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Review on sorghum grain mold and its sustainable management methods through host resistance

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ABSTRACT

Fungal pathogens targeting the grains such as grain mold, loose smut, head may pose serious threats to global food security. Grain mold is a complex fungal disease of sorghum grain as its causal agents involving many fungal species. It is a result of infection by multiple fungal pathogens which reduces yield and grain quality. It is devastating particularly in the regions with high humidity and temperature during grain development. These pathogens can destroy sorghum panicles and reduce yields if conditions favorable for disease persist. The pathogen can cause grain loss of 30-100% in susceptible varieties and yield reductions are due to caryopsis abortion, reduced seed filling and lower grain density while seed quality and market values are affected due to surface discoloration, embryo and endosperm deterioration and contamination by toxigenic fungi and their mycotoxins. To mitigate the grain loss caused by these pathogens, it is necessary to be able to detect and identify them early in the infection process. Furthermore, the rapid identification of fungal disease by timely recognition of their symptoms is an effective management practice and may help control and prevent their spread and progress. Providentially, most diseases of grain sorghum can be managed by planting resistant varieties and adopting certain cultural practices. This research review primarily focuses on biology, distribution, economic significance, and sustainable control strategies through host plant resistance.

Keywords: Fungi, grainmold, grainquality, grain yield, host resistance, sorghum.

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Introduction

Sorghum (Sorghum bicolor L. Moench), a tropical plant is the fourth most extensively produced cereal in the world. For millions of subsistence farmers in Africa, it is one of the principal food crops.In the arid and semi-arid tropics, where drought has a significant impact on crop productivity, sorghum is the predominant crop (Begna.T, 2021). Sorghum is presently farmed annually on more than 42 million hectares across six continents as a result of its high genetic variety and resistance to challenging environmental factors including drought (FAOSTAT, 2020). Following Nigeria and Sudan, Ethiopia is regarded as Africa's third-largest producer of sorghum (FAOSTAT, 2018). A total of 4,517,350.21 tons of sorghum are produced annually in Ethiopia on a land area of about 1,679,277.06 hectares (FAO, 2021). Sorghum is grown by about 4.5 million smallholders in the country's east and northwest (FAO, 2021; Mohammed *et al*., 2022). All of the sorghum produced in the nation is used domestically, and it makes a sizable contribution to food security according to the Central Statistical Agency, states report CSA (2020). In terms of the total number of producers participating, area covered, and grain production, sorghum ranks third among Ethiopia's food cereal crops behind maize and teff. Injera, local bread, boiled gruel or porridge, malted beverages, popped grain, and handcrafted local beverages are among the common things created with it (Legesse, 2018). It is Ethiopia's second-most significant crop after teff for producing high-quality injera.

Although sorghum grain is a staple crop for smallholder farmers in Sub-Saharan Africa, especially Ethiopia, biotic stresses are the main obstacles to its production, marketing, and consumption. Grain mold is one of the most significant illnesses of sorghum in many nations in Asia, Africa, North America, and South

America among major biotic restrictions (Frederiksen et al. 1982; Louvel and Arnoud 1984). The most significant grain mold-causing fungi in the field are Fusarium and Curvularia spp., despite the fact that the disease is brought on by complicated pathogens. According to some academics, saprophytic pathogenic fungi that infiltrate dead grain tissue and are completely driven by the environment can also be the cause of grain mold (Forbes *et al*., 1992; Audilakshmi*et al*., 2011).In humid, tropical and subtropical regions, the disease is particularly significant on sorghum cultivars with compacted heads that develop during the rainy season. Both young and mature grains in the field are susceptible to infection. A few pieces of literature have classified the stages of grain degradation into two phases: grain weathering, which happens after physiological maturity, and grain mold, which occurs before physiological maturity (Bandyopadhyay *et al*., 2000; Das et al., 2020). However, rather than pathogenic mold, grain weathering had been the main focus of the majority of investigations on resistance breeding. However, due to the numerous mechanisms determining resistance, complex genetics, and significant environmental influence, success in breeding for resistance to grain weathering has been gradual (Hall et al. 2000). The development of resistance against mold components, particularly the pathogenic components, has recently received more attention than GMDC (Nutsugah and Wilson 2007; Das *et al*. 2010; Prom *et al*. 2011; Sharma *et al*. 2011). Following the identification of resistance genes against pathogenic components, the resistance can be pyramided into a single sorghum cultivar employing the proper breeding method. However, not much is known about efforts that are specifically related to pathogenic grain mold (Nida*et al*., 2019; Mohammed *et al*., 2020). There are a lot of reviews of the literature on grain mold. The most significant fungi that cause grain mold in the sorghum field are Fusarium and Curvularia spp. This research review primarily focuses on biology, distribution, economic significance, and sustainable control strategies through host plant resistance.

Biology and life Cycle of major sorghum grain mold causing fungi (Fusarium spp.)

In 1809, Link was introduced the genus Fusarium (Link 1809). As recently reviewed by Das *et al*., 2020, this genus contains some of the most significant and widely distributed plant diseases on the planet. The current taxonomy of Fusarium species is divided into two categories: morphology and sexual cross-fertility (mating type). There are 14 known species of F. moniliforme (Leslie and Marasas 2002, Das *et al*., 2013, 2020). Of these, it has been found that F. napiforme is linked to sorghum field debris while F. andiyazi, F. nygamai, F. proliferatum, F. thapsinum, and F. verticillioides are related with sorghum grain. Other Fusaria, such as F. anthophilum, F. chlamydosporum, F. culmorum, F. equiseti, F. graminearum, F. oxysporum, F. pallidoroseum, F. sacchari, F. semitectum, F. solani, and F. sporotrichioides, have also been regularly isolated from sorghum grain in various nations but are not F. moniliforme. Numerous Fusarium species are connected to sorghum, from seedling to harvest and thereafter grain storage. A number of sorghum diseases, including as seedling blight, root and stalk rot, twisted top, grain mold, and head blight, are caused by the bacterium F. moniliforme.Fusarium isolates from the Liseola part of the genus that was found in grain and sorghum stalks have historically been referred to as F. moniliforme (Wollen- weber and Reinking 1935). It is noteworthy that the aforementioned species were separated from mature (weathered) sorghum grain that was harvested from fields, stored by farmers, or procured from markets. Thus, it's possible that not all of them are true pathogens that can contaminate sorghum florets and result in GM. Nonetheless, a few of these saprophytes might be crucial for the field weathering of sorghum grain. Only a few pathogenic Fusarium species have been shown to be able to induce grain mold in sorghum to date (F. andiyazi, F. proliferatum, and F. thapsinum, for example) (Summerell*et al*. 2003).

According to Hassan 2020, Up to five propagules, or "spores," can be produced by Fusarium species. These propagules include four different types of "spores": asexual macroconidia and microconidia, sexual ascospores, and long-lasting protective chlamydospores that can withstand harsh environmental conditions.

The Fusarium species that cause sorghum grain mold can be found in any part of an infected plant, from the root to the blossom, and can travel by the air, the soil, or plant debris (; Leslie et al. 1990; Klittich et al. 1997). In the field, plant residues and soil detritus that contains fungus hyphae and conidia appear to be the main sources of inocula. It's possible that certain fungal structures like chlamydosporesare not necessary for F. moniliforme to survive the winter. It has been shown by Manzo and Claflin (1984) that this fungus's conidia and hyphae in sorghum stalks could withstand two Kansas winters without losing any of their viability or pathogenicity. Further research by Liddell and Burgess (1985) revealed that F. moniliformemicroconidia can endure for up to 900 days in a lab setting at various humidity and temperature settings. According to Nelson et al. (1983), crop residue that is buried 30 cm below the surface usually survives longer. According to Bandyopadhyay et al. (1991), the natural inocula that are present over sorghum fields during the rainy season may be sufficient to cause grain mold disease without the need for an artificial inoculation.

Economic importance of grain mold

One of the main obstacles to the growth of sorghum is grain mold, particularly in countries that are important producers of the grain, such as Asia, Africa, North America, and South America (Louvel and Arnoud 1984; Das, *et al*., 2020). Millions of dollars are thought to be lost worldwide each year as a result of grain mold, and the damage is greatest in countries where sorghum is grown in humid, wet settings. Depending on the cultivar and the weather between flowering and harvest, production loss might range from 30 to 100% (Singh and Bandyopadhyay 2000). It is a devastating disease that affects grain sorghum grown during the rainy season all over the world, resulting in both quantitative and qualitative losses. The disease significantly affects grain output, quality, market value, seed quality, and ultimately, the final goods made from grains (Das, 2019). Under optimum environmental conditions, yield losses of up to 100% may be seen in cases of very susceptible cultivars (Williams RJ and Rao KN. 1981; Das *et al*., 2020). Early infection reduces the development of the caryopsis, stops the growth of the kernel, and reduces the quantity and density of the grain (Little and Magill, 2000). The grain yield finally reflects all of these. According to reports, F. moniliforme and C. lunata, two of the most common grain mold fungi; infection reduces seed size and weight without obvious mold formation by interfering with carbohydrate transport to growing kernels. The amount of grain weight lost as a result of mold infection might range from 40 to 70% (Glueck and Rooney. 1976). Marketability & grain quality Aside from production increase, quality is another crucial factor that is negatively impacted by grain mold (Audilakshmi*et al.,* 2007). The illness lowers the grain's quality and market attractiveness. Sorghum grains are mostly colonized by saprophytic fungi during the process of post-maturity weathering, which results in discolouration and a decrease in market price (Little CR. 2000). Molded grains with obvious mold signs sell for around 20% less on the open market than unmolded grains. Additionally, enzymes that can break down starch in endosperm and germ tissues are secreted by grain mold fungi. The bacterium F. moniliforme may promote the production of the enzymes necessary for the start of germination and the subsequent destruction of endosperm tissue. These enzymes lower the grain's feed or food value regardless of the source. Molded grains also affect other crucial sorghum grain properties, including storage quality, food and feed processing quality, cooking quality, and nutritional value of food and feed (Das *et al*., 2013; Mohammed *et al*., 2020). Poor stands in fields are frequently the result of fungus-infected seeds showing reduced germination and emergence. The growth of seedlings emerging from deformed seed may be stunted or terminated after emergence (Bhatnagar, 1971). According to Little and Magill. 2003, infected seeds show poor germination, losses in seed mass,grain density, , and seed viability have been linked to specific grain mold pathogens. With rising temperature and relative humidity, which encourage mold fungus colonization and sporulation, parameters affecting seed quality decrease (Tonapi*et al*., 2007). Compared to other fungi, fusarium species have a considerably greater negative impact on the germination of sorghum seeds (prom *et al*., 2011; Garud.*et al*., 2000).

Recent reviews of Ethiopia's mycotoxin prevalence in various food crops' economic and health effects were conducted (Mamo*et al*., 2020; Mohammed *et al*., 2022). However, these new mycotoxins did not inspire confidence, probably as a result of the lack of comprehensive published data in the nation. In fact, Chala*et al*.2014 made an effort to describe various mycotoxins in sorghum and finger millet. The current study, however, included a vast geographic area where sorghum is produced. Therefore, the current study's objective is to identify the main fungi and mycotoxins linked to post-harvest sorghum in eastern Ethiopia, namely in the East and West Hararghe zones.

Favorable conditions for disease development

The weather and host conditions are more important for grain mold development than the other two elements of the disease triangle. The pathogen, which is present in the air often and in large quantities in grain mold, is the third factor. When spray watering was used to guarantee adequate relative humidity, it was found that either artificial inoculation of panicles with fungal spores or no inoculation had little effect on the growth of mold in the field (Bandyopadhyay and Mughogho 1988; Das *et al.*, 2013, 2020).Consequently, for this disease, the functions of the pathogen, parasite, and saprophyte are less varied. Nonetheless, there can be differences in the incidence of infections between various fungi and phases of grain development, suggesting that different fungi may have distinct windows for maximum infection during these periods (Thakur *et al.*, 2004). After grain maturation, spores of Fusarium, Curvularia, and Alternaria are more common in the field during the post-flowering to hard dough stages. Grain mold is conceivably among the few crop plant diseases where meteorological conditions, especially relative humidity, have a major and decisive influence.

The most critical climatic elements for grain mold formation are temperature and humidity, especially during the transitional period from blossoming to maturity. The disease is more likely to occur in warm, humid climates. Grain mold growth requires moist weather conditions after flowering, and the longer the wetness period, the higher the incidence of mold development (Rao and Williams 1977; Das *et al.*, 2020). Grain infection by C. lunata, Cladosporium, Fusariumoxysporum, Bipolarisaustraliensis, F. moniliforme, F. Pallidoroseum, and Phomasorghina increases in proportion to an increase in the duration of wetness (Navi*et al.*, 2005).Grain mold resistance varies greatly throughout sorghum genotypes, including improved lines, cultivars, and germplasm, suggesting that the host plays a specific role in grain mold growth. Mold typically develops more readily on short (~150–200 cm) plants with compact panicles and little glum cover on the seed. The rapid drying of the panicle following rain is one of the potential explanations for the reduced number of molds on tall plants with loose panicles. Grain mold and premature seed rot are significantly influenced by glum cover and panicle structure, which can be utilized to accurately assess the disease (Das *et al.*, 2013). Grain mold and numerous other plant or grain characteristics are closely related; they will be covered in the mechanism section.

Management of sorghum grain mold

Manystrategies are available to manage gain mold disease in case of sorghum. However, choosing and implementing any disease management strategy in agriculture is based on the benefit-cost ratio. The last 40 years have seen the development of numerous technologies and tactics, even though the most sustainable and environmentally friendly tactic is host resistance method. Increasing sorghum resistance is the best practical and long-term solution to reduce production losses caused by anthracnose, a devastating disease caused by complex fungal pathogens. Agronomic methods alone will not be sufficient to reduce the anthracnose infection rate and yield losses it causes. Small-scale farmers cannot afford to use fungicides, despite the fact that doing so is an effective way to manage the disease and reduce output losses. Moreover, it is not an environmentally friendly tactic (Acharya*et al.*, 2019; Mohammed et al., 2020; Das et al., 2020). The most effective method of managing complex grain mold disease is to grow disease-resistant sorghum cultivars, which is a key component of an integrated management strategy. Sorghum landraces have a high genetic diversity and wide grain mold-resistance variation that can be studied and employed in its breeding program to improve resistance to the disease (Afolayan*et al.*, 2019; Cuevas and Prom, 2020; Mengistu*et a*l., 2020).

In addition to host plant resistance, there are other management methods such as avoidance or use of chemical, botanical or biological control measures however, they are not always practically feasible or effective. Sorghum farmers hardly take any management practice for disease control on standing crop and they need technology intensive seed materials that will take care of all problems. Therefore, host plant resistance has been the most preferred method of sorghum grain mold management under integrated disease management strategies. And for long time major share of research activities on mold management has been on the aspect of improving host resistance.

Host plant resistance

The most popular approach to managing sorghum grain mold has been host plant resistance.Efforts to produce sorghum cultivars with tolerance to grain mold by conventional breeding methods have yielded partially successful results, where tolerance is effective under moderate disease pressure. A high degree of resistance that can be effective under high rainfall conditions could not be built-in. The main reasons behind this include the facts that the resistance is complex, involves many fungi, governed by many genes, with significant (Das et al. 2013, 2020). The grain mold resistance of sorghum hybrids and cultivars has significantly increased over the past few decades in areas of the world where sorghum is grown. In several countries that produce sorghum, there have been declining trends in grain mold score, a measure of mold resistance, as a result of rigorous and coordinated research. The most crucial component of a sorghum program in generating resistant varieties to grain mold is the identification and implementation of that resistance genes (Das *et al*., 2020). Molecular markers may be helpful in locating mold resistance QTL, which would increase the breeder's selection effectiveness. The recent study, Nida*et al*., 2019, used Ethiopian sorghum landraces germplasm to conduct genome wide association mapping research and found genes associated with sorghum grain mold resistance QTLs that contained tightly linked transcription factors, Y1 and Y3 genes defining a small genomic region that could be used for grain mold resistance selection.

In growing grains and glume tissues of resistant lines, the Y1 and Y3 genes are expressed in response to fungal infection, whereas there was no expression in the susceptible lines.In a similar vein, Jambunathan*et al* 1990 examined the concentration of ergosterol in mold-susceptible and mold-resistant sorghum at various phases of grain development and its relationship to flavan-4-ols. They also found a strong association between ergosterol and flavan-4-ols. In response to pathogen infection in resistant lines with functional Y1 and Y3 genes, the expression of genes in the pathway that produces flavonoids is increased in growing sorghum grains. According to Nida*et al*. (2019), suggested genes in the flavonoid biosynthesis pathway that is controlled by one or both of the putative transcription factor R2R3 MYB genes are crucial for grain mold resistance.

Conclusion

Grain mold is common fungal disease throughout most of the continent and a major issue for sorghum production, particularly in prolonged rainy season agroecosystems. Grain mold causes significant yield loss in Asia and Africa, where white grain sorghum is widely farmed. Genotypes with prolonged grain filling period and photoperiod-sensitive sorghums that bloom and fill grain in dry weather are less sensitive to grain mold. So growing advanced colorful genotypes or cultivar is one the most important component of sustainable grain mold management option. It is critical to be able to detect and identify these pathogens early in the infection phase in order to prevent grain loss caused by them. Furthermore, quick recognition of fungal disease signs is an important management approach that may help control and prevent the development and progression of the disease.

Conventional breeding techniques have produced several somewhat successful sorghum cultivars that are tolerant to grain mold when there is a moderate disease pressure. The grain mold resistance of sorghum hybrids and cultivars has significantly increased over the past few decades in areas of the world where sorghum is grown. Molecular markers are helpful in locating mold resistance QTL, which would increase the breeder's selection effectiveness. Recent sorghum grain mold found genes associated with sorghum grain mold resistance QTLs that contained tightly linked transcription factors, Y1 and Y3 genes defining a small genomic region that could be used for grain mold resistance selection. Fortunately, most grain sorghum infections may be controlled by planting resistant types and using appropriate cultural techniques.

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