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Concurrent Improvement of Stem Sugar, Stover and Grain Yield in Sudanese and Exotic Sorghums II: Heritability, Genetic Advance and Association Studies

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Authors' contributions

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

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ABSTRACT

Aims: To investigate heritability, genetic advance from selection and the possibility of combining high levels of stem sugar with grain and stover yields in one cultivar.
Methodology: Twenty eight exotic and local sorghum (*Sorghum bicolor* (L.) Moench) genotypes arranged in Alpha lattice design were evaluated for stem juice, grain and stover yields and related traits.
Results: Apart from brix and extractability, genotype and environment (G x E) interaction was highly significant for all traits curtailing differences among genotypes and resulting in extremely low values for heritability and related genetic parameters. Analysis of variance performed in each season revealed highly significant differences among genotypes for all traits with medium to high heritability values coupled with high genetic advance from selection. Millable cane yield, stover yield, grain yield/plant, extractability and juice yield are expected to respond better to selection during summer

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while brix respond better during winter. All of the stem juice traits attributing to sugar yield other than brix were positively associated with grain and stover yield. Brix and grain yield showed weak negative correlation. Plant height and days to flowering showed favorable or at least trouble-free associations with the major productive traits.

Conclusion: The results suggest the importance of seasonal impacts when selecting for traits attributing to stem juice, grain and stover traits. The association study suggests the possibility of incorporating high levels of stem sugars, grain and stover yield in one cultivar.

Keywords: G x E interaction; seasonal effects; genetic variance; variability.

1. INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is known for its wide genetic diversity. It is a C4 species with greater resource-use photosynthetic efficiency employed to support the multipurpose economic utility of the crop. Owing to its versatility and ability to endure wide array of harsh conditions, sorghum is certainly one of the most capable crops to provide both food and fodder to the unsecured resource-poor farmers in the sub-Saharan Africa, and the sub-continent of India. The crop can be grown as mono-purpose commodity (either grain or fodder) or dual-purpose (both grain and fodder). The grain had been initially used for food; however, grain for feed is now overtaking that for food [1]. The sweet juicy sorghums were initially grown for producing syrup before being widely adopted for forage production. Recently, sorghum also appeared to have great potential as an annual energy crop. Invoked by the oil crisis of 1973 -76, research on sweet sorghum as a bio-fuel crop started since 1970s [2]. The three known types of sorghum (grain, sweet and fodder) could be utilized in energy production depending on the feedstock [3].

Earlier studies showed that favorable associations exist between different traits attributing to grain and fodder production [4]. Recent studies indicated small or no tradeoffs between biomass, grain and sugar production [5] supporting the possibility of developing a three in one cultivar (food, feed and bio-fuel). However, Research workers capitalizing on the multi-merits of sorghum have faced the question of whether to consider bio-fuel as ultimate objective or an added value to grain and stover. Workers in the United States [6] investigated the potential of developing high-starch grain sorghums with increased stem sugar for the ultimate goal of improving sorghum as a dedicated energy crop. On the other hand, sorghum breeders at ICRISAT–India [7] are advocating pro-poor breeding strategy, whereby food and feed traits are included as added values to enhance the competitiveness of the bioenergy feedstock. They argued that the bioenergy revolution should not marginalize the poor, raise food prices and degrade the environment. Such fuels vs. food concerns make the question of breeding sorghum as feedstock an ethical one.

Understanding heritability, genetic advance expected from selection and other related parameters is a prerequisite for a successful breeding program. Heritability is not governed by genetic factor alone, but also depends on the environment under which the genotype is studied, therefore, for accurate estimates of heritability, environmental effects and their interaction with genotype (GxE) should be considered. Importance of the interaction is also emphasized by [8]. This is specially true for productive traits which are highly responsive to environmental effects. Research works studying stem-sugar in sorghum in relation to other grain and fodder attributes are very few. Studying associations in 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 objectives of this study were to investigate heritability and genetic advance as affected by season for different stem-juice, grain and stover traits in exotic and local sorghum populations and to provide some information on how different multi- purpose economic traits in sorghum are interrelated to assess the possibility of developing cultivars combining high potential for stem sugars, grain and stover yield.

2. MATERIALS AND METHODS

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. Fourteen local and 14 exotic genotypes were studied. The exotic materials are sweet sorghum genotypes received from USDA, University. of Nebraska. The local materials represent 3 types, namely: Abu Sabin (dual forage /grain), Garawi (local Sudangrass) and Ankolib (local sweet sorghum). Most of the local materials have undergone improvement for Juiciness and/or forage production. The materials were sown in the Experimental Farm of Shambat Research Station (Sudan) (Lat.15° 39 N; Long.32° 31 E) during summer 22/ July/2012 and winter 6/ Dec/2012 seasons. The experimental design used was alpha lattice [9]. The data taken included :Millable cane yield (t/ha), Juice yield (l/ha), Grain yield/plant (g), Juice extractability (ml/kg), Brix value (%), Grain yield/plant (g), and Stover yield (t/ha) Yield related traits : 1000 seed weight; number of seeds/panicle; plant height; stem diameter and days to flowering were also measured. Further details about plant materials, trials management and data taken could be found in the accompanied paper

2.1 Statistical Analysis

For the purpose of calculating broad sense heritability the data was analyzed following the standard procedure of analyzing RCB design. Separate ANOVA was performed before running the combined ANOVA. The variance components were estimated as functions of the mean squares from the ANOVA as follows :

Environmental variance $(\sigma^2_e) = MS_E$

Genotype x Environment variance $(\sigma^2_{GE}) = (MS_{GE} - MS_e)/r$

Genotypic variance $(\sigma^2_G) = (MS_G - MS_{GE})/re$

Phenotypic variance (σ^2_P) for GxE model $= \sigma^2_G + \sigma^2_{GE}/e + \sigma^2_e/re$

Where: $MS_{E,}$ MS_{GE} and MS_G are mean squares for error (residual plots), genotype x environment and genotype, respectively, e = number of environments (trials), r = number of replicates per trial. Heritability (H) for GxE model [10] was calculated as follows:

$$H = \sigma^2_G / [\sigma^2_G + (\sigma^2_{GE}/e) + (\sigma^2_e/re)].$$

Broad sense heritability (h^2) in each season was calculated [11].

The genotypic (GCV) and phenotypic (PCV) coefficients of variation (%) were calculated [12] by dividing the square root of the respective variance by the grand mean of a character and multiplying by 100. Genetic advance (GA) assuming 5 % selection pressure was estimated [11]. Pearson's correlation coefficient between grain, fodder and juice attributes was calculated.

3. RESULTS AND DISCUSSION

Tables 1 and 2 show mean squares from combined ANOVA for productive and yield related traits, respectively. Differences among genotypes were not significant for most of the studied traits. Lack of significant difference could be attributed to the GxE mean squares being greater in magnitude than that of genotypes in some cases. However, highly significant differences among genotypes were encountered for extractability, brix, and 1000 seed weight.

3.1 Heritability and Genetic Advance from Selection

Variability indicators, heritability for GxE model (H) and genetic advance as percent of the mean (GAM) based on combined analysis are shown in Table 3. The results obtained clearly indicated that genetic parameters of the population under study were highly affected by the GxE interaction for most traits. Negative genetic variances (GV) were observed for juice yield, millable cane yield, stover yield, number of seed per head and stem diameter. The true values of negative variances as assumed by Robinson et al. [13] are small positive quantities but the negative estimates resulted from sampling error. In the present study, the GxE mean square for these traits was greater in magnitude than that for the genotype, hence, mathematically resulting in negative values. Thus, high GxE interaction coupled with sampling error were behind the negative genotypic variances observed in this study. Genetic parameters for traits with negative genotypic variance were, therefore, not worked out. The heritability values for grain yield and days to flowering were extremely low (< 0.1) with considerably low GAM values. The values of genotypic coefficient of variation (GCV) were lower than their respective phenotypic coefficient of variation (PCV) for all traits indicting the involvement of environmental factors in influencing their expression [14]. Compared to other productive traits, heritability and GAM for brix and extractability were relatively less affected by GxE interaction with respective values above 0.50 and 20%. 1000-seed weight showed the highest values for heritability (0.85) and GAM) (61%) indicating that selection for this trait is largely not affected by GxE interaction.

The markedly high GxE interaction noticed for most traits could be explained by the differential response of genotypes to the seasonal effects of sowing at summer (hot long days) and winter (relatively cool short days). Photoperiod and thermo –sensitivity are known to effect timing of heading and flower bud initiation in sorghum [15] with some variability existing among genotypes for responding to both effects. Flowering time, on the other hand has indirect effect through plant height on productive traits i.e. cane, juice and stover yields; as evident from this study (discussed below) or shown by other studies [16, 17]. This explains the low heritability and genetic advance values obtained for these traits due to GxE interaction.

Very contrasting results have been obtained when heritability and genetic parameters were extracted from single ANOVA in each environment (Table, 4). No negative genetic variances were encountered and medium to high heritability values were obtained for all traits. For example, heritability value for days to flowering jumped from 0.03 (Table, 3) when affected

Table 1. Mean squares from combined ANOVA for different productive traits in sorghum

Source of variation	D.f	Millable cane (t/ha)	Juice yield (t/ha)	Stover yield (t/ha)	Seed yield (t/ha)	Extractability (ml/kg)	Brix
Season (E)	1	705.28*	15077477.9*	879.77*	3593.63*	10993.2	4.339
Reps in E	4	39.281	807797.1	79.059	291.58	2123.05	25.649
Entry (G)	27	35.707	730014.8	72.692	327.78	3541.64**	43.054**
G × E	27	45.238 **	897572.3**	91.451**	258.18**	718.24**	9.339**
Error	108	6.470	132101.5	11.081	28.484	295.28	1.557

** ,** = Significant at 0.05 and 0.01 probability levels, respectively*

Table 2. Mean squares from combined ANOVA for some yield-related traits in sorghum

Source of variation	D.f	1000 Seed wt (gm)	Seed No / head	Days to flowering	Plant height (cm)	Stem diameter (cm)
Season (E)	1	45.054	8448394.5**	2476.3	18021.4*	4.199**
Reps in E	4	138.09	479221.8	559.95	985.89	0.045
Entry (G)	27	266.28**	368706.1	588.45	1138.04*	0.032
G × E	27	19.720**	627557.9**	543.56**	709.76**	0.057**
Error	108	8.221	116987.9	17.380	82.430	0.009

** ,** = Significant at 0.05 and 0.01 probability levels, respectively*

Table 3. Variability indicators for different traits in *Sorghum* based on combined ANOVA over two seasons

Trait	Mean	Range	GV	PV	PCV	GCV	H	GA	GAM
Brix (%)	17.0	12.5-21.5	5.619	9.770	18.37	13.93	0.58	3.70	21.76
Extractability (ml/kg)	129	83.5-178	470.6	731.3	25.69	16.88	0.64	29.36	22.85
Juice yield (l/ha)	1190	441-1869	-27926						
Millable cane yield (t/ha)	9.10	5.19-14.4	-1.589						
Stover yield (t/ha)	16.5	8.95-22.7	-3.127						
Grain yield / plant (g)	17.4	8.5-34.0	11.60	131.2	65.79	19.56	0.09	2.09	11.98
Days to flower	74.9	61.0-102	7.481	273.5	22.10	3.655	0.03	0.93	1.245
Plant height (cm)	136	114-164	71.38	398.8	14.73	6.227	0.18	7.36	5.430
Stem diameter (cm)	0.83	0.71-0.97	-0.004						
Seed number/head	907	337-1379	-43142						
1000-seed weight (g)	20	10.5-35.5	41.09	48.30	34.78	6.227	0.85	12.18	60.96

Note : Genetic variance (GV), phenotypic variance (PV), phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability for GxE model (H), genetic advance (GA) and genetic advance as percent of the mean (GAM)

Table 4. Mean performance, genetic variance (GV), phenotypic variance (PV), genetic coefficient of variation (GCV), heritability in broad sense (h^2) and genetic advance as percent of the mean (GAM) from single ANOVA for different traits in sorghum

Genetic parameter	Mean		GV		PV		GCV		h^2		GAM (%)	
Character	S*	W*	S	W	S	W	S	W	S	W	S	W
Brix (%)	16.82	17.23	5.581	10.45	7.961	11.28	14.04	18.76	0.701	0.926	24.2	37.2
Extractability (l/kg)	136.6	120.4	719.5	498.0	993.9	817.1	19.64	18.53	0.724	0.609	34.4	29.8
Juice yield (l/ha)	1489.8	890.6	333341	112573	527600	196166	38.75	37.67	0.632	0.574	63.5	58.8
Millable cane yield (t/ha)	11.15	7.05	18.86	2.786	29.76	5.512	39.0	23.68	0.634	0.505	63.9	34.6
Stover yield (t/ha)	18.83	14.25	34.97	8.568	56.13	14.91	31.4	20.60	0.623	0.575	51.1	32.1
Grain yield/ plant (g)	22.09	12.80	158.9	16.44	202.0	30.60	57.06	31.66	0.787	0.537	104.3	47.8
Days to flowering	71.1	78.75	153.3	207.9	178.1	219.4	17.44	18.31	0.861	0.947	33.3	36.7
Plant height (cm)	145.9	125.4	449.7	147.3	565.2	212.7	14.54	9.68	0.796	0.692	26.7	16.6
Stem diameter (cm)	0.991	0.674	0.006	0.018	0.020	0.022	8.01	19.63	0.318	0.801	8.78	37.1
Seed number/head	1131.2	682.6	123138	105649	343381	157489	31.02	47.62	0.359	0.671	38.3	80.3
1000-seed weight (g)	19.43	20.54	44.37	42.01	54.70	48.73	34.29	31.56	0.811	0.862	63.6	60.4

** : Summer and winter season, respectively*

Table 5. Correlations between different productive traits and related attributes in 28 *Sorghum* genotypes grown for two seasons

Character		Coefficient of correlation									
Extractability	1	-									
Juice yield	2	0.4077**	-								
Brix	3	0.1671*	-0.0204	-							
Days to flowering	4	-0.2067**	-0.0620	0.3829**	-						
Millable cane yield	5	0.0575	0.9119**	-0.0582	0.0254	-					
Plant height	6	0.0707	0.6685**	-0.1849*	0.0845	0.6984**	-				
No of seed /head	7	0.3586**	0.4369**	0.0549	0.0645	0.3685**	0.4260**	-			
1000 seed weight	8	-0.2714**	0.0929	-0.4765**	-0.1332	0.2191**	0.1516*	-0.1833*	-		
Grain yield /plant	9	0.1969**	0.4943**	-0.1791*	0.0031	0.5009**	0.4863**	0.7423**	0.4029**	-	
Stem diameter	10	0.3806**	0.5749**	0.1114	0.1254	0.5232**	0.4902**	0.5575**	-0.0512	0.5383**	-
Stover yield	11	0.0740	0.8662**	-0.0323	0.0973	0.9287**	0.6701**	0.3075**	0.1379	0.3881**	0.4681**
		1	2	3	4	5	6	7	8	9	10

**, ** = significantly different from zero at 0.05 and 0.01 probability level, respectively* by GxE interaction to 0.95 when analyzed from single environment. Such results imply that selection within the present population for most of the studied traits can be more effective when practiced in each environment (season) separately. Olweny et al. [18] found significant influence of G×E interaction on sugar and biomass production in sweet sorghum and arrived to a conclusion that selection for plant height, girth, brix juice, juice volume and stalks weight have to be carried out separately in each environment. GAM values read along with their respective heritability ones provide better indicator for selection efficiency than each parameters alone. As indicated by Table 4, all productive traits in both seasons showed high GAM values (24%-104%) coupled with medium to high heritability values (0.51- 0.93) indicating that selection for these traits could be practiced in each season. However, selection during summer is expected to be more effective for all productive traits other than brix, as the summer values for GCV, heritability and GAM were greater than those obtained in winter. This is specially true for grain yield/plant, millable cane yield and stover yield. In contrast the opposite is true for brix for which selection will be more effective during winter.

3.2 Associations

Correlations among productive traits and their related attributes are depicted in Table 5.The study revealed that - apart from brix - all of the stem juice traits attributing to sugar yield were positively associated with grain and stover yield. Such results point to the possibility of combining stem sugar, grain and stover yields in one cultivar. The negative association between brix and grain yield shown by this study is evident in the literature [19,20,6,16] but this is not considered detrimental to developing varieties combining high levels of stem brix and grain yield [5,20,16]. Moreover, the negative association between grain yield and brix though significant was of small magnitude (r= -0.179) compared to that of grain yield with juice yield (r=0.494). Juice yield and not brix (sugar concentration) is the limiting factor to high sugar yields [6]. Therefore, high juice yield can mitigate the unfavorable association of brix with grain yield when selecting for developing dual grain / stem sugar cultivars.

The study showed that stover yield has striking positive correlation with juice yield (r = 0.866) and significant positive correlation with grain yield (0.388) but has no correlation with brix (r= -0.032). Such results suggest that high stover yield can be easily incorporated with high sugar and grain yields in dual purpose breeding programs. Similar results and /or conclusions were reached by some workers [20,21].

Plant height and days to flowering play a pivotal role in compromising grain, stover and sugar yields when breeding for multifunctional sorghum cultivars. In this study, plant height and days to flowering showed (with minor exceptions) favorable or at least trouble-free associations with the major productive traits. Plant height correlated favorably with grain (r = 0.486), stover (r = 0.670), juice (r = 0.669) and millable cane yields (r = 0.698). On the other hand correlation coefficients were extremely low for days to flowering indicating that this character works independently from the major productive traits.

The unfavorable correlations of brix with plant height (r= -0.185) and days to flowering (r= 0.383) were low or moderate and can be mitigated by the favorable ones of juice yield. Disagreeing results were reported by some workers [16,22]. The latter workers expressed some concerns about what they argued a difficulty in combing greater grain and stover yields in Indian sorghums due to contradicting associations with plant height and days to flowering. Days to flowering has weak and insignificant associations with juice yield (r= -0.062) and millable cane yield (r= 0.025), has negative significant correlation with extractability (r= -0.207) and positive significant correlation with brix (r= 0.383). Apart from brix, such results point to possibility of incorporating earliness with high juice yielding genotypes. Earliness is a desirable trait under local production systems and production of ethanol from sweet sorghum.

4. CONCLUSION

Genotype and environment (G x E) interaction was highly significant for all traits curtailing differences among genotypes for all traits other than brix and extractability that seemed to be less influenced by seasonal effect. Genetic improvement in the studied population could be expected if selection is practiced in each season separately. A seasonal trend for response to selection was noticed whereby millable cane yield, stover yield, grain yield/plant, extractability and juice yield were expected to respond better to selection during summer while brix respond better during winter. The correlation study revealed the possibility of incorporating high levels of stem sugars, grain and stover yield in one cultivar.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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