Plant Breeding 117, 33—36 (1998)

ISSN 0179-9541

Early-maturing dual-purpose sorghums: Agronomic trait variation and covariation among landraces

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With 5 tables

Received May 16, 1997 Accepted August 12, 1997
Communicated by H. H. Geiger

Abstract

Landrace cultivars represent potentially valuable source material for breeding dual-purpose (grain and stover) sorghums. To characterize the genetic variation and interrelationships for major agronomic traits among potential dual-purpose sorghum landraces, 74 accessions, primarily from Southern Africa, the Sudan, and India, were evaluated in five environments at Patancheru, India. These environments, at 17 N with 520–540 mm rainfall during the growing season, are representative of the major sorghum-growing areas in India and the Sudanian Zone of Western and Central Africa. Significant genetic variation and high heritabilities ($P = 0.01$, $h^2 = 0.63$–0.92) were observed for seedling vigour, grain and stover yields, growth rate and harvest index. Time to flower was correlated with stover yield ($r = 0.48$, $P = 0.01$) and an index (I_{ev}) of total economic value ($r = 0.44$, $P = 0.01$) but not with grain yield ($r = 0.22$, $P = 0.05$). Grain and stover yields varied independently ($r = 0.22$, $P = 0.05$) and were similarly related to I_{ev} values ($r = 0.79$ and $r = 0.77$ ($P = 0.01$), respectively). The 13 landraces with the highest I_{ev} values (adjusted for maturity) had above-average growth rates and harvest indices that ranged from 20 to 38%. Landraces from Botswana and India were more highly represented in the high I_{ev} set than in the full set of accessions.

Key words: *Sorghum bicolor* — dual-purpose — economic value — genetic resources — grain — growth rate — stover

Dual-purpose sorghums (*Sorghum bicolor*), producing grain for human consumption and stover for livestock feed, predominate in the semi-arid tropics (SAT) (Bramel-Cox et al. 1995). Sorghum grain is a staple food prepared in many forms in Africa (Debrah 1993, Mukuru, 1993) and India (Kelly and Parthasarathy Rao 1993). In SAT regions of Africa, stover is of considerable economic importance as fodder for livestock (Youngquist et al. 1990). Cattle derive up to 45% of their feed from crop residues in various parts of sub-Saharan Africa, and up to 80% in critical periods of drought (Sanford 1989). In India, the role of sorghum stover as livestock feed is even greater, with most of the sorghum grown being characterized as dual purpose (Kelly et al. 1991). The average contribution of sorghum stover to total economic value was estimated to be approximately equal to that of grain, based on the All-India Coordinated Sorghum Improvement Project trial data from 1987 to 1989 (Kelly et al. 1991). Its value as livestock feed is expected to remain high in India owing to increasing livestock populations and stagnating areas under forage crops (Kelly et al. 1991).

The lack of acceptance of modern cultivars in dual-purpose sorghum-growing areas in India results from their low stover yields and their perceived inferior stover quality relative to local cultivars (Jansen 1988). Dry fodder of local sorghums has been reported to carry a 41% premium in price over that of modern cultivars (Kelly et al. 1991).

Early-maturing dual-purpose sorghums are important in drier environments where moisture scarcity limits growth duration and total biomass available for livestock feed, and the greater value of stover in drought years helps to stabilize incomes. New relay cropping systems in traditional dual-purpose sorghum growing areas of the Indian Deccan Plateau also represent potentially important areas for early-maturing sorghums that would enable timely sowing of subsequent crops (Jansen 1988; B. S. Rana, pers. comm.).

There are no published studies on the genetic variation and covariation of major agronomic traits of dual-purpose landrace sorghums. This study was thus undertaken to facilitate the utilization of landrace cultivars in breeding dual-purpose sorghums by, (1) describing the genetic variation available for major agronomic traits among landrace cultivars representing potential dual-purpose sorghum parental material, (2) determining trait associations that would facilitate or hinder selection for economically important trait combinations, and (3) identifying and describing the landrace cultivars in this set that show the greatest potential as source material for breeding dual-purpose sorghum cultivars. This study focuses on early-maturing landraces.

Materials and Methods

The 74 landrace cultivars of sorghum (*Sorghum bicolor* (L.) Moench) evaluated in this study were chosen from a set of 325 accessions on the basis of time to flower (< 61 days) and plant height (> 170 cm) passport data (unreplicated evaluations conducted in different years by the ICRISAT Genetic Resources Division). The assembly of the 325 accessions involved geographic and taxonomic sampling of the world sorghum collection maintained at ICRISAT (Prasada Rao et al. 1989). The accessions in this study originated from South Africa (19), Botswana (13), Sudan (10), India (8), United States (4), Yemen (3), Zimbabwe (3), Ethiopia (2), Turkey (2), and one each from China, Egypt, Nigeria, Pakistan, Portugal, Senegal, Somalia, the former Soviet Union, Syria, and Uganda.

The controls were the hybrid 'CSH 6' and the variety 'ICSV 1' that represent the earliest maturing cultivars released in India (approximately 5–10 days earlier than the mean of current varieties. They are both grain sorghums based on 'Zera Zera' germplasm.

The experiments were conducted at the ICRISAT Asia Centre near Hyderabad, India. Experiments were conducted with different soil types and fertility regimes so as to sample the edaphic range in which dual-purpose sorghums are cultivated in India. During the rainy seasons of

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Table 1: Agronomic trait means and ranges among 74 sorghum land-races and units of measure

Trait	Abbreviation	Unit	Mean	Minimum	Maximum
Seedling vigour	SV	Score (1, low, to 9, high)	5.7	3.3	7.6
Days to flower	DF	Days after sowing (DAS)	60.3	54	67
Physiological maturity[1]	PM	DAS	93.3	86	100
Plant height	HT	cm	216	151	295
Grain yield	GY	t/ha	2.06	1.29	3.44
Stover yield	SY	t/ha	4.69	2.84	7.70
Biomass	BM	t/ha	7.43	4.95	11.27
Growth rate[1]	GR	$g/m^2 \cdot day$	7.06	4.21	10.13
Harvest index	HI	%	28.4	14.4	38.1
Lodging score[1]	LS	Score (1, low, to 9, high)	3.8	1.7	7.6

[1]Over three environments only.

both 1991 and 1993, the trials were sown in vertisols with high (80 kg/ha N and 42 kg/ha P_2O_5) and low (40 kg/ha N and 21 kg/ha P_2O_5) fertilizer applications. The nitrogen was split between a basal application and side dressing at approximately 20 days after emergence. An additional evaluation was made in 1993 in an Alfisol field at low fertility (20 kg/ha N and 18 kg/ha P_2O_5). Genotypes were randomized in a triple lattice design in each environment, with plots composed of two rows at 75 cm spacing and 4 m length in 1991 and 2 m in 1993. Plots were oversown and thinned to 12–15 cm between plants.

Seedling vigour was visually scored between 15 and 20 days after sowing (DAS) on a 1 (low) to 9 (high) scale based on leaf area (integrating leaf number, length and width). Days to flower (DAS to 50% anthesis), physiological maturity (DAS to 50% black layer formation in the middle of the panicle (1993 only)), plant height, and lodging score (1–9 scale, with 1 = no lodging, 3, 5, 7 and 9 for 10, 30, 50 and >80% lodging, respectively) were recorded. Panicle weights were measured following sun-drying for a minimum of 3 days at ambient temperatures (35°C). Grain yields were determined from threshed grain weight of the whole plot. Stover yields were estimated by multiplying the fresh stover weight from the whole plot by the percentage dry matter, determined by drying a subsample (approximately 1 kg) at 50°C. Calculated traits included biomass (sum of stover yield and panicle weight), growth rate (biomass divided by days to physiological maturity), and harvest index (grain yield divided by biomass).

A base index of economic value, defined as $I_{ev} = w_1y_1 + w_2y_2$, was calculated where y_1 and y_2 are, respectively, the grain and stover yields which have been assigned the economic weights $w_1 = 1.00$ and $w_2 = 0.33$. These economic weights were based on market data in one dual-purpose sorghum-growing region in India where adequate data on both stover and grain prices were available (Kelly et al. 1991).

An index of maturity-adjusted economic value was also calculated as $I_{evma} = w_1y_1^* + w_2y_2^*$, where $w_1 = 1.00$, $w_2 = 0.33$, $y_1^* = pX_m$, $y_2^* = (1-p)X_m$, p = harvest index, and X_m = maturity-adjusted biomass estimated by using days to flower as the covariate. The y_1^* and y_2^* values, so derived, represent the maturity-adjusted grain and stover yields, respectively.

To estimate the maturity-adjusted biomass X_m, a subset of 18 landraces, composed of two genotypes with the highest biomass within each date of flowering (56–64 days), was used to determine the linear dependence of biomass on days to flower among the most productive landraces. The resulting linear regression coefficient of biomass on days to flower was used to estimate X_m.

Analyses of variance were conducted within each environment. Lattice-adjusted mean values (or simple means where the lattice design was not efficient) for genotypes were used for combined analyses over environments. Genotypes and environments were considered as random. Pooled error terms were computed from the individual environment analyses according to Cochran and Cox (1957). Variance components were estimated by setting mean squares equal to their expectations. Broad-sense heritabilities were estimated on an entry mean basis. PLABSTAT (Utz, 1988) and SAS statistical routines were used for all analyses. Significance at P = 0.05 and P = 0.01 is indicated by * and **, respectively.

Results

Sources of variation

The sorghum landraces exhibited large genetic variation for all measured and calculated traits. Yields of stover, biomass and growth rates differed by twofold, and grain yield by nearly threefold (Table 1). The harvest indices ranged from 14 to 38%. There was a 13-day range in time to flower among genotypes. The heritability estimates were high for all traits, ranging from 0.63 to 0.94 (Table 2).

The test environments differed considerably for total productivity, with mean biomass ranging from 5.0 to 9.1 t/ha. However, biomass yields in the high- and low-fertility environments of 1991 did not differ significantly.

Genotype × environment (G × E) interactions were highly significant (P = 0.01) for all traits. Estimates of G × E variance components were approximately the same magnitude as the genetic components for grain yield, biomass, and growth rate, but much smaller for all other traits (Table 2). Partitioning of G × E interaction variance for grain yield and biomass into heterogeneity of genetic variance and lack of correlation between environments (Cooper and Delacy 1994) indicated that two-thirds of the interaction was due to the latter source.

Trait correlations

The estimates of genotypic and phenotypic correlation coefficients were similar and only phenotypic correlations are

Table 2: Estimates of genetic (G), genotype × environment (G × E), and error (E) variance components, scaling factor, and entry mean heritabilities for agronomic characteristics of 74 sorghum landraces over five environments

Trait	Variance components[3] G	G × E	E	Scaling factor[1]	Heritability
SV	6.41	2.11	1.28	1	0.90
DF	7.80	1.80	0.77	0	0.94
PM[2]	8.75	0.89	1.53	0	0.89
HT	7.74	0.85	0.75	−2	0.96
GY	1.22	1.07	0.49	−1	0.80
SY	1.10	0.60	0.30	−2	0.86
BM	1.50	1.12	0.51	−2	0.82
GR[2]	1.14	1.57	0.48	0	0.63
HI	2.05	0.50	0.43	−1	0.92
LS[2]	7.69	4.31	5.81	1	0.75

[1]Power of 10, the product of the scaling factor and actual variance component estimates are presented for G, G × E and E.
[2]Over three environments only.
[3]All G and G × E estimates were larger than twice their standard error.

presented (Tables 3 and 4). Because there were large differences among genotypes in time to flower and significant correlations between time to flower and productivity traits (Table 3), partial correlations to assess trait relationships independent of time to flower were also estimated (Table 4).

Grain and stover yields of the landraces averaged over all environments were not significantly correlated (Table 4). The correlations of grain and stover yields with biomass and harvest index were in the directions to be expected from their contributions to these calculated traits. The strength of these relationships differed, however, between the low- and high-fertility environments. Grain yields in the high-fertility environments were more closely related to biomass (r = 0.64**) than to harvest index (r = 0.35**) and a moderate positive relationship between grain and stover yields (r = 0.39**) was observed. In contrast, grain yields in the three low-fertility environments were more closely related with harvest index (r = 0.57**) than biomass (r = 0.44**) and there was no relationship between grain and stover yields (r = 0.07).

Mean grain and stover yields were similarly correlated with the economic-value index (I_{ev}) over all environments (Table 4) and within the low- and high-fertility environments.

Stover yield and biomass showed moderate positive correlations with time to flower (Table 3). A much stronger relationship between biomass and time to flower was observed in the subset of 18 genotypes composed of the two highest-ranked genotypes for biomass in each date of flowering. The relationship was linear (b = 0.34 t/ha.day, significant at P = 0.01) and accounted for 53% of the variation. Little additional variation was accounted for with a quadratic term. The correlations of days to flower with both grain yield (r = 0.48*) and I_{ev} (r = 0.71**) in this subset were also much stronger than those observed in the full set of 74 landraces (Table 3). Grain and stover yields, however, showed no correlation (r = −0.02).

The easily measurable vegetative growth traits, seedling vigour score and plant height at maturity, were positively related to stover yield, biomass and I_{ev} but not to grain yield (Table 3).

Table 3: Phenotypic correlations of agronomic traits and index of economic value with plant growth and lodging characteristics

Trait[1]	SV	DF	PM	HT	LS
GY	0.05	0.22	0.23*	0.20	0.17
SY	0.59**	0.48**	0.30**	0.70**	0.28*
BM	0.53**	0.50**	0.33**	0.66**	0.32**
HI	−0.49**	−0.33**	−0.14	−0.49**	−0.13
I_{ev}	0.40**	0.44**	0.34**	0.56**	0.29*

*, ** Significant at P = 0.05 and P = 0.01, respectively.
[1]Trait abbreviations defined in Table 1.

Table 4: Phenotypic correlations (above diagonal) and partial correlations independent for days to flower (below diagonal) for agronomic trait means and index of economic value of 74 sorghum landraces over five environments

Trait[1]	GY	SY	BM	HI	I_{ev}
GY	—	0.22	0.53**	0.45**	0.79**
SY	0.14	—	0.94**	−0.74**	0.77**
BM	0.50**	0.92**	—	−0.50**	0.94**
HI	0.56**	−0.71**	−0.41**	—	−0.18
I_{ev}	0.79**	0.71**	0.92**	0.03	—

*, ** Significant at P = 0.05 and P = 0.01, respectively.
[1]Trait abbreviations defined in Table 1.

Characterization of landraces ranked highest for an index of economic value adjusted for maturity (I_{evma})

The 13 highest-ranked landraces for I_{evma} are shown in Table 5. The index values of all 13 were numerically larger than that of the variety check and approached or even equalled that of the hybrid control. These genotypes represented a range of flowering dates (54–64 days) and, on average, flowered 1 day later than the hybrid control but 7 days earlier than the variety control.

The grain yields of most of these 13 landrace cultivars were much lower than those of the controls. Grain yields of two landraces, however, did not differ significantly from the controls. The stover yields ranged from 3.3 to 7.7 t/ha, with eight landraces having significantly higher stover yields than the hybrid control and four higher than the later-maturing cultivar control. Landraces with stover yields higher than those of the controls had growth rates that were also numerically, but not significantly, larger.

These 13 landraces also varied in their balance between grain and stover yields. Five genotypes had particularly greater stover yields (mean = 7.3 t/ha) and relatively less grain (mean = 2.2 t/ha) with an average harvest index of only 22.4%. The remaining eight lines had a mean harvest index of 33.2%, similar to that of the controls (Table 5). The simple correlation between grain and stover yields of these 13 landraces was still low (r = −0.10) although the partial correlation, adjusting for flowering, was considerably negative ($r_{GY \times SY.DF}$ = −0.64).

All five genotypes with low harvest index had seedling vigour scores and plant heights significantly above the mean at P = 0.01 (Tables 2 and 5). In contrast, the eight genotypes with higher harvest index had a range of height that centred close to the mean and only three of these had significantly greater seedling vigour.

Discussion

The large genetic variation among landraces for grain yield (genetic coefficient of variation (GCV) of 54%) and stover yields (GCV 22%) and lack of negative correlation between grain and stover yields in the full set of landraces shows that there is considerable opportunity for selection among landraces for higher grain and stover yields.

The strong correlation between the economic index (I_{ev}) and biomass suggests that biomass could be used as a proxy for I_{ev}. Rosielle et al. (1977) found that the relative economic weightings for grain and stover yields had very little influence on the selection response for total economic value of spring oats (*Avena sativa*). They found that an optimum index for biomass, with restrictions on flowering and height, was as effective as an index containing grain and stover yield components.

The five accessions in this study ranked highest for biomass had a mean biomass of 10.5 t/ha, compared with 9.1 t/ha for the two controls (Table 5). These accessions were of diverse origin, and thus may be able to contribute unique genes for biomass. Furthermore, the mean growth rate (GR) of these same five accessions was 9.8 g/m^2. day, compared with only 8.5 for the controls, suggesting that landraces may provide genes for enhancing productivity per unit time.

The strong correlation of biomass with maturity, particularly when considering the most productive accessions in each maturity class, shows the need for some type of restriction on time to flower when identifying germplasm for breeding early-maturing dual-purpose sorghums. The approach taken in this study was to calculate an economic index adjusted for maturity (I_{evma}). By

Table 5: Accession numbers, origin and trait means of accessions ranking highest for an index of economic value adjusted for time to flower (I_{evma})

Entry	Origin	DF[1]	GY	SY	BM	HI	GR	SV	HT	I_{evma}
IS 19159	Sudan	62.8	2.61	7.70	11.3	22.9	10.2	7.2	258	5.06
IS 869	USA	63.8	2.37	7.60	11.0	20.3	10.0	7.4	261	4.61
IS 23897	Yemen	61.2	1.90	7.37	9.9	20.5	9.9	7.6	295	4.51
IS 19457	Botswana	61.5	2.22	6.52	9.5	23.5	9.6	6.6	241	4.46
IS 22270	Botswana	61.8	2.12	6.99	9.9	20.7	9.5	6.6	228	4.41
IS 7124	Somalia	56.7	2.70	5.81	9.2	29.4	9.9	6.7	245	5.55
IS 24335	India	64.4	3.44	5.83	10.4	33.5	9.2	5.8	218	5.01
IS 22500	Sudan	54.4	2.14	4.53	7.4	29.4	6.3	6.6	221	5.01
IS 19463	Botswana	54.6	2.34	3.30	6.2	38.1	5.9	5.8	220	4.83
IS 1063	India	57.8	2.41	4.70	7.9	31.2	8.1	7.0	215	4.71
IS 12835	Turkey	56.7	2.35	3.58	6.7	37.0	7.1	5.1	212	4.61
IS 24436	India	63.2	3.13	4.98	9.1	34.8	8.4	5.3	179	4.60
IS 14320	Botswana	58.5	2.42	4.44	7.5	32.6	7.4	5.8	222	4.45
Controls										
CSH 6	India	59.3	3.37	3.88	8.2	41.1	8.2	7.2	179	5.20
ICSV 1	India	67.8	3.40	5.49	10.0	34.1	8.7	5.9	191	4.16
LSD (P = 0.05)		2.0	0.49	1.18	1.6	3.8	2.3	0.7	16	—

[1]Trait units and abbreviations given in Table 1.

using the I_{evma}, the number of early-maturing accessions (<61 days to flower) included in the selected set (ranked higher than the variety control) was increased to five, whereas only one was included without the adjustment for maturity.

The disproportionate number of accessions from Botswana and India among the highest-ranking landraces for I_{evma} indicates that future evaluations of landraces from these countries for early maturing, dual-purpose source materials would be of high priority. The world collection currently contains 3325 accessions with passport data for height >1.7 m and flowering 61 days or less, of which 97 are from Botswana and 453 are from India.

The nutritional quality of stover would also be an important component of economic value of dual-purpose sorghums. Genetic variation for stover quality has been observed in sorghum (Ross et al. 1983, Powell et al. 1991, Badve et al. 1993). Although stover quality parameters were not measured in this study, the significant variation among landraces for lodging resistance and harvest index suggests that differences in stem composition and stover quality exist, as the stem strength and extent of dry matter translocation from the stover to the grain are expected to influence stover quality.

Acknowledgements

The author thanks J. W. Stenhouse for his critical review of this manuscript and K. E. Prasada Rao and Gopal Reddy, Genetic Resources Division, ICRISAT, for providing seed of the sorghum landraces used in this study.

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