Characterization of grain mold resistant sorghum germplasm accessions for physio-morphological traits

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Abstract

One hundred and fifty-six sorghum germplasm accessions that were identified resistant to grain mold in 1988 were reevaluated during the 2006 and 2007 rainy seasons in grain mold nursery at ICRISAT, Patancheru, India to confirm their resistance and characterize them for various physio-morphological traits that are likely to be associated with grain mold resistance. The visual panicle grain mold rating (PGMR) of the 156 test accessions varied from 1 to 3.5 (on a 1–9 scale) compared to 8.5 to 9.0 of the susceptible checks. During the 2006 screen, of the 156 test accessions, 19 were highly resistant (1.0 score), 134 resistant (1.1 to 3.0 score) and 3 moderately resistant (3.1–3.5 score). These accessions varied for various traits, such as time to 50% flowering (47 to 86 days), plant height (90 to 375 cm), panicle type (loose to compact), glumes coverage of grains (25 to 75%), glumes color (straw to black) and grain color (white to dark brown). Of 69 single-plant selections, from as many agronomically desirable grain mold resistant accessions, screened during 2007, two were highly resistant and the remaining 67 were resistant. Some of these lines that have desirable agronomic traits could be preferred for utilization in grain mold resistance breeding.

Introduction

Despite prolonged efforts made in breeding for resistance to grain mold (caused by several unspecialized fungal pathogens and saprophytes) in sorghum (*Sorghum bicolor*) there are no cultivars available that offer adequate resistance to grain mold. Modern cultivars, especially F_1 hybrids that have been deliberately bred for early and medium maturity, shorter plant height and higher grain yield with compact panicle in white-grain background often succumb to grain mold compared to late maturing, tall local land races with colored grain. At the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India, efforts have been made to identify genetic resistance to grain mold in diverse range of germplasm accessions (Bandyopadhyay et al. 1988). Several of the resistant germplasm accessions have been used to breed varieties, restorer lines and hybrid seed parents and some advances have been made to develop white-grain high-yielding grain mold tolerant experimental hybrids (Reddy et al. 2000). Resistance to grain mold is a complex trait and several morphological traits have been shown to be associated with resistance (Audilakshmi et al. 1999). Thus, there is a need to identify morphologically diverse sources of genetic resistance with desirable agronomic traits for utilization in breeding to develop hybrids and varieties for diverse use as food, feed and other industrial products. After a gap of about 25 years, these accessions were reevaluated using a refined screening method (Thakur et al. 2006) during the 2006 rainy season in the grain mold nursery at ICRISAT, Patancheru to confirm their resistance and characterize them for several morphological traits and agronomic desirability that would facilitate their utilization in resistance breeding program.

Materials and methods

Germplasm accessions and their selections. Of 7132 sorghum germplasm accessions screened at ICRISAT during 1980–85 in the grain mold nursery, 156 were found resistant. These 156 accessions originated from 25 countries of Asia, Africa and USA (Bandyopadhyay et al. 1988). Sixty-nine single-plant selections from as many grain mold resistant accessions belonged to 18 countries, including 21 from South Africa, 14 from USA, 8 from Lebanon, 5 from India and 4 from Zimbabwe.

Screening for grain mold resistance. The 156 sorghum germplasm accessions along with one resistant (IS 14384) and two susceptible checks (Bulk Y and SPV 104) were grown in an unreplicated experiment in the grain mold nursery during the 2006 rainy season at ICRISAT. Each accession was planted in 2 rows of 2 m with 10 plants per row. The sprinkler irrigation was provided twice a day for 30 min each between 10 and 12 AM, and between 4 and 6 PM on rain-free days from flowering to physiological maturity to provide high humidity (>90% RH) and panicle wetness essential for mold development. In each row 5 plants of uniform height and flowering were tagged at the 50% flowering stage. The visual panicle grain mold rating (PGMR) was scored on each of the tagged plants at the right physiological maturity (Thakur et al. 2006) using a progressive 1 to 9 scale, where 1 = no mold infection, 2 = 1–5%, 3 = 6–10%, 4 = 11–20%, 5 = 21–30%, 6 = 31–40%, 7 = 41–50%, 8 = 51–75% and 9 = >75% molded grains on a panicle. The refined screening method included just one time scoring for grain mold severity at the right physiological maturity stage, and not at several stages and on threshed grains as used to be done earlier. Depending on the maturity period of the accessions, they were assessed at different times. Similarly, 69 single-plant selections were screened during the 2007 rainy season along with susceptible checks. The experiment was conducted using a randomized block design (RBD) in two replications with 2 rows of 2 m having 10 plants per row.

Data recording and analysis. In addition to PGMR, in both experiments, data were recorded for time to 50% flowering, plant height, panicle type, glumes coverage, glumes color and grain color at the appropriate time of crop growth and development. As most of them are genetically fixed traits and are expressed uniformly in all plants of an accession the data were recorded as an overall expression of the trait for each accession. The variation in qualitative morphological traits, such as panicle type, glumes color and grain color were assigned numerical ratings following the DUS (Distinctiveness, Uniformity and Stability) ratings developed by National Research Centre for Sorghum (NRCS), Hyderabad, India (Reddy et al. 2006a) to facilitate statistical analysis. The physio-morphological data sets of the 69 selections were subjected to Average Linkage Cluster Analysis for classifying them into different groups.

Results

Grain mold resistance. The PGMR of the 156 test accessions varied from 1 to 3.5 (on a 1–9 scale) compared to 8.5 to 9.0 on the susceptible checks, Bulk Y and SPV 104, and 1.0 on the resistant check IS 14384 (Table 1). Of these 156 accessions, 19 were highly resistant (1.0 score), 134 resistant (1.1 to 3.0 score) and 3 moderately resistant (3.1–3.5 score). Among the 69 single-plant selections, the PGMR ranged from 1.0 to 2.9 (Table 1) and 2 selections (IS 14384 and 14387) were highly resistant and the remaining 67 resistant to grain mold (Table 2).

Variation in physio-morphological traits. Large variations were recorded for different traits in germplasm accessions and their selections. In 156 accessions evaluated during the rainy season 2006, time to 50% flowering varied from 47 to 86 days, plant height from 90 to 375 cm, panicle type from score 3 (loose) to 9 (compact), glumes coverage from 25 to 75%, glumes

Table 1. Variation for panicle grain mold rating (PGMR) and different morphological traits of 156 grain mold resistant sorghum germplasm accessions and their 69 selections during the rainy season 2006 and 2007 at ICRISAT, Patancheru, India.

Trait	156 germplasm accessions		69 selected germplasm accessions		Susceptible checks[1]	Resistant check (IS 14384)
	Mean ± SE (m)	Range	Mean ± SE(m)	Range		
PGMR (1–9 scale)[2]	1.8 ± 0.04	1.0–3.5	2.1 ± 0.49	1.0–2.9	8.5–9.0	1.0
Time to 50% flowering (days)	65.0 ± 0.83	47–86	58 ± 1.3	49–77	48–68	76
Plant height (cm)	250.0 ± 5.0	90–375	226 ± 2.8	140–375	133–193	315
Panicle type (1–9)[3]	4.9 ± 0.12	3–9	5.8 ± 0.24	3–9	3–7	3
Glumes coverage (%)	37.0 ± 1.33	25–75	55 ± 1.22	50–75	25	88
Glumes color (1–8 scale)[3]	6.0 ± 0.10	2–8	4.7 ± 0.27	2–8	3–5	8
Grain color (1–7 scale)[3]	5.9 ± 0.09	1–7	5.7 ± 0.09	1–7	1–1	7
Grain tannin content (CE%)[4]	2.95 ± 0.18	0.1–10.7	3.2 ± 0.26	0.2–9.2	0.1	0.3

1. SPV 104 and Bulk Y.
2. PGMR: 1 = no mold infection, 2 = 1–5%, 3 = 6–10%, 4 = 11–20%, 5 = 21–30%, 6 = 31–40%, 7 = 41–50%, 8 = 51–75% and 9 = >75% molded grains on a panicle.
3. Panicle type: 1 = very loose, 3 = loose, 5 = semi-loose, 7 = semi-compact and 9 = compact.
   Glumes color: 1 = green, 2 = straw, 3 = brown, 4 = light red, 5 = red, 6 = yellow, 7 = purple and 8 = black.
   Grain color: 1 = white, 2 = chalky white, 3 = pearly white, 4 = yellow, 5 = red, 6 = light brown and 7 = dark brown.
   Scores for panicle type, glumes color, grain color and plant agronomic aspect were based on DUS-testing procedure reported by Reddy et al. (2006a).
4. Source: Bandyopadhyay et al. (1988).

Table 2. Grain mold severity and variable morphological traits of single-plant selections from sorghum germplasm accessions screened during 2006 and 2007 rainy season at ICRISAT Patancheru, India.

Germplasm accession	Origin	Race[1]	Testa[1]	Grain tannin content (CE%)[1]	PGMR[2] 2006	PGMR[2] 2007	Time to flowering[3] (days)	Plant height[3] (cm)	Panicle type[4] (%)	Glumes coverage[3] (%)	Glumes color[5]	Grain color[5]
IS 79-10	Mexico	C	P	3.6	2.0	2.4	62	200	SC	50	B	B
IS 620-1	USA	C	P	1.4	2.4	2.3	52	175	C	50	BL	R
IS 623-3	USA	C	P	1.8	2.0	2.2	68	265	C	50	R	B
IS 624-4	USA	C	P	1.1	2.0	2.0	61	215	L	50	BL	R
IS 625-10	USA	C	P	3.3	2.0	2.0	51	205	L	50	B	R
IS 715-6	USA	C	P	1.4	2.0	2.0	64	280	SC	50	B	B
IS 2453-2	USA	C	P	1.4	2.0	2.0	58	230	SC	50	B	B
IS 2454-1	USA	C	P	1.3	1.7	2.0	55	220	SC	50	B	B
IS 2560-2	USA	C	P	1.8	1.6	2.1	54	225	SC	50	R	R
IS 2821-3	Zimbabwe	C	P	1.9	2.0	2.4	49	140	SC	50	B	B
IS 2825-1	Zimbabwe	C	P	1.9	2.0	2.2	56	165	SC	50	B	B
IS 2867-3	South Africa	C	P	1.4	2.0	2.1	52	215	SC	50	B	B
IS 3789-2	Taiwan	DB	P	1.0	2.0	2.0	50	225	L	75	B	B
IS 4006-2	India	C	P	2.5	2.0	2.0	59	255	L	50	BL	B
IS 6047-2	India	DC	P	2.6	2.0	2.0	60	245	SC	50	B	B
IS 6335-8	India	C	P	2.1	1.1	2.0	51	235	L	75	B	B
IS 7237-4	Nigeria	C	P	1.6	2.0	2.0	61	220	C	50	B	R
IS 8525-6	Ethiopia	C	P	2.1	2.0	2.5	50	185	SC	50	B	B
IS 8545-10	Ethiopia	C	P	1.9	2.0	2.1	58	185	SC	50	B	B
IS 8763-4	South Africa	C	P	1.1	1.8	2.4	50	170	SC	50	B	B
IS 8848-1	Kenya	CB	P	2.8	1.8	1.5	52	235	L	75	BL	R
IS 9058-1	Kenya	C	P	3.2	2.0	2.2	58	225	L	50	BL	B
IS 9308-2	South Africa	C	P	2.6	2.0	2.2	57	175	SC	50	R	R
IS 9326-9	South Africa	C	P	2.4	2.0	2.0	60	255	SC	50	B	B
IS 9353-5	South Africa	K	P	1.6	2.0	2.0	61	270	SC	50	R	B
IS 9471-2	South Africa	C	P	1.2	2.0	2.0	59	280	SC	50	R	B
IS 9482-10	South Africa	C	P	3.0	2.0	2.0	58	260	L	50	B	B
IS 9484-1	South Africa	C	P	2.4	2.0	2.0	62	260	SC	50	BL	B
IS 9487-1	South Africa	C	P	2.7	2.0	2.0	58	225	SC	50	R	B
IS 9494-10	South Africa	C	P	3.4	2.1	2.0	56	225	SC	50	BL	B
IS 9498-3	South Africa	C	P	3.3	2.0	2.0	62	275	SC	50	R	B
IS 9499-10	South Africa	C	P	2.6	2.4	2.0	60	220	SC	50	B	B
IS 9554-2	South Africa	C	P	1.6	1.7	2.0	60	240	SC	50	BL	B
IS 9804-2	Sudan	CB	P	7.2	2.0	2.0	53	190	L	75	BL	B
IS 10301-3	Thailand	K	P	3.3	2.0	2.0	58	230	L	50	R	B
IS 10390-10	Uganda	CB	P	8.9	2.0	2.6	62	195	SC	75	BL	B
IS 10942-9	USA	C	P	5.1	2.5	2.7	52	145	SC	50	B	B
IS 12932-2	China	CB	P	2.1	1.1	1.9	57	245	L	50	W	B
IS 13267-4	India	DC	P	2.9	1.8	2.3	56	190	SC	50	B	B
IS 13804-10	South Africa	CB	P	1.8	1.6	2.1	56	235	SC	50	B	B
IS 13817-10	South Africa	–	P	3.9	2.0	2.0	59	250	SC	50	B	B
IS 13885-8	South Africa	G	A	0.8	1.0	2.1	68	260	SC	50	BL	R
IS 13934-10	South Africa	CB	P	4.0	2.1	2.6	49	165	SC	50	B	B
IS 13945-1	South Africa	C	P	5.1	2.0	2.0	64	270	SC	50	B	B
IS 13958-10	South Africa	C	P	3.0	2.0	2.0	58	240	SC	50	B	B
IS 13965-5	South Africa	CB	P	2.8	2.0	2.0	57	215	SC	50	B	B
IS 13969-1	South Africa	C	P	5.7	2.0	2.0	58	245	SC	75	B	B
IS 14384-1	Zimbabwe	G	A	0.3	1.0	1.0	69	325	L	75	BL	R
IS 14387-1	Zimbabwe	GB	P	4.2	1.0	1.0	68	295	L	75	BL	R
IS 14388-1	Swaziland	DC	P	3.4	2.0	2.0	57	235	SC	50	B	B
IS 18135-2	Lebanon	–	P	0.2	2.0	1.5	58	220	L	75	BL	B
IS 18139-2	Lebanon	–	P	8.4	2.0	1.5	59	235	L	75	BL	B
IS 18141-4	Lebanon	–	P	5.2	2.0	1.7	68	260	L	50	BL	R
IS 18146-1	Lebanon	–	P	5.0	2.0	2.7	52	175	L	50	BL	R
IS 18149-1	Lebanon	–	P	5.1	2.0	2.0	57	230	L	50	BL	B

contd.

Table 2. (contd.)

Germplasm accession	Origin	Race[1]	Testa[1]	Grain tannin content (CE%)[1]	PGMR[2]		Time to flowering[3] (days)	Plant height[3] (cm)	Panicle type[4] (%)	Glumes coverage[3] (%)	Glumes color[5]	Grain color[5]
					2006	2007						
IS 18154-1	Lebanon	–	P	3.6	2.3	2.1	51	180	SC	50	BL	R
IS 18175-2	Lebanon	–	P	7.7	2.1	2.0	65	190	SC	50	B	B
IS 18219-7	Lebanon	–	P	5.0	2.2	2.0	58	225	L	75	B	B
IS 18528-8	India	–	P	6.6	2.0	2.0	60	230	L	50	BL	R
IS 18759-2	Nigeria	–	P	2.0	2.0	2.7	49	170	SC	50	B	B
IS 20620-2	USA	C	P	3.0	1.9	2.1	52	180	SC	50	B	B
IS 20639-6	USA	–	P	5.4	2.0	2.0	61	260	L	50	B	B
IS 20708-8	USA	B	A	0.4	2.0	2.9	52	155	SC	50	B	B
IS 20757-2	USA	C	P	9.2	2.0	2.1	57	225	SC	75	B	B
IS 20831-7	USA	GC	P	8.1	2.0	2.6	58	225	SC	75	B	B
IS 20843-2	South Korea	C	P	2.3	2.0	2.0	60	255	SC	50	B	B
IS 22617-1	Burma	CB	P	6.6	2.0	1.5	60	315	L	75	R	R
IS 25017-1	Sudan	C	A	0.2	1.6	2.0	77	375	SC	50	B	W
IS 25084-5	Ghana	GC	P	2.8	1.0	2.2	55	155	SC	50	B	B
Mean				3.21	1.9	2.1	58	226		55		
SE(m)±				0.26	0.2	0.49	0.6	5.2		0.87		

1. Source: Bandyopadhyay et al. (1988).
   Race: B = *bicolor*, C = *caudatum*, CB = *caudatum-bicolor*, DB = *durra-bicolor*, DC = *durra-caudatum*, G = *guinea*, GB = *guinea-bicolor*, GC = *guinea-caudatum*, K = *kafir*.
   Testa: P = present, A = absent.
2. PGMR = panicle grain mold rating. Mean of 20 tagged plants from 2 replications using 1–9 scale where 1 = no mold infection and 9 = >75% grain molded on a panicle at physiological maturity.
3. Mean of 2 replications.
4. C = compact, SC = semi-compact, L = loose.
5. B = brown, BL = black, R = red, W = white.

color from score 2 (straw) to 8 (black) and grain color from 1 (white) to 7 (dark brown) (Table 1). In 69 selections, plant height ranged from 140 to 375 cm; however, the height of only 3 lines was more than 300 cm. Time to 50% flowering varied from 49 to 77 days, and most lines (65) were early flowering (≤65 days), had loose to semi-compact panicles with 50–75% glumes coverage of grains. The lines also varied for grain and glumes color; most lines had red or brown grain and brown or black glumes (Table 2).

Correlation between PGMR and physio-morphological traits. In both sets of accessions, significant negative correlations were observed for PGMR with plant height, time to 50% flowering, glumes coverage and grain color, and significant positive correlation with panicle type (Table 3). Among different morphological traits, dark grain color and greater glumes coverage of grains appeared to be more closely associated with grain mold resistance than other traits. The selected 69 accessions had 50–75% glumes coverage and were dark grained (brown or red) except IS 25017, a white-grained accession.

Grouping of resistant selections. Cluster analysis of the 69 selections classified them into eight diverse groups (Fig. 1). There were two major groups, I and II that included 23 and 17 selections, respectively. Groups IV, V and VI had 8, 6 and 6 selections, respectively, while groups III and VII were minor groups representing only 5 and 3 selections, respectively. However, a white-grained accession IS 25017-1 was morphologically very distinct and thus could not be assigned to any of these groups.

Discussion

The results showed that grain mold resistance identified in germplasm accessions some 25 years ago (Bandyopadhyay et al. 1988) was still holding up. This resistance stability could be attributed mainly to the little or no change in the fungal species complex that causes grain mold and the near uniform environmental conditions maintained in the grain mold nursery at ICRISAT. Of the 156 grain mold resistant accessions, five (IS 2825, IS 13817, IS 13885, IS 14384 and IS 20708) have been used in resistance breeding at

ICRISAT, Patancheru to develop hybrid seed parents, restorers and varieties (Reddy et al. 2000). However, many of these accessions have undesirable traits, such as longer time to flowering, taller plant height, very loose panicles and dark colored grains that make them agronomically undesirable for direct utilization in a resistance breeding program. Single-plant selections from 69 accessions that have near-desirable agronomic traits could be more useful for utilization. The above five accessions used in resistance breeding are within this group, and are distributed into four diversity groups (Fig. 1).

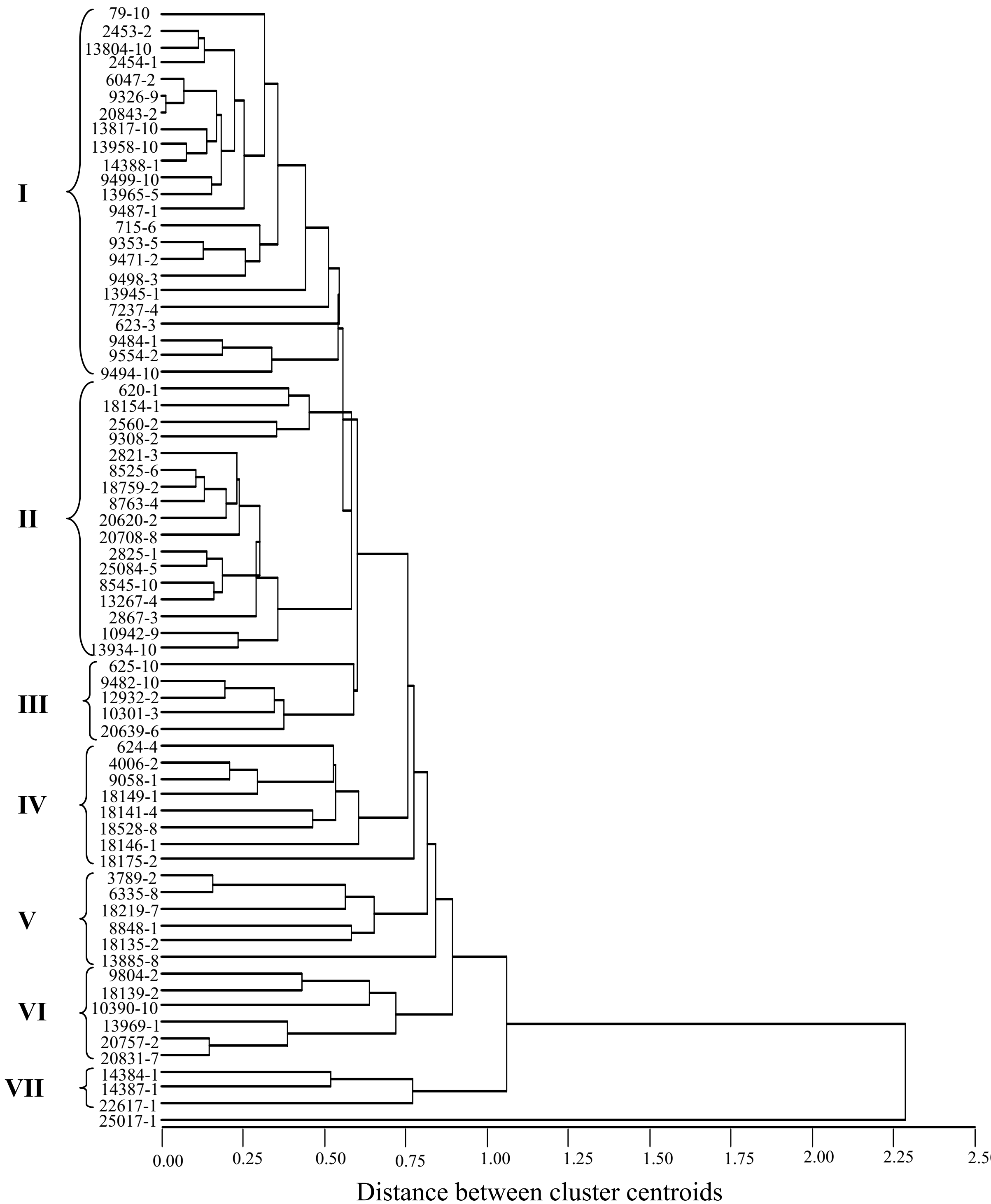

Figure 1. Grouping of sorghum germplasm accessions (IS lines) based on morphological traits.

Table 3. Correlations between panicle grain mold rating (PGMR) and different morphological traits in sorghum[1].

Trait	Time to flowering	Glumes color	Glumes coverage	Grain color	PGMR	Panicle type
Glumes color	0.22					
Glumes coverage	0.13	0.04				
Grain color	–0.04	–0.13	0.03			
PGMR	–0.26**	–0.09*	–0.25**	–0.33**		
Panicle type	–0.04	0.01	–0.48	0.05	0.29**	
Plant height	0.82	0.19	0.27	–0.03	–0.38**	–0.22

1. * = Significant at P >0.1 (df = 154); ** = Significant at P >0.001.

Inheritance and mechanisms of resistance to grain mold have been highly variable due to the involvement of several fungal pathogens, and several physio-morphological and biochemical traits contributing to resistance. In the earlier study (Bandyopadhyay et al. 1988), large variations were found for tannin content and presence or absence of testa layer in resistant accessions and it was suggested that tannin content was not always associated with testa layer and resistance to grain mold (Table 2). However, majority of mold resistant sorghum lines have been reported to have a pigmented testa and high tannin levels (Menkir et al. 1996). Some physio-morphological traits, such as taller plant height, loose to semi-compact panicles, dark grain color and larger glumes coverage have been shown to be associated with grain mold resistance (Rao and Rana 1989, Audilakshmi et al. 1999, Reddy et al. 2000, 2006a). However, none of these traits were strongly associated with resistance. In this study, we found significant negative or positive correlations, but not very strong correlations between PGMR and plant height, time to 50% flowering, grain color, glumes coverage and panicle compactness indicating that these traits, individually do contribute partly to grain mold resistance and are quantitative resistance traits governed by minor genes. A resistance breeding program that can accumulate these minor genes in agronomically desirable lines could produce varieties with stable resistance to grain mold. In this study, morphologically diverse accessions belonging to different race types clustered in different groups might have different mechanisms of resistance and thus serve as useful sources of resistance for the resistance breeding program.

In a recent study of hybridization between resistant line (R) and susceptible line (S) it was shown that there was a greater possibility of producing grain mold resistant hybrids from crosses of R × R and R × S than those of S × R and S × S, indicating the diverse and complementary mechanisms, each with small effects, may be acting synergistically leading to higher levels of resistance in some of the hybrids (Reddy et al. 2006b, Thakur et al. 2006). Thus, it is desirable to select parents with diverse mechanisms of mold resistance in order to develop a grain mold resistant hybrid.

Note: Small quantity seed of these resistant lines are available on request to senior author.

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