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Comparative productivity and drought response of semi-tropical hybrids and open-pollinated varieties of sorghum

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SUMMARY

While the relative advantage of hybrids over open-pollinated varieties has long been established for temperate sorghums in developed countries, similar information for semi-tropical sorghums used in Africa and India is relatively scant, especially under conditions of drought stress. This study compared 23 hybrids with 21 open-pollinated varieties, all developed in India and/or Southern Africa. Materials were field-tested under conditions of stored soil moisture at two levels of drought stress (dryland or one supplemental irrigation) at Bet Dagan, Israel in 1989.

Irrespective of the water regime, grain yield and harvest index increased and leaf area index decreased with a shorter growth duration of the genotypes. Hybrids were earlier, had a larger leaf area index, more than double the harvest index and produced more grain compared with varieties. In spite of their longer growth duration, varieties were less water-stressed than hybrids, as judged by their midday leaf water potential, relative water content and the extent of leaf rolling. The relatively poor plant water status of the hybrids could be partly ascribed to their larger leaf area index. Hybrids produced more biomass per day than varieties under low stress while varieties produced more biomass per day than hybrids under high stress. Thus, in terms of plant water status and mean daily biomass production, varieties were more drought resistant than hybrids. However, the physiological superiority of the varieties under drought stress did not result in a higher grain yield because of their inherent relatively poor harvest index, typical of the tall and late African sorghums. The superior physiological resistance to drought stress of these varieties could be translated into a yield advantage under drought stress if their potential harvest index is improved.

INTRODUCTION

An important factor in the genetic improvement of sorghum (*Sorghum bicolor* L. Moench.) to increase and stabilize its production in semi-tropical environments is the assessment of hybrids compared with open-pollinated varieties. The problem is most urgent in some developing countries, where the transition from open-pollinated varieties (henceforth referred to as 'varieties') to hybrid seed production and utilization can be hampered by certain technological, economic and social limitations. The comparative studies of hybrids and varieties which led to the rapid adoption of sorghum hybrids in developed countries were almost exclusively performed with temperate sorghum varieties, typical of materials adapted to the USA. This information is not necessarily relevant to the semi-tropical sorghum which is commonly grown in India and Africa and consists of different germplasm than that utilized in temperate regions. This material not only differs in genetic background but also in terms of the selected traits, such as plant phenology and height. Specific studies with this material are therefore warranted in order to establish the relative merit of hybrids for semi-tropical conditions.

Many considerations are involved in the decision to adopt hybrids rather than varieties in a developing country. This work did not attempt to address all the issues, but was done to investigate whether semi-tropical hybrids have an advantage over improved semi-tropical varieties under variable conditions of drought stress. This study was also stimulated by our recent findings that some improved semi-tropical varieties may yield as well as temperate hybrids (Blum *et al.* 1989), while heterosis in temperate sorghum hybrids may be ascribed to physiological stability in response to environmental stress (Blum *et al.* 1990)

Table 1. *Parentage, days to heading, plant height and dryland grain yield at Bet Dagan, Israel, of SADCC/ICRISAT sorghum hybrids. All hybrids were developed by the SADCC/ICRISAT programme at Zimbabwe and were based on female lines from ICRISAT (India) or Texas A&M University (USA) and selected male lines from India or Zimbabwe*

Entry	Parentage	Days to heading	Height (cm)	Grain yield (g/m²)
SDSH 49	ICSA19 × LARSVYT19	56	115	268
SDSH 2	D2A × SDS22 2688	57	125	241
SDSH 6	D2A × SDS2850	56	125	240
SDSH 8	D2A × SDS4261	60	140	239
SDSH 76	SPL177A × SDS2690 2	61	145	226
SDSH 38	ATX623 × SDS238	67	170	219
SDSH 5	D2A × SDS22 1	56	125	214
SDSH 48	ICSA12 × LARSVYT13	65	120	212
SDSH 73	D2A × SDS3223	55	115	196
SDSH 3	D2A × SDS3227	62	125	196
SDSH 4	D2A × SDS3880	67	170	193
SDSH 1	D2A × SDS22	56	135	188
SDSH 47	SPL109A × SDS238	75	155	183
SDSH 65	M70079A × SDS348	67	105	176
SDSH 51	ICSA37 × LARSVYT61	64	115	168
SDSH 35	M70079A × SDS3423	71	115	159
SDSH 74	M40079A × SDS2271	71	125	148
SDSH 61	SPL23A × SDS260	71	105	148
SDSH 28	SPL10A × SDS3185	77	115	138
SDSH 42	SPL9A × SDS107	79	95	131
SDSH 43	SPL23A × SDS511	66	120	128
SDSH 59	SPL23A × SDS1835	65	120	116
SDSH 57	SPL9A × SDS1835	86	90	51

MATERIALS AND METHODS

Twenty-three hybrids and 21 open-pollinated varieties developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India and in Zimbabwe (South African Development Coordination Conference Sorghum and Millet Improvement Programme SADCC/ICRISAT) were tested. The experiment was performed at Bet Dagan (on the Coastal Plain of Israel) on deep and fertile chromoxerert with a high available K content and an excellent water holding capacity. Fertilizer was applied before sowing at a rate of 120 kg/ha of N and 100 kg/ha of P_2O_5. The experiment was planted on 3 April 1989 in a split-split plot design with 4 replicates (two varieties had only 3 replicates). Each plot consisted of three rows 5 m long spaced 0.9 m apart and planted to 20 seeds per metre of row. The main treatment consisted of two water regimes, supplemental irrigation and dryland, each divided into two groups of entries, hybrids and varieties. The dryland treatment consisted of crop growth on stored soil moisture only, where drought stress progressed with the season. Total available soil moisture was 289 mm as determined gravimetrically to a depth of 180 cm at sowing. The irrigated treatment was sprinkler irrigated once at 35 days after emergence (DAE) at the rate of 100 mm. This irrigation was not sufficient to attain stress free conditions throughout the season and the two treatments were considered to represent two levels of drought stress.

Heading date (determined when 50% of the stems fully exserted panicles) and plant height to the base of the panicle were recorded in all plots. Leaf area index (LAI) was determined in each dryland plot at heading by linear measurements of all visible leaves in a section 1 m in length. Single leaf area was [illegible] by multiplying its length by its width by 0.[illegible]. The extent of leaf rolling (0 = no rolling, [illegible] = extreme rolling) was visually scored in all dryland plots at [illegible] weekly intervals beginning at 36 DAE.

The following data were recorded in the middle rows of all dryland plots of a random sample of five hybrids and five varieties at 1-weekly intervals beginning at 36 DAE (one day after supplemental irrigation was applied to the irrigated treatment). Midday canopy temperatures were recorded with a hand held infrared thermometer (model [illegible], Telatemp Corporation, Fullerton, California) [illegible] to view only the plot canopy. The [illegible] was approximately 30 cm. The thermometer [illegible] a measure of canopy temperature as well as the [illegible] to air temperature differential. Canopy temperature of each plot in a block was expressed as a percent of the mean canopy temperature of the block. Midday leaf water potential (LWP) was measured with a pressure chamber (custom-made as described by Blum *et al.* 1973) in four uppermost and fully expanded leaves per plot. At the same time one 2 × 4 cm section was cut from each leaf and placed in a stoppered vial. These samples were processed in the laboratory for the measurement of midday relative water content (RWC). Leaf sections were weighed and floated on deionized water for 3 h at 10 °C, after which their wet and dry weights were recorded. In the morning, four additional top fully expanded leaf laminae were sampled from each plot of both treatments and placed with their cut edge in water. They were then transferred to the laboratory and remained in water at 10 °C overnight in order to regain full turgor. A sample was then taken from the mid-section of each leaf (excluding the midrib) and frozen at −18 °C, after which samples were thawed and measured for their osmotic potential by the psychrometric method. The difference in osmotic potential at full turgor between the dryland and the supplemental irrigation treatment was taken as an estimate of osmotic adjustment under dryland conditions.

The central row of each plot was harvested. Panicles were counted, oven dried and weighed before and after threshing. Kernel weight was determined in grain samples from each row section. The remaining stover was harvested at the ground surface and a sample of *c.* 1 kg of each row section was oven dried at 85 °C for 48 h. Total above-ground biomass included the dry matter of stover and whole panicles. Harvest index was calculated as the proportion of grain in the total biomass.

RESULTS

The detailed information on dryland yield and phenology for all entries is presented in Tables 1 and 2. A comparative summary for hybrid and variety means is presented in Table 3. For most traits measured, main (water stress level) and secondary (group) effects were significant, while stress level by group interactions were not (except for grain yield). All following comparisons of 'hybrids' and 'varieties' refer to the means of each of the two groups.

Hybrids yielded more grain than varieties, though varieties produced significantly more biomass than hybrids, under both stress levels. Consequently, hybrids had more than double the harvest index of varieties. Hybrids tended to have a shorter growth duration than varieties. Overall, grain yields significantly increased with shorter growth duration across all genotypes under both stress levels (Fig. 1). The rate of increase in yield with shorter growth duration did not differ between hybrids and varieties but was greater under low stress than under high stress conditions. No simple correlation was found between days to heading and biomass, neither for hybrids ($r = 0{\cdot}16$) nor for varieties ($r = 0{\cdot}09$). At both stress levels, hybrids had a greater number of panicles per unit area and a greater number of kernels per panicle, as compared with varieties (Table 3). On the other hand, varieties had heavier kernels than hybrids under both treatments.

For any given trait, the value under high stress as a percentage of that under low stress expressed the rate of change as drought stress increased and may be considered as a simple expression of the relative drought resistance for the tested level of stress (Table 3). In this sense, varieties were more resistant than hybrids for plant height, biomass, grain yield, kernels per panicle and kernel weight. Hybrids were relatively more resistant for harvest index and number of panicles per unit area. However, while the yield of varieties tended to change less than the yield of hybrids when stress increased, hybrids still yielded more than varieties because of their higher absolute yields, which could be ascribed at least partly to their high harvest index and large panicles. The significant stress level by group interaction for grain yield (Table 3) was a result of the fact that four varieties (but none of the hybrids) had reduced yield when given supplemental irrigation. This could not be ascribed to lodging (which did not occur in the trial) nor to mineral deficiencies under the good fertility conditions of the trial. These varieties were also characterized by a reduction in harvest index with supplemental irrigation, contrary to the general trend for an increase in harvest index with supplemental irrigation (Table 3). A representative example is cv. E117 1, which under supplemental irrigation produced as much as 1321 g/m² biomass with a harvest index of only 0·07 (0·09 under dryland). Apparently, such varieties were inefficient, using the improved moisture conditions for the production of stover but not grain.

Leaf area index increased with days to heading in both hybrids and varieties (Fig. 2). The variation in LAI was greater among hybrids than among varieties. However at almost any given growth duration, LAI was appreciably higher in hybrids than in varieties. It was *c.* 3 in varieties and between 3 and 6 in hybrids. The rate of increase in LAI with longer growth duration was also greater in hybrids than in varieties.

Plant water stress under dryland conditions, as expressed by LWP and RWC, increased in both hybrids and varieties as the season progressed (Fig. 3). However, on most dates of measurement, mean LWP and mean RWC were significantly lower in hybrids than in varieties, indicating relatively greater water deficits in hybrids. Mean canopy temperature over all genotypes increased from 28·5 °C to 30·4 °C during the 4-weekly measurement dates in the dryland trial. These values corresponded with mean leaf-to-air temperature differentials of −3·1 °C to 2·7 °C, indi-

Table 2. *Parentage, days to heading, plant height and dryland grain yield at Bet Dagan, Israel, of ICRISAT varieties of sorghum. All materials originated at ICRISAT (India) as germplasm lines or cross-bred lines and were subsequently further selected in the SADCC/ICRISAT programme at Zimbabwe*

Entry	Source	Days to heading	Height (cm)	Grain yield (g/m^2)
IS 18530-1	DR* germplasm line from ICRISAT India	67	235	226
IS 18530-2	DR germplasm line from ICRISAT India	66	230	198
IS22126	DR germplasm line from ICRISAT India	72	165	191
IS 2874-1	DR germplasm line from ICRISAT India	69	215	175
D 71396	DR line from ICRISAT India	79	225	173
SPV-138	Indian variety	88	175	159
E 117-1	DR line from ICRISAT India	80	260	128
IS 22343-1	DR germplasm line from ICRISAT India	83	200	128
IS 8564	DR germplasm line from ICRISAT India	70	165	89
E 1257	DR germplasm line from ICRISAT India	71	235	87
SPV 86	Indian variety	76	125	78
D 69707-2	DR line from ICRISAT India	91	105	64
F 1734-2	DR line from ICRISAT India	76	195	53
IS 10748	DR germplasm line from ICRISAT India	79	185	51
IS 1347-2	DR germplasm line from ICRISAT India	86	155	43
M35-1	Indian variety	88	165	40
IS 1347-1	DR germplasm line from ICRISAT India	86	175	30
IS 2871-2	DR germplasm line from ICRISAT India	91	130	17
IS 2871-1	DR germplasm line from ICRISAT India	91	105	15
D 69707-1	DR germplasm line from ICRISAT India	91	95	13
IS 22353-2	DR germplasm line from ICRISAT India	91	155	9

* Classified as being 'drought resistant', based on past field performance tests.

Table 3. *Mean phenology, productivity and yield components (± S.E.) for hybrids and varieties of sorghum subjected to two levels of drought stress (dryland, high stress; supplemental irrigation, low stress), at Bet Dagan, Israel, 1989*

	Low stress		High stress		Drought resistance index*			
	Hybrids	Varieties	Hybrids	Varieties	Hybrids	Varieties	Stress level effect†	Group effect†
Days to heading	61·9 ± 1·41	79·5 ± 2·02	64·9 ± 1·77	80·5 ± 1·85	104·8	101·3	1·19	86·4
Plant height (cm)	172 ± 6·4	212 ± 9·3	124 ± 4·3	176 ± 10·2	72·1	81·1	21·15	21·10
Biomass (g/m^2)	1085 ± 40·9	1230 ± 74·0	753 ± 22·0	1019 ± 59·8	69·4	82·8	28·38	16·29
Grain yield (g/m^2)	295 ± 16·0	124 ± 11·8	182 ± 10·4	94 ± 15·2	61·8	75·1	27·49	89·76
Harvest index	0·27 ± 0·010	0·13 ± 0·011	0·25 ± 0·013	0·09 ± 0·009	92·6	69·2	4·90	116·58
No. of panicles/m^2	14·3 ± 0·48	10·5 ± 0·75	14·1 ± 0·66	8·4 ± 0·68	98·6	80·0	3·12	50·10
No. of kernels/panicle	970 ± 63·4	547 ± 41·3	735 ± 53·3	443 ± 63·2	75·8	81·0	9·06	40·06
Kernel weight (mg)	23·1 ± 0·56	24·5 ± 1·27	19·8 ± 0·45	23·7 ± 1·04	85·7	96·7	5·51	9·01

* Value at high stress expressed as a percentage of value at low stress.
† F ratio. Stress level by group interaction was significant ($P \leq 0{\cdot}05$) only for grain yield.

cating a general trend for an increase in plant water stress with time under dryland conditions. On each date of measurement, genotypes differed significantly ($P \leq 0{\cdot}05$) in canopy temperature. However, in spite of the difference in their leaf water status, the two groups did not differ in mean canopy temperature.