99	"	Sweet sorghum
3	KansasCollies	"	Sweet sorghum
4	BlueRibbon	"	Sweet sorghum
5	Hastings	"	Sweet sorghum
6	Red-x	"	Sweet sorghum
7	Waconia-L	"	Sweet sorghum
8	Fremont	"	Sweet sorghum
9	Brawley	"	Sweet sorghum
10	SugarDrip	"	Sweet sorghum
11	N110	"	Sweet sorghum
12	N100	"	Sweet sorghum
13	Colman	"	Sweet sorghum
14	E-35-1	"	Sweet sorghum
15	AGSilo200	Marketplace	Sweet sorghum
16	Ank18	FIP-Shambat*	Ankolib
17	Ank43	"	Ankolib
18	Ank36	"	Ankolib
19	AnkNyala	Niyala Research Station	Ankolib
20	SG32-2a	FIP-Shambat	Sudan grass
21	SG54	"	Sudan grass
22	SG33	"	Sudan grass
23	SG12-1	"	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
29	Kambal	FIP-Shambat	Abu Sabin

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Juice collection and preparation

The Juice was collected from the first press of the cane produced in the whole plot when each variety reached physiological maturity of the grain. The plants were cut 5-7 cm above ground level. The panicles were removed and leaves (blade + sheath) were stripped off. The fresh cane was immediately taken to the lab where it was washed, left to dry for a while and then passed through hand driven two-roller mill. The juice received was filtered using muslin cloth. The juice was kept in tightly closed plastic bottles, labeled and stored under deepfreeze condition for future investigations.

Data collection

The juice analysis was carried out in the laboratory of Kenana Sugar Factory, Rabak, Sudan. The following juice quality traits were determined:

Brix (%): The brix (total soluble solids) was recorded from samples taken from the entire volume of the extracted juice using digital refractometer RFM 340.

Pol %: The sucrose percentage of the juice (Pol) was estimated following Horne's dry lead acetate clarification method [12] using automatic polarimeter (AP-300).

Reducing sugar %: Reducing sugars (invert sugars) were estimated using dinitro-salicylic acid (DNSA) method [13].

Total sugars %: Calculated as the combined percentages of sucrose and reducing sugars in a sample.

Purity %: Measured as apparent purity using the formula: $(\text{pol} \times 100)/\text{Brix}$

pH: Recorded from 200 ml sample of juice using pH meter.

Statistical Analysis

The data collected were subjected to single analysis of variance (ANOVA) before performing the combined ANOVA following the standard procedure of analyzing RCB design ([14]. Least Significant Difference (LSD) procedure was used to separate the means. The statistical package GenStat [15] was used to run the analysis.

Results

Tables 2 and 3 show mean squares for studied traits resulting from single and combined ANOVA, respectively. Differences among genotypes were mostly highly significant for all traits in single and combined analysis. Apart from total sugars, genotype x season (GxE) interaction was significant, specifically for reducing sugars and pH where it was highly significant.

Brix (%): The average brix in winter and summer seasons (Table 4) were 16.81% and 16.05%, respectively. The exotic sweet sorghum varieties performed better than the local ones in brix percentage. Three exotic varieties, namely: Brawley, BlueRibbon and KansasCollies gave above 20% brix in both seasons, with overall average of 21.42%, 21.39% and 20.63%, respectively. Of the local materials, the best performing were 3 varieties belong to Ankolib group, namely: Ank36, Ank18 and AnkNyala with respective average of 18.75%, 17.99% and 17.62%. The lowest brix values were obtained by the local varieties S.70 and Ank43, averaging 11.6% and 12.34%, respectively.

Pol (%): The average pol in winter and summer seasons (Table 5) were 8.01% and 7.55%, respectively. The exotic varieties: BlueRibbon, KansasCollies and Brawley showed the highest pol in both seasons, averaging 16.37%, 15.38% and 14.18%, respectively. Some exotic varieties gave pol range of 10% - 11%, viz: Hastings, N110, Red-X and Waconia-L. Among the local varieties, the highest pol average was shown by the Ankolib varieties, viz: Ank36 (11.42%), AnkNyala (9.74%) and Ank18 (8.05%). Pol average of 5 to 6% were shown by SG32-2a, S.158 and Kambal. The lowest pol was shown by the Abu Sabin varieties: S.154 (1.96%) and S.70 (2.33%).

Reducing Sugars%: Reducing sugars (Table 6) averaged 6.75% and 5.95% in winter and summer seasons, respectively. Among exotic materials, BlueRibbon, Brawley and KansasCollies displayed the lowest reducing sugars % in both seasons averaging 3.95%, 4.18% and 4.23%, respectively. Above average values were displayed by Hastings (6.70%), Red-X (6.70%) and N110 (6.53%). Most of the local materials, specially Abu Sabin and Sudan grass groups displayed above average values of 6.5%-10.0%. The Ankolib variety Ank18 averaged 5.18% whereas AnkNyala and Ank43 gave an average of 6.85%. Some varieties showed differential performance in reducing sugar, i.e. N100 and SugarDrip displaying 10.0% during winter vs 5.35% and 4.50% during summer, respectively.

Total sugars %: Total sugars (Table 7) amounted to 14.77% and 13.49% in winter and summer seasons, respectively. The highest varieties in total sugars were BlueRibbon, KansasCollies, Brawley and Hastings averaging between 18.20% to 20.32%. The varieties N110, N100 and Red-X

came next averaging from 17.53% to 17.64%. The Ankolib variety Ank36 averaged 16.60%. S.158 (Abu Sabin) and SG32-2a (Sudan grass) averaged 13.93% and 12.89%, respectively.

Purity %: The average values obtained for purity (Table 8) in both seasons were around 45%. The highest purity averages were shown by BlueRibbon (76.25%) and KansasCollies (74.50%). Brawley showed purity of 65.20%. Apart from Ank36 (61.00%) and AnkNyala (53.27%), most of the local materials displayed below average purity. The purity of Abu Sabin group varied between 14.25% (S.154) and 40.26% (S.158).

pH: The pH averaged 5.298 and 5.401 in winter and summer seasons, respectively (Table 9). The overall average of pH was 5.349. KansasCollies showed the lowest pH (4.947). The highest pH was shown by S.126 (5.742). Apart from SugarDrip (5.378) and AGSilo200 (5.343) all of the exotic materials showed below average pH whereas the opposite is true for the local ones. Generally, most varieties displayed lower pH in winter than summer season.

Discussion

Variability: The highly significant differences among genotypes for juice quality parameters indicated that most of the variability observed were attributable to genetic differences. However, GxE was also significant, pointing to the differential performance of genotypes for all traits other than total sugars. Therefore, although some varieties have similar performance across seasons, the choice of variety should be considered in each season separately for traits other than total sugars. Similar results showing variety x season interaction for juice quality parameters in sweet sorghum were reported [16].

Juice quality performance: With few exceptions, the results of juice quality parameters obtained in this study were within the range reported in the literature. The brix values which indicates total soluble solids were near to those reported by Almodares and Hatamipour (11.6%-23.01%) [17]; apparently higher than those reported by Balole (8.3%-15.1%) [18] and slightly lower than those of Kulkarni et al. (15%-23%) [19]. The results of pol which indicates the sucrose percentage were within the range of those reported by Almodares and Hatamipour (6.00%-16.06%) [17]; Nandini et al. (7%-13%) [4] and Salunkhe and Deshpande (5.8%-10.4%) [20]. Reducing sugars shown by this study (3.99%-10.0%) were specifically high when compared to those reported by Salunkhe and Deshpande (0.73%-1.99%) [20] and Nandini et al. (1%-6%) [4]. Total sugars were comparable to those reported by Rao et al. (12.6%-16.4%) [21]. The range of apparent purity in this study (14%-76%) was close to that of Inman-Bamber (11.0%-770%) [22]; higher than that of Balole (16.6-38.8%) [18] and lower than that of Mukabane et al. (33.89%-83.91%) [3]. Most of the materials studied gave pH values falling within the range reported in the literature i.e. Nandini et al. (4.7-5.5) [4]; Salunkhe and Deshpande] (4.9-5.3) [20].

Identification of materials: As far as juice quality traits are concerned, sweet sorghum varieties showing high reducing sugars relative to sucrose content with brix greater than 15% are more preferred for syrup production [16, 4]. Based on the results of this study, the exotic varieties: N100, Red-X, Hastings and N110 as well as the local Ankolib varieties: AnkNyala and Ank36 could have potential for syrup production. On the other hand, varieties suitable for sugar (jaggery) production require high purity (minimum of 75%) with pol of 10%-14% and total sugars of 13% to 17% (i.e. relatively low reducing sugars) [3, 18]. In this study, such requirements were more or less met by the exotic varieties: BlueRibbon, KansasCollies and Brawley. However, the latter showed moderate performance in purity (65.2%).

The varieties BlueRibbon and Red-X were reported to have good performance in the yields of juice, stover and grain ([10]. Since the quality parameter of the juice was evaluated at the physiological maturity of the grain, the two varieties may have the potential for concurrent production of three products i.e. Jaggery or syrup, grain and stover (leaves and bagasse). Such results point to the possibility of combining high stem sugar, grain and stover yields in one cultivar, however, in Sudan,

emphasis should be placed on grain for food rather than for feed, a choice which is not offered by the exotic cultivars but largely met by the local materials, specially Abu Sabin group, which unfortunately, of low sugar yield. Therefore, a local x exotic crossing project was started by the Forage Improvement Program (FIP) to transfer the desired traits from exotic to local materials by selection in the filial generation. Very promising materials in F5 generation are now accumulating with attributes matching the project objectives.

Conclusions

The study revealed some exotic and local (Ankolib) sweet sorghum varieties having juice quality parameters suitable for syrup and/or sugar (jaggery) production in the Sudan. Interaction of variety x season and yield parameters for juice, grain and stover should be considered when determining the choice of the variety. Future research should focus on developing multi-purpose varieties capable of concurrent production of syrup/sugar, grain and stover.

Conflict of Interest

The authors declare that there is no conflict of interest.

Table 2. Mean squares from single ANOVA for different traits of sweet sorghum varieties grown in summer and winter Seasons

Source of variation	d.f.	Brix (%)	Pol (%)	Reducing Sugars (%)	Total Sugars (%)	pH
Summer Season						
Rep	1	60.058	22.147	0.6002	15.455	0.000209
Genotype	28	21.628**	39.405**	5.3921**	26.951**	0.084890**
Residual	28	6.011	1.823	0.6645	2.383	0.003748
Winter Season						
Rep	1	1.320	8.44	2.442	19.97	0.037257
Genotype	28	15.893**	32.43**	4.669**	25.89*	0.089412**
Residual	28	1.296	10.25	1.364	11.17	0.003432

Table 3. Mean squares from combined ANOVA for different traits of sweet sorghum varieties grown in summer and winter Seasons

Source of variation	d.f.	Brix (%)	Pol (%)	Reducing Sugars (%)	Total Sugars (%)	pH
Season ((E)	1	16.440	6.289	18.881	46.965	0.306221
Residual	2	30.689	15.295	1.521	17.711	0.018733
Genotype (G)	28	30.453**	61.389**	6.340**	43.291**	0.162102**
GxE	28	7.068*	10.445*	3.722**	9.550	0.012199**
Residual	56	3.653	6.039	1.014	6.778	0.003590

Table 4. Brix (%) values obtained by exotic and local sweet sorghum varieties in the winter and summer seasons (Shambat, 2012)

Variety	Winter	Summer	Combined
AGSilo200	16.31	13.81	15.06
Ank18	16.95	19.02	17.99
Ank36	18.61	18.90	18.75
Ank43	12.32	12.35	12.34
AnkNyala	14.58	20.66	17.62
BlueRibbon	20.59	22.19	21.39
Brawley	20.80	22.04	21.42
Colman	19.49	16.75	18.12
E-35-1	18.52	18.85	18.69
Fremont	16.21	12.89	14.55
Hastings	18.61	18.53	18.57
Kambal	12.21	13.39	12.80
KansasCollies	20.88	20.39	20.63
N100	20.53	16.29	18.41
N110	20.80	18.40	19.60
N98	16.25	15.68	15.97
N99	16.46	18.19	17.33
Red-X	20.08	17.41	18.74
S.126	14.36	16.46	15.41
S.134	14.17	13.64	13.90
S.154	12.94	16.60	14.77
S.158	16.13	13.48	14.81
S.70	12.29	10.91	11.60
SG12-1	15.05	11.17	13.11
SG32-2a	15.84	13.28	14.56
SG33	14.42	14.79	14.61
SG54	14.76	12.16	13.46
SugarDrip	17.59	11.33	14.46
Waconia-L	19.63	15.99	17.81
Mean	16.81	16.05	16.43
SE±	0.805	1.734	0.956
LSD (0.05)	2.332	5.022	2.707
CV (%)	6.8	15.3	11.6

Table 5. Pol (%) obtained by exotic and local sweet sorghum varieties in the winter and summer seasons (Shambat, 2012)

Variety	Winter	Summer	Combined
AGSilo200	9.74	8.70	9.22
Ank18	7.07	9.03	8.05
Ank36	12.04	10.81	11.42
Ank43	1.47	4.80	3.14
AnkNyala	5.95	13.54	9.74
BlueRibbon	14.95	17.80	16.37
Brawley	11.72	16.64	14.18
Colman	8.88	5.54	7.21
E-35-1	7.07	9.67	8.37
Fremont	6.94	6.76	6.85
Hastings	11.74	11.26	11.50
Kambal	3.18	7.16	5.17
KansasCollies	15.71	15.05	15.38
N100	10.18	9.57	9.87
N110	15.02	7.21	11.11
N98	9.44	6.27	7.86
N99	9.07	7.26	8.16
Red-X	12.09	9.57	10.83
S.126	3.18	2.79	2.98
S.134	4.01	5.05	4.53
S.154	2.26	1.65	1.96
S.158	7.70	4.46	6.08
S.70	3.71	0.94	2.33
SG12-1	4.55	2.19	3.37
SG32-2a	8.75	4.99	6.87
SG33	4.22	2.80	3.51
SG54	6.90	1.75	4.32
SugarDrip	3.43	5.74	4.58
Waconia-L	11.46	9.89	10.68
Mean	8.01	7.55	7.78
SE±	2.264	0.955	1.229
LSD (0.05)	6.560	2.766	3.481
CV (%)	40.0	17.9	31.6

Table 6. Reducing Sugars (%) obtained by exotic and local sweet sorghum varieties in the winter and summer seasons (Shambat, 2012)

Variety	Winter	Summer	Mean
AGSilo200	6.20	4.20	5.20
Ank18	7.35	4.20	5.78
Ank36	4.50	5.85	5.18
Ank43	7.50	6.20	6.85
AnkNyala	8.35	5.35	6.85
BlueRibbon	4.70	3.20	3.95
Brawley	4.70	3.65	4.18
Colman	9.00	5.85	7.43
E-35-1	7.35	6.20	6.78
Fremont	6.20	5.00	5.60
Hastings	6.70	6.70	6.70
Kambal	5.85	5.85	5.85
KansasCollies	4.65	3.80	4.23
N100	10.00	5.35	7.68
N110	5.70	7.35	6.53
N98	6.20	4.70	5.45
N99	6.70	6.15	6.43
Red-X	6.70	6.70	6.70
S.126	6.70	9.00	7.85
S.134	6.50	8.35	7.43
S.154	10.00	10.00	10.00
S.158	6.70	9.00	7.85
S.70	5.35	6.20	5.78
SG12-1	7.35	5.00	6.18
SG32-2a	5.85	6.20	6.03
SG33	5.85	6.20	6.03
SG54	6.70	6.70	6.70
SugarDrip	10.00	4.50	7.25
Waconia-L	6.50	5.00	5.75
Mean	6.75	5.95	6.35
SE $\pm$	0.826	0.576	0.5035
LSD (0.05)	2.392	1.670	1.4264
CV (%)	17.3	13.7	15.9

Table 7. Total sugars (%) obtained by exotic and local sweet sorghum varieties in the winter and summer seasons (Shambat, 2012)

Variety	Winter	Summer	Combined
AGSilo200	15.94	12.90	14.42
Ank18	14.41	13.23	13.82
Ank36	16.54	16.66	16.60
Ank43	8.97	11.00	9.98
AnkNyala	14.30	18.88	16.59
BlueRibbon	19.65	21.00	20.32
Brawley	16.41	20.29	18.35
Colman	17.88	11.39	14.63
E-35-1	14.42	15.86	15.14
Fremont	13.14	11.76	12.45
Hastings	18.43	17.96	18.20
Kambal	9.02	13.01	11.02
KansasCollies	20.35	18.85	19.60
N100	20.17	14.92	17.55
N110	20.71	14.56	17.64
N98	15.64	10.97	13.30
N99	15.77	13.41	14.59
Red-X	18.79	16.27	17.53
S.126	9.88	11.79	10.83
S.134	10.51	13.40	11.95
S.154	12.26	11.65	11.96
S.158	14.40	13.46	13.93
S.70	9.06	7.14	8.10
SG12-1	11.90	7.19	9.54
SG32-2a	14.60	11.18	12.89
SG33	10.07	9.00	9.54
SG54	13.59	8.45	11.02
SugarDrip	13.43	10.23	11.83
Waconia-L	17.96	14.89	16.43
Mean	14.77	13.49	14.13
SE±	2.364	1.092	1.302
LSD (0.05)	6.847	3.162	3.688
CV (%)	22.6	11.4	18.4

Table 8. Purity (%) obtained by exotic and local sweet sorghum varieties in the winter and summer seasons (Shambat, 2012)

Variety	Winter	Summer	Mean
AGSilo200	59.39	72.24	65.82
Ank18	42.16	47.51	44.84
Ank36	64.76	57.24	61.00
Ank43	11.90	37.62	24.76
AnkNyala	41.05	65.48	53.27
BlueRibbon	72.50	80.00	76.25
Brawley	54.98	75.41	65.20
Colman	45.49	32.94	39.22
E-35-1	35.88	51.13	43.51
Fremont	42.92	57.19	50.06
Hastings	63.24	60.90	62.07
Kambal	24.40	52.71	38.55
KansasCollies	75.19	73.81	74.50
N100	49.31	58.65	53.98
N110	72.18	39.16	55.67
N98	57.91	39.88	48.90
N99	54.35	39.29	46.82
Red-X	60.20	54.79	57.49
S.126	21.88	16.94	19.41
S.134	26.67	36.94	31.80
S.154	18.65	9.84	14.25
S.158	47.37	33.15	40.26
S.70	28.62	7.24	17.93
SG12-1	30.11	19.10	24.60
SG32-2a	55.26	37.05	46.15
SG33	29.70	19.07	24.39
SG54	46.71	16.10	31.40
SugarDrip	19.10	51.17	35.14
Waconia-L	58.41	62.93	60.67
Mean	45.18	45.02	45.10
SE±	12.66	7.51	7.36
LSD (0.05)	36.66	21.75	20.84
CV (%)	39.6	23.6	32.6

Table 9. pH values obtained by exotic and local sweet sorghum varieties in the winter and summer seasons (Shambat, 2012)

Variety	Winter	Summer	Combined
AGSilo200	5.260	5.425	5.343
Ank18	5.245	5.460	5.353
Ank36	5.365	5.355	5.360
Ank43	5.420	5.470	5.445
AnkNyala	5.370	5.410	5.390
BlueRibbon	5.110	5.105	5.107
Brawley	5.000	5.160	5.080
Colman	5.115	5.420	5.268
E-35-1	5.330	5.470	5.400
Fremont	5.175	5.250	5.213
Hastings	5.150	5.165	5.158
Kambal	5.685	5.770	5.728
KansasCollies	4.950	4.945	4.947
N100	5.205	5.415	5.310
N110	5.165	5.430	5.297
N98	5.010	5.060	5.035
N99	5.035	5.035	5.035
Red-X	5.195	5.250	5.223
S.126	5.845	5.640	5.742
S.134	5.675	5.640	5.658
S.154	5.530	5.620	5.575
S.158	5.350	5.595	5.473
S.70	5.460	5.545	5.502
SG12-1	5.465	5.580	5.522
SG32-2a	5.355	5.515	5.435
SG33	5.350	5.540	5.445
SG54	5.345	5.565	5.455
SugarDrip	5.265	5.490	5.378
Waconia-L	5.220	5.300	5.260
Mean	5.298	5.401	5.349
SE±	0.04142	0.04329	0.02996
LSD (0.05)	0.12000	0.12540	0.08487
CV (%)	1.1	1.1	1.1

References

- [1] A. Bibi, H. A. Sadaqat, H. M. Akram, M. I. Mohammed, Physiological markers for screening sorghum (*Sorghum bicolor* L. Moench) germplasm under water stress conditions, International Journal of Agriculture and Biology. 12 (2010) 451–455.
- [2] L. R. House, Sorghum: One of the world's great cereals, J. African Crop Sci. 2(1995)135-142.
- [3] B. G. Mukabane, G. Thiongo, B. Gathitu, H. Murage, N. O. Ojijo, W. O. Owino, Evaluating the potential of juice from some sweet sorghum varieties grown in Kenya to crystallize, Food Science and Quality Management. 30 (2014) 31-39.
- [4] N. Nandini, N.M. Kolekar, J. H. Akade, A. K. Rajvanshi, Syrup production from sweet sorghum. Nimbkar Agricultural Research Institute (NARI), Phaltan. (2006) Available at: https://www.researchgate.net/publication/238449544_Syrup_Production_from_Sweet_Sorghum

-
- [5] V. S. B. Reddy, K. A. Ashok, R. P. Sanjana, Sweet sorghum: A dry land-adapted, pro-poor bioethanol feedstock yielding both grain and fuel (2010), Available from www.icrisat.cgiar.org
- [6] A. Beldados, L. Constantini, Sorghum exploitation at Kassala and its environs, North Eastern Sudan in the second and first millennia BC, Nyame Akuma. 75 (2011) 33-39.
- [7] D. Q. Fuller, Early Kushite agriculture: Archaeobotanical evidence from Kawa, Sudan and Nubia. 8 (2004) 70-74.
- [8] P.K.E. Rao, M. M.H. Mengesha, Sorghum and millet germoplasm collection in Eastern Sudan, Progress Report, Genetic Resources-16 (1979). ICRISAT, India.
- [9] M. I. Mohammed, M. A. Mohamed, Evaluation of newly developed sweet sorghum (*Sorghum bicolor*) genotypes for some forage attributes, American-Eurasian J. Agric. & Environ. Sci. 6 (2009) 434-440.
- [10] S. I. Abdalbagi, M. I. Mohammed, Concurrent improvement of stem sugar, stover and grain yield in Sudanese and exotic sorghums I: Identification of materials, Journal of Advances in Biology & Biotechnology. 17 (2018) 1-8.
- [11] M. I. Mohammed, S. I. Abdalbagi, Concurrent improvement of stem sugar, stover and grain yield in Sudanese and exotic sorghums II: Heritability, genetic advance and association studies, Journal of Advances in Biology & Biotechnology. 17 (2018) 1-8.
- [12] J. G. N. Gaskin, R. J. Mesley, The effect of basic lead acetate solution upon the optical rotation (polarization) of solutions of sucrose, fructose and glucose and of various mixtures of these solutions. Int. Sug. J. 60 (1958) 65-71.
- [13] G. L. Miller, use of dinitrosalicylic acid reagent for determination of reducing sugar. Anal. Chem. 31 (1959) 426-428.
- [14] W. G. Cochran, G. M. Cox, Experimental designs. 2nd edn. John Wiley and Sons, Inc. New York. (1957) 293-316.
- [15] Genstat, Lawes Agricultural Trust (Rothamsted Experimental Station), VSN International, Ninth edition (2009) Version – 9.1.0.174. Hertfordshire. UK.
- [16] A. M. Abd El-Razek, S.Y. Besheit, Potential of some sweet sorghum (*Sorghum bicolor* L. Moench) varieties for syrup and ethanol production in Egypt, Sugar Tech. 3 (2009) 239-245.
- [17] A. Almodares, M.S. Hatamipour, Planting sweet sorghum under hot and dry climatic condition for bioethanol production. World Renewable Energy Congress. Bioenergy Technology (Be), (2011). Linköping, Sweden.
- [18] T. V. Balole, Strategies to improve yield and quality of sweet sorghum as a cash crop for small scale farmers in Botswana, PhD theses (2001) University of Pretoria.
- [19] D.B. Kulkarni, H.W. Deshpande, B.K. Sakhale, V.S. Pawar, Sweet sorghum syrup as natural sweetener for glazed tamarind candy, Int J Nutr Sci. 3 (2018) 1023.
- [20] D.K. Salunkhe, S.S. Deshpande, Foods of plant origin: Production, technology, and human nutrition, In: Sugar Crops, Desai B. B. et al. © Van Nostrand Reinhold. (1999) 413-489.
- [21] S. S. Rao, J. V. Patil, A. V. Umakanth, J. S. Mishra, C. V. Ratnavathi, G. S. Prasad, B. D. Rao, Comparative performance of sweet sorghum hybrids and open pollinated varieties for millable stalk yield, biomass, sugar quality traits, grain yield and bioethanol production in tropical Indian condition, Sugar Tech. 15 (2013) 250–257.
- [22] N. G. Inman-Bamber, an evaluation of sweet sorghum as a sugar crop in the Midlands Mistbelt, Proceedings of the South African Sugar Technologists' Association. (1980) Pp 105-108.