

Prevalence and Losses Caused by Red Rot (*Colletotrichum falcatum*) Disease in Sugarcane Grown in District Tando Muhammad Khan

Pir Arshad Ahmed Jan Sirhandi

PhD Scholar, University of Sindh Jamshoro

Assistant Professor, Govt Boys Degree College Tando Muhammad Khan

Corresponding Author: Pir Arshad Ahmed Jan Sirhandi sirhandijan79@gmail.com

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ABSTRACT

*Sugarcane is a major cash crop in Pakistan but production is limited by fungal pathogens, especially red rot (*Colletotrichum falcatum*). The aim of this study was to determine the incidence and yield losses of red rot in sugarcane fields of District Tando Muhammad Khan, Sindh. The study employed a quantitative field approach to assess disease incidence, severity, and their effects on yield components in the field. The findings showed red rot disease was prevalent throughout the study region, with incidence ranging from low to high in different fields and cane varieties. Disease severity was found to be positively correlated with yield losses, suggesting the later stages of the disease impacted cane weight, stalk height and the quality of sugar cane juice. Yield reduction was found to be significant, demonstrating the impact of the disease on farmers and sugar companies. Favorable environmental factors for disease development and progression included high humidity and moderate temperatures. This research underscores the need for a comprehensive disease management approach, including the development of resistant varieties, optimal cropping practices, and early detection techniques. Managing red rot disease is crucial to improve sugarcane yields and promote sustainable farming practices.*

Keywords: Sugarcane, Red rot, *Colletotrichum falcatum*, Disease incidence, Crop loss, Tando Muhammad Khan, Pakistan, Plant pathology, Fungal pathogen, Crop management

INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is a major economic crop globally and plays a vital role in Pakistan's agriculture. It is the main source of sugar and plays a vital role in rural livelihoods and industry. However, sugarcane production is hampered by various biotic stresses, especially fungal pathogens that impact the yield and quality. Of particular concern is red rot disease, caused by the fungus *Colletotrichum falcatum*, which is considered to be the most serious disease of sugarcane and has resulted in crop losses in many sugarcane-producing countries (Viswanathan, 2010; Singh et al., 2018). This disease has attracted attention because of its prevalence and the damage it causes to the sugarcane industry.

Red rot predominantly affects the stalks of the plant, causing red-coloured patches with white flecks in the infected tissues. The disease results in tissue deterioration, resulting in drying and lodging of cane. The disease is spread through natural openings or wounds and flourishes in suitable environmental conditions. Humid and moderately warm environments, such as those found in the sugarcane-growing regions of Sindh such as District Tando Muhammad Khan (Rao et al., 2016; Khan et al., 2021), are conducive to the spread of the disease. Such climatic conditions play a crucial role in promoting the growth and spread of the disease, which makes it challenging to manage.

Disease incidence of red rot is affected by various factors, including host susceptibility, crop rotation and management. Monocropping with susceptible varieties and using diseased seed cane are major factors that increase the survival and spread of the pathogen. Researchers have revealed that continuous cropping and

absence of crop rotation leads to increased inoculum load in the soil, which in turn increases disease severity (Ghazanfar et al., 2017; Alam et al., 2019). Additionally, poor hygiene and field management practices provide an opportunity for pathogen survival and spread. Lack of effective disease management coupled with traditional farming practices has also exacerbated the situation in Pakistan.

The causal pathogen, *Colletotrichum falcatum*, is highly variable in pathogenicity, with different strains varying in virulence. This makes it difficult to develop resistant varieties and other control strategies. It produces conidia that can be disseminated by irrigation, rain and infected crop debris, resulting in rapid spread of the disease within and across fields (Singh et al., 2016; Viswanathan and Rao, 2019). The pathogen's long survival in crop residues and soil adds to the challenges of disease control. Disease severity is also influenced by environmental conditions such as temperature, relative humidity, and rainfall (Kumar et al., 2020).

Apart from the yield loss, red rot disease significantly affects the quality of sugarcane. Canes affected by red rot disease show lower sucrose content and higher fiber content than healthy canes, which in turn affects sugar recovery. The reduced juice quality leads to reduced sugar yield, and also impacts sugar mill efficiency. Research has shown that the disease, when it occurs in severe form, can result in reduction of sugar recovery, which in turn has an impact on farmers' and sugar industry's income (Hossain et al., 2020; Khan et al., 2022). This effect on yield and quality highlights the economic significance of the disease.

The problem is especially worrying in District Tando Muhammad Khan, given the agro-climatic suitability for sugarcane cultivation as well as disease development. It has a warm climate with relatively high humidity, favorable for *C. falcatum* growth and development. Additionally, the use of traditional cultivation methods and the lack of disease-resistant sugarcane varieties compound the issue. Lack of information about early symptoms and disease control measures further contribute to the disease incidence and losses (Raza et al., 2021; Ali et al., 2023).

Combining cultural, biological and chemical strategies are essential for controlling red rot disease. Planting disease-free material and resistant varieties is the best method of disease control. Furthermore, good sanitation, crop rotation and harvesting at the right time can help control the disease. While fungicides are sometimes employed, they are generally ineffective due to the nature of the pathogen (internal) and environmental considerations (Viswanathan and Padmanaban, 2008; Singh et al., 2018). So, more focus needs to be on prevention rather than cure.

The application of new techniques in plant pathology and biotechnology has opened up new avenues for the control of red rot disease. Molecular methods for pathogen identification and characterisation have enhanced knowledge of the pathogen's diversity and epidemiology. These technologies can be applied to breed resistant sugarcane varieties and develop appropriate disease control measures. But the use of these technologies is not widespread in many developing countries including Pakistan owing to lack of resources and technical know-how (Kumar et al., 2020; Ali et al., 2023).

Overall, the sugarcane disease red rot (caused by *Colletotrichum falcatum*) is a major concern in District Tando Muhammad Khan and other sugarcane-growing areas in Pakistan. The widespread occurrence of the disease, its high impact on productivity and quality, demand urgent attention from scientists, policy makers and farmers. Knowledge of the epidemiology, distribution and losses caused by the disease is crucial for its management. This research seeks to address this knowledge gap by surveying the incidence of red rot disease and the losses due to the disease in the study area, providing a foundation for future studies and control strategies.

LITERATURE REVIEW

Sugarcane red rot caused by *Colletotrichum falcatum* is known as one of the most devastating diseases of sugarcane. This pathogen is well-studied because of its devastating effects on yield and quality, and its capacity to spread with favourable climatic conditions. Previous research has described red rot as a "cancer of sugarcane" due to its chronic and destructive nature, which can result in total loss of yield in the susceptible varieties (Viswanathan and Padmanaban, 2008). Over the years, there have been more studies on the variability of the pathogen and epidemiology of the disease, as well as host resistance and control strategies.

The fungus *Colletotrichum falcatum* is a hemibiotrophic pathogen that infects sugarcane internodes, causing red discoloration, white areas and ultimately desiccation of the cane. Genetic analyses have indicated that the pathogen has a complex genome and is closely related to other *Colletotrichum* pathogens of cereal crops, suggesting its evolutionary diversity and adaptation (Rao et al., 2016). Recent genomic studies have also revealed genetic variability in *C. falcatum*, leading to variations in pathogenicity and virulence (Silva et al., 2024) in different areas and varieties. This presents a major obstacle in managing the disease, especially in areas where multiple virulent populations are present.

Epidemiology and environmental conditions affecting red rot disease have been highlighted in a number of studies. The main factors contributing to disease incidence and severity include high humidity levels, moderate temperatures, and continuous rainfall (Kumar et al., 2020; Hossain et al., 2020). These factors are commonly found in tropical and subtropical countries, such as Pakistan, making sugarcane plantations vulnerable to infection. The disease is transmitted through diseased planting material, water, and plant residues, which provide a source of inoculum (Singh et al., 2016). Monocropping and the absence of crop rotation also contribute to the survival and spread of the pathogen (Ghazanfar et al., 2017).

Numerous studies have reported the economic losses caused by red rot disease. Yield losses have been reported to vary between 10% and 75%, depending on the level of infection, susceptibility of the cultivar, and other environmental factors (Hossain et al., 2020). In extreme cases, fields may be completely destroyed, resulting in substantial losses for growers and the sugar industry. Besides yield loss, the disease negatively impacts juice quality by reducing sucrose concentration and increasing the fiber content, which affects sugar extraction (Singh et al., 2018). The recent study confirms that red rot disease remains a threat to sugarcane production worldwide, including outbreaks in new areas (Silva et al., 2024).

Sugarcane resistance has been regarded as one of the most promising control measures against red rot disease. Many studies have assessed sugarcane varieties for resistance to *C. falcatum*. For example, in screening trials, some cultivars have been found to be resistant or moderately resistant, whereas others are highly susceptible (Ghazanfar et al., 2017). But resistance is often short-lived because of the evolution of new races of the pathogen. This phenomenon, referred to as "breakdown of resistance", is common in sugarcane-producing areas, and suggests the need for ongoing breeding to develop resistant sugarcane varieties (Viswanathan, 2010; Singh et al., 2018).

Apart from resistance, cultural control is important in managing disease. Maintaining field hygiene, clearing diseased plant debris, using disease-free planting material and rotating crops are key practices to minimize disease spread (Khimani et al., 2024). Recent research demonstrated that planting with healthy material greatly reduces the initial inoculum and the time of disease development. Additionally, modifying planting and irrigation schedules can reduce conducive environmental conditions for disease development. However, cultural controls may not be sufficient, particularly in regions with a high disease burden.

Pesticide control, such as fungicide treatments, has been investigated to control red rot disease. In vitro and in vivo experiments have shown varying degrees of efficacy of fungicides against *C. falcatum* (Khosro

et al., 2024). But the internal nature of the pathogen makes chemical control less effective because fungicides may not reach the pathogen inside the stalk. Also, over-dependence on chemicals can have environmental, economical and resistance issues. Consequently, integrated disease management (IDM) practices, which involve a combination of cultural, biological and chemical control measures, are now advocated.

Biotechnology and precision farming technologies have also provided new opportunities for red rot disease diagnosis and control. Genetic tools like polymerase chain reaction (PCR) have enhanced pathogen detection accuracy and efficiency, allowing timely management (Kumar et al., 2020). What's more, image processing and machine learning models have been created to accurately detect early symptoms. For instance, deep learning models have reached accuracy rates of over 98% in identifying disease symptoms of red rot, demonstrating their potential deployment for disease surveillance (Shirazi and Yousaf, 2024). These tools can be used to improve disease monitoring and management in agriculture.

Another critical aspect emphasised in the literature is the diversity and evolution of pathogens in disease outbreaks. Research has shown that *C. falcatum* populations are highly variable, allowing the pathogen to respond to various environmental factors and overcome plant resistance (Rao et al., 2016; Silva et al., 2024). This highlights the importance of pathogen population surveillance and region-specific disease management. The use of molecular tools and conventional plant pathology techniques has been proposed to overcome this challenge.

Within Pakistan, although there is limited but crucial research on red rot. It has been reported that the disease is widespread in sugarcane-growing areas of Pakistan, such as Punjab and Sindh, with suitable climatic conditions for the growth of pathogen (Khan et al., 2021; Raza et al., 2021). But there is a dearth of detailed studies on the disease's prevalence and losses at the district level, such as Tando Muhammad Khan. This research gap underscores the need for region-specific studies to understand the disease and its management in specific areas.

In summary, the literature indicates that red rot disease continues to pose a significant challenge for sugarcane growers. While much progress has been made in understanding the pathogen and its management, factors like variability of the pathogen, resistance overcome and low uptake of new technologies present barriers to effective disease control. A holistic approach, including the use of resistant varieties, best practice farming and advanced technologies, is crucial for disease control. Future studies should concentrate on local studies, especially in the less-studied areas, to give a full picture of disease occurrence and economic losses.

METHODOLOGY

Research Design

A field-based quantitative research design was used to study the occurrence and effects of red rot (*Colletotrichum falcatum*) in sugarcane. The study aimed to quantify the incidence, severity and yield losses of the disease in the field. This approach was deemed suitable as it enabled disease observations in the field.

Study Area

The study was carried out in District Tando Muhammad Khan, Sindh, Pakistan, which is one of the major sugarcane-producing areas. The site was chosen because of the suitable weather for sugar cane production and the occurrence of red rot disease. The warm climate and higher humidity of the district favoured the growth and spread of *C. falcatum*.

Sampling Technique

Multistage random sampling was used to select the study sites. Firstly, the major sugarcane-growing union councils of the district were identified. Then, villages were randomly chosen from each union council. Sugarcane fields from these villages were then selected by simple random sampling. Around 20-30 fields were surveyed to cover the study area.

Data Collection Procedure

Surveys were conducted in the field during the main growing season in which disease symptoms appeared. A systematic sampling approach was adopted in each field. Five points were sampled in a diagonal line across the field and at each point, ten sugarcane plants were randomly chosen. This resulted in a total of 50 plants being assessed for disease per field.

Assessment of Disease Incidence

The disease incidence was calculated as the proportion of infected plants out of the total plants examined. Infected plants displayed characteristic red rot symptoms, including red discolouration and white patches. The incidence was measured using the formula:

$$\text{Disease Incidence (\%)} = (\text{Number of infected plants} / \text{Total number of plants observed}) \times 100$$

Assessment of Disease Severity

Disease severity was determined by using a disease severity scale based on the degree of internal tissue damage and symptom development. Stalks of some plants were cut open to check for internal discolouration. The ratings were made according to the published scales (Viswanathan, 2010; Singh et al., 2018). Average severity index was determined for the field.

Estimation of Yield Loss

The yield loss caused by the red rot disease was measured by comparing infected and non-infected plants in the field. The weight of the cane, length of the stalk and the health of the plant were measured. Yield loss percentage was estimated, comparing average yield of healthy and infected plants using the usual methods. This method gave an indication of the loss in field conditions.

Collection of Supporting Information

Information on crop management, varietal susceptibility, and farmers' experiences was obtained in farmers' interviews. This information was used to supplement field observations and aid in the understanding of disease establishment. But these data were not incorporated into statistical analyses and were used only for descriptive purposes.

Environmental Data Collection

Weather data, such as temperature and humidity, were collected throughout the season to evaluate their impact on disease. Additional data from local agricultural authorities were also consulted to confirm field observations and to detect seasonal variations in disease outbreaks.

Data Analysis

Data were analyzed using descriptive statistics. Disease incidence and severity were presented as percentage and mean values, respectively. Yield loss was determined and tabulated. Furthermore, basic correlation analysis was conducted to investigate the correlation between disease severity and yield loss, since this is biologically significant in plant disease research (Kumar et al., 2020). Reliability of data was ensured by not using sophisticated statistical methods, as the study was based on field observations and measurements.

Ethical Considerations and Reliability

Observations were made in farmers' fields with their permission. Observations and data were taken in accordance with standard plant pathology practices. Multiple observations were conducted to reduce the error and enhance consistency in disease rating.

DATA ANALYSIS AND RESULTS

Data from the field observations showed that the red rot disease (*Colletotrichum falcatum*) was common in sugarcane fields in District Tando Muhammad Khan. The level of disease incidence varied among surveyed areas, reflecting the variability of sugar cane varieties, crop management and environment. The symptoms like red colour inside stalk, white patches and discoloured tissues were seen in most of the surveyed fields. The average incidence suggested that red rot was a serious disease in the region and affected sugarcane production.

Table 1: Disease Incidence (%) in Surveyed Fields

Field No.	Total Plants Observed	Infected Plants	Disease Incidence (%)
1	50	12	24.0
2	50	18	36.0
3	50	10	20.0
4	50	22	44.0
5	50	15	30.0
6	50	8	16.0
7	50	20	40.0
8	50	14	28.0

Table 1 indicated that the incidence ranged between 16% to 44% in different fields with an estimated average incidence of about 29.75%. The highest incidence observed in Field 4 may be explained by the

presence of susceptible varieties and poor hygiene in the field. Conversely, lower incidence in other fields implied good crop management or cultivation of less susceptible varieties. The wide variation in the incidence of the disease illustrated the impact of local crop management factors on disease development.

Disease Severity Analysis

To further understand the impact of disease, we also measured the severity of disease, which refers to the damage to the plant tissue. This gave us a better understanding of the impact of the disease, as it captured the progress of the disease through the stalk.

Table 2: Disease Severity Index in Selected Fields

Field No.	Average Severity Score (0–5 Scale)	Severity (%)
1	2.0	40.0
2	3.0	60.0
3	1.5	30.0
4	3.5	70.0
5	2.5	50.0
6	1.0	20.0
7	3.2	64.0
8	2.2	44.0

The severity results showed that fields with the highest incidence also had the highest severity. Once again, Field 4 had the highest severity (70%), suggesting it was in the later stages of infection and had considerable damage to the stalk tissues. Fields with low severity, like Field 6, indicated early infection or resistance. This confirmed that disease severity was correlated with disease progression and was a key factor in yield loss.

Yield Loss Assessment

Yield loss was measured by comparing the yield of healthy and diseased plants grown in the same fields. This analysis showed a significant decline in cane weight and yield in response to red rot infection.

Table 3: Comparison of Yield Parameters

Parameter	Healthy Plants	Infected Plants	% Reduction
Average Cane Weight (kg)	1.8	1.1	38.9
Stalk Length (cm)	220	165	25.0

Juice Quality (Brix %)	20.5	15.2	25.9
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The findings showed that the infected plants had consistently lower values for all the parameters. The most significant reduction was in the cane weight (33.9%) which had a direct impact on the farmer's income. Likewise, the decrease in stalk height and juice quality also indicated the negative effect of red rot disease on yield and sugar recovery. These results were in line with other reports of significant yield losses from red rot infection (Hossain et al., 2020; Singh et al., 2018). Impact of Disease Severity on Yield In order to understand the relationship between disease development and crop yield loss, a correlation study was done between severity and yield loss.

Table 4: Correlation Between Severity and Yield Loss

Field No.	Severity (%)	Yield Loss (%)
1	40.0	28.0
2	60.0	42.0
3	30.0	20.0
4	70.0	48.0
5	50.0	35.0
6	20.0	15.0
7	64.0	45.0
8	44.0	30.0

The results clearly showed a positive correlation between severity and yield loss. The fields showing higher percentages of severity had higher yield losses. This established that as the disease spread throughout the plant, the productivity loss was greater. The link between disease severity and yield reduction was justified by the fact that the disease caused extensive tissue damage, thereby limiting the transport of nutrients and affecting plant growth. Thus, severity rating was a good predictor of yield loss.

In conclusion, the data analysis showed that red rot disease was widespread in District Tando Muhammad Khan and had a profound impact on the yield and quality of sugarcane. The differences in disease incidence and severity among fields indicated that disease management, environmental factors and different varieties contributed to disease occurrence. The positive correlation between disease severity and yield loss also highlighted the importance of early diagnosis and disease management. This study confirmed the economic significance of red rot disease and the need to adopt integrated disease control strategies to reduce losses.

DISCUSSION

The current study confirmed that sugarcane production in District Tando Muhammad Khan is still threatened by red rot disease caused by *Colletotrichum falcatum*. The moderate to high disease incidence in the studied fields indicated that the pathogen was prevalent in the area. This confirmed previous reports that red rot is one of the most destructive diseases of sugarcane in tropical and subtropical regions,

especially in high humidity and temperature areas (Viswanathan, 2010; Singh et al., 2018). The field-to-field variation in disease incidence indicated that the local agronomic practices, cane variety and environmental factors all contributed to the disease incidence.

The severity study also indicated that fields with a higher incidence of disease also had greater damage to internal tissues, suggesting severe disease development. This incidence-severity link is well documented in the field of plant pathology where increased exposure to conducive environmental conditions promotes pathogen growth and disease development (Kumar et al., 2020). In this study, severity was higher in fields with poor sanitation, continuous cropping, and susceptible varieties, which was consistent with earlier reports which stressed the importance of management practices in disease incidence (Ghazanfar et al., 2017; Khan et al., 2021). The survival of *C. falcatum* in residues and infected setts possibly sustained the disease in the region.

The yield loss analysis clearly showed red rot disease significantly affects sugarcane yield. Infected plants were found to have significantly lower cane weight, stalk height and juice quality than the healthy plants. This observation was consistent with previous studies which reported that red rot not only affects biomass production but also negatively impacts the sucrose percentage, hence sugar recovery (Hossain et al., 2020; Singh et al., 2018). The juice quality reduction observed in the current study also highlighted the economic loss of the disease, as it has a direct impact on farmers' and sugar industry's earnings.

The direct correlation between disease severity and yield loss in this study further highlighted the damaging effects of the red rot disease. This suggests that as the disease progressed, the damage to plant tissues and physiological functions increased, leading to higher yield losses. These findings are consistent with other studies, where disease severity was found to be a good predictor of yield loss (Kumar et al., 2020). This correlation underscores the need for early disease identification and management to reduce yield losses.

District Tando Muhammad Khan's environmental conditions seemed to play a significant role in disease development. The hot and humid growing season provided an ideal environment for disease development and spread. These observations were in line with research from other sugarcane-growing areas that point to temperature and humidity as being significantly involved in the development of red rot (Rao et al., 2016; Ali et al., 2023). The repeated sugarcane cultivation in the area and lack of use of resistant varieties also contributed to the issue.

In conclusion, the findings of this study were in close accordance with previous studies, further confirming that red rot disease is still a major threat to sugarcane production. The research also showed the need to combine field observations with prior knowledge to gain a better understanding of the local disease status. The study concluded that unless properly managed, red rot disease will continue to affect sugarcane production and sustainability in the area.

Figure 1: Red rot symptoms in sugarcane stalk



CONCLUSION

In summary, the current study showed that red rot disease caused by *Colletotrichum falcatum* is widespread in sugarcane fields of District Tando Muhammad Khan and has a large negative impact on yield. The occurrence and severity of the disease were found to differ among fields, suggesting environmental, varietal and management effects. The study showed a significant loss in yield and quality attributes, such as cane weight, stalk length and juice quality, confirming the economic significance of the disease. The positive correlation between disease severity and yield loss also confirmed that the disease at a severe stage causes significant damage and yield loss. In conclusion, the study offered a holistic picture of the occurrence and consequences of red rot disease, highlighting the need for sustainable and effective disease management to ensure the productivity of sugarcane in the region.

RECOMMENDATIONS

In light of the results obtained in this study, we recommend farmers practice integrated disease management to minimise red rot disease. It's important to recommend disease-free and resistant varieties of sugarcane, as resistance is the most effective and environmentally safe control measure. Appropriate field hygiene measures, such as removing and destroying diseased plant remains, should be encouraged to reduce the pathogen inoculum load. Avoiding monocropping and rotating crops should be promoted to break the disease cycle. Education and extension activities should be promoted to inform farmers about disease symptoms and management practices. Environmental monitoring and intervention can also aid in disease control. Finally, research should be conducted to develop resistant varieties and employ modern diagnostic techniques to enhance disease management in sugarcane-producing areas.

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