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DEVELOPMENT OF DUAL PURPOSE SORGHUM: CORRELATION AND PATH-COEFFICIENT ANALYSIS OF GRAIN YIELD AND STEM SUGAR TRAITS

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ABSTRACT

Information on the relationship between grain yield, stem sugar and biomass is important in developing dual-purpose sorghums. The objective of this study was to determine, correlations and path-coefficients between grain yield and stem sugar traits. The study was conducted using 100 sorghum genotypes evaluated in six environments in southern Africa. Grain yield, the dependent variable, was positively and significantly (P<0.05) correlated with stem sugar, stem biomass, days to 50% flowering, number of leaves per plant, plant height and stem diameter. Grain yield was negatively significantly (P<0.05) correlated with stem juice score (r = -0.049), suggesting that high grain yielding cultivars are generally low in stalk juice. However, the significance of the positive correlation coefficient between grain yield and stem sugar (r = 0.071) suggested that the traits are not mutually exclusive. The identification of hybrids that combined high performance for both traits supported this. Path-coefficient analysis revealed that the number of leaves per plant had high, positive direct effect on grain yield, implying that selection for high performance in this trait improves grain yield. In contrast to the overall correlation coefficient, stem sugar had a negative direct effect on grain yield; suggesting that selection for high stem sugar content directly reduces grain yield. However, this was masked by the indirect effect, hence the significant positive and significant (P<0.001) correlation coefficient between the two traits.

Key Words: Plant height, stem biomass, stem juice

RÉSUMÉ

L'information sur la relation entre le rendement en grain, en sucre de la tige et en biomasse est importante dans le développement des sorghos à double objectifs. L'objectif de cette étude était de déterminer, les corrélations et les coefficients de piste entre les rendements en grain et en teneur en sucre de la tige. L'étude a été conduite en utilisant 100 génotypes du sorgho évalués en six environnements en Afrique du Sud. Le rendement en grain, la variable dépendante, était positivement et significativement (P<0,05) corrélé avec la biomasse de la tige, le nombre de jours à 50% de floraison, nombre de feuilles par plant, la hauteur de la plante et le diamètre de la tige. Le rendement en grain était négativement et significativement (P<0.05) corrélé avec le score du jus dans la tige (r= - 0,049), suggérant que les cultivars à rendement élevé sont généralement faible en jus de la tige. Néanmoins, la signifiance de la corrélation positive entre le rendement en grain et le sucre dans la tige (r=0.071) suggérant que les traits ne sont pas mutuellement exclusifs. L'identification des hybrides contenant une performance élevée pour les deux traits confirme ceci. L'analyse du coefficient de piste a révélé que le nombre de feuilles par plante avait un fort, et positif effet direct sur le rendement en grain, impliquant que la sélection pour une forte performance dans les traits améliore le rendement en grain. Contrairement au coefficient de corrélation en général, la teneur en sucre de la tige avait un effet direct négatif sur le rendement en grain ; suggérant que la sélection pour une forte teneur en sucre directement réduit le rendement en grain. Toutefois, ceci a été masqué par l'effet indirect ; d'où le coefficient de corrélation positif et significatif (P<0,001) entre les deux traits.

Mots Clés: Hauteur de la plante, biomasse de la tige, jus de la tige

INTRODUCTION

Success in breeding of dual-purpose sorghum (*Sorghum bicolor* L. Moench) for grain and stem sugar depend on the understanding of the relationship between the two and the associated traits. The general notion is that improving grain yield results in a reduction in stem sugar yields (Srinivasa *et al*., 2009; Vermeriris *et al*., 2014). The argument is that the two represent powerful sinks for the limited photo-assimilates. Based on this argument, it is assumed that high grain yielding cultivars are low in stem sugar, and *vice versa*. However, there is no strong evidence to support this view.

Reports on the relationship are scarce. Guiying *et al*. (2000) reported a negative relationship between stem sugar and weight of 1000 seeds (r = -0.472). Although 1000 seed weight is a grain yield component and gives pointers to the relationship, it can be argued that it is not a good reflection of overall grain yield per plant or hectare. The trait, for example, is dependent on the number and size of the seeds per plant. From the same sorghum head, different seed sizes are obtained and some seed companies pack similar sized seed of the same variety separately, a process called fractionation (Sulewska *et al*., 2014).

Therefore, using grain yield per hectare or per plant represents the most dependable analysis of the relationship, which should include the associated traits. Understanding this relationship is important because it helps crop improvement scientists to formulate and optimise breeding strategies for developing dual-purpose sorghum varieties, such as choosing between direct *versus* indirect selection or compromising between equally important traits showing strong negative relationships.

Relationships between plant traits have been studied using simple correlation coefficients (Makanda *et al.,* 2009). These measure simple linear relationships among traits, that is, mutual association without regard to cause and effect. Therefore, when used alone, correlation coefficients do not give a clear representation of relationships (Bidgoli *et al.*, 2006; Makanda *et al*., 2009). This necessitates a further breakdown of the correlation coefficients into non-linear connecting paths of influence, called path-coefficients (Bidgoli *et al.*, 2006). Path-coefficients give both the direct and indirect influences of individual traits to a dependent variable (García del Moral *et al*., 2003). This is based on the fact that as the number of parameters influencing a particular dependent variable increase, so does the interdependence among those parameters (Ofori, 1996). This information is critical because it informs a breeder's choice of direct or indirect selection capitalising on correlated responses.

Correlation and path-coefficient analyses have been used to study relationships between traits in many crops including sorghum (Maman *et al*., 2004), wheat (Aycicek and Yildirim, 2006), groundnuts (Bera and Das, 2000), bambara groundnuts (Makanda *et al*., 2009), linseed (Akbar *et al*., 2001), safflower (Bidgoli *et al.*, 2006), and tomato (Rani *et al*., 2008).

Nevertheless, there are no such reports elucidating these relationship for stem sugar and grain yield traits in dual-purpose sorghums. Further, results obtained elsewhere do not necessarily reflect relationships in a different environment (Maman *et al*., 2004). The objective of this study was to establish the relationship between grain yield and stem sugar traits in dual sorghum grown in southern Africa.

MATERIALS AND METHODS

Germplasm study site. The study was based on data collected from 100 sorghum genotypes that included 80 dual-purpose experimental hybrids, 18 parents and 2 check varieties. The 18 parents were divided into two groups based on the status of their cytoplasm. Eight cytoplasmic male-sterile (CMS) A-lines were designated as females and crossed to 10 cytoplasmic male-fertile lines (R-lines) in accordance with a North Carolina Design II mating scheme to generate 80 hybrids. The males were constituted from introduced (improved lines) and southern African (adapted materials) germplasm; while female parents were obtained from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India (Table 1).

During hybridisation, two heads of each CMS female lines were self-pollinated to ensure no breakdown of the CMS system. The hybrids, 18 parents and two check varieties were evaluated in trials, with the iso-cytoplasmic B-lines grown in lieu of their respective CMS A-lines.

The experiments were conducted at Chokwe Research Station (CRS) (24° 312 S; 33° 02 E, 40 m.a.s.l) in Mozambique and at Makhathini Research Station (MRS) (27º 24'S; 32º 11' 48" E, 72m.a.s.l.) in South Africa during off-season (May to September 2008) and in-season (November 2008 to April 2009). Further in-season trials were conducted at Rattray-Arnold Research Station (RARS) (17º 40' S; 31º 14' E, 1308 m.a.s.l.) in Zimbabwe and at Ukulinga Research Farm (URS) (30º 24' E; 29º 24' E, 781 m.a.s.l.) in South Africa. Standard agronomic practices for sorghum production were followed at all sites.

Both CRS and MRS represent the tropical lowland environments in southern Africa, where there is potential for sorghum production both in-season and off-season without adverse effects of low temperatures. The two sites have annual long term mean rainfall of about 600 mm and maximum temperatures of about 25-30 ºC (Fig. 1).

RARS and URF represent the mid-altitude environments with annual rainfall of about 800 mm and maximum temperatures of 20-30 ºC (Fig. 1). Although the rainfall is seasonal at all sites, the temperatures and availability of irrigation facilities at CRS and MRS make them ideal for sorghum production throughout the year, unlike URF and RARS where low winter temperatures make it impossible to grow cold sensitive crops like sorghum during May to September. Both CRS and MRS are surrounded by small-scale irrigation schemes with perennial water sources from rivers and dams.

Data collection and analyses. Stem sugar concentration was measured in °brix, using an Atago PAL-1 digital, hand-held pocket refractometer, at the hard dough stage of each entry. The stems were divided into three equal sections and three brix measurements were taken from the middle internode of each section by squeezing the juice into the sample stage of the refractometer using a pair of pliers. Both the pliers and the refractometer sample stage were rinsed with distilled water and dried before the next sample was measured to avoid cross sample contamination.

It has been shown that total sugar content and stem brix has a linear relationship and, thus stem brix is a good measure of stem sugar content (Ma *et al*., 1992).

Stem diameter was measured from the three mid internode sections, using a veneer calliper and stem juiciness was measured using a rating scale of 1, 3, 5, 7 and 9; where 1 (juicy) to 9 (dry), depending on the ease of pressing and resultant juice pressed, respectively (Makanda *et al*., 2010). The final values for stem brix, diameter and juice score were each an average of the three measurements.

Stem biomass was measured at the hard dough stage, by stripping five plants of all leaves and heads, then cutting at ground level and weighing the stems. Grain yield was measured on a per plot basis and converted into per hectare after adjusting to 12.5% grain moisture content.

TABLE 1. Origin and pedigree of parental sorghum lines used in the study of the relationship between grain yield and stem sugar traits at CRS, RARS, MRS and URS in southern Africa

Sorghum line	Fertility	Origin	Pedigree	Role
ZLR1 †	CMF	Zimbabwe	Landrace	Male
MRL15	CMF	Unknown	Unknown	Male
ICSV700	CMF	ICRISAT India	(IS 1082 x SC 108-3)-1-1-1-1-1	Male
ICSV93046	CMF	ICRISAT India	(ICSV 700 x ICSV 708)-9-1-3-1-1-1	Male
S35	CMF	ICRISAT India	-	Male
Macia	CMF	Mozambique	SDS 3220	Male
ZLR2	CMF	Zimbabwe	Landrace	Male
ICSR165	CMF	ICRISAT India	SPV 422	Male
ICSR57	CMF	ICRISAT India	(SC 108-3 x 148)-12-5-3	Male
Thar	CMF	Unknown	Unknown	Male
ICSA731	CMS	ICRISAT India	ICSV 1171BF	Female
ICSA479	CMS	ICRISAT India	[9ICSB 70 x ICSV 700) x PS 19349B]-5-4-1-2-2	Female
ICSA4	CMS	ICRISAT India	[(BTx 622 × UChV2)B lines bulk]-10-1-1	Female
ICSA724	CMS	ICRISAT India	ICSP 1B/R MFR-S 7-303-2-1	Female
ICSA307	CMS	ICRISAT India	[(ICSB 26 × PM 1861)×(ICSB 22 × ICSB 45) × (ICSB 52 × ICSB 51)]1-3-12-3-1	Female
ICSA474	CMS	ICRISAT India	(IS 18432 x ICSB 6)11-1-1-2-2	Female
ICSA26	CMS	ICRISAT India	[(296B x BTx 624)B lines bulk]-2-1-1-3	Female
ICSA623	CMS	ICRISAT India	(ICSB 11 x PM 17467B)5-1-2-1	Female
Introduced checks				
Saccaline	CMF	USDA	Unknown	
Grassl	CMF	USDA	Unknown	

† = local check; CMF = cytoplasmic male fertile; CMS = cytoplasmic male sterile; - = unknown pedigrees

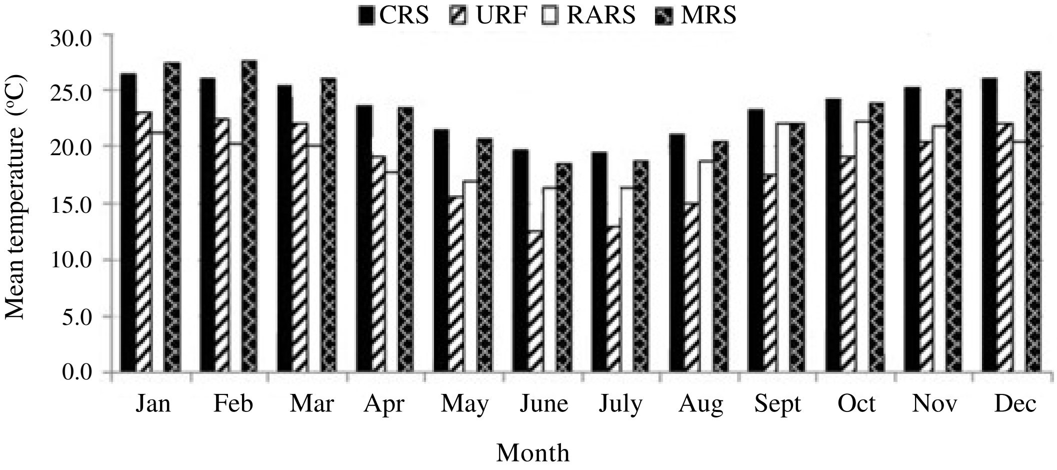

Figure 1. Long term (five year) mean temperatures for the sites at CRS, RARS, MRS and URS in Southern Africa. Data source: Agricultural Research Council-ISCW AgroMet Potchefstroom (2009); Seed Co. Zimbabwe Ltd. (2009); Gaisma (2007).

Grain moisture was measured using a DICKEY-John mini GAG® Plus moisture meter. Plant height was measured using a graduated 3.0 m measuring stick. Number of days to 50% flowering (time in days taken for half of the plants in a plot to reach anthesis) were also measured by visual inspection.

In this study, the phenotypic correlations (r_p) were assumed to be equal to the genetic correlations (r_g) because the number of genotypes evaluated was high (100), evaluated over many environments (six) totalling 14 replications over sites. This is based on the fact that, as the sample size and the environments in which the genotypes were evaluated increase, r_p and r_g coincide due to the removal of the environmental effects by multi-location evaluation (Cheverud, 1988; Waitt and Levin, 1998).

Two studies on correlations and path-coefficient studies were conducted. The first using grain yield as the dependent variable, and the second was a correlation coefficient study performed on a subsample of the top 20 performing genotypes on stem sugar, grain yield and stem biomass. The second analysis was done to establish the relationship between the traits among the candidate "elite" genotypes based on performance.

Correlation coefficients (r) between all the traits were computed in GenStat computer package (Payne *et al.,* 2007). Path-coefficients (P) were calculated by regression method based on the work of Wright (1960), and Cramer *et al.* (1999). In this procedure, all the independent variables (1 to n) are regressed against the dependent variable. The regression coefficient (*b*) of each of the independent traits is its direct effects to the dependent variable (Cramer *et al.*, 1999). The indirect effects are then computed by multiplying the correlation coefficient between the target independent variable and the independent variable in its path by the direct effect, *b*, of the independent variable in that path to the dependent variable (Cramer *et al.*, 1999).

The relationships are presented in Figure 2, where the one-headed arrows represent the direct effects and the double headed arrows represent the correlation coefficients between the determinant traits.

In addition to the correlation and path-coefficient analysis, a selection of the entries

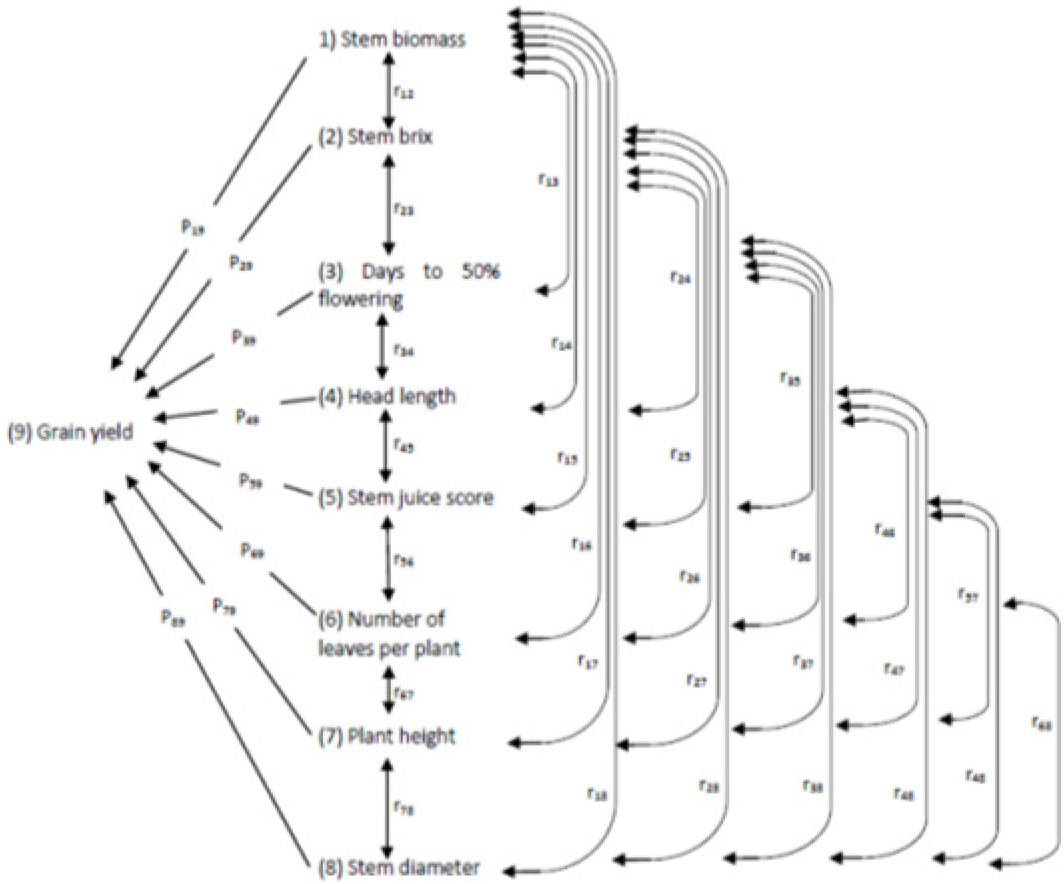

Figure 2. Path diagram showing relationships between grain yield against stem biomass, stem brix, head length, stem juice score, number of leaves per plant, plant height and stem diameter in the current experiments conducted in southern Africa.

from the study showing high performance on stem sugar, stem biomass and grain yield was used to help answer the question of whether it is possible to breed a dual-purpose sorghum with high performance across the three traits.

RESULTS

Correlation and path coefficient analysis. The correlation coefficient between grain yield components and stem sugar traits are presented in Table 2. The first, unexpected finding was the positive and significant correlation coefficient between grain yield and stem brix (r = 0.071; P<0.01), a measure of stem sugar. Stem brix was also, positive and significantly correlated with head length (r = 0.084; P<0.05), number of leave per plant (r = 0.458; P<0.01), and plant height (r = 0.183; P<0.05). However, its correlation with stem juice score was negative and significant (r = -0.265; P<0.01). Further, positive and significant (P<0.05) correlation coefficients were observed between stem biomass and (i) grain yield (r = 0.046; P<0.01), (ii) head length (r = 0.226; P<0.01), (iii) number of leaves per plant (r = 0.181; P<0.05), (iv) plant height (r = 0.434; P<0.01), and (v) stem diameter (r = 0.172; P<0.05).

TABLE 2. Correlation coefficients between grain yield and stem sugar content with selected agronomic traits in sorghum

	SBX	GY	SBW	DT50F	HDL	SJS	NLP	PHT
Stem brix (SBX)	1.000							
Grain yield (GY)	0.071**	1.000						
Stem biomass weight per ha (SBW)	0.102	0.046**	1.000					
Days to 50% flowering (DTF)	0.117	0.049*	-0.076	1.000				
Head length (cm) (HDL)	0.084*	0.024*	0.226**	-0.253	1.000			
Juice score (SJS)	-0.265**	-0.049*	-0.117	-0.110**	-0.230	1.000		
Number of leaves per plant (NLP)	0.458**	0.124**	0.181*	0.387*	-0.113**	-0.081	1.000	
Plant height (cm) (PHT)	0.183*	0.070**	0.434**	0.144	0.134*	-0.032	0.404**	1.000
Stem diameter (mm) (SD)	0.005	0.093**	0.172*	0.443	0.132**	-0.316**	0.302**	0.193**

**, * significant at P<0.01 and P<0.05, respectively

Days to 50% flowering were positively and significantly (r = 0.387; P<0.05) correlated with number of leaves per plant, but the relationship with stem juice score was negative and significant (r = -0.110; P<0.01). Head length was positively and significantly (r = 0.134; P<0.05) correlated with plant height and stem diameter; while its correlation with number of leaves per plant was negative and significant. There was a positive and significant correlation coefficient (P<0.01) between number of leaves per plant and both plant height (r = 0.404) and stem diameter (r = 0.302). Plant height was in turn positively and significantly (P<0.01) correlated with stem diameter.

The significance of some correlation coefficients and the regression analysis indicated that it was prudent to proceed with path-coefficient analyses on the traits to different indirect relationships forming the overall correlation coefficients. The direct effects of the traits on grain yield, and the path-coefficients representing indirect effects are presented in Table 3.

Although stem brix at maturity had a positive and significant (P<0.01) correlation coefficient with grain yield, its direct effect was negative and significant (r = -0.1042). Stem biomass had a positive and significant (P<0.01) correlation coefficient (Table 2) with grain yield, although the direct and indirect effects (Table 3) were low and non-significant. The correlation coefficient between grain yield and (i) days to 50% flowering, (ii) head length, (iii) plant height, and (iv) stem diameter were significant (Table 2), but with low direct effects (Table 3). Stem juice score exhibited a significant (P<0.01) and negative correlation coefficient and direct effect on grain yield. Number of leaves per plant displayed a positive and high correlation coefficient and direct effect on grain yield. The indirect effects of all the traits to grain yield were generally low (Table 3).

Grain yield and stem sugar traits. The correlation coefficients between grain yield and

TABLE 3. Direct and indirect path coefficients of selected sorghum traits on grain yield across six environments at CRS, RARS, MRS and URS in southern Africa

	Direct path coefficient on grain yield	Indirect path values through:							
		SBW	SBX	DTF	HDL	SJS	NLP	PHT	SD
SBW	0.0000		0.0050	-0.0003	0.0075	0.0052	0.0241	0.0004	0.0044
SBX	-0.1042**	0.0000		0.0006	0.0021	0.0093	0.0228	0.0000	-0.0017
DTF	0.0041	0.0000	-0.0142		-0.0084	0.0049	0.0513	0.0001	0.0114
HDL	0.0332	0.0000	-0.0065	-0.0010		0.0102	-0.0149	0.0001	0.0034
SJS	-0.0443*	0.0000	0.0220	-0.0004	-0.0076		-0.0108	0.0000	-0.0081
NLP	0.1326*	0.0000	-0.0179	0.0016	-0.0037	0.0036		0.0003	0.0078
PHT	0.0008	0.0000	0.0039	0.0006	0.0044	0.0014	0.0536		0.0050
SD	0.0257	0.0000	0.0071	0.0018	0.0044	0.0140	0.0401	0.0002	

**, * significant at P<0.01 and P<0.05, respectively; SBX = stem brix at maturity; SBW = stem biomass weight; DTF = days to 50% flowering; HDL = head length; SJS = stem juice score; NLP = number of leaves per plant; PHT = plant height; SD = stem diameter

stem brix at maturity (r = 0.1470) and stem brix and stem biomass (r = -0.2344) for the top 20 grain yield performers were not significant. Only the correlation coefficient between grain yield and stem biomass was high, positive and significant (P<0.01).

The top and bottom grain yield performers based on stem brix, grain yield and stem biomass are presented in Table 4. Although most of the entries, such as ICSV93046× ICSA4, showed high performance for one or two traits and performed dismally on the other, entries that showed general high performance across the three traits were identified. These were hybrids ICSV700×ICSA731, ICSR165×ICSA307, ZLR1×ICSA26, ICSR165×ICSA4, ICSV700×ICSA307, ICSR165×ICSA479, ICSR165×ICSA26, and S35×ICSA4.

DISCUSSION

The correlation and path-coefficient study has demonstrated important relationships between grain yield and stem sugar traits association in sorghum in southern Africa (Table 3). The first and surprising result was the positive and significant correlation coefficient between grain yield and stem brix both at grain maturity. Although it was low (r =0.071), the observation of its significance contradicts the general notion that the two traits are inversely related; and suggests that breeding can improve both traits simultaneously in one cultivar, using conventional plant breeding. This is consistent with Gutjahr *et al*. (2013), who reported that change in sugar concentration was not negatively correlated with grain yield, although their study only analysed a period from anthesis to grain maturity.

The direct effect of stem brix on grain yield was negative, high and significant (Table 3). This supports the findings by Guiying *et al*. (2000), although their study used weight of 1000 seeds, not productivity *per se* and is in agreement with the general notion that the traits are negatively related. The negative direct effects was masked by positive indirect effect mainly through stem biomass, days to 50% flowering, plant height, and number of leaves per plant (Table 3). The direct effect through number of leaves per plant was very high and highly significant (r = 0.458).

The negative indirect effect of stem brix through juice score, although very high, was obscured by these positive indirect effects. Therefore, the direct effect of selecting for high stem sugar is a reduction in grain yield, supporting the general notion. However, the

TABLE 4. Stem brix, stem biomass and grain yield performance and standard heterosis of selected sorghum hybrids and parents across environments at CRS, RARS, MRS and URS in Southern Africa

Entry	Stem brix (ºbrix)				Stem biomass (kg ha^{-1})				Grain yield (kg ha^{-1})			
	MA	TL	Mean	StdH	MA	TL	Mean	StdH	MA	TL	Mean	StdH
Top 20 stem brix performers												
ICSV93046×ICSA4	14.8	12.5	13.5	125	41272	29669	32948	97	1505	1018	1261.6	72
ICSV700×ICSA731	14.4	12.3	13.2	122	51497	38325	42088	124	2810	3261	3035.6	173
ICSR165×ICSA307	13.9	12.0	12.8	118	51641	49615	50194	147	2410	2552	2481.0	141
ZLR1×ICSA26	13.9	11.4	12.4	114	57868	30218	38118	112	2271	1807	2039.0	116
ZLR1×ICSA307	15.0	10.5	12.3	113	43023	25194	30288	89	1446	1072	1259.2	72
MRL15×ICSA26	12.9	11.9	12.2	112	19935	34804	30556	90	2754	2118	2435.8	139
ICSB479	14.8	10.8	12.1	112	30333	15837	20669	61	869	764	816.5	412
Saccaline	13.5	9.2	12.0	111	36363	24673	32466	95	3879	1348	2613.5	142
ICSR165×ICSA724	14.5	10.4	12.0	111	41418	32817	35275	104	2865	1930	2397.4	136
MRL15×ICSA4	14.6	10.2	11.9	110	51205	32115	37570	110	1045	5168	3106.6	177
ICSR165×ICSA4	12.8	10.7	11.8	109	49441	37592	40978	120	4437	3555	3995.8	227
ICSV700×ICSA307	13.1	11.1	11.8	109	48229	34444	38686	114	3956	4071	4013.4	228
ICSR57	14.3	9.2	11.7	108	21402	16231	17708	52	1935	1932	1933.4	110
ICSR165×ICSA479	16.0	7.4	11.7	108	59048	25797	33186	97	4187	2310	3248.3	184
ICSR165×ICSA26	14.0	9.3	11.6	108	81346	42432	51588	152	4076	2386	3231.0	183
S35×ICSA4	12.2	10.9	11.5	107	34826	57248	43795	129	5332	4999	5165.7	294
ICSV700	13.2	10.3	11.4	106	40725	30147	33994	100	1751	2385	2067.8	118
Macia×ICSA307	10.7	12.2	11.4	106	24485	21974	22746	67	1840	1780	1809.8	103
ICSV93046×ICSA731	11.7	11.0	11.3	104	45288	40314	41844	123	2193	1733	1962.8	112
ICSV700×ICSA4	13.3	9.9	11.2	104	21917	32625	29565	87	1774	2280	2027.0	115

TABLE 4. Contd.

Entry	Stem brix (ºbrix)				Stem biomass (kg ha^{-1})				Grain yield (kg ha^{-1})			
	MA	TL	Mean	StdH	MA	TL	Mean	StdH	MA	TL	Mean	StdH
Bottom 5 stem brix performers												
MRL15×ICSA724	10.4	5.9	7.4	68	23594	24651	24299	71	2384	1766	2074.8	118
ZLR2×ICSA724	9.6	6.0	7.2	66	28389	25816	26551	78	2537	1496	2016.4	115
Msinga	7.1	7.1	7.1	65	19899	22457	21434	63	2201	960	1580.3	90
ICSV700×ICSA474	7.3	6.9	6.9	63	44844	38715	40466	119	1836	2230	2032.8	116
Robbocane 11/59	7.4	6.5	6.8	63	16717	12064	13756	41	2389	970	1679.3	96
ZLR2×ICSA307	6.1	7.1	5.8	53	10095	27861	21939	64	459	395	427.0	24
Standard check varieties												
Stem sugar and biomass check (ZLR1)	10.6	10.8	10.7	100	44598	23512	34055	100				
Grain yield check (Macia)									1976	1541	1758.3	100
Environment mean	11.4	9.2	10.5		29130	34166	31648		2559	1972	2265.7	
P-value			<0.01				<0.01				<0.01	
SED			1.52				7694				823.0	

MA = Mid-altitude environment; TL = Tropical-lowland environment; StdH = Standard heterosis; SED = Standard error of difference overall effect is an improvement in grain yield due to the positive indirect effects. This observation attests to the fact that plants with many leaves tend to have higher photosynthetic capacities, thereby producing more photo assimilates used to build both stem sugars and grain yield. This can explain the positive correlations coefficients between number of leaves per plant and both grain yield (r = 0.124) and stem brix (r = 0.458) (Table 2). Therefore, although leafy plants might have positive or no relationship between stem sugar and grain yield, the less leafy ones (at the same photosynthetic rates) tend to have a negative relationship between the two traits due to competition for the limited photo-assimilates.

Piper and Kulakow (1994) reported that 42 to 74% of grain yield was attributed to plant biomass, results that are consistent with the positive and significant correlation coefficient between the two traits observed in the current study, although this is true only within a certain range after which the biomass start competing with the grain for photo-assimilates. The observed positive correlation coefficient between stem biomass and (i) head length, (ii) number of leaves per plant; (iii) plant height, and (iv) stem diameter (Table 3) could be attributed to the fact that plant height and stem diameter are major components contributing to the overall plant stem biomass. The findings are consistent with earlier reports in sorghum (Alam *et al.*, 2001; Ekshinge *et al.*, 1983; Piper and Kulakow, 1994; Ezeaku and Mohammed, 2006) that the traits are major contributing components plant stem biomass.

The positive correlation coefficients between plant height and both head length and number of leaves per plant suggests that the latter two traits increase as plant height increases (Table 3), which is consistent with earlier reports in sorghum by Alam *et al.* (2001) and in other crops like rice by Babar *et al.* (2007).

Most tall plants have longer heads than their shorter counterparts, a phenomenon that was given as one of the explanations for heterosis in sorghum (Patanothai and Atkins, 1971) and can explain the positive correlation coefficient between the head length and plant height. Alam *et al.* (2001) also reported a positive relationship of the two traits. However, this relationship can be altered by growing conditions and through breeding for improved harvest index in grain sorghum, as it ensures larger heads relative to the plant height. Therefore, this has to be taken in context of growing crops and breeding history of the reference sorghum base population.

However, the negative correlation between head length and number of leaves per plant implies that plants with many leaves have smaller heads, and *vice versa*. The reason for this observation is not clear as both traits are genetically controlled, although the head length can be influenced by the environment. This could mean that the many leaves were competing with the head for photo-assimilates and implies that breeding for high grain yield can be achieved indirectly through breeding for reduced leafiness to optimum levels. However, these optimum levels have to be established for each cultivar because it is logical that differences in plant architecture (including height) and environmental conditions result in varying photosynthetic levels and efficiencies (Sarlikioti *et al.*, 2011).

The positive relationship between stem diameter and number of leaves per plant can be attributed to more photo-assimilates from more leaves that are used to build tall and thick stemmed plants. This can explain the positive and significant correlation between stem diameter and plant height because plant growth occurs both in height and girth.

CONCLUSION

Overall, the observed positive correlation coefficient between grain yield and stem sugar suggest that it is possible to improve both traits in one cultivar, answering the question as to whether dual purpose sorghum combing high grain yield and stem sugar can be developed. Although the direct effect of stem brix on grain yield was negatively significant, the identification of hybrids ICSV700×ICSA731, ICSR165×ICSA307, ZLR1×ICSA26, ICSR165×ICSA4, ICSV700×ICSA307, ICSR165×ICSA479, ICSR165×ICSA26, and S35×ICSA4, that combined high performance for grain yield, stem brix and stem biomass confirmed this suggestion.

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