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Review Article **Open Access**

CURRENT STATUS OF GRAIN DISCOLORATION DISEASE OF RICE IN PAKISTAN AND ITS MANAGEMENT

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Abstract *Rice is an essential export and a staple food in Pakistan, but it also meets numerous challenges from diseases, such as rice grain discoloration, which is made worse by climate change. This situation challenges economic stability by affecting yield and quality due to a variety of biotic and abiotic causes. Temperature fluctuations, extreme humidity, and microbial diseases are all linked to discoloration. Effective management techniques have been investigated, emphasizing the contribution of silicon to improving plant resistance. These techniques include cultural practices, biological control, and chemical treatments. Inducing physiological changes and functioning as a mechanical barrier, silicon reduces the severity of disease. Additionally, the development of disease-resistant rice varieties is made possible by developments in molecular breeding and biotechnology, such as marker-assisted selection. The comprehensive review emphasizes the necessity of ongoing studies to lessen the effects of grain discoloration and enhance Pakistani rice production.*

Keywords: *Rice; disease resistance; discoloration; physiology; molecular breeding*

Introduction

In Pakistan, rice is a major export as well as a staple food crop. However, Pakistan's rice crop is susceptible to a number of diseases that lower output and affect quality. A novel disease that reduces productivity called "rice grain discoloration" has become a serious danger to rice harvests in recent years. As of right now, neither rice types nor efficient control methods completely eradicate this disease. In the past, plant infections that prefer higher temperatures have appeared or proliferated globally, resulting in a wide range of diseases (Junaid and Gokce, 2024; Schaad, 2008). Despite being a relatively minor disease, discoloration has become more significant in agriculture as a result of the effects of global warming. These effects include unpredictable hailstorms, delayed or insufficient rainfall, and higher temperatures and humidity levels after the flowering stage. Due to these climate-related issues, the agencies have loosened their procurement guidelines. Seeds with noticeable discoloration are usually of lower quality and are linked to the presence of bacteria (Bodalkar and Awadhiya, 2014). In rice crops, a minimum threshold of 3% is required for the procurement of discolored kernels; samples that over this barrier are discarded. Rice seeds become discolored for a variety of biotic and abiotic factors. The term "glume discoloration" describes how mature seeds lose some of their natural color, which causes problems for seed certification processes. Even though this disease is regarded as small, it reduces the crop's vigor and output and results in grain discoloration when it reaches maturity, which lowers the crop's economic and market value. The year-round cultivation of economically significant crops such as wheat and paddy, coupled with the prevalent practice of monoculture, has progressively made the issue of seed discoloration worse (Abbas et al., 2024a; Bala and Pannu, 2017). Another reason for this problem is the abundance of infections and pests that harm both crops. Because of how important rice is, more study and development are needed on the several fungal species that can affect the vigor, yield, morphology, and constitution of recently introduced, higher-yielding, aromatic rice cultivars. Whether pathological or not, the reasons of such discolorations are not usually clearly known. Discolored rice seeds are frequently linked to microorganisms, mainly fungus, however insect attacks, physiological conditions, and genetics can also play a role. In the past, attempts have been made to identify the causative agents of seed discoloration and employ chemicals to manage them. To demonstrate the advancements made in the treatment of rice grain discoloration, a synopsis of pertinent research publications is given (Abbas et al., 2024b; Abbas et al., 2021; Chhabra and Vij, 2020).

Causes of Grain Discoloration

Numerous biotic and abiotic factors can lead to rice grain discoloration, including microorganism attacks (fungi, bacteria, viruses), high humidity and moisture levels, certain stages of panicle emergence and grain filling, elevated temperatures, strong wind pressure during pollination, weakened plant defense systems, nutrient deficiencies, low plant density, immature grain development, inadequate pollination or fertilization, chemical treatments (fungicides), rainfall during the maturity stage, and lesions that appear as rusty or water-soaked spots on the lemma or palea. In addition, this condition may show up as lighter, immature brown grains in the panicle, glume discoloration, kernel discoloration, grain rot, and disease- and insect-induced discoloration (Ashfaq et al., 2013; Yan et al., 2010).

Symptoms of Grain Discoloration

Grain surfaces exhibiting bands of blackish brown color, panicles with unfilled grains as a result of infection, and brown or black patches on grains are all signs of rice discoloration. Grain discoloration modifies the size and form of the grains (Ashfaq et al., 2017b).

An overview of studies conducted to address rice grain discoloration

Numerous diseases of rice crops that cause discoloration of the grain occur in tropical regions of the world and are caused by a variety of pathogens, including bacterial, fungal, viral, and other biotic and abiotic causes. Numerous scientists have noted that such diseases include seedling rot, panicle blight, sheath rot complex, grain rot, and other developing diseases (Ashfaq et al., 2017b; Cottyn et al., 2001). *Phenicillium* species, *Helminthosporium oryzae*, and *Fusarium moniliforme* in particular have been identified as seed-borne fungus that cause germination failure, stem rot, foot rot, and seedling blight in rice (Ashfaq et al., 2017b). Abiotic stresses and climate variations can have an adverse impact on a plant's physiology and growth factors. The impact on rice crops is contingent upon the quantity, timing, and intensity of precipitation (Modarresi et al., 2015). Discoloration of rice grains is becoming a serious threat to Pakistan's rice harvest (Arshad et al., 2009; Chau Tan Phat et al., 2005). Discoloration of rice grains influences both qualitative and quantitative characteristics (Sumangala et al., 2009; Tariq et al., 2016) that ultimately lead to a yield penalty. Numerous biotic factors, including insect infestations, brown spot grain disease, and other common illnesses, also affect rice productivity (Jabeen et al., 2012; Khanzada and Shah, 2012; Tariq et al., 2016). It has been reported that losses from grains with brown spots might range from 16% to 43% (Datnoff et al., 1997). In addition, these diseases have been shown to have an adverse effect on grain quality, breaking rice grains during milling, cause weight loss, lower crop output, decrease exports, and ultimately harm Pakistan's economy (Ghazanfar et al., 2013).

An estimated 14–18% of rice yields worldwide are reduced as a result of different rice diseases (Mew and Gonzales, 2002; Mew et al., 2004). These diseases have the potential to severely reduce yields in some areas by 50 to 90% (Agrios, 2005). For instance, yield losses reached 39% in Tamil Nadu (Shanmugam et al., 2006). When it comes to finding new rice lines that are resistant to disease and other biotic and abiotic challenges, rice molecular markers play a critical role in screening, selecting, and identifying these lines (Choudhary et al., 2013; Pinta et al., 2013). In addition to conventional breeding methods, molecular markers are an invaluable tool for finding new genes and choosing resistant rice lines, which will ultimately result in the creation of new resistant genetic material (Mizobuchi et al., 2013; Yu et al., 2008). Additionally, it has been discovered that molecular markers are helpful in the screening and identification of plant diseases (Mannan and Hameed, 2013). Furthermore, *B. glumae* is an important source of inoculum for emerging panicles. Infection usually occurs at the heading or booting stage, and *B. glumae* cells are found on flag leaf sheaths (Yuan, 2005). According to Chau et al.(Chau Tan Phat et al., 2005), insect and disease-related losses in rice yield have gotten worse. It is recognized that grain discoloration is a common problem in the Mekong Delta. During the panicle-emergence stage that follows protracted droughts that are followed by storms and rainfall, glume discoloration may appear. In wetland areas that receive rain, the incidence of disease is generally higher than in arid places. Unbalanced NPK fertilizer use has been associated with a rise in disease incidence in rice cultivars with different resistance levels. On the other hand, it has been demonstrated that supplementing NPK fertilizers with silicon, magnesium, or straw ash can lower the rate of disease (Chhabra and Vij, 2020). Eliminating pathogen-linked sources of contamination, such as by applying low-temperature treatments to possibly kill the pathogens, is a crucial technique for managing plant diseases efficiently. Every year, grain discoloration has a big influence on the crop, and this impact is seen in all of Pakistan's main rice-growing regions (Table 1).

Table 1: Pathogens that cause disease in rice grain discoloration

Sr. #	Pathogens/ other effects	Percentage of pathogen	Yield loses	References
1	Fungi	1-80%	Severe	(Agarwal et al., 1989)
2	Virus	25-50%	Moderate	(Lamey and Everett, 1967)
3	Bacteria	18-65%	Severe	(Cottyn et al., 1996; Saberi et al., 2013)
4	Environmental effects	Less than 10%	Low	(Lee et al., 1986; Mew et al., 2004).
5	Insect and pest	2-12%	Low	(Lee et al., 1986; Mew et al., 2004; Salim et al., 2001)

Table 2: Effect of disease on rice crop yield

Sr. #	Disease	Pathogen	Loses	Favorable Environment	References
1	Bacterial Blight	*Xanthomonas oryzae pv. Oryzae*	Severe	Wet/ High	(Dye et al., 1980; Srinivasan et al., 1959)
2	Brown Spot	Cochliobolus miyabeanus	Severe	Temperate	(Ashfaq et al., 2017a; Roy, 1993)
3	Blast	*Pyricularia grisea*	Severe	Temperate Humid	(Padmanabhan, 1965)
4	Stem Root	*Magnaporthe salvinii*	Moderate	Wet/High Humidity	(Ashfaq et al., 2017a)
5	False Smut	*Ustilaginoidea virens*	Moderate	Temperate Humid	(Atia, 2004; Rush et al., 2000)
6	Grain Discoloration/kernel spotting/Grain rot/Seedling rot	*Burkholderia glumae Pseudomonas glumae/ Fuscovaginae, Curvularia spp, Fusarium spp, Sarocladium oryzae*	Severe	Wet/ Humid	(Lee et al., 1986; Misra and Vir, 1992)
7	Sheath Blight	*Cochliobolus miyabeanus/ Pseudomonas sp*	Severe	High Humidity	(Savary et al., 1995)
8	Tungro virus	*RTBV/RTSV*		Temperate	(Khush and Ling, 1974)
9	Seedling Blight	*Rhizoctonia solani* And *Thanatephorus cucumeris*	Moderate	Temperate/Humid	(Azegami et al., 1988; Azegami et al., 1985)
10	Bacterial panicle blight	*Burkholderia glumae* And *Burkholderia gladioli*	Severe	Temperate/Humid	(Nandakumar et al., 2009)
11	Black kernel	*Curvularia lunata*	Moderate	High humidity	(Boedijn, 1933; Martin, 1939)
12	Bakanae	*Gibberella fujikuroi*	Severe	Temperate/Humid	(Hemmi et al., 1931)
13	Bacterial leaf streak	*Xanthornonas oryzicola*	Moderate	Wet/temperate	(Fang et al., 1957)

Management

Previous researchers have reported on a variety of approaches for managing this condition. (Schaad, 2008) states that there aren't any rice types that show total resistance to the disease or efficient control methods in place at the moment.

Cultural practices

Using clean seeds enhances production while lowering the spread of diseases transmitted by rice seeds. In the dry season, it decreases the percentage of empty grains by 5.83–8.73%, while in the rainy season, it decreases the percentage of discolored seeds by 8.32–8.65%. Seed quality can be effectively improved by using simple manual washing approaches (Khamari, 2020). Reduced microbial infestation, high vigor index, and strong germination rates are displayed by seeds with low moisture content and high physical purity (Khamari et al., 2018). Farmers usually winnow and dry their seeds, but they frequently forget to treat the seeds before planting. As a result, using seed treatments is essential for managing disease.

Biological Management

Frequent application of fungicides can result in resistance development and present hazards to human health and the environment (Jayawardana et al., 2016). Biological control agents like *Trichoderma* and a variety of botanical extracts like neem, nishinda, garlic, and alamanda can be used as efficient seed treatment agents, increasing yields of different crops and promoting better plant establishment, higher germination rates, and decreased incidence of disease (Naher et al., 2016). Treating seeds before sowing is therefore crucial. It has been demonstrated that treating seeds with *Trichoderma viride* inhibits *Curvularia lunata*, which is linked to grain discoloration, and increases seed germination up to 90.05% with a vigor index of 1170.00. According to (Koulagi et al., 2011), *Bacillus subtilis* increases seed germination by 87.99% and vigor index by 989.11. It also lessens the number of contaminated seeds and helps rice blast disease. as rice seeds are treated with microbial agents such as *B. subtilis* and *T. asperellum* and heated to 50°C/15 min, the proportion of blast-infected rice seeds decreases from 4.3% to 52.7% as compared to untreated seeds. *Fusarium moniliforme* and *Curvularia lunata*, which cause grain discoloration in vitro, have been effectively controlled by *Trichoderma harzianum* and *T. viride* (Pratap et al., 2020).

Chemical Management

Grain discoloration disease in rice can be effectively controlled by seed treatment and foliar application of synthetic fungicides (Agarwal et al., 1989; Arshad et al., 2009). Vitavax 200 seed treatment resulted in a significant reduction in the incidence of the following pathogens: *Aspergillus* spp. (from 0.0% to 1.5%), *Fusarium moniliforme* (from 2.16% to 5.83%), *Fusarium oxysporum* (from 0.0% to 3.0%), *Curvularia lunata* (from 0.0% to 2.56%), and *Bipolaris oryzae* (from 0.15% to 3.75%), *Alternaria padwickii* (from 0.0% to 3.0%), *Fusarium moniliforme* (from 2.16% to 5.83%), *Fusarium oxysporum* (from 0.0% to 3.0%), and *Bipolaris oryzae* (from 0.15% to 3.75%), and *Aspergillus* spp. (from 0.0% to 1.5%), as compared to untreated conditions (Naher et al., 2016). Additionally, this treatment led to a 25.70% increase in seed germination (Bhuiyan et al., 2013).

The growth of *Helminthosporium* sp. and *Curvularia* sp. was entirely inhibited by antracal. The growth of *Helminthosporium* was 50% suppressed by thiophenate methyl, mancozeb, and derosal. *Curvularia* sp. growth was likewise 50% inhibited by mancozeb and thiophenate methyl (Butt et al., 2011). Research conducted in vitro revealed that the highest mycelial growth inhibition of *Curvularia lunata* was achieved by Thiophanate methyl at a concentration of 0.1% (92%), with tricyclazole at 0.5% (91.80%) coming in second. Maximum mycelial growth inhibition of *Fusarium moniliforme* was attained at a concentration of 0.2% copper oxide (90.91%), with carbendazim at 0.1% (90.51%) following (Pratap et al., 2020).

When applied as a foliar spray at 1 mL/L during the tillering and early flowering stages, the silicon-based formulation Gainexa UPL has demonstrated outstanding effectiveness in preventing grain discoloration in rice caused by *Curvularia lunata* and *Curvularia pallescence*. The disease is effectively managed by applying preventive fungicide sprays during the heading stage (Arunyanart et al., 1981). It is especially beneficial to apply fungicides prior to the dough stage. Furthermore, *Drechslera oryzae (C. miyabeanus)*-caused glume blotch can be minimized by spraying during the heading and grain maturity stages (Kulkarni et al., 1981). Fungicide application at the milk stage—just prior to the dough stage—can also aid in minimizing discoloration of the seeds.

Grain discoloration incidence can be reduced by more than 50% by applying AmistarXtra 28 SC (triazole, estrobilurin, cyproconazole, and azoxystrobin) at 1.5 mL/L, Glory 75 WG (mancozeb + azoxystrobin) at 3.0 g/L, Antracol 70 WP (propineb) at 5.0 g/L, and Carbendazim 50 SC (carbendazim 50%) at 1.5 mL/L (Persaud et al., 2020). In field demonstrations in Guyana, these treatments have dramatically decreased grain discoloration by 48.58% to 92.85% while simultaneously boosting the number of filled grains, test weight, and grain production in comparison to controls (Persaud et al., 2020).

The Role of Silicon in Controlling Grain Discoloration

Numerous studies have been conducted on the advantages of using silicon, either as silicates or as silicic acid, for the purpose of plant nutrition and disease suppression. The mechanisms underlying Si-mediated reduction of disease infestation are supported by two hypotheses:

1. The mechanical barrier that silicon deposition creates prevents pathogen infiltration.

2. Because silicon induces specific physiological changes, it increases resistance to disease.

Since the exact mechanisms of defense responses in silicon-treated plants against disease infection are yet unclear, both ideas are reasonable and should be taken into consideration (Prabhu et al., 2012). Beyond providing mechanical resistance to fungal penetration, silicon is involved in a more complex defense process (Rebitanim et al., 2015). It is suggested that more research be done in the future to better understand these defensive reactions. It's also important to determine whether these two mechanisms depend on one another.

(Prabhu et al., 2012) investigated the potential of silicon to mitigate brown spot disease by analyzing eight genotypes of rice grown in natural environments. The severity of brown spots and silicon application were found to be negatively correlated in a linear fashion. A quadratic negative association between grain discoloration and silicon rates was found through additional research on 48 rice cultivars cultivated in upland environments. Consequently, it may be said that silicon plays a major role in rice's resistance to problems like brown spot disease and grain discoloration.

Innovative Methods to Enhance Rice Crops

Conventional plant breeding and molecular approaches have greatly increased rice output by controlling diseases and other abiotic variables. Precision breeding is becoming increasingly possible because of developments in biotechnology, proteomics, genomics, rice molecular markers, and other cutting-edge techniques. When efficiently obtaining the desired gene combination, these methods are very effective (Raghuvanshi et al., 2010). To improve a variety of crops, including rice and other cereals, DNA markers were converted into PCR-based markers (Collard and Mackill, 2008; Collard et al., 2008). The identification of several markers, especially SSR markers, for marker-assisted selection was made possible by rice molecular mapping and DNA sequencing. These markers are useful for screening, selection, and the creation of new rice varieties (Gupta and Varshney, 2000).

By comparing the cultivars of *Oryza sativa* L. with *Oryza glaberrima* L., robust and promising single nucleotide polymorphism (SNP) markers have been found (Shen et al., 2004). Researchers have also created partial sequences of particular locations across different rice genotypes to identify SNP markers (Fatima et al., 2023; Monna et al., 2006; Shirasawa et al., 2007). Selecting, screening, and identifying novel rice varieties is made much easier with the use of new molecular breeding technologies, especially when it comes to resistance to diseases and other factors that can affect rice productivity. Numerous techniques, such as genetic diversity, genotype screening and selection, genotype identification, specific gene identification, marker-assisted backcrossing, gene pyramiding, population mapping, and the creation of new rice varieties, can be employed to improve rice crops through marker-assisted selection (MAS) (Collard and Mackill, 2008; Jain et al., 2004; Javed et al., 2024; Perez et al., 2008; Rasheed and Malik, 2022). Considerable work has been done to boost resistance because of the significance of rice diseases such bacterial leaf blight and blast. In the meantime, with yearly losses rising, rice grain discoloration has become a new hazard throughout the last ten years. Improvement using such strategies is necessary to lessen these losses.

By employing a marker-assisted, map-based strategy, the rice genome has been used to clone multiple genes that enhance tillering capacity, salt tolerance, submergence tolerance, disease resistance, heading date, shattering, yield, and grain quality (Fitzgerald et al., 2009; Huang et al., 2009; Rasheed et al., 2024; Sakamoto and Matsuoka, 2008). Through breeding and molecular methods, these genes and QTLs are extremely helpful for creating new rice lines and improving germplasm for later use (Ashfaq et al., 2017b).

Conclusion

The production of rice in Pakistan is seriously threatened by rice grain discoloration, which is made worse by climate conditions including rising temperatures and humidity. The disease has become more well-known despite its traditionally modest position because of global warming and evolving agricultural methods like monoculture. Grain discoloration is caused by a variety of pathogens, including as bacteria, viruses, and fungus, as well as abiotic variables that have an impact on production and quality. Cultural, biological, and chemical methods have all been incorporated into management techniques throughout the years. While biological control agents provide environmentally favorable options, clean seeds, and proper seed treatments are essential. Even if chemical treatments are successful, there is a risk of resistance and environmental damage. Molecular breeding and other innovative approaches hold potential for improving the resilience of rice crops. The production of disease-resistant rice varieties is made easier by advances in molecular markers, while silicon plays a role in plant defense. Sustainably producing rice depends on ongoing research and integrated management techniques to lessen the effects of rice grain discoloration.

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All authors contributed equally.

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