Heterosis in white-grained grain mold resistant sorghum hybrids

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Introduction

Sorghum (*Sorghum bicolor*) is an important food and feed crop grown in more than 90 countries. Globally it is grown on over 40 million ha predominantly in tropical Africa and India for food and in temperate areas (Americas, Europe and Australia) as a feed crop (Reddy et al. 2011). India has largest area (7.5 million ha) under sorghum and 40% of this area is in rainy season while postrainy season sorghum accounts for the remaining area. Grain mold, a highly destructive disease of sorghum cultivated in the rainy season, is widely distributed in the semi-arid tropics of Africa, Americas and Asia including India (Stenhouse et al. 1997). Grain mold is broadly defined as pre-harvest grain deterioration caused by several fungal genera interacting parasitically and/or saprophytically with developing grain (Thakur et al. 2006). In India, *Fusarium verticillioides*, *Curvularia lunata* and *Alternaria alternata* are more pathogenic than other fungi (Thakur et al. 2003). The disease is particularly important on improved, short- and medium-duration sorghum cultivars that mature during rains in humid tropical and subtropical climates. Grain mold results in reduction of seed mass, seed germination, storage and food/feed processing quality and hence reduces the market value. Production losses due to grain mold range from 30% to 100% depending on the cultivar, time to flowering and prevailing weather conditions from flowering to harvesting (Singh and Bandyopadhyay 2000). Grain mold resistance had been shown to be determined by several qualitative trait loci that include grain hardness, panicle compactness and shape, presence or absence of a pigmented testa, photoperiod sensitivity, glume coverage, production of phenols, antifungal proteins and other secondary metabolites. However, these loci do not account for all the variation observed for grain mold resistance in sorghum (Rooney and Klein 2000). Sorghum cultivars with white grain pericarp are particularly more vulnerable to grain mold than those with brown and red grain pericarp (Thakur et al. 2006). Hybrids are the cultivar options and white-grained hybrids are preferred for food in India but there are no commercial white-grained hybrids possessing grain mold resistance (Ashok Kumar et al., in press). At present, grain mold is tackled by developing host plant resistance and modifying the cultural practices with some success (Ashok Kumar et al. 2008).

Research efforts for grain mold resistance at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and other places (USA and India) have met with partial success in breeding cultivars with high levels of grain mold resistance and higher grain yields (Audilakshmi et al. 2005, Ashok Kumar et al., in press). We present in this paper the strategy adapted for diversifying the sorghum hybrid parents for grain mold resistance and developing the heterotic hybrids for grain mold resistance and grain yield in the white-grain background.

Materials and methods

Twenty-two sorghum hybrids developed at ICRISAT, Patancheru were evaluated along with their parents (7 B-lines and 6 R-lines) to assess their grain mold resistance and agronomic performance. The female lines used were grain mold resistant B-lines developed under genetic diversification program and identified in 2008 rainy season as white-grained grain mold resistant B-lines compared to widely used female parent 296 B (Table 1). However, under severe disease pressure they succumb to grain mold but still perform better than the control 296 B (Table 1). In 2008 postrainy season, these female lines were randomly crossed with six R-lines based on their nicking and 22 hybrids obtained to assess their agronomic performance and grain mold resistance. These hybrids along with their parents and four controls, 296 B (a high-yielding B-line), CSH 23 (commercially released hybrid by Directorate of Sorghum Research, Hyderabad, India), IS 14384 (a grain mold resistant landrace) and SPV 104 (a grain mold susceptible cultivar), were evaluated at ICRISAT, Patancheru (altitude 545 m above mean sea level, 17.53° N latitude and 78.27° E longitude) in 2009

Table 1. Panicle grain mold rating (PGMR) score of new sorghum B-lines in comparison with 296 B during 2008 rainy season at ICRISAT, Patancheru, India.

B-line	Pedigree	PGMR
ICSB 29007	(ICSB 403 × ICSB 11)-1-1-3-1-4-1-1-1-1-1-1-1-1-1-1	7.7
ICSB 29010	(ICSB 403 × ICSB 11)-1-1-3-1-4-1-1-6-1-1-1-2-1-1-2	8.0
ICSB 29012	(ICSB 403 × ICSB 11)-1-1-3-1-6-1-1-1-1-1-1-1-1-1-1	7.0
ICSB 29013	(ICSB 403 × ICSB 11)-1-1-3-1-6-1-1-1-1-1-1-1-1-1-2	7.0
ICSB 29014	(ICSB 403 × ICSB 11)-1-1-3-1-6-1-1-1-1-1-1-1-1-1-3	7.0
ICSB 29015	(NRCS GMR 4 × SRT 26B)-1-2-1-1-2-2-1-1-2	7.3
ICSB 29016	(ICSB 333 × (ICSB 403 × ICSB 11)-1-1-3-1-4-1)-4-1-1-1-1-1-1	7.3
Bulk Y	Susceptible control	9.0
296 B	High-yielding B-line	9.0
IS 14384	Resistant control	2.0
Mean		6.98
SE±		0.31
CD (5%)		0.88

and 2010 rainy season in a randomized complete block design (RCBD) trial with three replications in breeding block for evaluation of agronomic traits and the same set was planted for grain mold resistance evaluation in the screening block. The plot size was two rows of 2 m length with 75 cm between the rows and 10 cm between the plants, in both breeding block and screening block. In the screening block, sprinkler irrigation method without artificial inoculation was used since flowering time to maintain high humidity and conidial-mycelial suspension (Castor 1981) during the grain-filling period. The recommended agronomic practices were followed to raise a good crop. When there was no rainfall, sprinklers were operated for one hour in the morning and one hour in the evening to create favorable conditions for fungal development. The data were recorded for time to 50% flowering (days), plant height (m), plant aspect score for agronomic desirability (on a 1 to 5 scale, where 1 = more desirable and 5 = least desirable) and grain yield (t ha^{-1}) in breeding block. Panicle grain mold rating (PGMR) score was recorded in the screening block at grain maturity stage on a scale of 1 to 9, where 1 = <10% and 9 = >90% mold infected grain (Bandyopadhyay et al. 1988). The data were analyzed using GENSTAT (Edition 10) to test the significant differences among the genotypes and for mean performance to select the high-yielding genotypes with grain mold resistance as suggested by Singh and Narayanan (1993) and heterosis over mid parent and better parent were estimated as per Hays et al. (1955).

Results and discussion

ANOVA showed significant differences among the genotypes, years and genotypes × years interactions for all the traits (Table 2). Higher magnitude of mean squares due to years indicated that the environments were quite different in two years of testing. Higher mean squares for time to flowering indicated that good options exist for selecting the genotypes with different maturity levels.

Table 2. Mean sum of squares (ANOVA) of sorghum genotypes for agronomic traits and grain mold resistance in 2009 and 2010 rainy season at ICRISAT, Patancheru, India[1].

Source of variation	df	Time to 50% flowering	Plant height	Plant aspect score	Grain yield	df	Panicle grain mold rating
Replication	2	8.25	0.11	0.29	0.64	2	1.13
Genotype (G)	38	232.01**	2.05**	1.98**	5.87**	38	5.08**
Year (Y)	1	62.91**	0.31*	4.22**	22.66**	1	43.75**
G × Y	35 (3)	38.58**	0.23**	0.81**	2.05**	34 (4)	4.14**
Error	148 (6)	4.25	0.07	0.23	0.21	146 (8)	0.35
Total	224 (9)					221 (12)	

1. * = Significant at 5% level; ** = Significant at 1% level.

Performance of hybrids and parents. All the hybrids evaluated (Table 3) showed 14 to 48% less PGMR score than control CSH 23 under natural screening conditions at ICRISAT, Patancheru. Nine hybrids, ICSA 29013 × PVK 801, ICSA 29010 × PVK 801, ICSA 29010 × ICSR 196, ICSA 29016 × SPV 1411, ICSA 29014 × SPV 1411, ICSA 29014 × ICSR 196, ICSA 29012 × PVK 801, ICSA 29014 × PVK 801 and ICSA 29016 × ICSR 196, were significantly superior (by 4 to 38%) for grain yield with 14 to 46% less PGMR score compared to CSH 23. These were 3 to 7 days late than CSH 23 for flowering but 0.3 to 1.3 m taller than CSH 23 indicating their suitability as dual-purpose types in a close maturity range. Slightly delayed maturity is a favorable attribute to overcome grain mold infection. Interestingly, PVK 801, an ICRISAT-Marathwada Agricultural University (MAU) partnership white-grained grain mold tolerant variety, is the male parent of four of these hybrids indicating its potential as a good combiner. These results are in conformity with earlier finding that the probability of realizing grain mold resistance in hybrids is high when both parents used in its derivation possess resistance to grain mold. Among these hybrids, all showed better agronomic desirability score, ie, 1.2 to 1.7 compared to CSH 23 (1.7 score) except two hybrids (ICSA 29016 × SPV 1411, ICSA 29014 × SPV 1411). These seven hybrids can be used as grain mold resistant, high-yielding dual-purpose hybrids for food purposes in India after further testing. All the hybrids were white-grained having good seed set percentage. The seven B-lines developed for grain mold resistance and used in deriving the hybrids showed less PGMR score (by 2 to 26%) and more grain yield (by 38 to 109%) than control 296 B. They were taller (0.3 to 0.8 m) than 296 B. All these are white-grained with larger grain size (100 grain weight 3.4 to 4.1 g) compared to 296 B (3.0 g).

Heterosis in hybrids. Heterosis of the 22 hybrids over mid parental values and better parent is given in Table 4. For computing better parent heterosis for grain yield, hybrids were compared with their high-yielding parents whereas for computing better parent heterosis for grain mold resistance, parents with low PGMR score were used. Among them, three hybrids (ICSA 29012 × S 35, ICSA 29013 × PVK 801 and ICSA 29016 × PVK 801) were significantly heterotic for PGMR than better parent (by 23 to 26%) and mid parent (by 27 to 31%) indicating that it is feasible to develop heterotic hybrids for grain mold resistance by using both parents with grain mold resistance. ICSA 29013 × S 35 was heterotic to better parent (by 26%) and ICSA 29016 × S 35 was heterotic to mid parent (by 27%). Thirteen hybrids were significantly heterotic than better parent (by 33 to 93%) and mid parent (by 47 to 127%) for grain yield.

Cultivar selection with grain mold resistance and high grain yield is an important component of disease management for increased production. All the seven B-lines used in this experiment were superior for grain yield and PGMR score over 296 B. Among the nine superior hybrids, ICSA 29013 × PVK 801 showed higher grain yield (by 38%) and lower PGMR score (by 46%) than control hybrid CSH 23 and was significantly heterotic for grain yield (by 87% for better parent and 114% for mid parent) and for PGMR (by 26% for better parent and 29% for mid parent). The hybrids ICSA 29010 × ICSR 196 (grain yield 4.3 t ha^{-1} and PGMR score 4.7), ICSA 29010 × PVK 801 (grain yield 4.3 t ha^{-1} and PGMR score 4.1), ICSA 29014 × SPV 1411 (grain yield 4.0 t ha^{-1} and PGMR score 3.7) and ICSA 29016 × SPV 1411 (grain yield 4.0 t ha^{-1} and PGMR score 3.9) were significantly superior to the control CSH 23 (grain yield 3.1 t ha^{-1} and PGMR score 5.9) for grain yield and grain mold resistance.

Conclusion

White-grained sorghum hybrids are preferred for food purpose in India and there are no commercial hybrids available with grain mold resistance in white-grain background. This work demonstrated that it is possible to develop white-grained heterotic sorghum hybrids by genetic diversification of hybrid parents for grain mold resistance in white-grain background and using both parents with grain mold resistance in white-grain background to derive the hybrids. The hybrids identified in this study with higher grain yield and superior grain mold resistance fit well for rainy season adaptation in India. Similarly the new B-lines reported here can be used in developing improved hybrids. Small quantities of above hybrids and parents can be obtained from ICRISAT.

Table 3. Mean performance of sorghum hybrids and parental lines for agronomic traits and grain mold resistance in 2009 and 2010 rainy season at ICRISAT, Patancheru, India.

Hybrid/Parent	Time to 50% flowering (days)	Plant height (m)	Plant aspect score[1]	Grain yield (t ha^{-1})	Panicle grain mold rating score[2]
ICSA 29013 × S 35	79	3.1	3.0	1.9	2.9
ICSA 29012 × S 35	79	3.5	2.5	1.0	2.9
ICSA 29013 × PVK 801	62	2.5	1.7	4.6	3.0
ICSA 29016 × S 35	82	3.7	2.3	1.9	3.2
ICSA 29016 × PVK 801	66	2.2	1.3	2.9	3.3
ICSA 29016 × ICSV 25263	78	3.4	2.5	1.9	3.5
ICSA 29014 × PVK 801	62	2.5	1.3	3.7	3.5
ICSA 29012 × PVK 801	61	2.4	1.5	3.7	3.5
ICSA 29013 × ICSR 196	66	2.5	1.5	3.1	3.5
ICSA 29007 × ICSR 56	62	2.3	1.7	3.0	3.6
ICSA 29014 × SPV 1411	62	3.2	2.8	4.0	3.7
ICSA 29014 × S 35	73	3.3	2.5	1.8	3.8
ICSA 29016 × SPV 1411	65	3.3	2.3	4.0	3.9
ICSA 29013 × SPV 1411	58	3.0	2.3	3.0	3.9
ICSA 29007 × ICSV 25263	78	3.4	2.5	1.5	4.0
ICSA 29014 × ICSR 196	65	2.5	1.5	3.9	4.0
ICSA 29015 × PVK 801	63	2.1	1.2	3.2	4.0
ICSA 29010 × PVK 801	64	2.5	1.2	4.3	4.1
ICSA 29012 × ICSR 196	65	2.5	2.0	3.1	4.2
ICSA 29016 × ICSR 56	62	2.1	2.0	2.9	4.4
ICSA 29016 × ICSR 196	63	2.3	1.2	3.5	4.4
ICSA 29010 × ICSR 196	64	2.8	1.3	4.3	4.7
B-lines					
ICSB 29007	74	2.0	1.7	1.8	3.9
ICSB 29010	75	2.0	1.8	2.0	4.1
ICSB 29012	69	1.9	2.3	1.8	4.7
ICSB 29013	74	2.2	1.3	1.9	4.0
ICSB 29014	69	2.3	1.8	2.1	4.2
ICSB 29015	71	1.8	1.8	2.7	5.2
ICSB 29016	71	1.8	1.5	2.2	4.8
R-lines					
ICSR 56	65	1.9	2.0	1.9	4.7
ICSR 196	69	1.9	2.0	2.3	3.9
ICSV 25263	77	2.7	1.8	1.2	3.3
PVK 801	69	2.0	1.2	2.5	4.4
S 35	70	2.8	1.7	2.2	3.9
SPV 1411	74	3.5	3.3	1.4	1.7
Controls					
CSH 23	58	2.0	1.7	3.1	5.9
296 B	73	1.5	2.0	1.0	5.6
IS 14384 (Resistant control)	68	3.1	3.0	3.3	1.1
SPV 104 (Susceptible control)	66	2.2	3.0	2.1	5.7
Mean	68	2.55	1.92	2.64	3.93
SE±	1.16	0.15	0.27	0.25	0.33
CD (5%)	3.33	0.44	0.77	0.73	0.96

1. Scored on a 1 to 5 scale, where 1 = more desirable and 5 = least desirable.
2. Scored on a 1 to 9 scale, where 1 = <10% and 9 = >90% mold infected grain.

Table 4. Percentage heterosis of sorghum hybrids over better parent and over mid parent for grain mold resistance and grain yield in 2009 and 2010 rainy season at ICRISAT, Patancheru, India[1].

Hybrid/Parent	Panicle grain mold rating score[2]	Better parent heterosis (%)	Mid parent heterosis (%)	Grain yield (t ha^{-1})	Better parent heterosis (%)	Mid parent heterosis (%)
ICSA 29013 × S 35	2.9	–26.36*	–27.57	1.9	–12.96	–6.23
ICSA 29012 × S 35	2.9	–24.55*	–31.46*	1.0	–52.31	–47.31
ICSA 29013 × PVK 801	3.0	–25.75*	–28.86**	4.6	86.69**	113.86**
ICSA 29016 × S 35	3.2	–17.83	–26.64*	1.9	–14.73	–13.18
ICSA 29016 × PVK 801	3.3	–23.45*	–27.21*	2.9	16.53	22.46
ICSA 29016 × ICSV 25263	3.5	5.15	–14.32	1.9	–13.39	11.82
ICSA 29014 × PVK 801	3.5	–17.14	–18.6	3.7	47.18**	60.79**
ICSA 29012 × PVK 801	3.5	–19.54	–22.22	3.7	48.39**	74**
ICSA 29013 × ICSR 196	3.5	–8.57	–10.32	3.1	33.77*	47.7*
ICSA 29007 × ICSR 56	3.6	–7.18	–16.11	3.0	60.22**	64.64*
ICSA 29014 × SPV 1411	3.7	118.56	24.36	4.0	93.2**	127.43**
ICSA 29014 × S 35	3.8	–1.81	–5.82	1.8	–15.28	–13.27
ICSA 29016 × SPV 1411	3.9	130.54	19.01	4.0	80.36**	119.57**
ICSA 29013 × SPV 1411	3.9	132.34	36.86	3.0	59.46**	79.33**
ICSA 29007 × ICSV 25263	4.0	19.7	9.72	1.5	–14.77	0.33
ICSA 29014 × ICSR 196	4.0	3.12	–1.37	3.9	72.81**	81.57**
ICSA 29015 × PVK 801	4.0	–8.74	–16.6	3.2	18.8	22.96
ICSA 29010 × PVK 801	4.1	–0.49	–3.43	4.3	73.39**	93.26**
ICSA 29012 × ICSR 196	4.2	9.09	–1.18	3.1	33.77*	51.36*
ICSA 29016 × ICSR 56	4.4	–8.03	–8.71	2.9	30.36	42.44
ICSA 29016 × ICSR 196	4.4	14.81	2.2	3.5	53.07**	54.42**
ICSA 29010 × ICSR 196	4.7	22.6	18.74	4.3	88.16**	101.88**

1. * = Significant at 5% level; ** = Significant at 1% level.
2. Scored on a 1 to 9 scale, where 1 = <10% and 9 = >90% mold infected grain.

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