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# Genetic Enhancement for Grain Mold Resistance and Grain Yield in White Pericarp Sorghum

**Ashok Kumar, Belum V.S. Reddy, R.P. Thakur, Rajan Sharma, B. Ramaiah and V.P. Rao**

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**ABSTRACT :** Sorghum is the fifth most important cereal crop grown in the world after wheat, maize, rice and barley. Grain mold, caused by several non-specialized fungi is an important biotic constraint of sorghum and it seriously compromises the yield and quality of grains obtainable from improved cultivars. This study was an attempt to demonstrate the feasibility of developing white pericarp grain mold resistant high grain yielding sorghum hybrids with stable performance over years. Of the 70 hybrids developed using grain mold resistant hybrid parents, 9 promising hybrids were identified and these along with their parents were tested during three rainy seasons (2006-08) for stability of grain mold resistance and grain yield at ICRISAT-Patancheru. From these, two hybrids (ICSA 101 × PVK 801 and ICSA 52 × ICSV 96105) with white pericarp, higher grain mold resistance and higher grain yield were identified that can be commercialized for food uses after testing for regional adaptation. The hybrid parents ICSB 400, ICSB 52, PVK 801, ICSR 89058, ICSR 91011 and IS 41675 identified in this study can be further used in developing hybrids with enhanced grain yield and grain mold resistance by crossing them with other parents with desirable agronomic traits and high adaptability.

**Key words :** Sorghum, Grain mold resistance, Hybrid parents, Hybrids, Correlations

Sorghum (*Sorghum bicolor* (L.) Moench) is a staple food in Africa and South-Central India. It is a major food grain and industrial raw material in rest of the world (Reddy *et al.,* 2009; Ashok Kumar *et al.,* 2011). Sorghum grain mold caused by a complex of pathogenic and saprophytic fungi (Forbes *et al.,* 1992; Navi *et al.,* 1999), is the greatest constraint for optimum grain yield and quality in the semi-arid tropics of India, Africa and the America (Williams and McDonald, 1983). Annual global losses due to grain molds have been estimated at US$130 million (ICRISAT, 1992). Sorghum cultivars with white grain pericarp which are commonly used for food in India are particularly more vulnerable to grain mold than those with brown and red grain pericarp. Grain mold is more severe on early-maturing, high grain yielding hybrids that are grown during the rainy season (Thakur *et al.,* 2009). Grain molding and weathering are two successive events occurring on sorghum caryopsis. Grain molding occurs during anthesis and physiological maturity – characterized by formation of black layer on the grain hilum, while grain weathering succeeds grain molding in which saprophytic fungi colonize physiologically matured grain prior to harvest (Waniska, 2000). Both these events are greatly favored by the prevailing high humidity and panicle wetness during the rainy season resulting in grain discoloration and considerable reduction in seed viability. In different sorghum growing areas of India, the major pathogens associated with grain mold across variable weather conditions (humidity and temperature) during the rainy season are *Fusarium* spp., *Curvularia lunata, Alternaria alternata* and *Phoma sorghina* (Indira *et al.,* 1991; Thakur *et al* 2003a, 2006a, 2006b). Damage resulting from these early infection events includes reduced kernel development, discoloration of grain, colonization and degradation of endosperm, decreased grain density, decreased germination, decreased seedling vigor and possible mycotoxin contamination particularly with *Fusarium* species (Waniska, 2000; Leslie *et al.,* 2005; Navi *et al.,* 2005).

Among several approaches to manage the sorghum grain mold, host-plant resistance is the most effective and economical option (Thakur *et al.,* 1997, 2003b; Reddy *et al.,* 2000). Studies on biology and epidemiology of sorghum grain mold (Bandyopadhyay, *et al.,* 2000) led to the development of an effective field screening technique (Bandyopadhyay and Mughogho, 1988) and a number of resistant lines were identified by screening a large number of germplasm accessions at ICRISAT (Bandyopadhyay *et al.,* 1988). Following the field screening of more than 13000 photoperiod-insensitive germplasm lines, Bandyopadhyay *et al.,* 1988 identified 156 lines, including one white-grain line having tolerance/resistance to grain mold. Resistance has been found mostly in colored grain sorghums with and without tannins and also in very few white-grain sorghums (Bandyopadhyay *et al.,* 1988; Audilakshmi *et al.,* 1999, 2000, 2005). 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.,* 2011b). To tackle this, by involving the identified resistant lines as donors in crossing programs, a number of hybrid parents with grain mold resistance and high grain yield have been developed at ICRISAT and elsewhere (Reddy *et al.,* 2006; Ashok Kumar *et al.,* 2008 and 2011). Using these resistant hybrid parents, we developed more than 70 hybrids at ICRISAT-Patancheru and evaluated them in replicated trials for grain mold resistance and grain yield. Nine promising hybrids among this group selected based on their yield superiority and grain mold resistance were tested along with their parents over three years for stability of grain mold resistance and grain yield at ICRISAT-Patancheru and the results are presented here.

## Materials and Methods

Nine grain sorghum hybrids (ICSA 101 x PVK 801, ICSA 101 x ICSR 89058, ICSA 101 x IS 41675, ICSA 101 x GD 65028, ICSA 101 x GD 65055, ICSA 382 x GD 65055, ICSA 384 x ICSR 91011, ICSA 52 x ICSV 96105 and ICSA 400 x GD 65028) developed at ICRISAT, Patancheru were evaluated along with their parents (5 B-lines and 7 R-lines) and four controls (296 B – a high yielding B-line; CSH 16 – commercial cultivar, IS 14384 – a grain mold resistant landrace and Bulk Y – a grain mold susceptible cultivar) during the three rainy seasons in 2006, 2007 and 2008 at ICRISAT, Patancheru (altitude 545 m, latitude 17.53$^0$ N and longitude 78.27$^0$ E). The material was planted in a randomized complete block design (RCBD) with three replications in alfisols in all three years for evaluation for grain yield and other agronomic traits in four rows of two m length. The same set was also planted for screening against grain mold in RCBD with three replications in grain mold nursery. Screening was done without artificial inoculation since sufficient natural inocula of mold fungi are present during the rainy season over sorghum fields at ICRISAT, India for natural field epiphytotic conditions (Bandyopadhyay and Mughogho 1988, Thakur *et al.,* 2007). The material was planted in the first half of June so that grain maturing stages coincided with periods of frequent rainfall in August-September. To enhance mold development, high humidity (>90% RH) was provided through sprinkler irrigation of test plots twice a day for 30 min each between 10 and 12 noon, and between 4 and 6 PM on rain-free days from flowering to physiological maturity. Ten uniformly flowering plants were tagged in each row. The visual panicle grain mold rating (PGMR) was taken on each of the tagged plants at the prescribed physiological maturity 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 = 76-100% molded grains on a panicle. The data were recorded for days to 50 per cent flowering, plant height (m), plant aspect score for agronomic desirability (agronomic desirability score taken on a scale where 1= more desirable and 5= least desirable) and grain yield (t ha$^{-1}$) in agronomic block. The data from agronomic block and screening block were analyzed using GENSTAT (Edition 10) to test the significant differences among the genotypes, for mean performance to select the high yielding genotypes with grain mold resistance and to estimate the correlations among the traits.

## Results and Discussion

The ANOVA showed significant differences among the hybrids (H) and years (Y) for all the traits studied (Table 1). The significant differences were observed for H×Y interactions for days to 50 per cent flowering, plant aspect score, grain yield and panicle grain mold rating indicating that the response of the hybrid varied with environment in different years. The mean performance of hybrids and parents is presented in Table 2. Among the hybrids, ICSA 101 × PVK 801 (6.2 t ha$^{-1}$) showed significantly higher grain yield (by 10%) than CSH 16 (5.3 t ha$^{-1}$) where as two hybrids – ICSA 52 × ICSV 96105, ICSA 400 × GD 65028 were on par with it; among the parents - IS 41675, ICSR 91011, PVK 801, ICSR 89058, ICSB 400 and ICSV

**Table 1 : Mean sum of squares (ANOVA) of sorghum hybrids in grain mold resistant hybrids and parents trial in 2006, 2007 and 2008 rainy seasons, at ICRISAT, Patancheru.**

| Source of variation | df | Days to 50% flowering | Plant height (m) | Plant aspect score | Grain yield (t ha$^{-1}$) | Panicle grain mold rating |
|---|---|---|---|---|---|---|
| Replication | 2 | 7.09 | 0.07 | 0.05 | 0.06 | 0.30 |
| Hybrids (H) | 24 | 161.06** | 1.65** | 1.85** | 9.31** | 31.31** |
| Year (Y) | 2 | 287.28** | 1.70** | 8.69** | 278.65** | 32.67** |
| H x Y | 48 | 13.09** | 0.05 | 0.38** | 3.06** | 4.31** |
| Error | 148 | 2.34 | 0.04 | 0.20 | 0.36 | 0.17 |
| Total | 224 | | | | | |

** Significant at 1% level

96105 showed significantly higher grain yield up to 44 per cent than 296B (2.9 t ha$^{-1}$). All the hybrids and parents showed significantly higher grain mold resistance (up to 66%) than respective controls CSH 16 (PGMR: 5.1) and 296B (PGMR: 8.4) where as the susceptible check showed PGMR 8.7. Higher grain mold tolerance in improved sorghum B-lines was reported earlier (Reddy *et al.,* 2005 and Thakur *et al.,* 2009). The parents ICSR 89058, ICSV 96105, ICSB 52, ICSB 101, ICSB 384 and IS 41675 were significantly earlier (by up to three days) than 296B. The hybrid ICSA 384 × ICSR 91011 was on par with CSH 16 (2.2 m) for plant height and all other eight hybrids were significantly taller than CSH 16 (up to 0.8 m) and among the parents all were significantly taller up to 1.3 m compared to 296 B indicating their suitability as dual purpose lines.

The correlations among the traits are presented in Table 3. PGMR was significantly negatively associated with days to 50 per cent flowering and plant height indicating that grain mold incidence was higher in early maturing and dwarf cultivars leading to lower grain yields. This is in contrast earlier to finding where in significant positive correlation between PGMR and early flowering was reported (Reddy *et al.,* 2006). Tall lines that matured late showed lower PGMR and higher grain yields as indicated by significant positive association between plant height and grain yield and significant negative association between PGMR and days to 50 per cent flowering. Higher grain yields in these lines may be due to the fact that tall lines are more exposed to heat and light and also they matured late thus getting reduced grain mold incidence compared to the dwarf early maturing lines. As expected the PGMR showed significant negative association with grain yield. A significant negative correlation between PGMR and grain yield was reported earlier (Reddy *et al.,* 2006 and Reddy *et al.,* 2000).

The overall performance of promising hybrids and parents over three years is presented in Table 4. The hybrid ICSA 101 × PVK 801 (grain yield: 6.2 t ha$^{-1}$ and PGMR: 3.6) showed significantly higher grain yield and significantly lower PGMR compared to the control CSH 16 (grain yield: 5.3 t ha$^{-1}$ and PGMR: 5.1). Two hybrids ICSA 52 × ICSV 96105 (grain yield: 5.3 t ha$^{-1}$ and PGMR: 3.1) and ICSA 400 × GD 65028 (grain yield: 5.2 t ha$^{-1}$ and PGMR: 2.3) showed grain yield on par with CSH 18 with significantly higher grain mold resistance. The hybrids ICSA 101 × PVK 801 and ICSA 52 × ICSV 96105 have white pericarp and thus can be preferred for commercial cultivation for food in India after testing for regional adaptation. Two B-lines ICSB 400 (grain yield: 3.4 t ha$^{-1}$ and PGMR: 3.9) and ICSB 52 (grain yield: 3.4 t ha$^{-1}$ and PGMR: 6.3) and four R-lines PVK 801 (grain yield: 4.6 t ha$^{-1}$ and PGMR: 3.7), ICSR 89058 (grain yield: 4.6 t ha$^{-1}$ and PGMR: 4.6), ICSR 91011 (grain yield: 4.7 t ha$^{-1}$ and PGMR: 4.7) and IS 41675 (grain yield: 4.7 t ha$^{-1}$ and PGMR: 4.1) used in the study showed significantly higher grain yield and significantly lower PGMR over three years compared to 296 B (grain yield: 2.9 t ha$^{-1}$ and PGMR: 8.4) indicating their utility in developing high yielding,

**Table 2 : Mean performance of sorghum hybrids and hybrid parents evaluated in 2006, 2007 and 2008 rainy seasons, at ICRISAT-Patancheru**

| Entry number | Hybrid/Parent | Days to 50% flowering | Plant height (m) | Plant aspect score[1] | Grain yield (t ha$^{-1}$) | Panicle grain mold rating[2] |
|---|---|---|---|---|---|---|
| 1 | ICSA 101 x PVK 801 | 67 | 2.3 | 1.3 | 6.2 | 3.6 |
| 2 | ICSA 101 x ICSR 89058 | 66 | 2.3 | 1.3 | 4.8 | 3.2 |
| 3 | ICSA 101 x IS 41675 | 67 | 2.9 | 2.0 | 5.2 | 2.8 |
| 4 | ICSA 101 x GD 65028 | 66 | 2.2 | 1.9 | 4.9 | 2.7 |
| 5 | ICSA 101 x GD 65055 | 67 | 2.3 | 1.6 | 4.1 | 1.7 |
| 6 | ICSA 382 x GD 65055 | 67 | 2.5 | 1.9 | 4.5 | 1.8 |
| 7 | ICSA 384 x ICSR 91011 | 64 | 2.1 | 1.7 | 4.3 | 3.4 |
| 8 | ICSA 52 x ICSV 96105 | 66 | 2.8 | 1.9 | 5.3 | 3.1 |
| 9 | ICSA 400 x GD 65028 | 69 | 2.2 | 1.6 | 5.2 | 2.3 |
| B-lines | | | | | | |
| 10 | ICSB 52 | 65 | 1.7 | 2.1 | 3.3 | 6.3 |
| 11 | ICSB 101 | 67 | 1.8 | 2.1 | 3.1 | 6.3 |
| 12 | ICSB 382 | 69 | 2.0 | 2.4 | 2.8 | 4.6 |
| 13 | ICSB 384 | 67 | 1.9 | 2.3 | 2.8 | 4.0 |
| 14 | ICSB 400 | 70 | 1.5 | 1.9 | 3.4 | 3.9 |
| R-lines | | | | | | |
| 15 | PVK 801 | 68 | 2.0 | 1.7 | 4.6 | 3.7 |
| 16 | ICSR 89058 | 67 | 1.8 | 1.6 | 4.6 | 4.6 |
| 17 | ICSR 91011 | 70 | 2.0 | 1.9 | 4.7 | 4.7 |
| 18 | IS 41675 | 66 | 2.8 | 2.3 | 4.7 | 4.1 |
| 19 | GD 65028 | 76 | 2.1 | 2.1 | 3.1 | 3.3 |
| 20 | GD 65055 | 73 | 2.1 | 1.8 | 3.1 | 5.1 |
| 21 | ICSV 96105 | 65 | 2.4 | 2.9 | 3.4 | 3.0 |
| Controls | | | | | | |
| 22 | Bulk Y | 52 | 1.4 | 3.0 | 2.4 | 8.7 |
| 23 | IS 14384 | 73 | 3.0 | 2.6 | 4.3 | 1.2 |
| 24 | CSH 16 | 65 | 2.2 | 1.3 | 5.3 | 5.1 |
| 25 | 296 B | 69 | 1.4 | 1.6 | 2.9 | 8.4 |
| Mean | | 67 | 2.14 | 1.95 | 4.11 | 4.06 |
| SE+ | | 0.88 | 0.11 | 0.26 | 0.34 | 0.24 |
| CV (%) | | 2.27 | 8.93 | 22.83 | 14.29 | 10.06 |

[1]Agronomic desirability score taken on a scale where 1= more desirable and 5= least desirable.
[2]Panicle grain mold rating score taken on a 1-9 scale where 1= no mold infection and 9 = 76-100% molded grains on a panicle

**Table 3 : Correlation coefficients of sorghum hybrids in 2006, 2007 and 2008 rainy seasons, at ICRISAT, Patancheru**

| Trait | Days to 50% flowering | Plant height (m) | Plant aspect score | Grain yield |
|---|---|---|---|---|
| Plant height (m) | 0.233 | | | |
| Plant aspect score | -0.266 | 0.025 | | |
| Grain yield | 0.055 | 0.599** | -0.585** | |
| Panicle grain mold rating | -0.419* | -0.742** | 0.147 | -0.534** |

** significant at 1% and * significant at 5% level

**Table 4 : Overall performance of selected sorghum hybrids and parents for grain yield and grain mold resistance in 2006, 2007 and 2008 rainy seasons, at ICRISAT-Patancheru**

| Hybrid/Parent | Grain yield (t ha$^{-1}$) | | | | | | | | | Panicle grain mold rating[1] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2006 rainy | Rank | 2007 rainy | Rank | 2008 rainy | Rank | Overall mean | Rank | % superiority for grain yield over CSH 16 for hybrids and 296B for parents | 2006 rainy | 2007 rainy | 2008 rainy | Overall mean | % superiority for PGMR% over CSH 16 for hybrids and 296B for parents |
| Hybrids | | | | | | | | | | | | | | |
| ICSA 101 x PVK 801 | 7.9 | 2 | 4.0 | 2 | 6.6 | 3 | 6.2 | 1 | 10 | 4.0 | 3.0 | 3.7 | 3.6 | -27 |
| ICSA 52 x ICSV 96105 | 5.5 | 11 | 4.5 | 1 | 5.8 | 10 | 5.3 | 3 | -6 | 4.3 | 2.0 | 3.0 | 3.1 | -37 |
| ICSA 400 x GD 65028 | 8.3 | 1 | 1.4 | 18 | 6.0 | 6 | 5.2 | 4 | -7 | 2.0 | 1.0 | 4.0 | 2.3 | -52 |
| B-lines | | | | | | | | | | | | | | |
| ICSB 52 | 4.2 | 19 | 2.1 | 12 | 3.7 | 21 | 3.3 | 18 | 2 | 6.3 | 5.7 | 7.0 | 6.3 | -23 |
| ICSB 400 | 4.7 | 16 | 2.4 | 7 | 3.0 | 25 | 3.4 | 17 | 5 | 3.7 | 2.7 | 5.3 | 3.9 | -53 |
| R-lines | | | | | | | | | | | | | | |
| PVK 801 | 6.6 | 7 | 1.7 | 14 | 6.0 | 7 | 4.6 | 10 | 45 | 4.0 | 1.0 | 6.0 | 3.7 | -55 |
| ICSR 89058 | 6.9 | 5 | 2.0 | 13 | 4.9 | 18 | 4.6 | 11 | 43 | 4.7 | 3.3 | 5.7 | 4.6 | -44 |
| ICSR 91011 | 5.2 | 14 | 1.2 | 19 | 7.6 | 1 | 4.7 | 9 | 45 | 4.0 | 4.0 | 6.0 | 4.7 | -43 |
| IS 41675 | 5.9 | 9 | 1.7 | 15 | 6.4 | 5 | 4.7 | 8 | 46 | 4.0 | 3.0 | 5.3 | 4.1 | -50 |
| Controls | | | | | | | | | | | | | | |
| Bulk Y | 3.3 | 23 | 0.4 | 25 | 3.5 | 23 | 2.4 | 25 | | 9.0 | 8.7 | 8.3 | 8.7 | 70 |
| IS 14384 | 4.8 | 15 | 2.2 | 9 | 5.9 | 8 | 4.3 | 13 | | 1.0 | 1.3 | 1.3 | 1.2 | -76 |
| CSH 16 | 7.0 | 4 | 2.4 | 4 | 6.4 | 4 | 5.3 | 2 | | 5.3 | 4.0 | 6.0 | 5.1 | 0 |
| 296 B | 3.6 | 21 | 0.9 | 22 | 4.1 | 20 | 2.9 | 22 | | 7.3 | 9.0 | 9.0 | 8.4 | 65 |
| Mean | 5.22 | | 1.89 | | 5.25 | | 4.11 | | | 4.07 | 3.40 | 4.72 | 4.06 | |
| SE+ | 0.47 | | 0.13 | | 0.31 | | 0.34 | | | 0.16 | 0.24 | 0.30 | 0.24 | |
| CV (%) | 15.74 | | 12.08 | | 10.19 | | 14.29 | | | 7.00 | 12.09 | 10.85 | 10.06 | |
| CD (5%) | 1.35 | | 0.96 | | 0.91 | | 0.38 | | | 0.47 | 0.66 | 0.84 | 0.67 | |

[1]Panicle grain mold rating score taken on a 1-9 scale where 1= no mold infection and 9 = 76-100% molded grains on a panicle

grain mold resistant hybrids. Close observation of the PGMR scores of hybrids vis-a-vis the parents indicated that to develop grain mold resistant hybrids, we need to use both parents resistant to grain mold or at least one parent with grain mold resistance. This is in conformity with earlier studies (Thakur *et al.,* 2006a). Seeds of these lines in small quantities can be obtained from ICRISAT-Patancheru.

## Conclusion

This study demonstrated that it is feasible to develop white pericarp grain mold resistant high yielding sorghum hybrids with stable performance by using improved grain mold resistant white pericarp hybrid parents, at least one of the parents being resistant to grain mold. The hybrids identified from the study can be commercialized after testing them for regional adaptation. Similarly, the promising hybrid parents identified in the study can be used in the development of improved hybrids with grain mold resistance in high yielding backgrounds. Small quantities of seeds of above parents can be obtained from ICRISAT on request.

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