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Red Rot of Sugarcane: A Comprehensive Review of Pathogen Biology, Epidemiology and Current Management Paradigms

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

India is the largest consumer and second largest producer of sugar in the world and sugar is an important commercial commodity in the world. *Colletotrichum falcatum*is one the most known pathogen of sugarcane crop causing red rot disease. Red rot disease is considered as the main constraint for sugarcane production and due to its devastating nature also known as cancer of sugarcane. The pathogen variability plays crucial role in the breakdown of red rot resistance as it is highly variable in nature, the resistant sugarcane varieties gets prone to red rot within a short time period. Farmers should pay adequate attention in adoption of improved production technologies

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toovercome the problem of sugarcane production. Red rot continues to be the major production constraint that always threatens crop productivity as well as economic stability in the sugar sector. Continuous research, awareness among farmers, and coordinated disease management efforts will be required to reduce the menace caused by this "cancer of sugarcane" and ensure resilient and profitable sugarcane cultivation for the future.

Keywords: Sugarcane; Red rot disease; Colletotrichum falcatum.

1. INTRODUCTION

Sugarcane is a monocotyledon, perennial belong to family Gramineae (Poaceae), class Monocotyledons and order Glumaceae, sub-family Panicoidae, tribe Andripogoneae and sub tribe Saccharininea and genus *Saccharum.*Genus *Saccharum*contains six speciesnamely *Saccharum officinarum* (2n=80), *Saccharum barberi* (2n=82-142), *Saccharum sinense* (2n=60-194), *Saccharum robustum* (2n=60-80), *Saccharum spontaneum* (2n=40-128) and*Saccharum edule* (2n=74) (Daniels and Roach, 1987). “It has four growth phases *viz.,* Germination phase (up to 45 days after planting-DAP), Tillering phase (45-120 DAP), Grand growth phase (120-270 DAP), Maturity or Ripening phase (270-360 DAP) each with a specific climatic requirement” (Moore and Frederik, 2014; Ashwin et al., 2017).

2. PRODUCTION AND PRODUCTIVITY

“India is the largest consumer and second largest producer of sugar in the world. Indian sugar industry is the second largest agro based industry, next only to the textiles which contributes around 6% of the agricultural GDP. Sugarcane holds an important position in the Indian economy” (Anonymous, 2006; 2008). Sugarcane is an important agro industrial and cash crop of India as well as world. Sugarcane is cultivated about 26.9 million hectare with worldwide harvest of 1910 million tonnes. It is grown in 123 countries on an about 24 million hectare land. The important sugarcane producing countries are Brazil, India, China, Thailand, Pakistan, Mexico, Colombia, Indonesia and Philippines. Quantitatively, it is world’s largest crop by production. Worldwide, the area under sugarcane cultivation is 24 M ha. In 2023, India contributes area under sugarcane production of 58.83 lakh hectares, production 494.22 million tonnes, and productivity 84.01 T/Ha” (Veerbhan and Malik, 2025; Hossain et al., 2020).

“The major sugarcane growing states are Uttar Pradesh, Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh and Bihar etc. In Uttar Pradesh, during 2023- 24 Sugarcane was cultivated in an area of 2179 thousand hectares and production was 176706 thousand tones with the productivity of 81100 Kg. per hectares (Viswanathan, 2012). Sugarcane is cultivated over about 5 million ha area including both sub-tropical and tropical regions of the country (Khan et al., 2011). Sugarcane is a very valuable product because of its ability to store high concentrations of sucrose, or sugar, in the stem and more recently for the production of ethanol, which is an important renewable bioenergy source” (Moore and Frederik, 2014).

Table 1. Sugarcane: All-India Area, Production and Yield

Year	**Area (Million Hectares)**	**Production (Million Tonnes)**	**Yield (Kg./Hectare)**
2014-15	5.07	362.33	71511
2015-16	4.93	348.45	70720
2016-17	4.44	306.07	69001
2017-18	4.74	379.90	80198
2018-19	5.06	405.42	80105
2019-20	4.60	370.50	80497
2020-21	4.85	405.40	83566
2021-22	5.18	439.42	84906
2022-23	5.89	490.53	83349
2023-24	5.74	453.16	78953
2024-25*	5.36	450.12	84006

*Source: E,S &E Division, DA&FW; *3rd Advance Estimates*

3. THE DISEASE AND ITS IMPORTANCE

The agro-climatic conditions influence the nutrient utilization efficiency, crop growth, diseases and pest incidence that individually or collectively affect cane yield (Singh et al., 2010). There are various biotic and abiotic factors responsible for yield loss but diseases are one of the major causes of concern**.** Diseases in sugarcane are mainly caused by fungi, bacteria, virus and phytoplasma. Apart from biotic causes nutritional imbalance is also responsible for various diseases. Among them fungal diseases got international importance (Bhatri et al., 2012; Costa et al., 2021) due to its impact on yield loss. As the crop remains in the field for about 12-18 months, it passes through various critical stages. The estimated average loss in crop production due to fungal disease is about 18-31%.

Table 2. List of sugarcane diseases in India

S. No.	Disease	Causal organism (s)
Major fungal diseases		
1	Red rot	*Colletotrichum falcatum* Went
2	Smut	*Sporosorium scitamineum*
3	Wilt	*Fusarium sacchari*
4	Pineapple disease	*Ceratocystis paradoxa*
5	Pokkahboeng	*Giberella moniliformis, Fusarium moniliforme*
6	Rust	*Puccinia melanocephala, P. kuehnii*
7	Stalk rot (rind disease)	*Phaeocytostroma sacchari* (Ell. & Ev.) B. Sutton
8	Eye spot	*Bipolaris sacchari* E. Butler (Shoemaker)
9	Brown spot	*Cercospora longipes*
10	Brown stripe	*Cochliobolus stenophilus, Helminthosporium stenopilum*
11	Ring spot	*Leptosphaeria sacchari* var Biedade Haan
12	Seedling rot (damping-off)	*Pythium, Rhizoctonia*
13	Yellow spot	*Mycovellosiella koepkei* (Kruger) Deighton
Minor fungal diseases		
1	Alternaria leaf spot	*Alternaria alternata* (Fr) Keisler
2	Arrow rot	*Fusarium* sp.
3	Banded sclerotial disease	*Rhizoctonia solani, Thanatephorus sasakii*(Shirai) Tu & Kimborough
4	Basal stem root and sheath rot	*Marasmius sacchari*, Mycelia sterilia
5	Black leaf spot	*Phyllacora sacchari* P. Henn
6	Black rot	*Ceratocystis adiposa* (E. Butler) C. Moreau
7	Bulaklak (Bunga)	*Aeginetiasaccharicola* Bakh
8	Collar rot	*Hendersomina sacchari* E. Butler
9	Curvularia leaf spot	*Curvulrialunata, C. Pallescens*
10	Downy mildew	*Peronosclerospora saccahri, P. Philippinensis*
11	Dry rot	*Botryosphaeria saccahri* E. Butler
12	Ergot	*Claviceps purpurea* (Fr) Tul
13	False floral smut	*Claviceps* sp.
14	Fusariumsett or stem rot	*Giberella fujikuroi* (Sawada) Wollenweber
15	Helminthosporium leaf scorch	*Helminthosporium sacchari*
16	Leaf blight	*Leptosphaeria taiwanensis* Yen & Chi
17	Leaf scorch	*Stagonospora sacchari* Lo & Ling
18	Leaf-splitting disease	*Peronosclerospora miscanthi* (T. Miyake) C.G.Shaw
19	Periconia leaf spot	*Periconia atropurpurea, P. Saraswatipurensis*
20	Pestalotia leaf spot	*Pestalotia fuscescens Sor*. var. *sacchari*
21	Phyllosticta leaf spot	*Phyllosticta sorghina* Sacc
22	Red rot of leaf sheath	*Pellicullariarolfsii, Hypochnuscentrifuges*
23	Red spot of leaf sheath	*Cercospora vaginae*
24	Schizophyllum rot	*Schizophyllum commune* Fr
25	Seeding blight	*Alternaria, curvularia, Drechslera, Cochliobolus*

S. No.	Disease	Causal organism (s)
26	Sheath rot	*Cytospora sacchari*
27	Sooty mould	*Capnodium* sp., *Fumago sacchari*Speg
28	Target blotch	*Helminthosporium* sp.
Bacterial diseases		
1	Gumming	*Xanthomonas campestris*pv.*vasculorum* (Cobb) Dye
2	Leaf scald	*Xanthomonas albilineans* (Ashby) Dowson
3	Ratoon stunting	*Leifsoniaxyli subsp. xyli* Davis et al.
4	Red stripe	*Pseudomonas rubrilineans* (Lee et al.) Stapp
5	Spindle rot	*Pseudomonas rubrileneans*pv. Spidulifoliens
6	Stinking rot	*Pseudomonas desaiana* (Burkholdre) Savulescu
Viral/Phytoplasma diseases		
1	Mosaic	*Sugarcane mosaic virus, Sugarcane streak mosaic virus*
2	Leaf freckle Sugarcane	*Bacilliform virus*
3	Red leaf mottle	*Pea nut clump furovirus*
4	Streak Maize	*Streak virus*
5	Striate mosaic	Virus (?)
6	Spike	Virus (?)
7	Yellow leaf Sugarcane	*Yellow leaf virus*
8	Grassy shoot	Grassy shoot phytoplasma

Source: Viswanathan and Rao (2011)

The major fungal diseases of sugarcane are red rot, wilt and smut. Red rot disease is considered as the main constraint for sugarcane production in India.Red rot disease of sugarcane is so devastating in nature that it has been referred to as “cancer of sugarcane”.In 1895, the situation aggravated and convulsed the backbone of farmers in sugarcane growing regions. In context to this situation, the regular cane area was reduced from about 2500 ha (1895) to 500 ha and in subsequent year a number of major outbreaks have been reported (Dattamajumdar, 2008). The epidemic of 1938-40 and 1992-96 in India were disastrous when the most widely grown varieties were wiped out of cultivation and the disease still remains to be serious concern. “The sugar industry in India suffered losses more than 500 million US dollars every year due to red rot” (Viswanathan and Samiyappan, 1999). “The fungus is prevalent mainly in the Indian sub-continent, keeps on producing new pathogenic strains leading to the breakdown of resistance in the newly released varieties. As pathogen variability plays crucial role in the breakdown of red rot resistance. As pathogen is highly variable in nature, the resistant sugarcane varieties gets prone to red rot within a short time period resulted in failure of some important Indian commercial sugarcane varieties. It reduces cane weight by up to 29% and loss in sugar recovery by 31% in moderately susceptible varieties and 100% loss in highly susceptible varieties” (Hassan et al., 2011; Silva et al., 2024). “The affected canes recorded 25-75% reduced sucrose content than the healthy canes. Sugar production is considerably reduced due to lowered weight and sucrose content of the canes reduced quality of juice. The pathogen hydrolyzed the stored sucrose by producing the invertase enzyme which breaks the sucrose molecule (crystalline state) into its component namely glucose, fructose (amorphous state), water and raw juice which converted into molasses thereby causing huge loss in the recovery of sugar”.

Causal organism: “The pathogen belongs to Kingdom: Fungi, Divison: Eumycota, Subdivision: Deuteromycotina, Class: Coelomycetes, Order: Melanconiales, Family: Melanconiaceae, Genus: *Colletotrichum*, Species: *falcatum*. *Glomerella tucumanensis* (Speg) Arx & Muller is the teleomorph (perfect stage) of *Colletotrichum falcatum* Went, the causal agent of sugarcane red rot. This perfect stage was earlier named as *Physalospora tucumenensis* (speg). The taxonomic status was re-examined by Arx and Muller who referred it to the genus *Glomerella* as *Glomerella tucumanensis* (Speg) Arx and Muller. The teleomorph belongs to Kingdom: Fungi, Phylum: Ascomycotina, Sub-phylum: Pezizomycotina, Class: Sordariomycetes, Subclass: Sordariomycetidae, Order: Glomerellales, Family: Glomerellaceae, Genus *Glomerella*and Species *tucumanensis*. *Colletotrichum falcatum* is a facultative saprophyte and keeps on changing its nature due to factors such as mutation, heterokaryosis

and adaptation. The red rot fungus *Colletotrichum falcatum* can be readily isolated from infected tissues. The key morphological identification features of fungus *Colletotrichum falcatum* are colony colour and growth rate, pigment production, asexual fruiting bodies known as acervuli (minute and velvety that is formed on the surface of the host part) usually with setae (thick-walled sterile hyphae usually pointed at the tip, dark-pigmented and unbranched) (Hassan et al., 2011). Its mycelium is bothintercellular and intracellular, linear or club shaped, hyaline conidiophores producing elongated, thin walled, single celled, colourless, uninucleate, falcate (sickle shaped), slimy conidia containing granular protoplasm having a large oil globule, absence or presence of the telomorph, greenish black chlamydospores and with the presence of appressoria (thick-walled swellings at the end of a hypha useful in attaching the fungus to thesurface of the host before penetration of the tissue) which are mostly used for genetic characterization. Morphological description" by Abbott (1938) reported that "length of conidia ranged from 16 to 40 µm. Sickle shaped or falcate conidia measuring 16-40 x 5-7 µm in size with oil globule in the middle. Conidial germinate by producing short, long and branched promycelia (Hassan et al., 2012). The colony is dark grey or white to light ashy in colour and had a velvety surface or cottony or sub floccose in texture. Its sexual stage known as *Glomerella tucumanensis* is responsible for the survival of the fungus on decaying leaves and formation of new virulent pathological races which are responsible for the frequent epidemics. *Colletotrichum falcatum*is a facultative saprophyte known to produce a phytotoxic metabolite which is identified as an anthroquinone compound".

Fig. 1. Red rot infected canes

Fig. 2. Mid-rib infection of red rot

Fig. 3. Development of eye/spilndle shaped spot on mid-rib

Symptomology: "Different types of symptoms were recorded on different varieties at various surveyed locations. The most common symptoms observed in red rot affected fields is discoloration and yellowing of the young crown leaves followed by drying of entire stalks in the affected field. The discoloration and withering continued from the tip to the leaf base until the whole crown withered and the plant died within 10-15 days. As the disease advanced the entire stalk rotted and the central tissues became pithy. The internodal tissues were reddened especially the vascular bundles, which were intensely red with many cross wise white patches, interrupting the reddened tissues as described by earlier workers" (Duttamajumder, 2008; Viswanathan, 2010; Viswanathan & Samiyappan, 1999a). "The internodes shrinked in affected varieties and when such canes were splitted open, large cavities were found in the centre and the pithy tissues appeared reddish-brown with vinegar and alcoholic smell. Infected cane also showed the red discoloration throughout the length of the stalk with longitudinal cavities containing fungal mycelium" (Viswanathan & Samiyappan, 1999b). Later the affected tissues turn muddy, shrink and dry out. Often a profuse whitish growth of the fungal mycelium was observed in the brown black colour grown of the host tissues. In some cases black, minute, velvety bodies, representing the acervuli of the fungus in the intermodal tissues were also seen. The other most important phase of the disease is the infection on leaf mid rib and leaf lamina. Typical midrib symptoms can be observed in most of the highly susceptible cultivars. High intensity of midrib lesions in the field is observed after summer rains and during monsoon months". symptoms include elongated lesions on the midribs, reddish areas on the sheaths and infrequently small reddish brown spots on the leaf blades. On the midribs, the infection first appears as small reddish brown spots on the upper and lower surface" (Viswanathan et al., 2011). "These may expand rapidly in both directions and coalesce to form long lesions. The length of the lesions may vary from few inches to entire length of the leaf or they may remain as a series of unconnected lesions. In the beginning, the spots are bright red at first but later become straw coloured in the centre with dark margins and frequently covered with black, powdery fruiting structures of the fungus. If conditions are conducive, all the newly emerging leaves show midrib lesions" (Viswanathan et al., 2011). "In the ratoon crop, the field symptoms of the disease are similar to those in plant crop. Additionally a crop stand with crop-free patches is commonly seen as a result of germination failure in stubbles" (Viswanathan, 2010).

Mode and sources of infection: "The pathogen mainly infects canes through nodes and other portals of entry are growth ring, leaf scar, buds and root primordia.The pathogen may also enter the stalk through root cuts, growth cracks and cut end of the setts" (Singh and Singh, 1989). "The perpetuation of red rot is through infected setts,

diseased stubble or debris and by resting propagules in the soil. A major source of primary spread of the pathogen is by infected planting material. The fungus is not a true soil borne organism and cannot persist more than 4 months in soil. The fungus could survive for 7 months when diseased debris was placed on the soil surface. It has also been claimed that in north Bihar fungus survives in the soil for one year. A stroma forming strain of the fungus, which may have a longer survival in the soil, has been reported by the IARI" (Chona, 1980).

Dissemination: "The primary transmission of the pathogen is mainly through diseased sets andsoil, while secondary transmission or spread takes place mainly through rain and irrigation water. Heavy dew also disseminates inoculum" (Chona, 1980). The conidia produced on the rind wash down with water and cause infection through nodes. Dissemination of inoculums by means of wind appears more difficult because of the mucilaginous nature of the spore mass. But the occurrence of the disease in the upper portion of the canes provides an indication of an aerial mode of dispersal of the inoculums.

Epidemiology of red rot disease: Red rot was first reported and described from Java (Indonesia) in 1893 by Went and within a decade it was also reported in several other countries such as West Indies (1904), India (1901), Hawaii (1908), USA (1910), Australia (1925) and others. The disease was eventually identified in all sugarcane growing countries of the world but it is regarded as a major disease in the sub-tropical countries, particularly the southern United States, India and Queensland. It was the case of decline and failure of the Noble canes in the cultivation at the time in Louisiana in 1926, bringing the industry almost to the brink of ruin. The first epidemic of red rot was reported in India by Barber in 1901 near Godavari Delta of Andhra Pradesh in two varieties Namula and Keli. Further in 1906, it was reported in Champaran and Muzaffarnagar in northern Bihar and in 1906 E. J. Butler, mycologist from Pusa, Bihar proposed a name "red rot" which is accepted worldwide.

In 1930, it caused the failure of POJ 213 which had placed the commercial noble canes and was considered resistant to red rot when released. In 1932, at IARI (Pusa, Bihar), a severe infection of the disease occurred in Co 210 suddenly after its complete absence for six years. "In the Punjab at Ferozepore, the cultivation of the local Ponda variety (a thick noble cane) had to be abandoned due to the ravages of red rot. The most widespread and precedent epidemic of red rot that the country has experienced is the one in eastern U.P. and northern Bihar during 1938-40, resulting in the complete devastation of thousands of cane fields of the predominant commercial cane variety, Co 213 and reducing the cane crush of several sugar mills in eastern U.P. to one-third of the normal in 1938-39 and to about one-half in 1939-40 owing to poor supplies of cane. The disease has several epidemics to its credit and virtually during 1938-1940 it wiped out sugarcane cultivation in northern Uttar Pradesh and Bihar" (Duttamajumder and Mishra, 2004). A reduction of about 70,000 tons of sugar production in the country was attributed to the red rot epidemic. It was also observed that contrary to the prevailing idea, the epidemic was not confined to low-lying or ill-drained fields only. Co 213 was badly affected in high land or low-lying fields of acidic or alkaline soils. "The others cane varieties Co 299 and Co 331 were also badly affected within 2-3 seasons and had to be replaced. During 1946-47, red rot broke out again as a severe epiphytotic in U.P. on Co 312. In the following three years, Co 313, Co 421, Co 453 and BO 11 were widely affected in northern Bihar and Uttar Pradesh. Red rot is a widely distributed and has been reported in 68 sugarcane growing countries of the world (Bharti et al., 2012). This disease has several epidemics to its credit and virtually during 1938-1940 it wiped out sugarcane cultivation in northern Uttar Pradesh and Bihar" (Duttamajumder and Mishra, 2004). "In Punjab, the disease was most common on Co 312 and Co 313 in Jagadhari area and some other tracts from 1950-51 onwards and on Co 312 in Delhi state during 1957-58. During 1959-61, a severe red rot epidemic was observed in the new Bhojpur factory zone in east Punjab (Chona, 1980). These epidemic compiles for sugarcane farmers to replace the varieties like Co 312 (1939-40, *Tarai* region), Co 312, Co 453, BO 11, BO 17, and BO 54 (1946-47, Punjab and *Tarai* region), BO 10 and BO 11 (1964-65, Uttar Pradesh), Co 997, CoS 562 and BO 3 (1968-69, Uttar Pradesh), Co 419 and Co 658 (1970-72, Andra Pradesh, Pondicherry and Tamil Nadu), CoC 671 (1981-82, Andra Pradesh), Co 997, Co 785, Co 419 (1982-84, Kerala), CoC 671 (1986-92, Tamil Nadu and Gujrat), CoC 92061(1992-98, Tamil Nadu and Pondicherry).

Red rot is one of the major constraints for sugarcane cultivation in India and many widely

cultivated cultivars were removed from cultivation due to their breakdown of resistance to red rot. Such breakdown is attributed due to emergence of new pathotypes in the fungal flora that have adapted to the cultivars under cultivation process by course of time. Successive failure of cultivars was attributed to the appearance of new strains. Emergences of new variants arecontinuing process over decades and many cultivars succumbed to the disease during each epidemic. The popular cultivars such as CoC 671 and CoC 92061 were removed from cultivation in disease endemic regions due to their high susceptibility to red rot. However, in the epidemics on CoC 671 and CoC 92061 in Tamil Nadu, Pondicherry, Karnataka and Gujarat complete crop drying in hundreds of hectares was noticed.

The red rot disease is a regular threat of knocking down the important commercial cultivars throughout the country, in Uttar Pradesh the disease was noticed in CoJ 64 and Co1148 (2-10%) in Shahjahanpur and Saharanpur, up to 75% in CoPant 84211 and CoJ 84 in Sitapur, Lakhimpur-Kheri districts, CoS770 and CoS 802 in central UP, and up to 100% red rot on CoPant 84212 and CoJ 83 in Pallia and Lakhimpur-Kheri Districts (Viswanathan, 2010). The disease has become a major threat to sugarcane cultivation in Punjab also. The other varieties Co7717, Co 89003, CoJ 78, CoS 767, CoS 88230 and CoPant 84212 also showed red rot in certain location in Punjab (Anon, 2006). In Haryana, loss to sugarcane production was noticed in 8 sugar mills of 13 surveyed. However, 12 to 100 % incidence was recorded on sugarcane varieties *viz.,* CoS 95422 and CoSe 98231 in most of the areas in Eastern Uttar Pradesh like Basti, Maharajganj, Kushinagar, Sardarnagar and Sant Kabirnagar (Anon, 2008). Since, the regular severe incidence of red rot disease has recorded in many important commercial cultivars of sugarcane in different parts of Uttar Pradesh, India. An extensive survey of sugarcane growing areas of Eastern, Central and Western regions of Uttar Pradesh *viz.,* Basti, Maharajganj, Kushinagar, Sardarnagar, Santkabirnagar, Deoria, Gorakhpur, Khalilabad, Lucknow, Bareilly and Shahjahanpur were conducted during July and August months of 2007-2008 to 2008-2009 to study the incidence of red rot disease (clump basis) on six different commercial growing cultivars of sugarcane (CoSe 8436, CoS 91269, CoJ 64, CoSe 95422, CoSe 98231 and CoLk 8102) under natural field conditions at different locations. And the symptoms of red rot disease were recorded on these cultivars. During survey of sugarcane crops in different parts of U. P., 100% incidence of red rot was recorded in variety CoSe 8436 at Shahjahanpur and Bareilly, variety CoLk 8102 at Basti and variety CoSe 95422 at Kushinagar respectively. Besides severe incidence of red rot ranging from 5-42 % was also recorded in west, central and eastern part of U. P. on CoS 8436, CoS 91269, CoJ 64, CoSe 95422, CoSe 92423 and CoLk 8102 sugarcane varieties.

4. GENETIC VARIABILITY OF THE PATHOGEN

“The pathogenic variability in *Colletotrichum falcatum*was first studied in 1920 by Edgerton and Moreland and later it was reported by various other researchers. In 1935 variability *in Colletotrichum falcatum*was described culturally as light and dark isolates byAbbott in correlation with pathogenicity and then they were identified with alphabets” (Rafay and Singh, 1957) and numbers without any designated nomenclature. *Colletotrichum falcatum* isolates in India are classified into different pathotypes based on their differential reaction. Later on theefforts were made to identify the pathotypes based on differential host interaction in tropical and subtropical regions in different periods of time and the pathotypeswere also named as tropical and subtropical based on origin. However, the results became inconsistent due to the influence of weather factors.

“Colletotrichum falcatum shows a great diversity in virulence and new physiological races have been frequently reported from different parts of the world. The Red rot pathotypes can easily distinguished by its morphological, physiological and pathogenic differences. Molecular techniques based on polymerase chain reaction PCR are being also used as a tool in genetic mapping, molecular taxonomy, evolutionary study, characterization and diagnosis of fungal species. Characterization of *Colletotrichum falcatum* by molecular techniques also helps to understand the mechanism of pathogenic variation in order to develop effective management strategies” (Adzitey *et al.,* 2013).

5. CONCLUSION

Red rot of sugarcane, incited by *Colletotrichum falcatum*, remains the most devastating and chronic menace in India and other major sugarcane-producing countries due to its

historical importance, frequent epidemics, and potential to destroy entire commercial cultivars. The urgent need for continued and integrated management approaches is underlined by the pathogen's great genetic variability prompted by mutation, heterokaryosis, and rapid adaptation, which helps it to escape host resistance within a very short period, causing repeated breakdown of resistant varieties that farmers heavily rely on.

Understanding the biology, epidemiology, and pathogenic diversity of *C. falcatum* will be central to developing durable disease management strategies. While substantial progress has been made in disease diagnosis, varietal screening, and cultural management, the continued emergence of new pathotypes has further challenged breeding programs. Active control thus requires an integrated approach using resistant varieties, pathogen-free seed material, appropriate agronomic practices, crop sanitation, and regular monitoring of pathotype diversity. Molecular tools for strengthening breeding programs, increasing the capacity of surveillance networks, and implementing adaptive management plans, targeting region-specific needs, will be crucial to sustainability.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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