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Grain Discolouration: An Emerging Threat to Rice Crop

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Abstract

Rice crop is threatened by more than 50 diseases which may appear at any growth stage of the plants. Grain discolouration is an emerging disease of paddy, reported from different countries of the world and is gradually becoming a serious problem. Out of numerous reasons for grain discolouration, association of microbes is important one. It affects the qualitative and quantitative traits such as germination ability, seed health, seed quality, seed morphology and ultimately it results into yield penalty. It is a complex disease exhibiting various symptoms depending on season, locality, variety and pathogens involved. To mitigate this serious malady, precise identification of pathogen is necessary. An integrated management strategy involving better utilization of genetic resources, use of improved agricultural practices, seed treatment with chemicals or biological agents are need to be under taken to manage this malady.

1. Introduction

Rice (*Oryza sativa* L.) is a widely grown cereal crop with the largest area under cultivation throughout the world. Asian countries dominate the global rice production and China tops the list producing 1,45,500 million tons followed by India (1,03,500 million tons). According to a projection of USDA, the rice area, yield and production will increase globally by 3.8, 7.2 and 11.3 respectively by 2025-26 (base year 2015-16). The highest rice productivity during 2015-16 was achieved by Japan (4.91 t/ha) followed by China (4.79 t/ha). Although India has the largest area under rice cultivation, productivity is quite low (2.4 t/ha). The demand for rice will grow in coming years at least to 2035 to feed the burgeoning population (FAO, 2017).

Being a staple food, 90% of produce is consumed in Asia only. China leads in the production followed by India. It provides food security to more than two-third populations and a means of livelihood to millions of rural households. It is cultivated in the diversified agroecosystem, from plains to an altitude of 2200 m above mean sea level in hilly tracts. Cultivation of Rice is 10000 years old, and it was the basis of social order & occupied a significant place in religions & customs once upon a time. It is staple food for the largest number of humanities in the world and is a single largest source of energy for poor people providing 21% of global human per capita energy and 15% of per capita protein. In developing countries, rice accounts for 715 kcal/ capita/ day, 27 percent of dietary energy supply, 20 per cent of dietary protein and 3 per cent of dietary fibre. The by-products of rice milling, including the bran and rice polish, are used as livestock feed, fuel, packing material, industrial grinding, fertilizers manufacturing, processing of oil, etc. Many Beverages, such as amazake and horchata and noodles can be prepared using rice flour. The straw is used for cattle feed, livestock bedding, roof thatching, mats, garments, packing material, and broom straws. In spite of high production and wide market for rice, the productivity is going down which seriously affects the pocket of farmers. Diseases at various stages of crop are important threat to the crop which affects productivity and deteriorates the quality of produce. Grain discolouration is an emerging disease of rice crop, which not only reduce its marketability but also quality. Precise identification of its cause and formulation of management strategy is the need of the hour which is elaborated in this article.

1.1. Constraints in Rice Production

Despite massive production and consumption throughout the world, there are many constraints in rice production which bring down productivity. The high labour cost, non-availability of suitable high yielding varieties, weak extension activities at the village level, high input cost, lack of conviction in the technology, inadequate power supply, labour scarcity, pest and disease attack and failure of seasonal rainfall are the major hindrance faced by the paddy farmers. Apart from these, it is threatened by different biotic and abiotic factors. Out of which biotic factors such as diseases are very critical which

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causes substantial economic loss.

1.2. Biotic Stresses of Rice

Biotic stresses include insect pest, diseases. Rice yield also affected by several biotic factors, *i.e.* insects such as stem borer, brown plant hopper, army worm and many predominant diseases like blast, sheath blight, brown spot, sheath rot, grain discolouration and false smut (Jabeen *et al*., 2012; Hajano *et al*., 2012; Tariq *et al*., 2012).

1.3. Diseases of Rice

Rice crop is affected by more than 50 diseases which may appear at any growth stage of the plants (Arshad *et al*., 2009). There are several fungal pathogens which have been isolated from rice grains and are responsible for several diseases from the nursery to the field. In nursery stage, blast, bacterial leaf blight and tungro diseases are commonly seen whereas, in the main area, blast, sheath blight, brown spot, sheath rot, grain discolouration and false smut causes huge loss to the crop (Nguefack *et al*., 2007). A very high yield loss was reported by incidence of bakanae disease of rice ranging from 3-9.5 %. On the other hand, rice blast is also a major disease which affects the rice yield in different parts of world with loss ranging from 11.9 to 37.8 % (Gupta *et al.,* 2015; Charles *et al.,* 2015; Duku *et al*., 2016; Mizobuchi *et al.,* 2016). Majority of destructive rice diseases prevalent across the globe are caused by fungus (Ling, 1980).

2. Seed Borne Diseases of Rice

In India, total seed requirement is met up 20% by certified seed and remaining 80% from farmers saved seed (Singh *et al*, 2017). Despite of availability of certified seeds, traditionally, farmers continue to produce their own local rice seed and reuse it without knowing the health status of seeds. Saved rice seeds are stored in very un-hygienic conditions; hence it is highly prone to seed inhabiting mycoflora especially at a moderate temperature and high humidity which are capable of deteriorating seed quality and poor plant stands. Spoilage of stored rice is attributed to storage fungi which were introduced during the post-harvest handling process (Javaid *et al*., 2002). In a report it is elaborated that tribal famers' saved hill rice seeds are more associated with seed borne mycoflora than the improved varieties.

Seeds are serve as a highly effective means for transporting plant pathogens over a long distance. Numerous examples exist in agricultural literatures for the international spread of plant disease as a result of the importation of seeds that were infected or contaminated with pathogens. Most of these seed borne pathogens could have severe economic and ecological consequences if they are introduced and become established in regions where they are not native (Rennie, 1998). Seed borne diseases are very important as it can introduce new pathogens, cause quantitative and qualitative crop losses and permanent contamination of soil (Anselme, 1981).

A number of seed borne diseases were reported from rice crop in different places by different group of workers. A total of 153 seed-borne pathogens were detected from rice, of which 18% are of quarantine importance, 65% are native and 17% are storage pathogens (IRRI, 1987). Ou (1985) observed 56 pathogens on rice seeds, of which 41 were seed-borne. *Bipolaris oryzae* and *Alternaria padwickii* are predominant among 27 fungal species isolated from samples collected in different Indian states. Infection by the same fungi ranged from 17 to 83.3% in Pakistan (Habib *et al.*, 2012; Ashfaq *et al*., 2015).

Brown leaf spot, rice blast, stem rot and bacterial leaf blight are also seed borne disease in rice caused by *Drechslera oryzae, Pyricularia oryzae, Rhizoctonia solani, Sarocladium oryzae, Sclerotium oryzae, Trichoconiella padwickii* and *Xanthomonas campestris* pv. *oryzae* (Khan *et al.,* 1990; Wahid *et al*., 2001; Gill *et al*., 1999). Apart from these, *Burkholderia glumae* (bacterial grain rot), *Xanthomonas oryzae* pv. *oryzae* (bacterial leaf blight), and *Acidovorax avenae* subsp. *avenae* (bacterial brown stripe) are also major seed-borne pathogens of rice. Fungal pathogens are the major cause of reduction in the quality of stored rice when insects and rodents are in control.

The seed borne pathogen may result in loss of germination, discoloration, shriveling, development of diseases, toxin productions from infected seeds. The low productivity is attributed to seed-borne diseases causing up to 50-80 % yield losses depending on the crop susceptibility, disease severity and agro-ecological factors. It also causes seed abortion, seed rot, seed necrosis, seedling damage resulting in disease development at later stages of crop by systemic infection or by local infection (Bateman and Kwasna, 1999; Khanzada *et al.,* 2002). Moreover, infected seeds are often discolored, an indication of poor seed quality (Danquah *et al.,* 1976). Different types of pathogens such as bacteria, fungi, virus and other abiotic factors are responsible for causing several diseases of rice crop and ultimately resulting in grain discoloration of Rice.

3. Grain Discolouration

Grain discoloration is an emerging yield reducing disease which is a potent threat to rice crops (Schaad, 2008). It is otherwise known as "glume discolouration" or "dirty panicle". It was reported as independent disease, causing significant economic yield loss (Mew *et al*., 2004; Arshad *et al*., 2009; Prabhu *et al*., 2012; Ashfaq *et al*., 2013; Chandramani and Awadhiya, 2014). The disease is generally seen from early grain filling to maturity stage (Yadahalli and Konnur, 2018). There are numerous reasons for grain discolouration. Change in cropping practice, introduction of high yielding varieties, favorable weather conditions, increased fertilizer application have great impact on it (Yadahalli and Konnur, 2018). Microbial infection is one of the major causes of the disease (Agarwal *et al.,* 1989). Rice grain discoloration affects the qualitative

Table 1: Micro-organisms Associated with Rice Seed

Sl. No.	Organisms associated with seeds	References
1	*Fusarium moniliforme, Alternaria* sp., *Helminthosporium* sp. and *Curvularia* sp.	Butt *et al*., 2011
2	*Xanthomonas oryzae, Rhizopus stolonifer, Aspergillus* spp. *Fusarium moniliforme, Phoma* sp., *Bipolaris oryzae, Curvularia lunata, Penicillium* sp. *Alternaria tenuissima, Nigrospora oryzae, Chaetomium globosum* and *Tilletia barclyana*	Ora *et al*., 2011
3	*Bipolaris oryzae* (2.5 to 8.53 %), *Alternaria padwickii* (5.3 to 13.35 %), *Fusarium moniliforme* (11.66 to 21.67 %), *Fusarium oxysporum* (1.25 to 4.35 %), *Curvularia lunata* (1.95 to 7.5 %) and *Aspergillus* spp (1.75 to 6.54 %)	Naher *et al*., 2016
4	*Pseudomonas avenae, P. syringae* var. *oryzicola, P. fuscovaginae* and *P. glumae*	Suryadi and Kadir, 2009
5	*Pyricularia grisea, Drchslera oryzae, Sclerotium, Fusarium solani, Alternaria alternata, A. padwickii, A. longissima, Aspergillus niger, Curvularia oryzae, C. lunata, F. moniliforme, F. semitectum, F. oxysporum* and species of *Phoma, Cercospora, Chaetomium, Penicillium, Myrothecium* and *Colletotrichum*	Khan *et al*., 2000; Habib *et al*., 2012
6	*Pyricularia oryzae, Alternaria alternata, A. padwickii, A. longissima, Curvularia oryzae, C. lunata, Drechslera oryzae, A. niger, Fusarium moniliforme, F. semitectum, F. oxysporum, F. solani* and species of *Phoma, Cercospora, Chaetomium, Sclerotium, Penicillium, Myrothecium* and *Colletotrichum*	Wahid *et al*., 2001; Javaid et al., 2002; Nguefack *et al*., 2007
7	*Bipolaris oryzae, Phoma sorghina, Alternaria padwickii, Pyricularia oryzae, F. moniliforme, F. grminearum, Nigrospora oryzae, Curvularia* spp. *Dichotomophthoropsis nymphacearum* and *Heterosporium echinunulatum*	Ou, 1985; Arshad *et al*., 2009
8	*Bipolaris oryzae, Alternaria padwickii, Fusarium moniliforme, Fusarium pallidoroseum, Microdochium oryzae, Sarocladium oryzae, Acidovorax avenae* sp. *avenae* and *Burkholderia glumae*	Huynh *et al*., 2001

and quantitative traits (Sumangata *et al*., 2009; Tariq *et al*., 2012) that ultimately result in yield penalty. Rice pathogens associated with discolored grains affects germination ability, seed health; seed quality, seed morphology and yield potential of the crop (Ou, 1985; Misra *et al*., 1990). Fungal association with discoloured seeds results in deterioration of nutritional value of seeds due to physical, physiological and biochemical changes in the seeds (Narain, 1992). It is also a serious problem in seed certification (Ray and Gangopadhyay, 1991). It reduces the commercial value of seeds due to their appearance and change in nutritional value.

3.1. Geographical Distribution and Economic Loss

Diseases are important factor for reduction in the yield of paddy worldwide heavy yield losses ranging from 50 to 90 %. Rice grain discoloration was reported as independent disease in the literature causing significant yield losses (Mew *et al.,* 2004; Arshad *et al*., 2009; Prabhu *et al.,* 2012; Ashfaq *et al.,* 2013; Chandramani and Awadhiya, 2014). The disease has been reported from different countries in the world such as Latin America (Zeigler and Alvarez, 1987), Gulf of Mexico (Shahjahan *et al*., 1998; 2000 a & b); Guyana (Persaud *et al.,* 2020), Pakistan as well as in other parts of Asia (Arshad *et al.,* 2009) and gradually becoming a serious problem. In India it was reported from different places like Assam (Roy, 1983), Karnataka (Ranganathaiah, 1985), Andhra Pradesh (Rao *et al.*, 2000), Odisha (Baite *et al.*, 2020), Eastern India (Raghu *et al.*, 2020). This threat is increasing year after year by decreasing the yield potential of rice crop up to 6%.

3.2. Symptoms of Grain Discolouration

The symptom of grain discolorations appears externally on the glumes or internally on the kernels or both (Ou, 1985; Arshad *et al.,* 2009). The dots varied in size, shape and colors depending on large number of fungi and bacteria or their association (Nghiem and Hoang, 1993).

The symptoms of rice discoloration involves brown or black spots on grain, hollow light weight panicle, blackish brown stripes on grain and infected panicle with unfilled grains. Darkening of glumes or spikelets, brown to black coloration in rotten glumes of grain are few important symptoms caused by one or more pathogens. The intensity ranges from sporadic discoloration to discoloration of whole glumes. It leads to grain rot, sheath rot complex, panicle blight, grain discoloration, seedling rot (Zeigler and Alvarez 1987; Cottyn, 2001). Grain discoloration affects the grain morphology in term of grain size and shape.

Discoloration of grain and whole panicle, distinct lesions, panicle blight, brown/ black spots on grain, discoloration of florets are other symptoms (Groth *et al.,* 1991; Shahjahan, 1998; Shahjahan, 2000 a & b). Poor grain filling (Arunyanart *et al.,* 1981), glume discolouration (Upadhay and Diwakar ,1984; Sachan and Agarwal, 1995), reduction in test weight and seed germination are important consequences of the disease. It produces spotting of husks and sterile spike lets. Seeds from infected panicles cause discolouration and sterility, thereby reducing grain yield and quality (Mew and Gonzales, 2002). Toxic metabolites release from it causes chlorosis and growth retardation of rice seedlings (Reddy *et al.,* 2000).

3.3. Causes of Grain Discolouration

A wide number of factors attributed to grain discoloration of rice such as panicle lodging, soil and climate changes and microbial infection. The high disease incidence triggered due to abrupt climate change which increase virulence of the once minor pathogen(s), to gain motion to cause devastation in rice crop. Biotic factors like microbial infections (fungal, bacterial and viral) are major cause of grain discoloration. The temperature ranged from 25 to 37 °C, moderate rainfall, high relative humidity (70–76 %) and high wind speed played a critical role in the disease outbreak in NRRI, Cuttack in 2019 (Baite *et al.*, 2020). High humidity and high moisture during panicle emergence stage (Tsushima *et al*., 1995; Shahjahan, 2000b) as well as grain filling stage, high temperature and high wind pressure during pollination, rainfall at maturity stage, weak plant defense system, nutrient deficiency, less plant population, lack of proper pollination/ fertilization, chemicals/ fungicides injuries are the important factors which cause grain discolouration of rice. Apart from these, disease spikelets are produced by inoculation during pollination (Shahjahan *et al*., 1998a).

Microbial infection is the major reason for the rice grain discoloration disease (Agarwal *et al*., 1989). A large number of fungi and bacteria are associated with rice grain discoloration (Ou, 1985). According to Ou (1985), two major groups such as field fungi and storage molds are associated in grain discoloration of rice. Field fungi like *Drechslera oryzae, Pyricularia oryzae, Alternaria padwikii, Fusarium moniliforme, Curvularia geniculata, Sarocladium oryzae* etc. whereas, storage molds, saprophytes *viz., Aspergillus* sp., *Penicillium* sp., *Mucor* sp., *Rhizopus* sp., etc. are more or less parasitic and infects grain before harvest. Many fungi are reported to be associated with it such as *Alternaria padwickii, Pyricularia oryzae, Bipolaris oryzae, Fusarium moniliforme, F. graminearum, Nigrospora oryzae, Phoma sorghina, Dichotomophthoropsis nymphacearum, Heterosporium echinunulatum, Curvularia lunata* and *Alternaria alternata* (Ou, 1985; Arshad *et al.,* 2009). Out of which *Curvularia lunata* (Wakker) Boedign is predominant (Bag, 2010; Koulagi *et al.*, 2011; Persaud *et al.,* 2020). *Drechslera oryzae* and *Curvularia lunata* were found to be predominantly associated with discoloured rice grain in Tamil Nadu (Subramanian, 1988). Field fungi such as *Drechslera oryzae*, *Curvularia lunata, Sarocladium oryzae, Trichoconiella padwickii, Fusarium moniliforme, Nigrospora* spp., *Pyricularia grisea* and *Microdochium oryzae* were predominantly associated with grain discolouration according to several workers (Vaid and Sharma, 1992; Saifulla *et al*., 1996).

Bacteria are associated with 28-32 % of discolored seed (Baldacci and Corbetta, 1964; Misra *et al*., 1990). Bacteria like *Pseudomonas avenae, P. fuscovaginae, P. syringae* var. *oryzicola,* and *P. glumae* are also responsible for grain discolouration in Rice (Suryadi and Kadir, 2009).

Various pathogens like fungi or bacteria developed on seed, disintegrate cells on the surface of seed, then entered inside to damage albumen, change the color of albumen and break the seed. Different fungi are attributed to different types of discolouration of Rice (Sachan and Agarwal, 1995). *Alternaria alternata* is responsible for ashy grey discoloration and *Drechslera oryzae* (*Cochliobolus miyabeanus*) attributed to black discoloration, dark brown spots and light to dark brown dot like spots are found in the seed coat and endosperm of discolored seed whereas, *C. geniculata* (*Cochliobolus geniculatus*) found responsible for eye shaped spots. Besides, *Fusarium equiseti, F. oxysporum* (*Gibberella zeae*)*, F. moniliforme* (*Gibberella fujikuroi*) found responsible for pink discoloration and *Sarocladium oryzae* is responsible for light brown discoloration on the seed coat, endosperm and embryo of seed (Sachan and Agrawal, 1994). Pratap *et al.* (2020) found that *Curvularia lunata* and *Fusarium moniliorme* are two important pathogens responsible for grain discolouration. Grain rot, seedling blight and seedling rot caused by bacterial pathogens *Pseudomonas glumae* (*Burkholderia glumae*).

3.4. Effect of Grain Discolouration on Seed Quality and Productivity

Rice grain discoloration affects the qualitative and quantitative traits (Sumangata *et al.,* 2009; Tariq *et al*., 2012) that ultimately result in yield penalty. Rice pathogens associated with discolored grains which affects germination ability, seed health; seed quality, seed morphology and yield potential of the crop (Ou, 1985; Misra *et al*., 1990). Production and productivity of rice is drastically reducing due to this emerging disease. It is a complex symptom due to the association of a number of pathogenic and saprophytic fungi that infect the rice grains both in field and storage conditions.

Grain discoloration reduces grain quality very seriously and also reduces consumer preference on rice. It also affects milling recovery, cooking and eating quality. The seed germination, viability, vigour and seedling height are badly affected by this malady (Bag, 2010). It causes weight loss of grain and affects post-harvest processing (Chhabra and Vij, 2020). The seed weight (13.10g), volume (24.28) and density (0.53) get reduced as compared to healthy grains with higher seed weight (14.85g), volume (25.22) and density (0.57) (Sumangala *et al.,* 2009). Broken rice (68.2g) increased in discolored grains in comparison to healthy grains (13.13g) as reported from sonamashuri variety. Higher endosperm chalkiness, low gelatinization temperature and poor organoleptic values like good aroma, slight tender, less cohesiveness, white and glossy are reported in discolored grains (Sumangala *et al.*, 2009). It also affects the grain quality causing breakage of rice grains during milling, weight loss, post-harvest losses, and crop yield

Table 2: Micro-organisms associated with different types of discolouration

Sl. No.	Seed discolouration	Pathogens attributed to discolouration	References
1	Ash gray discoloration	*Alternaria alternate*	Sachan and Agarwal, 1995
2	Light brown discolouration on the seed coat, endosperm and embryo of discolored seed	*Sarocladium oryzae*	Sachan and Agarwal, 1995
3	Black, dark purple, dark brown colur spots and light to dark brown dot like spots on the seed coat and endosperm	*Bipolaris oryzae*	Sachan and Agarwal, 1995
4	Light pink discoloration	*Fusarium equiseti, F. graminearum* and *F. moniliforme*	Sachan and Agarwal, 1995
5	Tip discolouration	*Fusarium moniliforme*	Pratap, D. B. *et al*., 2020
6	Base discolouration	*Curvularia lunata*	Pratap, D. B. *et al*., 2020
7	Eye shaped spots	*Cochliobolus geniculatus*	Sachan and Agarwal, 1995
8	Black or brown spots or blotches on grain	*Drechslera oryzae* [*Cochliobolus miyabeanus*] and *Trichoconiella* [*Alternaria*] *padwickii*	Ranganathaiah, K. G., 1985
9	Grey discolouration	*Alternaria alternate*	Bodalkar and Awadhiya, 2014
10	Black discolouration	*Cochilobolus miyabeanus*	Bodalkar and Awadhiya, 2014

loss and ultimately badly affects the economy of country. Rice grain discolouration is also a major limiting factor for rice yield.

It not only reduces yield and quality, but also produces harmful mycotoxins which are detrimental to human and animal life. It also reduces various nutrient content of grain. There is reduction of protein content in the range of 29.7 to 36.7 percent in rice seeds due this infection (Reddy *et al.*, 2000). The decrease in protein content initially might be attributed to their hydrolysis to simpler forms by fungal proteolytic enzymes. However, Sachan and Agarwal (1995) found significant increase in the protein content of seeds having discolouration. The decrease in starch content might be due to rapid degradation of starch by the enzymes produced by *Sarocladium* or a partial utilization of their synthesis or both (Reddy *et al.,* 2000). The chemical and physical characters changed in discoloured seeds. The protein content (8.0%) and ash content (0.000222%) becomes higher in discoloured grain in comparison to healthy seeds with protein and ash content of 7.5 and 0.00016 percent respectively in sonamashuri variety (Sumangala *et al.*, 2009). The moisture (0.0089%), fat (0.0023%) and carbohydrates (91.98%) levels reduces in discolored grains while it is 0.0041, 0.0027 and 92.48 percent moisture, fat and carbohydrates respectively in healthy seeds (Sumangala *et al.*, 2009).

4. Management

Management of this disease can be done by various methods which are reported by earlier workers. According to Schaad (2008), neither effective control measures nor rice varieties showing complete resistance to the disease are currently available.

4.1. Cultural Practices

Use of clean seeds not only reduces the transmission of rice seed-borne diseases but also increase the yield. It reduces 5.83-8.73% unfilled grains in the dry season and 8.32-8.65% discolored seeds in the wet season. Simple technique of manual seed cleaning effectively improves seed quality (Mathur *et al.,* 2001). Low moisture content, high physical purity gives a good germination, high vigour index with less microbial infestation (Khamari *et al,* 2018). Farmers usually dry and winnow seeds but did not care for seed treatment before sowing. Hence, seed treatments should be taken into consideration for management of the disease.

4.2. Biological Management

Repeated use of fungicides leads to health and environmental hazards and develops resistance (Jayawardana and Weerahewa, 2016). Many botanical extracts such as neem, nishinda, garlic, alamanda and biological control agent such as *Trichoderma* can be used as seed treating agent which results into higher germination, better plant stand, less disease incidence and increase yield of different crops (Naher *et al.*, 2016). Therefore seed should be treated before sowing.

Seed treatment with *Trichoderma viride* inhibited *Curvularia lunata* associated with grain discolouration and enhance seed germination upto 90.05 with vigour index of 1170.00. *Bacillus subtilis* enhances 87.99% seed germination and 989.11 vigour index (Koulagi, 2011; Hashim *et al.,* 2019). It also reduces number of infected seeds and blast disease of rice. Seeds treatment with microbial agents (*T. asperellum, B. subtilis*) and hot water (50 °C/ 15 min) reduces the percentage of blast infected rice seeds by 4.3 to 52.7 % relative to non-treated seeds. *Trichoderma harzianum* and *T. viridae* recorded maximum mycellial of *Curvularia lunata* and *Fusarium moniliforme* responsible for grain discolouration *in vitro* (Pratap *et al.,* 2020).

4.3. Chemical Management

Seed treatment and foliar application of synthetic fungicide are most effective in controlling grain discoloration disease of rice (Agarwal *et al.,* 1989; Arshad *et al*., 2009). Seed treatment with Vitavax 200 was most effective in reducing *Bipolaris oryzae* (0.15 to 3.75%), *Alternaria padwickii* (0.0 to 3.0%), *Fusarium moniliforme* (2.16 to 5.83%), *F. oxysporum* (0.0 to 3.0%), *Curvularia lunata* (0.0 to 2.56 %) and *Aspergillus* spp. (0.0 to 1.5 %) from 2.5 to 8.53 %, 5.3 to 13.35 %, 11.66 to 21.67 %, 1.25 to 4.35 %, 1.95 to 7.5 % and 1.75 to 6.54 % in untreated condition respectively (Naher *et al.*, 2016) and increase seed germination by 25.70% (Bhuiyan *et al.*, 2013). Antracal completely stops the growth of *Helminthosporium* sp. and *Curvularia* sp. Thiophenate methyl, mancozeb and derosal suppressed the growth of *Helminthosporium* by 50%. Thiophenate methyl and mancozeb suppressed the growth of *Curvularia* sp. by 50% (Butt *et al.*, 2011). Thiophanate methyl at 0.1% concentration recorded maximum mycellial growth inhibition of *Curvularia lunata* (92%) followed by tricyclazole at 0.5% (91.80%) whereas Copper oxide at 0.2% concentration recorded maximum mycellial growth inhibition of *Fusarium moniliforme* (90.91%) followed by carbendazim at 0.1% (90.51%) *in vitro* (Pratap *et al.,* 2020).

Gainexa UPL - a silicon-based formulation gave the best result in controlling grain discoloration in Rice caused by *Curvularia lunata* and *Curvularia pallescence* by foliar application of silicon supplements at 1 mL/L at tillering and early flowering stage.

Preventive spray with fungicides at heading stage can easily manage the disease (Arunyanart *et al.*, 1981). Spray of fungicide before dough stage is very useful (Ferrer *et al.*, 1980). Spraying at heading and during grain maturation can also reduce glume blotch caused by *Drechslera oryzae* (*C. miyabeanus*) (Kulkarni *et al.,* 1980). Spraying before dough stage, i.e., milk stage can reduce seed discolouration. Only one preventive spray of fungicides *viz.* validamycin (antibiotic) (200 ppm), vitavax (0.25%), captan (0.25%), thiram (0.25%) and bavistin + thiram (formulated) (0.25%) resulted in partial control of discolouration, not complete control of seed discolouration (Mishra and Vir, 1992).

Application of AmistarXtra 28 SC (Triazol, Estrobilurtina, Cyproconazol, Azoxystrobin) 1.5 mL L^{-1}; Glory 75 WG (Mancozeb + Azoxystrobin) at 3.0 g L^{-1}; Antracol 70 WP (Propineb) at 5.0 g L^{-1}; and Carbendazim 50 SC (Carbendazim 50%) at 1.5 mL L^{-1} reduces more than 50% incidence of grain discolouration (Persaud *et al.,* 2020). AmistarXtra 28 SC; Glory 75 WG; Antracol 70 WP; and Carbendazim 50 SC shows a significant reduction in grain discolouration from 48.58 to 92.85 % and increased number of filled grains, test weight and grain yield as compared to control in field demonstrations of Guyana (Persaud *et al.,* 2020).

5. Conclusion

Grain discoloration is emerging as a serious disease causing significant loss in paddy. Climate change, cropping practices and microbial infection are few of the major causes of the disease. Association of microbes such as fungi and bacteria enhances the disease incidence. Looking into the loss it cause, management strategies should be designed integrating improved cropping practices, utilization of genetic resources, management of pathogens using advance technology like bio-intensive practices, new generaion pesticide formulations, nano particles and silicon based formulations.

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