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

I. MAKANDA1, 2
1University of KwaZulu-Natal, P. Bag X01, Scottsville, Pietermaritzburg, 3209, South Africa
2Alliance for a Green Revolution in Africa (AGRA), P. O. Box 66773, Westlands 00800, Nairobi, Kenya

Corresponding author: itaimakanda@yahoo.com
(Received 21 July, 2016; accepted 10 July, 2017)

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 sorgos 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 signification 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; Vermerris 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-polliated to ensure no breakdown of the CMS system. The hybrids, 18 parents and two check varieties were evaluated in trials, with the isocytoplasmic B-lines grown in lieu of their respective CMS A-lines.

The experiments were conducted at Chokwe Research Station (CRS) (24° 31′ S; 33° 02′ E, 40 m.a.s.l) in Mozambique and at Makhathini Research Station (MRS) (27° 24′S; 32° 11′ E, 72 m.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) (17° 40′ S; 31° 14′ E, 1308 m.a.s.l.) in Zimbabwe and at Ukulinga Research Farm (URS) (30° 24′ E; 29° 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 °C (Fig. 1).

RARS and URF represent the mid-altitude environments with annual rainfall of about 800 mm and maximum temperatures of 20-30 °C (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.
| Sorghum line | Fertility | Origin      | Pedigree                                                                 | Role   |
|-------------|-----------|-------------|--------------------------------------------------------------------------|--------|
| ZLR1 †      | CMF       | Zimbabwe    | Landrace                                                                 | Male   |
| MRL15       | CMF       | Unknown     | Unknown                                                                  | Male   |
| ICSV700     | CMF       | ICRISAT     | (IS 1082 x SC 108-3)-1-1-1-1                                             | Male   |
| ICSV93046   | CMF       | ICRISAT     | (ICSV 700 x ICSV 708)-9-1-3-1-1-1                                        | Male   |
| S35         | CMF       | ICRISAT     | -                                                                       | Male   |
| Macia       | CMF       | Mozambique  | SDS 3220                                                                 | Male   |
| ZLR2        | CMF       | Zimbabwe    | Landrace                                                                 | Male   |
| ICSR165     | CMF       | ICRISAT     | SPV 422                                                                  | Male   |
| ICSR57      | CMF       | ICRISAT     | (SC 108-3 x 148)-12-5-3                                                 | Male   |
| Thar        | CMF       | Unknown     | Unknown                                                                  | Male   |
| ICSA731     | CMS       | ICRISAT     | ICSV 1171BF                                                              | Female |
| ICSA479     | CMS       | ICRISAT     | [9ICSB 70 x ICSV 700) x PS 19349B]-5-4-1-2-2                              | Female |
| ICSA4       | CMS       | ICRISAT     | [(BTx 662 x UChV2)B lines bulk]-10-1-1                                   | Female |
| ICSA724     | CMS       | ICRISAT     | ICSV 1B/R MFR-S 7-303-2-1                                               | Female |
| ICSA307     | CMS       | ICRISAT     | [(ICSB 26 x PM 1861) x (ICSB 22 x ICSV 45) x (ICSB 52 x ICSV 51)]1-3-12-3-1 | Female |
| ICSA474     | CMS       | ICRISAT     | (IS 18432 x ICSB 6111-1-1-2-2                                           | Female |
| ICSA26      | CMS       | ICRISAT     | [(296B x BTx 624)B lines bulk]-2-1-1-3                                   | Female |
| ICSA623     | CMS       | ICRISAT     | (ICSB 11 x PM 17467B)-5-1-2-1                                           | Female |

**Introduced checks**

|                     | Fertility | Origin | Pedigree                                                                 |        |
|---------------------|-----------|--------|--------------------------------------------------------------------------|--------|
| Saccaline           | CMF       | USDA   | Unknown                                                                  | Female |
| Grassl              | CMF       | USDA   | Unknown                                                                  | Female |

† = local check; CMF = cytoplasmic male fertile; CMS = cytoplasmic male sterile; - = unknown pedigrees
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
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 ($r = 0.071; P<0.01$), number of leaf per plant ($r = 0.458; P<0.05$), 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 ($r = 0.172; P<0.05$).
Days to 50% flowering were positively and significantly correlated with grain yield (r = 0.387; P<0.05) and stem diameter (r = 0.302; P<0.05). There was a negative and significant correlation between stem sugar traits and grain yield. Stem sugar content (SBC) had a positive and significant correlation with grain yield (r = 0.266; P<0.05). Stem juice score (SJS) had a negative and significant correlation with grain yield (r = -0.110; P<0.05). Number of leaves per plant (NLP) had a positive and significant correlation with grain yield (r = 0.458; P<0.01) and stem diameter (r = 0.302; P<0.05). Plant height (PHT) had a positive and significant correlation with grain yield (r = 0.183; P<0.05) and stem diameter (r = 0.134; P<0.01). Head length (HDL) had a positive and significant correlation with grain yield (r = 0.084; P<0.05) and stem diameter (r = 0.144; P<0.05). Stem biomass weight per ha (SBW) had a positive and significant correlation with grain yield (r = 0.102; P<0.05). Days to 50% flowering (DT50F) had a positive and significant correlation with grain yield (r = 0.117; P<0.05). Stem brix (SBX) had a positive and significant correlation with grain yield (r = 0.071; P<0.05).
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)     | 11.4  | 9.2   | 10.5 | 10.5 | 29130 | 34166 | 31648 | 100  | 1976  | 1541  | 1758.3 | 100 |
| Environment mean              | <0.01 | <0.01 | <0.01 |       |       |       |       |      | 1976  | 1541  | 1758.3 | 100 |
| P-value                       | <0.01 | <0.01 | <0.01 |       |       |       |       |      | 1976  | 1541  | 2265.7 | 100 |
| SED                           | 1.52  |       |       |       |       |       |       |      | 1976  | 1541  | 823.0  |      |

MA = Mid-altitude environment; TL = Tropical-lowland environment; StdH = Standard heterosis; SED = Standard error of difference
Development of dual purpose sorghum 273

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, ICSR165xICSA307, ZLR11xICSA26, ICSR165xICSA4, ICSV700xICSA307, ICSR165xICSA479, ICSR165xICSA26, and S35xICSA4, that combined high performance for grain yield, stem brix and stem biomass confirmed this suggestion.

ACKNOWLEDGEMENT

The author thank the Rockefeller Foundation New York for funding this work. Also acknowledged are Mr. Jurie Steyn of the Agricultural Research Council (ARC) based at Makhathini Research Station in South Africa, Dr. Pedro Fato and Mr. Egas Nhamuchu of the Instituto de Investigac¸a˜o Agraria de Moc¸ambique (IIAM) in Mozambique, and Mr. Caleb Souta and Mr. Walter Chivasa of Seed Co’s Rattray Arnold Research Station (RARS) in Zimbabwe for their assistance in running the sorghum trials. ICRISAT is acknowledged for providing the germplasm.

REFERENCES

Akbar, M., Khan N.I. and Sabir, K.M. 2001. Correlation and path-coefficient studies in linseed. Online Journal of Biological Sciences 1:446-447.
Alam, S., Ali, A., Qamar, I.A., Arshad, M. and Sheikh, S. 2001. Correlation of economically important traits in Sorghum bicolor varieties. Online Journal of Biological Sciences 1:330-331.
Aycicek, M. and Yildirim, T. 2006. Path-coefficient analysis of yield and yield components in bread wheat (Triticum aestivum L.) genotypes. Pakistan Journal of Botany 38:417-424.
Azhar, F.M., Khan, A.I. and Mahmood, I. 1999. Path-coefficient analysis of some advanced generation progenies of Gossypium hirsutum L. International Journal of Agriculture and Biology 3:85-87.
Bera, S.K. and Das, P.K. 2000. Path coefficient analysis in groundnut at different locations and years. Agriculture Science Digest 20: 9-12.
Bidgoli, A.M., Akbari, G.A., Mirhadi, M.J., Zand, E. and Soufizadeh, S. 2006. Path analysis of the relationship between seed yield and some morphological and phenological traits in safflower (Carthamus tinctorius L.). Euphytica 148:261-268.
Cheverud, J.M. 1988. A comparison of genetic and phenotypic correlations. Evolution 42: 958-968.
Cramer, C.S., Wehner, T.C. and Donaghy, S.B. 1999. PATHSAS: A SAS computer program for path coefficient analysis of quantitative data. Journal of Heredity 90:260-262.
Dewey, D.R. and Lu, K.H. 1959. A Correlation and path-coefficient analysis of components of crested wheat-grass seed production. Agronomy Journal 51:515-518.
Ekshinge, B.S., Shelke, V.B. and Musande, V.G. 1983. Correlation and path-coefficient analysis in sorghum and pigeon pea growth in intercropping system. Journal of Maharashtra Agricultural University 8:45-47.
Ezeaku, I.E. and Mohammed, S.G. 2006. Character association and path analysis in grain sorghum. African Journal of Biotechnology 5:1337-1340.
García del moral, L.F., Rharrabti, Y., Villegas, D. and Royo, C. 2003. Evaluation of grain yield and its components in durum wheat under Mediterranean conditions: An ontogenic approach. Agronomy Journal 95: 266-274.
Guiying, L., Weibin, G., Hicks, A. and Chapman, K.R. 2000. A Training Manual for Sweet Sorghum. FAO/CAAS/CAS, Bangkok, Thailand.
Gutjahr, S., Vaksmann, M., Dingkuhn, M., Thera, K., Trouche, G., Braconnier, S. and Luquet, D. 2013. Grain, sugar and biomass accumulation in tropical sorghums. I. Trade-offs and effects of phenological plasticity. Functional Plant Biology 40(4): 342-354.
Ma, Z.H., Li, D. and Ning, X.B. 1992. Study on Brix degree, total sugar content and their
relationship in the juice of sweet sorghum stem. *Journal of Shenyang Agriculture University* 23(3):187-191.

Makanda, I., Tongoona, P., Madamba, R., Icishahayo, D. and Derera, J. 2009. Path-coefficient analysis of bambara groundnut pod yield components at four planting dates. *Research Journal of Agriculture and Biological Sciences* 5:287-292.

Makanda, I., Tongoona, P., Derera, J., Sibiya J. and Fato, P. 2010. Combining ability and cultivar superiority of sorghum germplasm for grain yield across tropical low and mid altitude environments. *Field Crops Research* 116:75-85.

Maman, N., Mason, S.C., Lyon, D.J. and Dhungana, P. 2004. Yield components of pearl millet and grain sorghum across environments in the Central Great Plains. *Crop Science* 44:2138-2145.

Ofori, I. 1996. Correlation and path-coefficient analysis of components of seed yield in Bambara groundnut (*Vigna subterranea*). *Euphytica* 91:103-107.

Patanothai, A. and Atkins, R.E. 1971. Heterotic response for vegetative growth and fruiting development in grain sorghum (*Sorghum bicolor* (L.) Moench.) *Crop Science* 11:839-843.

Payne, R.W., Murray, D.A., Harding, S.A., Baird D.B. and Soutar, D.M. 2007. *GenStat for Windows (10th Edition)* Introduction. VSN International, Hemel Hempstead, UK.

Piper, J.K. and Kulakow, P.A. 1994. Seed yield and biomass allocation in *Sorghum bicolor* and *F₁* and backcross generations of *S. bicolor × S. halapense* hybrids. *Canadian Journal of Botany* 72:468-474.

Rani, C.I., Veeraragavathathan, D. and Sanjutha, S. 2008. Studies on correlation and path-coefficient analysis on yield attributes in root knot nematode resistant *F₁* hybrids of tomato. *Journal of Applied Sciences Research* 4:287-295.

Sarlikioti, V., de Visser, P.H.B., Buck-Sorlin, G.H., and Marcelis, L.F.M. 2011. How plant architecture affects light absorption and photosynthesis in tomato: Towards an ideotype for plant architecture using a functional-structural plant model. *Annals of Botany* 108(6):1065-1073.

Srinivasa Rao P., Rao, S.S., Seetharama, N., Umakath, A.V., Sanjana Reddy P., Reddy, B.V.S. and Gowda, C.L.L. 2009. Sweet sorghum for biofuel and strategies for its improvement. *Information Bulletin No. 77*. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 80pp. ISBN: 978-92-9066-518-2 Order code: IBE 077.

Sulewska, H., Ćmiatacz, K., Szymańska, G., Anasiewicz, K., Andurska, H. and Grówicka-Wołoszyn, R. 2014. Seed size effect on yield quantity and quality of maize (*Zea mays* L.) cultivated in South East Baltic region. *Zemdirbyste-Agriculture* 101(1):35-40.

Vermerris, W., Erickson, J., Wright, D., Newman, Y. and Rainbolt, C. 2014. Production of biofuel crops in Florida: Sweet sorghum. *UF/IFAS Extension*. http://edis.ifas.ufl.edu.

Watt, E.D. and Levin, D.A. 1998. Genetic and phenotypic correlations in plants: A botanical test of Cheverud’s conjecture. *Heredity* 80:310-319.

Wright, S. 1921. Correlation and causation. *Journal of Agricultural Research* 20:557-587.

Wright, S. 1960. Path coefficients and path regressions: Alternative or complementary concepts? *Biometrics* 16:189-202.