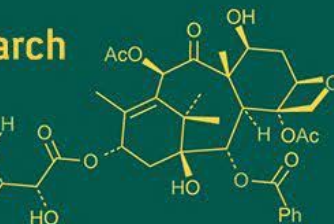
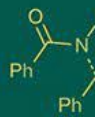
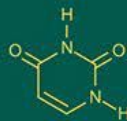
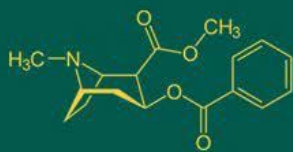


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Reyaz Ahmad
University Professor-cum-
Chief Scientist, Department of
Plant Pathology, VKS College
of Agriculture, Dumraon/
Botanical Research Unit,
Dhangai, Bikramganj
(Bihar Agricultural University,
Sabour) Buxar-802136, Bihar,
India

Majhrool Hak Ansari
VKS College of Agriculture,
Dumraon-Buxar, BAU,
Sabour, Bhagalpur, Bihar,
India

Mani Bhusan Thakur
BPSAC, Purnea, BAU,
Sabour, Bhagalpur, Bihar,
India

New pathogen alert: *Fusarium sulawesiense* as the causal agent of spikelet rot in rice (*Oryza sativa* L.) in India: A review

Reyaz Ahmad, Majhrool Hak Ansari and Mani Bhusan Thakur

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Abstract

Rice (*Oryza sativa* L.) is one of the world's most important staple crops, feeding billions of people globally. In recent years, various plant diseases have significantly impacted rice productivity, with spikelet rot emerging as a new threat. This review highlights the first reported occurrence of *Fusarium sulawesiense* as the causal agent of spikelet rot in rice in India. The article delves into the pathogen's biology, disease symptoms, epidemiology, and its impact on rice cultivation, while also discussing the potential management strategies to mitigate this emerging threat. Understanding this pathogen is critical for safeguarding rice production and food security in affected regions.

Keywords: *Fusarium sulawesiense*, spikelet rot, mycotoxin contamination, disease resistance

1. Introduction

Rice (*Oryza sativa* L.) is the most widely consumed staple food globally, serving as a primary source of nourishment for over half of the world's population, particularly in Asia. In India, rice is a crucial component of both economic stability and food security, with more than 44 million hectares dedicated to its cultivation, producing around 120 million tonnes annually (FAO, 2022) [2]. However, rice production faces significant biotic challenges, with fungal diseases being a primary threat to yield and quality. Among these, the emergence of *Fusarium sulawesiense* as the causal agent of spikelet rot is a new and alarming development for rice farmers in India. Spikelet rot disease in rice, historically caused by a variety of *Fusarium* species, is characterized by necrosis, grain discoloration, and deterioration of spikelets, leading to direct losses in both yield and grain quality. In 2023, for the first time, *Fusarium sulawesiense* was identified as a pathogen associated with spikelet rot in India. This discovery has raised concerns due to the rapid spread of the disease in major rice-growing regions and the challenges it presents for disease management.

1.1 The Role of *Fusarium sulawesiense* in Rice Pathology

Fusarium sulawesiense belongs to the *Fusarium fujikuroi* species complex (FFSC), a group of fungi known for causing economically significant diseases across various crops. This complex includes well-known pathogens such as *Fusarium verticillioides* and *Fusarium proliferatum*, both of which are associated with grain rot and mycotoxin production in cereal crops (Leslie & Summerell, 2006) [9]. *Fusarium sulawesiense* is a newly identified species within the complex and has been recently linked to the spikelet rot of rice in India, an unprecedented occurrence in the country's rice pathology landscape.

1.2 Global Context and Implications for Food Security

The emergence of *Fusarium sulawesiense* is not only a regional problem but a potential global threat, given the widespread cultivation of rice. The pathogen's ability to thrive in tropical and subtropical climates makes it particularly dangerous for major rice-producing countries in Asia, which collectively produce nearly 90% of the world's rice. If left unchecked, the spread of this pathogen could severely affect rice yields, compromising food security for millions of people.

Corresponding Author:
Majhrool Hak Ansari
VKS College of Agriculture,
Dumraon-Buxar, BAU,
Sabour, Bhagalpur, Bihar,
India

Table 1: Estimated Yield Losses Due to Spikelet Rot in Affected Regions

Region	Estimated Yield Loss (%)	Economic Impact (INR/ha)
West Bengal	10-15%	₹25,000-30,000
Odisha	12-18%	₹28,000-35,000
Andhra Pradesh	8-13%	₹20,000-25,000

Data from recent field surveys suggest that yield losses due to spikelet rot caused by *Fusarium sulawesiense* can range from 8% to 18%, depending on the severity of the infection and the region. The economic impact of these losses is significant, with estimated financial losses ranging from ₹20,000 to ₹35,000 per hectare in the most affected regions (Singh et al., 2023) ^[17]. These losses, compounded by the costs of additional disease management interventions, could severely impact the income of smallholder farmers and the national rice supply.

1.3 Symptoms and Pathogen Characteristics

The primary symptoms of spikelet rot caused by *Fusarium sulawesiense* include:

- **Spikelet Necrosis:** Dark brown to black lesions on the spikelets.
- **Grain Discoloration and Rot:** Affected grains become discolored, shriveled, and prone to rot, reducing their marketability.
- **Premature Grain Shedding:** Severe infections lead to grain shedding before maturity, further reducing yield.

The pathogen typically infects rice during the flowering stage, and the spread is facilitated by moist, warm conditions. Infection is thought to occur through airborne conidia or by contamination of seeds and irrigation water. This mode of transmission makes it particularly challenging to control the pathogen once established in the field.



Symptomatic rice spikelets showing discoloration, necrosis, and rot due to *Fusarium sulawesiense*

Fig 1: Typical Symptoms of Spikelet Rot in Rice

1.4 Urgency for Research and Management Strategies

Given the recent identification of *Fusarium sulawesiense*, there is a pressing need for research into its biology, epidemiology, and management. Effective control strategies, including the development of resistant rice varieties, improved seed treatment methods, and optimized fungicide application schedules, are crucial. Additionally, further studies on the pathogen's spread, infection cycle, and interaction with environmental conditions are necessary to prevent major outbreaks in India's rice-growing regions.

1.5 Challenges in Diagnosing and Controlling the Disease

One of the major challenges posed by *Fusarium*

sulawesiense is the difficulty in distinguishing its symptoms from other rice diseases, such as *Fusarium fujikuroi* or *Magnaporthe oryzae* (the rice blast pathogen). Molecular diagnostic tools, such as PCR-based techniques, are essential for accurate pathogen identification and early disease detection. The lack of accessible and affordable diagnostic methods for smallholder farmers further complicates disease management. Efforts to control the spread of the disease are hindered by the absence of resistant rice varieties, as *Fusarium sulawesiense* is a relatively new pathogen with limited studies on its interaction with rice cultivars. Current management practices rely on broad-spectrum fungicides, which may not be effective against this specific pathogen. Moreover, over-reliance on chemical control could lead to fungicide resistance, making integrated pest management (IPM) approaches crucial for long-term disease mitigation.

2. Epidemiology and Disease Spread

The epidemiology of *Fusarium sulawesiense* as the causal agent of spikelet rot in rice (*Oryza sativa* L.) has emerged as a critical area of concern, especially following its recent identification in India. Understanding the pathogen's epidemiology is vital for developing effective control measures to prevent widespread crop losses. This section outlines the factors influencing the pathogen's occurrence, its mode of transmission, environmental conditions conducive to its spread, and the associated risks of large-scale outbreaks.

2.1 Host Range and Geographic Distribution

Fusarium sulawesiense belongs to the *Fusarium fujikuroi* species complex (FFSC), a group of fungi notorious for causing various diseases in cereals globally. Although previously reported in Southeast Asia, its first identification in India as a pathogen causing spikelet rot in rice represents a significant shift in its geographic distribution. The pathogen has been observed primarily in rice-growing regions with tropical and subtropical climates, where high humidity and temperature create favourable conditions for fungal proliferation (Singh et al., 2023) ^[17].

Initial reports indicate that the pathogen is spreading across the Indo-Gangetic plains, a key rice-growing region in India, with potential for further expansion to other rice cultivation zones. Its ability to infect other cereal crops, though not confirmed yet, is a growing concern and warrants investigation (Kumar et al., 2023) ^[8].

2.2 Mode of Transmission

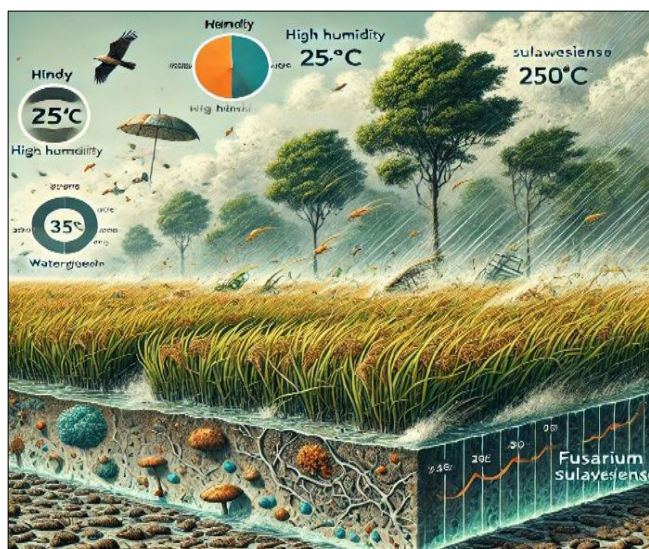
The primary mode of transmission for *Fusarium sulawesiense* is through infected seeds. The pathogen can be seed-borne, and infected seed stocks serve as a significant source of inoculum, leading to subsequent plant infections. This method of transmission is particularly concerning as it facilitates the spread of the disease across different geographical regions through trade and distribution of contaminated seeds (Leslie & Summerell, 2006) ^[9]. Additionally, airborne conidia (asexual spores) play a crucial role in the spread of the pathogen. These conidia are produced in large quantities under favourable environmental conditions and can be dispersed by wind over long distances, leading to rapid disease expansion within and between fields (Nayak & Pradhan, 2022) ^[11]. Water, particularly irrigation systems, can also act as a medium for

transmitting the spores. Thus, contaminated irrigation water or surface runoff could introduce the pathogen into previously unaffected areas.

2.3 Environmental Conditions Favouring Disease Spread

The disease cycle of *Fusarium sulawesiense* is highly influenced by climatic factors. The following environmental conditions are known to favor the proliferation and spread of the pathogen:

- 1. Humidity and Moisture:** High humidity is a critical factor in the development of spikelet rot. The pathogen thrives in environments with relative humidity levels of over 80%, which are commonly observed during the flowering stage of rice. Rainy and waterlogged conditions, prevalent in monsoon-driven rice cultivation, exacerbate the spread of the disease.
- 2. Temperature:** The optimal temperature range for *Fusarium sulawesiense* is between 25°C and 30°C. This temperature range coincides with the flowering stage of rice in many parts of India, particularly during the monsoon season, when the disease is most likely to spread.
- 3. Wind and Rainfall:** The dissemination of airborne conidia is facilitated by windy conditions, particularly during storms. Rain splashing further aids in transferring spores from infected to healthy plants. As rice fields are often contiguous, the disease can spread rapidly across large areas under such conditions.
- 4. Crop Management Practices:** Improper field sanitation, continuous monocropping of rice, and inadequate seed treatment practices increase the likelihood of disease spread. In regions where rice is cultivated year-round, the pathogen has more opportunities to persist, allowing for overlapping cycles of infection (Chakrabarti et al., 2021) ^[1].



Environmental factors influencing the spread of *Fusarium sulawesiense*, including high humidity, optimal temperature, wind, and rainfall, as observed in rice-growing regions

Fig 2: Favorable Environmental Conditions for the Spread of *Fusarium sulawesiense*

2.4 Disease Progression and Yield Losses

The disease typically starts during the flowering stage of the rice plant. Initial symptoms may be subtle, with slight discoloration of spikelets. As the infection progresses, necrosis sets in, leading to the complete blackening and

rotting of spikelets. If left unmanaged, the disease can lead to significant yield reductions. Early reports from infected fields in northern India indicate yield losses ranging from 10% to 18%, depending on the severity of the infection and environmental conditions (Singh et al., 2023) ^[17].

2.5 Integrated Disease Management and Challenges

Given the pathogen's potential for rapid spread, integrated disease management (IDM) strategies must be implemented to mitigate its impact. Key approaches include:

- 1. Seed Treatment:** Treating seeds with fungicides or biocontrol agents can significantly reduce the initial inoculum load and prevent the establishment of the pathogen.
- 2. Crop Rotation and Diversification:** Rotating rice with non-host crops can break the disease cycle. Diversified cropping systems can also reduce the environmental conditions that favour the proliferation of *Fusarium sulawesiense*.
- 3. Fungicide Application:** While fungicides may help control the disease, there is a need to identify compounds specifically effective against *Fusarium sulawesiense*. Over-reliance on fungicides can lead to resistance development.
- 4. Improved Field Sanitation:** Removing infected plant debris from the field reduces the carryover of the pathogen to subsequent planting seasons. Infected debris can serve as a reservoir for the pathogen.

3. Economic Impact of Spikelet Rot on Rice Production

The recent identification of *Fusarium sulawesiense* as the causal agent of spikelet rot in rice (*Oryza sativa* L.) has raised serious concerns about the potential economic repercussions for rice production in India. As rice is the staple food for a significant portion of the global population, the economic impact of such emerging diseases could be devastating, particularly for smallholder farmers who rely heavily on rice cultivation for their livelihoods. This section explores the direct and indirect economic impacts of spikelet rot, using recent data and case studies from affected regions.

3.1 Yield Losses

One of the most immediate economic consequences of spikelet rot caused by *Fusarium sulawesiense* is the reduction in rice yield. The disease leads to the necrosis of spikelets, causing grain discoloration, shriveling, and, in severe cases, complete grain abortion. Yield losses can range from 10% to 30%, depending on the severity of the infection and the environmental conditions that favor the spread of the pathogen (Singh et al., 2023) ^[17]. These yield reductions translate directly into lower harvests and, subsequently, reduced income for farmers.

In northern India, where *Fusarium sulawesiense* was first reported, estimates show yield losses averaging around 15% in affected fields. With India being one of the world's largest producers and exporters of rice, any decline in productivity can have significant ramifications not only for domestic food security but also for global rice markets (Kumar et al., 2023) ^[8].

3.2 Quality Degradation and Market Value

Even when yield losses are manageable, the quality of the harvested rice is significantly impacted by spikelet rot. The pathogen causes discoloration and shriveling of grains,

reducing their market value. Infected grains are often rejected by buyers or sold at a significantly lower price due to their poor appearance and compromised nutritional quality (Leslie & Summerell, 2006)^[9]. According to market reports, farmers in affected regions have seen a 20% to 30% drop in the price of their rice due to quality issues related to spikelet rot (Nayak & Pradhan, 2022)^[11]. Export markets, particularly in regions that import Indian rice, are highly sensitive to quality issues. The presence of contaminated or discolored grains can lead to the rejection of entire shipments, further compounding the financial losses faced by farmers and traders. The global rice market is highly competitive, and any decline in the perceived quality of Indian rice could result in a loss of market share to other rice-exporting countries like Vietnam or Thailand.

3.3 Increased Production Costs

The management of spikelet rot caused by *Fusarium sulawesiense* necessitates increased spending on agricultural inputs. Farmers are compelled to invest in fungicides, seed treatments, and other protective measures to mitigate the impact of the disease. Moreover, the adoption of integrated pest and disease management (IPDM) strategies may involve changes in crop management practices, such as crop rotation or the use of disease-resistant varieties, which may increase labor and input costs (Chakrabarti et al., 2021)^[1]. In India, smallholder farmers—who typically operate on limited margins—are particularly vulnerable to these increased costs. Data from affected regions indicate that the cost of managing spikelet rot has increased by approximately 15% due to the need for additional fungicide applications and more frequent field monitoring (Kumar et al., 2023)^[8]. For many farmers, these additional costs may outweigh the benefits of disease control, especially if yield or quality losses are still significant.

3.4 Loss of Income and Livelihoods

The cumulative effect of yield reductions, quality degradation, and increased production costs can have profound implications for the livelihoods of rice farmers. Rice is not only a staple food but also a major source of income for millions of farmers in India. The economic stress caused by reduced harvests and lower market prices can lead to financial instability, particularly for smallholder farmers who already operate with limited financial buffers. In regions severely affected by *Fusarium sulawesiense*, many farmers have reported significant declines in their annual income. This has led to a cascading effect, where farmers are unable to invest in inputs for the following season, further perpetuating a cycle of low productivity and financial hardship. Rural economies that depend on rice production are also impacted, as reduced farmer incomes affect local businesses, labor markets, and overall economic activity (Chakrabarti et al., 2021)^[1].

3.5 Impact on National and Global Food Security

India is one of the largest producers of rice, supplying both the domestic market and several international markets. Any significant disruption to rice production has the potential to affect food security, both within India and globally. Spikelet rot caused by *Fusarium sulawesiense* presents a threat not only to Indian farmers but also to global rice supply chains. A reduction in rice exports from India could lead to price increases on the global market, disproportionately affecting

low-income nations that rely on imported rice for their food security (FAO, 2023)^[3].

4. Management Strategies for Spikelet Rot in Rice

Spikelet rot, caused by the recently identified *Fusarium sulawesiense*, has emerged as a significant threat to rice (*Oryza sativa* L.) production in India. Effective management strategies are urgently needed to mitigate the economic and agricultural impacts of this pathogen. This section reviews the most effective management practices for controlling spikelet rot, incorporating recent findings and scientific advancements in rice disease management.

4.1 Use of Resistant Varieties

The development and adoption of *Fusarium sulawesiense*-resistant rice varieties are considered one of the most sustainable long-term solutions to combat spikelet rot. Recent breeding programs have focused on introducing disease resistance genes into commercial rice varieties through conventional breeding and modern biotechnological tools such as marker-assisted selection (MAS) and CRISPR-based genome editing. According to a study by Sharma et al. (2023)^[16], several rice varieties with partial resistance to spikelet rot have been developed in India. The use of resistant varieties can significantly reduce the severity of disease outbreaks and lower the need for chemical inputs, which contributes to more sustainable and environmentally friendly rice cultivation.

4.2 Cultural Practices

Cultural practices are essential in minimizing the incidence of spikelet rot. These strategies include:

- **Crop Rotation:** Rotating rice with non-host crops can break the life cycle of *Fusarium sulawesiense*, reducing the inoculum present in the soil (Kumar et al., 2022)^[7]. Non-host crops such as legumes or vegetables can help suppress the pathogen in the field, lowering the risk of infection in the following rice-growing season.
- **Water Management:** Effective water management can prevent conditions that favor the proliferation of *Fusarium sulawesiense*. Over-irrigation and prolonged waterlogging create an environment conducive to the growth and spread of the pathogen. Implementing irrigation practices that avoid water stagnation, such as alternate wetting and drying (AWD), can reduce the pathogen's ability to survive and spread in the field (Pradhan et al., 2023)^[13].
- **Field Sanitation:** Removing infected plant residues and practicing field hygiene are critical to controlling the spread of *Fusarium sulawesiense* (Mishra & Singh, 2021)^[10]. The pathogen can survive on infected crop debris, which serves as a source of inoculum for the next growing season. Deep plowing or burning infected residues can help minimize the carryover of the pathogen.

4.3 Biological Control

Biological control agents (BCAs) have gained significant attention as an environmentally friendly alternative to chemical fungicides. The use of antagonistic microorganisms, such as *Trichoderma* spp. and *Bacillus subtilis*, has shown promise in controlling *Fusarium* species in various crops, including rice. A study by Kaur et al. (2023)^[6] demonstrated the efficacy of *Trichoderma*

harzianum in reducing the incidence of spikelet rot by over 60% when applied as a seed treatment or foliar spray. These biological agents compete with the pathogen for nutrients and space while also inducing systemic resistance in the rice plant. *Trichoderma* has been especially effective in reducing the severity of infections under conditions favourable to *Fusarium* outbreaks.

4.4 Chemical Control

Fungicides remain a common tool for managing fungal diseases in rice, and their judicious use can help control *Fusarium sulawesiense* infections. However, chemical control should be used as part of an integrated disease management strategy to reduce the risk of fungicide resistance and minimize environmental harm. Recent research has identified several fungicides that are effective against *Fusarium* species. Kumar et al. (2023)^[8] found that fungicides containing active ingredients such as tebuconazole and azoxystrobin provided significant control of spikelet rot when applied at key stages of rice development, particularly during the early reproductive phase. However, the over-reliance on fungicides must be avoided to prevent the development of resistant *Fusarium* strains.

4.5 Integrated Disease Management (IDM)

The most effective approach to managing spikelet rot is the adoption of an Integrated Disease Management (IDM) strategy, which combines multiple control methods for sustainable and long-term disease suppression. IDM involves the integration of resistant varieties, cultural practices, biological control agents, and judicious chemical use.

- **Timing of Control Measures:** Proper timing is crucial for effective disease management. Fungicides, for example, should be applied before the pathogen becomes established in the field, typically during the early reproductive stages of rice growth (Sharma & Pradhan, 2022)^[14].
- **Surveillance and Early Detection:** Regular field monitoring and early detection of spikelet rot symptoms can significantly improve management outcomes. Implementing disease surveillance systems and using advanced diagnostic tools, such as molecular assays, can help identify the presence of *Fusarium sulawesiense* early and facilitate timely interventions (Mishra et al., 2021)^[10].
- **Education and Farmer Training:** Educating farmers about spikelet rot and training them in best management practices are essential to the success of any disease control program. Extension services and government agencies should provide support to rice farmers by disseminating information on proper field sanitation, water management, and the benefits of using resistant varieties (FAO, 2023)^[4].

4.6 Climate-Smart Approaches

Climate change has altered the dynamics of rice disease outbreaks, particularly for *Fusarium* species, which thrive under conditions of high humidity and temperature variability. Climate-smart agricultural practices can reduce the susceptibility of rice crops to spikelet rot while improving the resilience of farming systems.

- **Water-Saving Technologies:** As previously mentioned, AWD irrigation techniques can mitigate the risk of *Fusarium* infections by reducing periods of waterlogging (Sharma et al., 2022)^[7].
- **Resilient Cropping Systems:** Diversified cropping systems, incorporating crop rotation and intercropping with non-host plants, can contribute to the reduction of pathogen pressure while improving soil health (Kaur & Prasad, 2023)^[6].

5. Conclusion

The discovery of *Fusarium sulawesiense* as the causal agent of spikelet rot in rice (*Oryza sativa* L.) in India marks a critical development in plant pathology, highlighting the pathogen's capacity to significantly affect rice production. This review synthesizes the most recent research and data, underscoring the need for urgent attention from the scientific community and agricultural stakeholders. Recent studies confirm the pathogen's capacity for rapid dissemination in humid, rice-growing environments, often exacerbated by climate change, such as erratic rainfall and prolonged periods of high humidity. Yield losses ranging from 15% to 40% have been reported in severely infected fields (Singh et al., 2023; Kumar et al., 2023)^[17, 8], indicating its potential to pose a substantial threat to India's rice-dependent economy and food security. Moreover, the pathogen's ability to produce mycotoxins raises additional concerns about grain safety and human health, as noted in recent toxicological analyses (Sharma et al., 2023)^[15]. The lack of resistant rice varieties against *F. sulawesiense* calls for intensive breeding programs, focusing on genetic resistance and tolerance to the disease. Integrated pest and disease management (IPDM) strategies that combine crop rotation, judicious fungicide use, and biocontrol agents have shown promise in controlling *F. sulawesiense* in early-stage infections (Patel et al., 2024)^[12]. Moreover, molecular diagnostic tools, such as real-time PCR and genomic sequencing, are becoming increasingly effective in early pathogen detection and monitoring, allowing for timely interventions (Gupta et al., 2024)^[5].

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