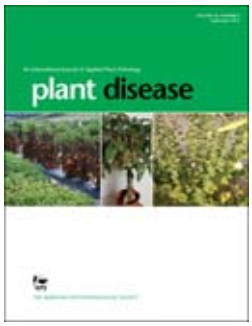

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Resistance to foliar diseases in a Mini-core Collection of Sorghum Germplasm

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Resistance to foliar diseases in a Mini-core Collection of Sorghum Germplasm

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ABSTRACT

Anthracnose, leaf blight and rust are important biotic constraints to grain and forage sorghum production worldwide and are best managed through host plant resistance. A sorghum mini-core collection, consisting of 242 germplasm accessions developed from a core collection of 2,246 landrace accessions, originating from 58 countries, was evaluated to identify sources of resistance to foliar diseases. The mini-core accessions were evaluated in anthracnose and leaf blight screening nurseries under artificial inoculation in the rainy and late rainy seasons, respectively, during 2009 and 2010. For rust resistance, screening was done under artificial inoculation in the greenhouse as well as in the field under natural infection. Thirteen accessions were found resistant (score ≤3.0 on a 1 -9 scale) to anthracnose and 27 to leaf blight in both 2009 and 2010. Six accessions exhibited resistance to rust, both in the greenhouse and in the field. In the resistant accessions, a wide range of diversity was observed for agronomic traits such as days to 50% flowering, plant height and grain yield/plant, and morphological characters such as grain/glume color, glume coverage, endosperm texture and panicle type (ear head compactness). Three mini-core accessions (IS 473, IS 23684, and IS 23521) exhibited resistance to all three diseases. These accessions with multiple disease resistance will be useful in sorghum disease resistance breeding programs.

Sorghum [*Sorghum bicolor* (L.) Moench] is the world's fourth most important cereal crop after wheat, rice and maize, and is the dietary staple of more than 500 million people in more than 30 countries (19). It is grown on 42 million ha in 98 countries in Africa, Asia, Oceania, and the Americas. Nigeria, India, USA, Mexico, Sudan, China and Argentina are the major producers of sorghum (http://test1.icrisat.org/sorghum/sorghum.htm). It is a major source of food, feed, fiber and fuel across a range of environments and production systems. Sorghum is an annual crop that is drought tolerant, making it an excellent choice for dry areas. Thus, sorghum is a major crop for the sustenance of human and livestock populations in hot and dry areas of the world. However, diseases and insects, in addition to abiotic stresses, are major impediments to realizing the high yield potential of sorghum cultivars. Developing cultivars resistant to these stresses is the key to improving sorghum productivity in farmers' fields.

Sorghum anthracnose, caused by *Colletotrichum sublineolum* Hann. Kabát et Bub. (syn. *C. graminicola* (Ces.) G.W. Wils.), is one of the most important sorghum diseases, and is a major limiting factor in some production areas (12, 29). Anthracnose weakens the plant, severely reducing grain yield and quality. Estimated grain sorghum losses caused by anthracnose are about 50% on susceptible cultivars (20, 22). The disease is more prevalent and severe in warm and humid environments, where it causes substantial economic losses. The pathogen causes seedling blight, leaf blight, stalk rot, head blight and grain molding, and thus limits both forage and grain production. Among these, foliar anthracnose is the most pronounced and devastating on forage and grain sorghum, especially on sweet sorghum cultivars (21).

Leaf blight caused by *Exserohilum turcicum* (Pass) Leonard and Suggs, is widely distributed, and at times one of the most damaging foliar pathogen of sorghum, causing significant grain losses due to the reduction of the photosynthetic leaf area (2). When infection occurs at the pre-flowering stage in susceptible cultivars, up to 50% grain yield losses may occur. However, in case of late infection, disease development is slower and yield losses are minimal. The disease is considered more important on dual-purpose grain sorghum, but is especially severe on sweet sorghum (8, 20).

Rust (*Puccinia purpurea* Cooke) is another foliar disease of sorghum that reduces forage quality and grain yield. It is widely distributed and occurs in almost all sorghum growing areas of the world. Epiphytotics of rust have been reported in cool and humid regions where sorghum is grown for forage. Under favorable conditions, rust development is fast and affects panicle exsertion and grain development, resulting in poor grain yield. The disease is important because its presence predisposes sorghum to other major diseases, such as stalk rot, charcoal rot, and grain molding (6).

Availability of adequate genetic variation is a prerequisite for genetic improvement of any crop species. Plant genetic resources will be the main contributing factor to future progress in developing new cultivars (28). Germplasm accessions collected and maintained in gene banks represent the vast genetic variation that can be utilized in crop improvement. However, large number of accessions in the germplasm collections often hinders their evaluation and utilization for specific breeding purposes. To overcome these problems, Frankel (5) proposed the establishment of a core collection (10% of the total) that could be selected from the existing collection of crop species resources in a gene bank. A core collection provides a convenient way to study and

utilize germplasm resources, and this method has received extensive attention all over the world. Core collections based on phenotypic data have been reported in several crops (3, 25, 26, 28, 32). Grenier et al. (7) developed a core collection of 2,247 sorghum landrace accessions originating from 58 countries at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India.

However, a core collection consisting of 10% of the total accessions could still be too large in crops like sorghum for a systematic evaluation of traits of economic importance, such as disease resistance. Consequently, Upadhyaya and Ortiz (24) suggested the concept of a mini-core collection (10% of the core, i.e., 1% of entire collection) that represents most of the useful variation in a crop species. Thus, a sorghum mini-core consisting of 242 accessions from the core collection of 2,246 landrace accessions was developed at ICRISAT in 2009 (27). The objective of this study was to identify sources of resistance to anthracnose, leaf blight and rust through evaluation of the sorghum mini-core collection, for use in disease resistance breeding programs.

MATERIALS AND METHODS

Seed source. Seed of the 242 germplasm accessions of the sorghum mini-core were obtained from the Genetic Resources Division, ICRISAT, Patancheru, India. The mini-core encompasses all five basic races [*bicolor* (20), *caudatum* (39), *durra* (30), *guinea* (29) and *kafir* (21)] and 10 intermediate races [*caudatum-bicolor* (30), *durra-bicolor* (7), *durra-caudatum* (19), *guinea-bicolor* (2), *guinea-caudatum* (27), *guinea-durra* (2), *guinea-kafir* (3), *kafir-bicolor* (2), *kafir-caudatum* (7) and *kafir-durra* (4)]

Screening for anthracnose resistance. The mini-core accessions were evaluated along with susceptible check H 112 (20) in the anthracnose screening nursery at

Patancheru (18°N, 78°E, 545 m above sea level), Andhra Pradesh, India, during the 2009 and 2010 rainy seasons. The experiment was conducted in a randomized complete block design (RCBD), with two replicates; each replicate consisted of 15 plants in a 2-m row plot with 75 cm row-to-row spacing. For weed management, a pre-emergence spray of Atrazine 50 WP (1kg/ha) was applied, and shoot fly was managed by spraying Cypermethrin 25 EC (0.5 L/ha) at 15 to 30 days after seedling emergence.

The pathogen (*C. sublineolum*) was isolated on potato dextrose agar (PDA) medium from the naturally infected leaves of susceptible line H 112, collected from sorghum fields at ICRISAT, Patancheru, India. The inoculum was multiplied by inoculating autoclaved sorghum grains with an actively growing pure culture of a local isolate and incubating at 28±1°C for 10 days under a 12-h photoperiod. The accessions were whorl-inoculated with infested sorghum grains (colonized by *C. sublineolum*) at 3 to 4 grains/plant at 30 days after seedling emergence. High humidity was maintained with overhead sprinklers twice a day on rain-free days until the soft dough stage. Anthracnose severity was recorded on 10 uniformly flowering plants at the soft-dough stage using a progressive 1-9 scale, where 1 = no disease and 9 = 76-100% leaf area covered with lesions (20).

Screening for leaf blight resistance. The mini-core was evaluated in the leaf blight screening nursery at Patancheru, planted during the 3rd week of September in 2009 and 2010 in a RCBD with two replicates. Each replicate consisted of 10 to 15 plants in a 2-m row. Inoculum was multiplied by inoculating the autoclaved sorghum grains with an actively growing pure culture of a local isolate of *E. turcicum* and incubating at 28±1°C

for 10 days with a 12-h photoperiod. The nursery was raised and evaluated as described above for anthracnose evaluation (20).

Screening for rust resistance. Urediniospores collected from infected foliage in the previous season were used as inoculum. Urediniospores were collected from susceptible plants in the field at Patancheru, using a vacuum spore collector. The urediniospores were spread on waxed paper overnight in an air-conditioned room to allow evaporation of excess moisture. Approximately 0.5 cc urediniospores were transferred into individual self-sealing plastic bags and stored at -80°C. Prior to use, plastic bags containing urediniospores were placed in a water bath at 40°C for about 10 min. The urediniospores were then suspended in water and a drop of a surfactant (Tween 20) was added to ensure the uniform dispersal of the spores. Pot-grown seedlings of mini-core accessions were spray-inoculated at the 3- to 5-leaf stage with an aqueous suspension of urediniospores (1×10^5 urediniospores mL^{-1}). The experiment was conducted in a completely randomized design (CRD) with two replicates; each replicate consisted of one pot with 10 seedlings. Inoculated seedlings were maintained in a moist chamber (>95% RH, 25±2°C) for about 18 h and then transferred to a greenhouse at 25±2°C for disease development. Rust severity was recorded 15 days after inoculation using the modified Cobb's scale (20).

The mini-core accessions were also evaluated for rust resistance under natural infection during late rainy season 2010. The accessions were grown in a CRBD with two replicates, with 10 to 15 plants per replicate. Rust severity was recorded at dough stage using the modified Cobb's scale (20).

Evaluation for agronomic traits. Agronomic performance of the Mini-core collection was evaluated at Patancheru, India in a field experiment using RCBD with three replicates in vertisol in the 2010-11 post rainy season (November to April). Five representative plants in each plot were selected to record observations on plant height (cm) (measured from the base of the plant to the tip of the panicle at maturity) and grain yield (g) per plant at maturity. An average of five plants was used for statistical analysis. The data recorded on a per-plot basis were days to 50% flowering (time of full panicle emergence in 50% of the plants in a row) and morphological traits such as panicle compactness (compactness of panicle at maturity), plant color (tan/non-tan), glume coverage (proportion of the grains covered with glumes at maturity), glume color and grain color at maturity, and endosperm texture (10, 16).

Statistical analysis. The replicate-wise values of disease scores and agronomic traits such as plant height, days to 50% flowering, and grain yield/plant, were used for statistical analysis of each environment (where "environment" is a season) using the residual maximum likelihood (REML) method and considering genotypes as random effects. Variance components due to genotypes (σ^2_g) and error (σ^2_e) and their standard errors were determined. Environment-wise best linear unbiased predictors (BLUPs) for the mini-core accessions were calculated. The significance of variance components was tested using respective standard errors.

For the pooled analysis, homogeneity of variance was tested using Bartlett's test (1). Environment was considered a fixed effect. The variances due to genotypes (σ^2_g) and genotype x environment interaction (σ^2_{ge}), and their standard errors were determined. The

significance of environment was assessed using the Wald statistic (30) that asymptotically follows a χ^2 distribution.

RESULTS

Anthracnose resistance. REML analysis indicated **s**ignificant ($P < 0.001$) variation among the 242 mini-core accessions for anthracnose resistance in both environments separately as well as in the pooled data (Table 1). Although there was significant interaction between accessions and environments (G×E), the variance component due to genotypes (σ^2_g) was quite high compared to G×E interaction (σ^2_{ge}), indicating that differences in the anthracnose scores were mainly contributed by the accessions. Wald statistic indicated a non-significant effect of environment; thus, data from both environments were pooled. Based on mean anthracnose severity for the two environments, 22 accessions were found resistant (score 1.0-3.0 on a 1-9 scale), 118 moderately resistant (score 3.1-5.0), 81 susceptible (score 5.1-7.0) and 21 highly susceptible (score >7.0). The susceptible check H 112 had a score of 8.5 (Fig. 1). Of the 22 resistant accessions (based on pooled data), 13 scored ≤ 3.0 in both 2009 and 2010; these were selected as resistance sources for use in resistance breeding programs. Among these 13 accessions, two each originated from India and USA, and one each from Zambia, Thailand, Indonesia, Cameroon, Mozambique, Nigeria, Tanzania, Ethiopia and Sudan. More than 60% of these lines were of the *Guinea* type. These 13 accessions also exhibited a wide diversity for agro-morphological traits (Table 2).

Leaf blight resistance. REML analysis indicated significant genotypic variance in both years separately, and genotypic and genotype x environment variances in the

pooled analysis (Table 1). Results for leaf blight scores of mini-core accessions were similar to those for anthracnose scores. Although significant interaction between accessions and environments was observed, the variance component due to genotypes (σ^2_g) was very high as compared to the G × E interaction (σ^2_{ge}), indicating that differences in leaf blight severity were mainly contributed by the accessions. The Wald statistic indicated that differences between environments were non-significant. Based on mean leaf blight severity for the two environments, 49 accessions were found resistant (score 1.0-3.0 on a 1-9 scale), 141 moderately resistant (score 3.1-5.0), 43 susceptible (score 5.1-7.0) and nine highly susceptible (score >7.0) compared with an 8.2 score for the susceptible check H 112 (Fig. 1). Seven of the 49 resistant accessions originated from South Africa, followed by four each from India and Kenya. Twenty-seven morphologically diverse accessions with ≤ 3.0 leaf blight score in both environments were selected as sources of resistance for sorghum breeding programs (Table 2).

Rust resistance. Significant differences were observed in the mini-core accessions for rust resistance (Table 1). In the field, under natural infection, 105 accessions recorded ≤ 10% rust. However, the number of accessions with ≤10% rust was drastically reduced in the greenhouse screening, indicating disease escape in the field screen. Only six accessions were resistant (≤10% severity), and 19 had moderate resistance (11-20% severity) under artificial inoculation (Fig. 1). These six accessions showed resistance both in the greenhouse and field screens. Two of the rust-resistant accessions originated from South Africa and one each from USA, Ethiopia, Mozambique and Tanzania. Four accessions were *Guinea* types, and one each was from the races *Bicolor* and *Kafir*.

Multiple disease resistance. Three mini-core accessions (IS 473, IS 23684 and IS 23521), all *Guinea* type sorghums, exhibited resistance to all three diseases. IS 473 has also been reported to be resistant to grain mold (18). A rust-resistant accession, IS 33023, also showed moderate resistance to anthracnose and leaf blight.

Agronomic performance of the selected mini-core accessions. Significant differences among accessions were observed for days to 50% flowering, plant height and grain yield/plant in the mini-core collection (data not given). Days to 50% flowering in the 38 selected accessions resistant to at least one disease ranged from 55 (IS 14861) to 94 (IS 24218) (Table 2). Three leaf blight-resistant accessions (IS 14861, IS 20743 and IS 9745), one anthracnose-resistant accession (IS16382), and one accession (IS 473) with multiple disease resistance were early-maturing (≤65 days to 50% flowering). Eighteen accessions were in the medium maturity group (66-75 days to 50% flowering) and the remaining 15 accessions were late (>75 days to 50% flowering). Plant height of the selected accessions ranged between 143 cm (IS 23521) to 302 cm (IS 7679). Only three (IS 23521, IS 26749 and IS 19153) of the 38 selected accessions were short (76-150 cm), 21 were of medium height (151-225 cm) and the remaining 14 accessions were tall. Among the selected accessions, the highest grain yield (35.44 g/plant) was observed in the anthracnose-resistant accession IS 20632. Nine accessions recorded significantly higher grain yield compared to the trial mean (Table 2).

DISCUSSION

The prime objective of this study of the sorghum mini-core collection was to identify sources of resistance to foliar diseases of sorghum for use in sorghum improvement. We identified 13 accessions resistant to anthracnose, 27 to leaf blight (resistant in both 2009 and 2010) and six to rust. Attempts in the past to identify sources of anthracnose resistance had lead to the selection of 32 lines from a field screening of about 13,000 sorghum germplasm accessions and advanced breeding lines at Pantnagar (North India) between 1982 and 1991 (15). Some of these resistant lines were converted into male-sterile lines through backcrossing with different sources of cytoplasmic male sterility (15). However, the long-term durability of resistance in these cultivars is hindered by variation in virulence within pathogen populations (12, 14, 21, 29). Pyramiding of resistance genes can aid in development of resistant cultivars, but additional sources of resistance are required for each disease. High levels of pathogenic variability in the anthracnose pathogen have been reported due to evolution of new pathotypes. Therefore, it is imperative to identify new and diverse sources of resistance for effective management of this disease through host plant resistance (14). The presence of a high level of pathogenic variability in leaf blight (4) and rust (31) populations heightens the need to locate new and diverse sources of resistance to these pathogens.

The ICRISAT gene bank with a large collection of sorghum germplasm is a reservoir of genetic diversity that can be exploited for the improvement of sorghum. However, it is difficult to evaluate the whole germplasm collection for identification of sources of biotic/abiotic stress tolerance. This can be better achieved by evaluating the mini-core accessions representing the entire germplasm collection, thereby avoiding extensive germplasm screening. In this study, we identified sorghum accessions resistant

to anthracnose, leaf blight and rust, and also a few accessions with multiple disease resistance with a wide range of diversity for other agronomic traits, such as days to 50% flowering, plant height, grain yield/plant, and morphological characters such as grain/glume color, glume coverage, endosperm texture and panicle type (ear head compactness). A single accession from the mini-core each from Indonesia, Mozambique, Tanzania and Sudan was resistant to anthracnose. This demonstrated that selection of additional sources of anthracnose resistance is possible from sorghum accessions of native origin. Similarly, four of the five mini-core accessions originating from Kenya were resistant to leaf blight, suggesting Kenyan accessions as potential sources of leaf blight resistance. None of the mini-core accessions belonging to race *Kafir* were resistant to anthracnose and no *Durras* were resistant to leaf blight. Seven of the 13 anthracnose-resistant accessions were *Guinea* or *Guinea-caudatum*, and nine of the 27 leaf blight accessions were from the *Caudatum* race. Thus, *Guinea* and *Caudatum* races could be good sources of anthracnose and leaf blight resistance, respectively.

One of the objectives of a sorghum hybrid development program is to develop resistant lines with white grain. Six white-grained accessions (IS 10302, IS 20956, IS 23684, IS 7679, IS 5301 and IS 19153) with high level of anthracnose resistance, two (IS 23644 and IS 23684) with leaf blight resistance and one (IS 23684) with rust resistance were identified from this mini-core evaluation. These would be the most desirable sources of resistance for breeding programs aiming to develop white-grained hybrids for human consumption, particularly in Asia and parts of west and central Africa.

Three accessions of the *Guinea* type sorghums (IS 473, IS 23684 and IS 23521), exhibited resistance to all three diseases. Among these, IS 473 has also been reported to

be resistant to grain mold (18). Being an early-maturing line with 65 days to 50% flowering, this accession is a useful source for the development of short-duration disease-resistant hybrids. Similarly, IS 23684 with 88 days to 50% flowering and 258 cm height is a useful source for breeding medium-duration dual-purpose (grain as well as fodder) hybrids. IS 473 represented cluster 18 of the core collection, which consists of 45 accessions (27). The cluster to which a particular accession with a trait of interest belongs provides important direction for further focused large-scale screening efforts, as the success rate of identifying additional resistant lines from these clusters has been found to be quite high ($P \leq 0.01$) (9). Thus, it would be useful to evaluate the remaining accessions from cluster 18 that were not included in the mini-core collection to identify additional sources of resistance to major sorghum diseases.

It is evident from this study that resistance to biotic stresses such as foliar diseases can be effectively identified from the mini-core collection comprising only 1% of the total germplasm. There are several such reports of mini-core collections being successfully used to identify resistance sources for diseases (13, 18), salinity (17) and drought (11, 23). Identification of disease-resistant accessions from the sorghum mini-core would permit use of diverse resistance sources for future breeding efforts and ensure better chances of success in sorghum improvement.

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Figure captions

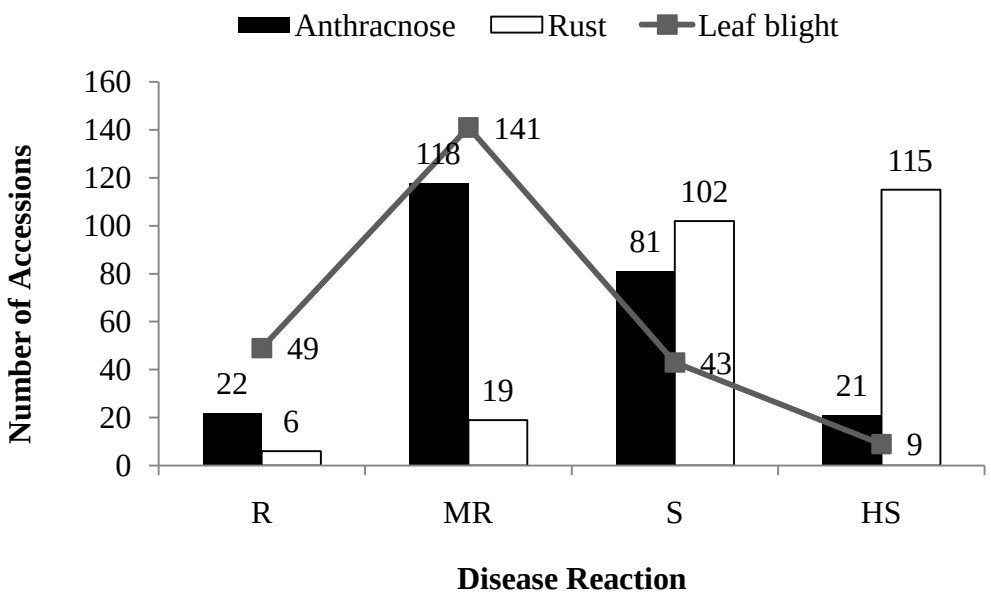
Fig. 1. Summary of disease reaction of sorghum mini-core accessions to foliar diseases.

R = resistant; score 1-3 for anthracnose and leaf blight and ≤10% rust severity.

MR = moderately resistant; score 3.1-5.0 for anthracnose and leaf blight and 11-20% rust severity.

S = susceptible; score 5.1-7.0 for anthracnose and leaf blight and 21-50% rust severity.

HS = highly susceptible; score 7.1-9.0 for anthracnose and leaf blight and >50% rust severity.


Anthracnose
Rust
Leaf blight
Number of Accessions
160
140
120
100
80
60
40
20
0
22
6
118
19
81
102
21
115
49
141
43
9
R
MR
S
HS
Disease Reaction

Tables

Table 1. Variance components due to genotypes (σ^2 g), genotype × environment (σ^2g.e) and their standard errors (s.e.) for anthracnose, leaf blight and rust severity in the sorghum mini-core collection

Disease	Season	σ^2g	s.e.	σ^2g.e	s.e.	Wald statistics (Season)	F prob
Anthracnose	2009	1.97362	0.18088				
	2010	1.69193	0.15538				
	Pooled	1.78179	0.16475	0.05103	0.00697	2.79	0.096
Leaf blight	2009	1.5874	0.1611				
	2010	2.3833	0.2591				
	Pooled	1.1436	0.1644	0.831	0.1066	1.07	0.303
Rust	Greenhouse	368.06	33.53				
	Field	512.89	79.73				

Table 2. Origin, race type, disease scores, agronomic performance, and morphological characteristics of selected accessions from the sorghum mini-core collection

IS no.	Origin	Race	Anthracnose score[a]		Leaf blight score[a]		Rust (%)[b]	DF[c]	Plant height (cm)	Grain yield/ plant (g)	Plant color[d]	Glume color[e]	Glume cover (%)	Grain color[e]	PC[f]	ET[g]
			2009	2010	2009	2010										
473	USA	*Guinea-kafir*	3.0	3.0	3.0	2.5	5	65	197	14.28	T	S	25	S	SL	MS
2382	South Africa	*Caudatum*	5.4	5.4	2.5	2.2	73	71	212	22.22	P	BL	25	RB	C	MS
5301	India	*Guinea-caudatum*	2.7	2.5	3.5	2.0	28	75	196	13.79	P	BL	0	W	L	CC
6354	India	*Durra*	3.0	2.9	3.5	2.5	60	70	208	31.63	P	P	50	S	SC	MS
7131	Uganda	*Durra-caudatum*	4.3	5.0	2.0	2.0	60	80	192	26.77	P	S	50	Y	SL	PC
7679	Nigeria	*Guinea*	2.2	3.0	5.5	2.4	78	74	302	24.15	P	LR	25	W	L	PC
9108	Kenya	*Caudatum*	5.0	5.1	2.0	2.0	63	68	207	30.51	P	Brown	25	RB	SC	CS
9177	Kenya	*Caudatum*	5.1	5.0	2.0	2.5	58	81	219	20.96	P	Purple	25	RB	C	CS
9745	Sudan	*Caudatum*	5.0	5.0	3.0	2.1	78	65	189	28.61	P	Purple	25	LR	C	PC

10302	Thailand	*Caudatum*	2.0	2.2	6.0	5.1	78	67	222	24.70	T	S	25	W	SL	MC
12937	Ethiopia	*Kafir*	7.5	7.6	2.5	2.0	73	68	221	22.68	P	R	50	LR	SC	MC
12945	Nicaragua	*Kafir*	3.0	3.5	3.0	2.0	68	77	253	24.86	P	BL	50	S	SL	PC
14861	Cameroon	*Caudatum*	2.4	3.7	2.0	2.0	73	55	187	16.71	P	S and B	25	R	SC	MS
16382	Cameroon	*Guinea*	3.0	3.0	4.0	2.3	43	58	183	8.22	P	LR	25	LR	SL	PC
19153	Sudan	*Guinea-caudatum*	2.0	2.5	4.0	2.3	35	68	146	24.83	P	S	75	W	SC	MS
19445	Botswana	*Kafir*	6.8	7.0	2.5	2.1	53	68	174	26.58	P	S	25	LR	SC	PC
20632	USA	*Caudatum*	2.7	3.0	3.5	5.0	60	77	265	35.44	P	S and B	50	Red	SL	MS
20743	USA	*Bicolor*	5.4	5.5	2.5	2.0	38	63	209	15.59	P	B	100	RB	L	PC
20956	Indonesia	*Durra-caudatum*	2.6	2.2	5.0	6.5	15	66	216	18.88	T	Straw	50	W	SL	MC
21083	Kenya	*Caudatum*	4.0	4.0	2.0	2.0	58	74	276	-	P	BL	25	RB	SL	-
23521	Ethiopia	*Guinea-caudatum*	3.0	3.0	3.0	2.1	0	68	143	21.97	T	LB	25	S	SL	PC
23644	Gambia	*Guinea*	2.4	3.2	2.5	2.3	30	69	227	14.38	P	R	0	W	L	MC
23684	Mozambique	*Guinea*	2.7	2.6	2.0	2.0	0	88	258	7.87	T	B	25	W	VL	CC

24175	Tanzania	*Guinea*	3.3	3.0	2.0	2.4	58	94	267	12.79	P	S	25	S	L	CC
24218	Tanzania	*Guinea*	2.6	2.5	2.5	4.5	35	94	277	23.18	P	S	25	S	VL	MC
24503	South Africa	*Bicolor*	5.6	5.0	2.0	2.0	10	67	223	2.38	P	S and B	100	B	L	CC
24939	Zambia	*Bicolor*	3.0	3.2	2.0	2.0	23	76	212	13.54	P	BL	75	RB	SL	MS
24953	Zambia	*Guinea-caudatum*	4.0	4.0	2.5	2.3	43	77	251	21.46	P	LR	25	RB	SL	MS
26694	South Africa	*Caudatum*	5.0	5.0	2.0	2.0	15	79	244	25.65	P	S	50	B	SL	MS
26737	South Africa	*Kafir*	4.5	4.4	3.0	3.4	8	69	223	33.79	P	S	50	LR	SL	PC
26749	South Africa	*Kafir*	5.2	5.2	3.0	2.4	43	66	144	27.63	P	S	50	LR	SL	PC
28614	Republic of Yemen	*Durra-caudatum*	6.0	6.1	2.5	2.0	43	66	229	13.30	P	RB	50	LR	SC	MS
29187	Swaziland	*Guinea-caudatum*	4.1	4.0	2.0	2.0	20	77	257	32.79	P	RB	50	RB	SL	MS
29233	Swaziland	*Kafir*	4.5	4.4	2.0	2.0	33	79	169	22.06	P	R	50	LR	SL	PC
29714	Zimbabwe	*Kafir-durra*	4.0	4.0	2.0	2.0	15	77	197	19.96	T	S and P	50	S	C	MC
31557	Burundi	*Caudatum*	4.5	4.0	2.0	2.2	15	86	285	19.73	P	S and B	25	B	L	CS

33023	Tanzania	*Guinea*	3.5	3.0	3.3	3.0	10	88	274	10.66	P	S and P	25	LB	L	PC
33353	Kenya	*Caudatum*	3.5	3.5	2.0	2.3	63	67	196	22.24	P	L	50	RB	SL	CS
Trial mean			4.8	4.9	4.1	4.0	47	70	214	20.77						
LSD (5%)			0.4	0.4	1.1	1.7	4.2	2.0	11.5	4.96						
CV%			4.5	4.5	14.6	23.3	4.5	1.8	3.3	15.30						

[a] Mean of 2 replicates, 10 plants/replicate at dough stage.

[b] Mean of 2 replicates, 10 plants/replicate in a greenhouse screen.

[c] DF: Days to 50% flowering.

[d] Plant color: T = tan; P = pigmented/non-tan.

[e] W = white, S = straw, Y = yellow, LR = light red, R = red, RB = reddish brown, LB = light brown, B = brown, P = purple, BL = black.

[f] PC = Panicle compactness: C = compact, SC = semi-compact, SL = semi-loose, L = loose, VL = very loose.

[g] EC = Endosperm texture: MS = mostly starchy, CS = completely starchy, PC = partly corneous, MC = mostly corneous, CC = completely corneous.