BREEDING FOR GRAIN MOULD RESISTANCE IN SORGHUM
{Sorghum bicolor (L.) Moench} - A REVIEW

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ABSTRACT

Sorghum is one of the most important food crops for a large section of people in Asia and Africa and also a source of fodder for cattle and industrial raw material. In India, the area under sorghum cultivation is fast declining due to low demand for food, limited yield increase and poor grain quality due to grain mould attack in kharif season. Grain moulds cause both qualitative and quantitative losses. Quantitatively, losses in grain yield due to this disease have been estimated to be 30 per cent. Qualitatively, grain moulds result in mouldy and discolored pericarp, soft and chalky endosperm, reduced seed germination, decreased grain filling leading to reduced grain density and mycotoxin development leading to low price of produce. Hence, efforts are to be taken up by the breeders to develop grain mould resistant varieties and hybrids inorder to cater the needs of the farmers. Breeding for grain mould resistance in sorghum is difficult as it is a complex fungal disease. Information on the inheritance of grain mould reaction is required to facilitate breeding of resistant cultivars. Tan plant type, hardness of grain and water absorption rate together furnishes useful criteria for breeding resistant types. The inheritance of hardness of seed and rate of water absorption are predominantly additive and selection for these characters could be effective. Higher levels of phenol and darker glumes also contributes to grain mould resistance. Grain mould resistance is generally governed by additive gene action.

Sorghum {Sorghum bicolor (L.) Moench} is one among the staple food grains for human in several Asian and African countries. It is infected by more than hundred diseases (Singh et al., 1993). Grain mould is the most widespread and devastating diseases of Sorghum in India and losses in grain yield due to this disease have been estimated to be 30%. Although about 40 fungal species have been reported to be associated with this disease complex, only three fungi namely Fusarium moniliforme sheld, F. pallidoroseum, and Curvularia lunata (wakker) Boedijn are predominant (Singh et al., 1995).

The problem of grain mould in sorghum is of great concern in seed production since it reduces the viability of seeds. Infected grains suffer breakdown of grain structure, increased chalkiness of endosperm and contamination with mycotoxins which lead to reduction in grain quality and ultimately lower its nutritional values. Mathur et al. (1975) reported that C. lunata and F. moniliforme interfere with carbohydrate translocation in developing kernels causing reduction in size and weight of seed. Grain mould also reduces the yield and market values of the grain. Grain mould affected grain contains mycotoxins which are hazardous to animals and human beings. Research workers identified grain moulds as one of the most serious problems in sorghum. In most cases, avoidance of chemical control is impracticable and therefore major research efforts have been focused on development of resistant cultivars for which knowledge of combining ability is necessary in selection of appropriate parents for hybridization.

Casual organisms

This disease is caused by fungus belonging to several genera, notably Fusarium, Curvularia, Phoma, Alternaria, Cladosporium, Olipitrichum and Trichotheum. Most of these fungi are unspecialised or facultative parasites and the predominant species vary with location, year and season. Infection by mould causing fungi...
may begin at anthesis in low frequency and continues beyond maturity till harvest.

In 1977, Castor reported that *Fusarium* and *Curvularia* isolates were the principal fungi, causing grain discoloration and reduction in viability. According to him, *Curvularia* did not reduce germination as much as *Fusarium* but *Curvularia lunata* can infect the grains at any stage of their development and make the grains black. The pathogen appears to interfere with translocation of carbohydrates resulting in smaller and lighter grains. It caused seed rot also. *Gonatobotrys ramosa* (Riess ex Fresenius) was isolated from affected grain and it produced a white powdery growth on inoculated seed, reducing the weight and germination (Narendrappa et al., 1985). An interaction between the complex grain mould pathogens of sorghum was noticed by Singh and Agarwal (1986). The results revealed *Fusarium moniliforme* was antagonistic to *Curvularia lunata* and *Phoma sorghina* while *Curvularia lunata* was antagonistic to *Phoma sorghina* in vitro and in vivo. Singh and Agarwal (1987) estimated that the infection of *Curvularia lunata* was high (27.7 per cent) followed by *Gibrella fujikoroi* (9.4 per cent) and *Phoma sorghina* (8.4 per cent).

**Favourable conditions**

Symptoms which develop as a result of infection by fungi depend upon the species of fungus, the time and severity of infection. Grains severely infected appear to be completely covered with pink and/or black mould and they disintegrate into powder during threshing. *Curvularia* turns the seed into a sooty black while *Fusarium* turns the seed into pink. Lightly infected grain may appear almost completely normal except for slight pink or black discoloration on a small part of the surface and internally the grain appears normal. Tarr (1974) reported that moulds develop in the sorghum inflorescence at any stage from the young inflorescence to the mature head, provided that climatic conditions are suitably moist. Generally it seems that wet weather following flowering is conducive for grain mould development and longer the wet period, the greater the mould development (Koteswara Rao and Poornachandrudu, 1971, Grey et al., 1971; Rao and Williams, 1977). Williams and Rao, (1981) reported that even grains which show no symptoms externally was infected by grain mould fungi namely *Fusarium* spp from the sorghum grains harvested during the rainy season.

Dry weather during flowering and grain development followed by wet weather during maturity will not promote such serious moulds. The severity of grain mould development increases when a prolonged wet period exists accompanied with delay in harvesting (Garud et al., 1994).

**Mechanisms of resistance to grain moulds**

Glueck *et al.* (1977) suggested that rate of water absorption and conductivity of seed leachates were possible mechanisms for resistance to grain moulds. Glueck and Rooney (1978) observed that lines susceptible to grain moulds absorb moisture more rapidly than the resistant lines with similar grain characteristics. Camargo (1982) noticed that seed of the different genotypes does not absorb moisture at the same rate. Singh and Agarwal (1989) reported that the 100 seed weight was reduced by 67% for *C. lunata*, 43% for *P. sorghina* 40% for *F. moniliforme*. It was noticed that *F. moniliforme* infection resulted in maximum loss of electrolytes in seed leachates and inhibited germination.

Ramamurthy *et al.* (1992) revealed the extent of mould damage as a measure of ergosterol concentration in grains. He adopted Stenvert method for determination of grain hardness and noticed negative correlation with ergosterol concentration. Capigenidin, flavon - 4-ols, tannin, kernal hardness and pericarp colour all of these properties contributed to grain mould resistance differently in white, red and brown pericarp sorghum accessions (Menkir *et al.*, 1996).
Somani and Indira (1998) reported about electrical conductivity of seed leachates. Sorghum seeds infected with Curvularia lunata, Fusarium moniliforme var. subglutinans and Phoma sorghina were more prone to breaking than healthy seeds. Somani and Indira (1999) reported that Curvularia lunata was observed to be more aggressive than Fusarium moniliforme in reducing grains test weight. According to Somani and Indira (2000), genotypes requiring more than 5 kg strength for breaking the kernels exhibited good resistance to grain moulds. They observed that water imbibition at 30°C was greater in susceptible sorghum genotypes during the first 2 hours and it increased many fold whereas water imbibition was comparatively less during the first 2 hours in resistant genotypes and then increased steadily with time.

Ramamurthi Jambunathan et al. (1986) have estimated the concentration of flavan-4-ols in mould-resistant and mould-susceptible sorghum cultivars on grains and leaves. They established a positive association between flavan-4-ols and grain mould resistance. In methanol and acidified methanol extracts of grains of mould-resistant cultivars, the levels of flavan-4-ols were two-to three folds higher than on mould susceptible cultivars. The cultivars that were resistant to moulding had a higher concentration of flavan-4-ols. Cultivars with high tannin content are being used as a source of resistance (Esele et al., 1993). According to Bueso et al. (2000), grain mould resistance corresponded to induction of Anti Fungal Proteins (AFP’s) synthesis in response to fungal stress and/or adverse field conditions. They reported that somatin and chitinase appeared to be an active part of the defense mechanism in the caryopsis against grain mould.

Sources of grain mould resistance

Photoperiod-sensitive guinea germplasm is a source for grain mould resistance. Prasada Rao et al. (1995) reported that the entries IS 7173 (Tanzania), IS 23773 (Malawi), IS 23783 (Malawi) and IS 34219 (Eastern Ghats, India) did not develop grain mould. Six entries viz., IS 7326, IS 4963, IS 5726, IS 4011, IS 5292 and IS 27761 developed low to moderate grain mould infection. The white grain sorghum entries viz., IS 18758-C-618, IS 18758-C-704, IS 18758-C-710, and IS 18758-C-496 showed extremely high levels of resistance. Most of these selections mature between 29 and 45 days after anthesis. All the selections developed some infection by Phoma spp at late stages of maturity (Singh et al., 1995).

Ghorade and Shekar (1996) has stated that the parents GMRP 4, B 75219, IS 24995, B 58581 and SPY 775 were good general combiners for increased 100 seed weight, grain hardness, grain density and germination per cent and decreased water absorption rate, conductivity and fungal load of grain mould-causing fungi. They can be used as potential parents to incorporate grain mould resistance in a desired genotype.

Audilakshmi et al. (1999) reported that improved lines generally had poorer grain mould resistance than the landraces like IS 14375, IS 14387, IS 18144 and IS 18528 (colored -seeded lines) and IS 21443, IS 24495 and IS 25017 (white -seeded lines) showed greater grain mould resistance. SP 33316, SP 333459 and GM 15018 are agronomically elite lines that can be used as sources of grain mould resistance for further improvement of white seeded sorghum for South Africa and other regions.

Screening for grain mould resistance

Visual appraisal of the extent of kernel deterioration has been commonly used to screen germplasm for resistance to grain mould in sorghum breeding nurseries (Bandyopadhyay et al., 1988; Williams and Rao, 1981). However, visual rating may not adequately reflect the degree of damage caused by the fungal invasion of the kernels (Sertz et al., 1983). Measuring the incidence of the different fungi in sorghum
seeds may readily differentiate genotypes with similar kernel appearance. It is also useful to determine fungal species that cause grain mould in a particular environment.

The screening nursery should be sown when rains and high humidity are expected during the grain-filling and maturation stage. Availability of sprinkler irrigation is valuable, as the screening nursery can be watered periodically for about 1 hour on rainfree days. Initially, at 50% flowering stage, the heads should be sprayed with a mixture of Curvularia and Fusarium spores. After spraying, the heads should be bagged using regular paper pollinating bags. Subsequently, adequate levels of grain moulding for good screening purposes can be realized without inoculation or head bagging as long as sprinkler or mist-type irrigation is available. However, for special studies on grain moulding, inoculation and head bagging should be done. Expression of head mould is maturity-related, so it is important to note the days to 50% flowering of all entries in the screening nursery. If possible, lines of the same maturity should be grouped together in the screening field. Scoring is undertaken about 55 days after flowering (House, 1985).

Grain mould scoring
Rating were based on a 1 to 5 scale.
Where,

1 = no visible mould symptom
2 = 1 to 10% of the kernels in the panicle moulded
3 = 10.1 to 25% of the kernels in the panicle moulded
4 = 25.1 to 50% of the kernels in the panicle moulded
5 = more than 50% of the kernels in the panicle moulded.

Breeding for grain mould resistance
Breeding for grain mould resistance in sorghum is difficult as it is a complex fungal disease. Knowledge of the association of grain mould resistance components is of significant importance in resistance breeding. Information on the inheritance of grain mould reaction is required to facilitate breeding of resistant cultivars. According to Rana et al. (1978), tan plant type, hardness of grain and water absorption rate together furnish useful criteria for breeding resistant types. The inheritance of hardness of seed and rate of water absorption are predominantly additive and selection for these characters could be effective. He has reported that hard x hard crosses within tan types are likely to yield quick results. Similar results have been reported by Utilkar et al. (1978). Hard grained sorghums have shown to be more resistant to grain mould than soft grained. Generally, the levels of flavan-4-ols were two to three folds higher in resistant cultivars than in the susceptible cultivars (Ramamurthi Jambunathan et al., 1986) Hence while breeding for grain mould resistance the scientist should take care that the level of flavan-4-ols is higher in content which imparts resistance to grain mould disease in a particular cultivar. Kumari and Chandrashekhar (1992) reported that hard grains showed fewer incidences of grain moulds than soft grains. Audilakshmi et al. (1999), obtained high significant correlations between measures of grain mould and seed hardness, seed phenol content and glume colour while weaker and less consistent correlations between measures of grain mould and seed colour. Mansuetus (1990) reported on the role of glumes to mould resistance. Less colonization and high levels of free phenolic compounds in glume tissues were characterized by resistance genotypes than in susceptible ones.

A breeding programme to utilize sources resistant to grain mould is outlined in Fig. 1. High yielding, good grain parents from various sources were selected and appropriate crosses were made in single, double and three way combinations. Selection in the F₂ was made under natural conditions, but from the F₃/F₄ generations, families were inoculated with
Curvularia and Fusarium spp. to identify those that were susceptible. It is important to protect entries in the mould screening nursery for headbug. Damage by these insects will interfere with mould rating (House, 1985).

**Genetic basis of grain mould resistance**

A thorough knowledge on the genetics of grain mould disease resistance will help the plant breeders to develop resistant lines. Rana et al. (1977) has reported that tan pigment, a monogenic recessive character is identified to impart resistance to grain deterioration in hard seeded grains. According to Rana et al. (1978), the water absorption capacity and seed hardness are governed by additive gene action with high heritability. General resistance to all the fungi causing grain deterioration was found to be a polygenic threshold character having low heritability (Rana et al., 1978). Dabholkar and Baghel (1980) reported that grain mould resistance is governed by additive gene action. Narayana (1981) reported that both additive and non-additive gene actions control Fusarium resistance while non-additive gene action is predominant for Curvularia resistance. Patel et al. (1983) in his study reported that grain mould resistance is predominantly governed by additive gene action. In a study undertaken by Rodriguez-Herrera et al. (2000) about the

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<table>
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<tr>
<th>Generation</th>
<th>Description</th>
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<tbody>
<tr>
<td>$F_1$</td>
<td>(Three way and multiple crosses)</td>
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<tr>
<td>$F_2$</td>
<td>Selection for clean grains and good plants in natural conditions.</td>
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<tr>
<td>$F_3$</td>
<td>Severe mould screening by artificial inoculation.</td>
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<tr>
<td>$F_4$</td>
<td>Severe mould screening. Adaptability, disease and pest evaluation to be done at least in three locations.</td>
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<tr>
<td>$F_5$</td>
<td>$S_3$ Evaluation for grain mould resistance.</td>
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<tr>
<td>$F_6$</td>
<td>$S_4$ Preliminary Yield Trials</td>
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<tr>
<td>$F_7$</td>
<td>$S_5$ Intense grain mould screening and food quality evaluation</td>
</tr>
<tr>
<td>$F_8$</td>
<td>$S_6$ Advanced yield trials</td>
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</tbody>
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**Fig. 1. Scheme for breeding varieties with grain mould resistance**
Inheritance of grain mould by generation mean analysis it was identified that at least 4 to 10 genes were estimated to contribute to grain mould resistance. The results of this study indicated that selection in specific environments is useful for enhancing resistance to mould in these environments, but it may not be as effective in providing grain mould resistance across a wide range of environments. Audilakshi et al. (2000) reported that sorghum grain mould was generally controlled by 2 or 3 major genes.

CONCLUSION

In order to tackle the problem of grain mould incidence during kharif season where the rainfall usually coincides with the grain maturity stage, harvesting of the sorghum earheads at physiological maturity (the moisture content in the grains will be around 30% at this stage) is recommended. The harvested earheads can be artificially dried using machines like ventilating seed drier so as to maintain the quality of kharif sorghum grains effectively and economically. Besides this, the quality of less moulded kharif sorghum grains can be improved by decortication or dehulling. In this process, the outer pericarp is removed which helps in fetching up a better market value than the grain mould affected grains.

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