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Research Article
Colletotrichum Falcatum

Major Fungal Diseases of Sugarcane in North India under Climate Change: Red Rot, Wilt, Smut, and Pokkah Boeng

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Sugarcane supports farm income and the rural processing economy of North India, yet its productivity and seed-cane security are repeatedly threatened by four important fungal diseases: red rot, wilt, smut, and pokkah boeng. Red rot, caused by Colletotrichum falcatum, remains the most destructive because infected planting material, aerial and local spread, pathogen variation, and large areas under a genetically uniform cultivar can combine to produce severe epidemics. The breakdown of Co 0238 resistance and the spread of pathotype CF13 illustrate this risk. Wilt, mainly associated with Fusarium sacchari, causes progressive drying, stalk shrinkage, internal purplish-brown discoloration, pithiness, and characteristic cavities; mixed infection with red rot can intensify stalk loss. Smut, caused by Sporisorium scitamineum, is both sett-borne and airborne and is recognized by its black whip-like sorus, thin shoots, and excessive tillering. Pokkah boeng is linked to a Fusarium fujikuroi species complex and ranges from chlorosis and twisting of young leaves to knife-cut lesions and top rot. Warm and humid periods, irregular rainfall, waterlogging, drought or heat stress, and changes in crop phenology may alter the timing and severity of these diseases. Evidence is strongest for short-term weather-disease relationships; direct attribution of individual outbreaks to long-term climate change remains limited. This review focuses on Uttar Pradesh, Bihar, Uttarakhand, Haryana, Punjab, and adjoining subtropical areas. It proposes an integrated framework based on clean and traceable seed, resistant-variety portfolios, rapid diagnosis, removal of inoculum, avoidance of diseased ratoons, drainage, balanced crop nutrition, need-based registered treatments, and district-level surveillance.

Keywords: colletotrichum falcatum, fusarium sacchari, sporisorium scitamineum, fusarium fujikuroi species complex, CF13, clean seed cane, disease forecasting, climate adaptation, subtropical india

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1. Introduction

Commercial sugarcane (Saccharum spp. hybrids) is a long-duration crop that links farmers, labourers, sugar mills, distilleries, and several small rural industries. North India - especially Uttar Pradesh, Bihar, Uttarakhand, Haryana, and Punjab - contains a large subtropical cane belt. The crop remains in the field through contrasting seasons and is commonly continued as a ratoon. This long exposure increases contact with pathogens, variable weather, water stress, and management constraints. Disease therefore affects not only cane yield, but also sucrose recovery, seed-cane availability, varietal replacement, and the stability of mill catchments.

Red rot, wilt, smut, and pokkah boeng represent distinct but connected threats. Red rot and wilt are destructive stalk diseases and may occur together. Smut is a systemic bud and shoot disease whose airborne teliospores create an area-wide risk, especially when susceptible ratoons are retained. Pokkah boeng mainly damages the young spindle and growing point. Their causal fungi, diagnostic signs, survival strategies, and immediate field responses differ, but all four can move through or be amplified by weak seed systems and extensive cultivation of susceptible varieties (Viswanathan, 2020; Chhabra et al., 2020; Bhuiyan et al., 2021).

Climate change adds uncertainty to these established host-pathogen problems. India has experienced rising mean temperature, changes in temperature extremes, and greater monsoon variability, with further warming and heavier precipitation events projected (Krishnan et al., 2020). Weather can influence pathogen growth, dispersal, infection, and host defence, while waterlogging, heat, drought, crop injury, and altered planting or irrigation practices can modify host susceptibility. Climate is not a stand-alone cause of an epidemic, however. Susceptible cultivars, infected seed, diseased ratoons, delayed roguing, poor drainage, and unbalanced nutrition may be equally or more important at farm scale.

This review examines how red rot, wilt, smut, and pokkah boeng develop and are managed in North Indian sugarcane under increasingly variable weather. It emphasizes differential diagnosis, pathogen and varietal change, seed-cane health, and actions that remain practical across wet, dry, and heat-stressed seasons. Its central argument is that climate resilience will come from coordinated prevention and surveillance rather than from any single treatment.

2. Review Approach and Scope

This critical narrative review synthesizes peer-reviewed studies and official Indian reports on red rot, wilt, smut, and pokkah boeng of sugarcane, with emphasis on North India. Searches combined the disease and pathogen names with climate, weather, epidemiology, diagnosis, resistance, seed health, and integrated management. Priority was given to Indian field studies, multi-location evidence, and authoritative reviews; international work was used where it clarified pathogen biology or control. Because methods, cultivars, and disease scales varied widely, a quantitative meta-analysis was not attempted, and seasonal weather associations were not treated as proof of long-term climate-change attribution.

3. North Indian Production Environment and Changing Disease Risk

The subtropical cane belt has a strongly seasonal production environment. Spring and autumn planting, hot summers, monsoon rainfall, cool winters, variable irrigation, and one or more ratoons create several host and pathogen niches. Monsoon growth produces dense canopies and prolonged humidity, while low-lying or compacted soils may remain waterlogged after intense rain. Later dry spells can impose physiological stress. Seed movement, irrigation channels, diseased stubbles, and ratooning connect fields within a mill zone. These features influence all four diseases, although red rot and wilt mainly damage stalks, smut establishes systemically through buds, and pokkah boeng develops in young spindle tissue.

The Ministry of Earth Sciences assessment reports that India warmed by about 0.7 °C during 1901–2018 and projects further warming, more frequent warm extremes, and changes in rainfall extremes (Krishnan et al., 2020). For the Indo-Gangetic region, the important disease question is not simply whether seasonal rainfall rises or falls. The timing, intensity, spacing, and duration of wet and dry periods determine leaf wetness, splash dispersal, soil saturation, canopy humidity, and host stress. A season with long dry intervals interrupted by intense rainfall may produce a different disease pattern from a season with the same total rainfall distributed evenly.

Climate effects also operate indirectly. Higher evaporative demand may increase irrigation frequency; extreme rain may increase waterlogging; warmer winters may alter ratoon survival and pathogen carry-over; and heat or drought can weaken the crop or increase injury. Farmers may respond by changing planting dates, irrigation, nitrogen application, or variety choice. These responses can reduce or amplify disease. Risk models should therefore include crop stage, cultivar, seed source, ratoon status, field history, drainage, and injury alongside weather variables (Zhao & Li, 2015; Msomba et al., 2024; Raj et al., 2025).

4. Red Rot: Pathogen, Symptoms, and Epidemic Development

4.1 Causal Organism and Diagnostic Features

Red rot is caused by Colletotrichum falcatum Went. It is a distinct sugarcane pathogen and should not be confused with other Colletotrichum species associated with anthracnose diseases. External symptoms may include yellowing, loss of vigour, drying of the upper leaves, and progressive death of the stalk. The most useful field diagnosis comes from splitting the cane longitudinally. Affected internodes show red discoloration interrupted by characteristic white crosswise patches, often accompanied by a sour or alcoholic odour. In advanced infection, the pith may become hollow or dry. External symptoms alone are not sufficient because drought, borer injury, wilt, and other stalk disorders can produce similar drying.

Laboratory confirmation is important for seed nurseries, resistance testing, and unusual outbreaks. Isolation on suitable media, morphological examination, and molecular assays can confirm C. falcatum. PCR-based tools improve specificity and can detect infection before severe field symptoms, but sampling remains critical because the pathogen may be unevenly distributed within stalk tissue (Hossain et al., 2020; Viswanathan, 2021a).

4.2 Sources of Inoculum and Routes of Spread

Infected seed cane is a major pathway for introducing red rot into a clean field. Apparently healthy stalks from a diseased crop can carry the pathogen, and cutting tools may transfer contaminated tissue. The pathogen can also persist in diseased stubbles, debris, and infected clumps. Soil-borne inoculum can infect susceptible cultivars under favourable conditions, although its importance depends on inoculum load, host resistance, soil moisture, and the presence of infected crop residues (Viswanathan et al., 2020). Water movement can redistribute inoculum within and between fields.

Recent severe epidemics in subtropical India have renewed attention to aerial spread. Sporulation on infected tissues and movement of conidia during humid, rainy weather can extend infection beyond the original clump and help explain rapid field-to-field expansion where a susceptible cultivar dominates (Viswanathan, 2023). The epidemiology should therefore not be reduced to seed transmission alone. Clean seed is essential, but area-wide control also requires removal of symptomatic clumps, avoidance of infected ratoons, and surveillance in surrounding fields.

4.3 Pathogen Variation, Co 0238, and Pathotype CF13

The most important recent lesson from North India is the interaction between pathogen variation and varietal uniformity. Co 0238 became exceptionally successful because of its cane yield, sugar recovery, and adaptation to the subtropical belt. Its rapid expansion, however, created a large and genetically uniform host population. New or previously rare virulence combinations in C. falcatum gained a major selective and epidemiological advantage once they could infect this cultivar.

The resistance breakdown of Co 0238 was linked to a newly designated pathotype, CF13. Controlled pathogenicity tests showed that isolates associated with the breakdown had a distinct virulence pattern, and later surveys found CF13 widely distributed in the subtropical region (Viswanathan et al., 2022, 2025a). This pattern resembles the classic “Vertifolia effect,” in which reliance on a highly productive resistance background is followed by widespread vulnerability when the pathogen population shifts.

Climate variability may influence when and how rapidly epidemics develop, but it does not replace this central host–pathogen explanation.

Pathotype surveillance must therefore be continuous. Resistance ratings are not permanent labels, and a cultivar that performs well against one inoculum mixture may fail against another. Screening programmes should use representative and recently collected isolates, multiple inoculation methods where appropriate, and repeated evaluation across environments (Malathi & Viswanathan, 2012; Viswanathan & Selvakumar, 2020). Variety release and seed multiplication should be linked to post-release disease monitoring so that early changes in resistance are detected before the cultivar occupies most of a mill zone.

4.4 Weather Sensitivity and the Climate-change Hypothesis

Red rot development is generally favoured by warm conditions, high humidity, rainfall, and prolonged soil or canopy moisture, particularly when susceptible cane is present. Rain can promote spore production, splash, and movement through water, while waterlogging can stress roots and stalks. Warm nights may extend periods suitable for pathogen growth. Conversely, severe heat or drought may suppress some infection processes but weaken the crop, promote cracking or injury, and increase later vulnerability when rain returns. These responses are stage-specific and need local validation.

Under climate change, the highest concern is an increase in favourable disease windows and greater year-to-year unpredictability rather than a uniform rise in disease every year. Intense rainfall after dry stress, repeated humid nights, delayed drainage, or warmer conditions during susceptible crop stages may accelerate epidemics. However, recent red rot losses in North India cannot be attributed to climate change without accounting for CF13, Co 0238 dominance, infected planting material, and field sanitation. The strongest defensible statement is that changing weather can modify epidemic timing and severity in a production system already made vulnerable by pathogen virulence and genetic uniformity (Kumar & Mukhopadhyay, 2025; Raj et al., 2025).

5. Pokkah Boeng: A Fusarium-associated Disease Complex

5.1 Aetiology and Taxonomic Caution

Pokkah boeng is associated with a complex of Fusarium species rather than a single universally dominant organism. Studies from different countries have implicated members of the Fusarium fujikuroi species complex, including F. sacchari, F. verticillioides, F. proliferatum, and F. andiyazi. Other Fusarium names occur in the literature, but detection from symptomatic tissue does not by itself prove causation. Reliable identification requires multilocus sequencing or a validated species-specific assay, followed by pathogenicity testing and re-isolation where possible (Lin et al., 2014; Costa et al., 2019; Bao et al., 2023).

Indian work established that F. sacchari isolates can be associated with both wilt and pokkah boeng, although the two diseases have different symptom patterns and epidemiological expression (Viswanathan et al., 2017). Recent molecular mapping of Indian isolates, available online in 2025, further showed that multiple Fusarium species occur among isolates from wilt and pokkah boeng samples (Viswanathan et al., 2025b). This diversity has practical consequences. A fungicide or biocontrol agent effective against one isolate may be less active against another, and resistance screening based on one isolate may underestimate the field challenge.

5.2 Symptom Phases and Differential Diagnosis

Pokkah boeng symptoms usually begin in the young spindle leaves. The chlorotic phase includes pale green or yellow areas, mottling, wrinkling, twisting, and shortened or malformed leaves. As disease progresses, reddish-brown streaks or ladder-like lesions may appear. In the knife-cut phase, narrow transverse cuts or splits develop in the leaf sheath or young stalk tissue. In the acute top-rot phase, the growing point rots and may die, leading to top death or side-shoot development. These phases are related but are not synonyms; a plant may show some features without progressing to severe top rot (Poorniammal et al., 2024).

Differential diagnosis is essential because herbicide injury, boron deficiency, top-borer damage, twisted top disease, and physical injury can also distort spindle leaves.

Red rot and wilt primarily produce internal stalk discoloration and clump decline, whereas smut is identified by excessive tillering and a dark whip-like sorus. Early pokkah boeng is concentrated in young leaves and the growing point. Mixed infection and secondary Fusarium colonization are possible, so research and nursery certification should combine symptom scoring with isolation and molecular identification.

5.3 Disease Cycle and Regional Epidemiology

Fusarium produces abundant asexual spores that can move in air currents and rain splash. Infected or colonized crop debris, soil, alternate plant substrates, and seed cane may contribute to survival and introduction. Spores deposited on the spindle can reach tender tissues where water films, humidity, and injury favour infection. Insects, including mealybugs, have been proposed as contributors to tissue injury or pathogen movement in some production systems, but their regional importance should be confirmed before they are treated as a universal primary vector.

Field observations in the north-west alluvial plains of Bihar found that minimum temperature, relative humidity, and rainfall were positively associated with pokkah boeng incidence, while maximum temperature and sunshine showed negative relationships in the studied season (Minnatullah et al., 2020). These results fit the broader observation that the disease is often most visible during rapid monsoon growth. Nevertheless, a single-season correlation does not establish a fixed threshold for all North Indian districts. Cultivar, planting date, crop age, canopy density, and inoculum pressure influence the response.

5.4 Climate-related Emerging Risks

Pokkah boeng risk may increase when warmer nights and humid conditions coincide with actively growing spindle tissue. Heavy rain can increase splash and leaf wetness; waterlogging can stress the host; and storm injury may create infection courts. More irregular monsoon rainfall may also produce alternating stress and rapid growth. Tender, nitrogen-rich tissue formed after irrigation or rain can be especially vulnerable, although this interaction requires more field testing in North Indian cultivars.

The changing climate may also alter the Fusarium community. Species and isolates differ in temperature response, sporulation, aggressiveness, and fungicide sensitivity. A warmer or more variable environment may favour a different subset of the complex, while greater movement of seed cane can introduce genotypes adapted to other areas. This is a plausible emerging risk, but long-term population data from North India are insufficient. Routine species-level surveillance is therefore more useful than assuming that the same causal species occurs in every district.

6. Wilt: A Destructive Fusarium Stalk Disease

6.1 Causal Agent and Diagnostic Features

Sugarcane wilt in India is mainly associated with Fusarium sacchari. Symptoms generally become clear after several months of growth and include gradual yellowing and drying of foliage, loss of vigour, stalk shrinkage, and poor cane weight. On splitting an affected stalk, the ground tissue may show light to dark purplish-brown discoloration, pithiness, and elongated or boat-shaped cavities, sometimes with an unpleasant odour. Unlike red rot, wilt usually lacks the diagnostic red tissue interrupted by white crosswise patches. Isolation and molecular confirmation are important because red rot, borer injury, drought, and mixed stalk rots can produce similar external drying (Viswanathan, 2020).

6.2 Inoculum, Spread, and Disease Development

Infected seed cane, diseased stubbles, crop residues, and infested soil can contribute to wilt carry-over. Root or stalk injury, insect damage, poor soil aeration, and host stress may help the pathogen enter or colonize vascular and pith tissues. The disease can persist unnoticed until stalk filling, which makes visual selection of seed from an affected field unsafe. The close relationship between wilt- and pokkah boeng-associated Fusarium populations also requires careful sampling: finding F. sacchari alone does not replace symptom-based disease definition and pathogenicity evidence (Viswanathan et al., 2017, 2025b).

6.3 Weather Sensitivity and Climate-related Risk

Wilt expression is influenced by crop stress and soil-water conditions. Warm, humid, and rainy periods may favour Fusarium activity and symptom increase, while drought, waterlogging, or alternating wet and dry conditions can weaken roots and stalks. Future risk may therefore depend on moisture extremes and crop injury as much as on mean temperature. North Indian weather-linked studies are still too short and local to define universal thresholds or to attribute wilt outbreaks directly to climate change; cultivar, soil, irrigation, borer damage, and seed source must be analysed with weather (Raj et al., 2025).

6.4 Management Priorities

Wilt management is preventive. Seed should not be taken from fields with unexplained drying or internal stalk discoloration. Resistant or consistently tolerant varieties, clean nurseries, removal of affected clumps and stubbles, rotation in heavily affected fields, balanced irrigation and nutrition, good drainage, and control of stalk injury reduce risk. A diseased field should not be ratooned or retained for seed. Fungicides cannot be expected to cure advanced systemic infection, so diagnosis and source-field exclusion are more reliable than late rescue treatments.

7. Smut: An Airborne and Sett-borne Systemic Disease

7.1 Pathogen, Symptoms, and Diagnosis

Sugarcane smut is caused by the biotrophic fungus Sporisorium scitamineum (formerly Ustilago scitaminea). Its characteristic sign is a long, curved, whip-like sorus that emerges from the shoot apex or a side shoot and is initially covered by a thin silvery membrane. When this membrane ruptures, masses of black teliospores are released. Infected stools may also develop many thin tillers, shortened internodes, narrow leaves, and a grassy appearance. Because the fungus can remain systemic before whip emergence, apparently normal planting material from an affected field is unsafe (Bhuiyan et al., 2021; Rajput et al., 2021).

7.2 Disease Cycle and North Indian Importance

Smut is both sett-borne and airborne. Teliospores released from whips can travel with wind and survive dry conditions for months. Once the spores germinate, compatible sporidia infect developing sugarcane buds. The fungus then grows systemically in meristematic tissue before the next whip forms. Ratoons often carry a higher risk because infected stools and latent buds remain in the field. Surveys across North Indian mill zones have documented smut in Haryana, Punjab, western Uttar Pradesh, Bihar, and Uttarakhand, with much higher incidence in some ratoon fields than in plant crops (Chhabra et al., 2020).

7.3 Weather Sensitivity and Climate-related Risk

Smut risk reflects a sequence of conditions rather than a single weather variable. Dry and windy periods can favour teliospore release and long-distance dispersal, whereas warm conditions with sufficient bud-surface moisture support germination and infection. Drought-stressed or poorly managed ratoons may express greater damage, but cultivar susceptibility and infected seed remain dominant drivers. Climate change may shift spore survival, dispersal, bud infection, and ratoon phenology, yet validated North Indian models linking these stages to long-term climate trends are not yet available (Bhuiyan et al., 2021; Raj et al., 2025).

7.4 Management Priorities

The main measures are resistant varieties, clean seed, recommended heat or registered sett treatments, and rapid removal of inoculum. Smut whips should be enclosed before cutting, removed before the membrane ruptures, and destroyed safely; the affected stool should also be removed. Diseased fields should not supply seed or be ratooned. Seed nurseries must be checked several times because one mature whip can release a large spore load. Fungicides have a preventive role in approved sett-treatment programmes, but they do not replace resistance, sanitation, and area-wide surveillance (Chhabra et al., 2020; Rajput et al., 2021).

Table 1: Comparison of red rot, wilt, smut, and pokkah boeng in North Indian sugarcane

Disease	Causal agent, diagnostic clue, and spread	Weather or stress sensitivity	First management priority
Red rot	C. falcatum; red internal tissue with white crosswise patches; infected setts, stubbles, soil or water, and aerial or splash-dispersed conidia.	Warm, humid, rainy periods and prolonged moisture; waterlogging and host stress can intensify epidemics.	Exclude infected seed; rogue clumps and stubbles; avoid diseased ratoons; diversify cultivars and monitor pathotypes.
Wilt	F. sacchari; purplish-brown pith, shrinkage, pithiness, and boat-shaped cavities; infected setts, stubbles, residues, and soil.	Warm rainy periods and soil-moisture extremes; drought, waterlogging, injury, and poor aeration may predispose stalks.	Use clean seed and tolerant varieties; reject affected source fields; improve drainage and avoid ratooning diseased fields.
Smut	S. scitamineum; black whip-like sorus, thin shoots, and profuse tillering; infected setts and airborne teliospores infect buds systemically.	Dry wind aids spore release and movement; warmth and bud moisture favour infection; susceptible ratoons amplify risk.	Plant resistant clean seed; use approved sett treatment; remove covered whips and stools before spores disperse.
Pokkah boeng	Fusarium fujikuroi species complex; twisted chlorotic spindle, knife-cut lesions, and top rot; conidia move in air or splash, with debris and seed associations.	Warm nights, high humidity, rain, leaf wetness, rapid spindle growth, and canopy density favour symptoms.	Confirm diagnosis; use inspected seed and resistant material; remove severe top rot and reduce prolonged canopy humidity.

Source: Synthesized from Viswanathan (2020, 2021a, 2023), Chhabra et al. (2020), Bhuiyan et al. (2021), Rajput et al. (2021), Viswanathan et al. (2017, 2022, 2025a, 2025b), and Poorniammal et al. (2024).

8. Joint Effects on Crop Productivity and Seed Systems

The four diseases damage different tissues but converge on the same economic outcomes. Red rot and wilt destroy millable stalks, reduce cane weight and juice quality, and may occur together. Smut diverts growth into thin, unproductive tillers and contaminates the surrounding crop with teliospores. Pokkah boeng damages the spindle and growing point, reducing canopy development and sometimes killing the top. Severe infection by any of them can lower cane supply and sugar recovery and remove fields from the seed chain.

Co-occurrence complicates diagnosis and control. Red rot-wilt complexes can obscure the internal symptom pattern, while borer injury, water stress, or secondary fungi may mimic stalk disease. Distorted tops may be confused with pokkah boeng, nutrient disorders, or insect injury, whereas early smut can remain latent until whip emergence. Farmers may respond with a late fungicide spray when the decisive action should instead be source-field rejection, roguing, or termination of the ratoon.

Regional cost is amplified when seed replacement is slow. A popular cultivar can occupy a large area before resistance erosion or disease susceptibility is recognized. Once red rot, wilt, or smut enters a seed chain, infected material can distribute risk across a mill zone. Varietal concentration also increases inoculum pressure for neighbouring fields. Seed health, cultivar diversification, and post-release disease monitoring must therefore be managed as linked regional services.

9. Integrated, Climate-informed Disease Management

9.1 Surveillance, Diagnosis, and Decision Thresholds

Surveillance should begin in seed nurseries and continue through commercial fields and ratoons. Red rot and wilt scouting should intensify from monsoon onset through maturity, using stalk splitting to distinguish internal symptoms. Pokkah boeng surveys should focus on actively growing spindle leaves during warm, humid periods. Smut inspection must be frequent enough to detect whips before their membrane ruptures. Reports should record cultivar, crop age, plant or ratoon status, seed source, incidence, severity, field history, drainage, and recent weather.

A tiered diagnostic system is practical. Field signs provide the first alert: red-white stalk mottling for red rot, purplish-brown pith and cavities for wilt, a black whip for smut, and spindle distortion or top rot for pokkah boeng. Isolation and microscopy can support local confirmation, while PCR, qPCR, or LAMP can be used for nurseries, latent infection, unusual outbreaks, and pathogen surveillance.

Molecular detection must be interpreted with symptoms and sampling because pathogen DNA does not by itself establish disease severity or causation.

9.2 Healthy Seed Cane and Nursery Hygiene

Healthy planting material is the foundation for all four diseases. Seed cane should come from inspected, traceable nurseries that remain free of red rot and wilt symptoms, smut whips, and severe pokkah boeng. Source fields should be monitored more than once because latent infection or late symptom development may be missed during a single visit. Cutting tools and sett-treatment equipment should be cleaned between lots, and infected or unverified cane should never be mixed with certified material.

Heat, aerated-steam, or registered fungicidal sett treatments can reduce selected sett-borne infections, especially in a validated smut-control programme, but schedules must follow current official recommendations. Treatment cannot rescue heavily infected cane or substitute for a clean source. A three-tier seed system - breeder or nucleus, foundation, and certified or commercial seed - should retain lot identity so that a disease focus can be traced and contained.

9.3 Resistant Varieties and Varietal Diversification

Host resistance is the most scalable tool, but it should be deployed as a portfolio rather than a monoculture. Mill zones should avoid allowing one cultivar to dominate plant and ratoon area. Replacement cultivars should combine acceptable yield and sugar recovery with resistance or stable tolerance to locally important red rot pathotypes, wilt, smut, and pokkah boeng. Diversification reduces the probability that a new virulence type, Fusarium population, or smut strain can exploit most of the regional crop at once.

Red rot screening should include locally relevant pathotypes, including CF13 where appropriate. Wilt evaluation needs clear internal symptom criteria and multi-environment field validation. Smut screening should use standardized inoculum and observations across plant and ratoon crops, while pokkah boeng testing should include several well-characterized Fusarium isolates and separate chlorotic, knife-cut, and top-rot phases.

Molecular selection can accelerate breeding, but predicted resistance must be validated under representative pathogen pressure and field environments.

9.4 Field Sanitation, Ratoon Management, Drainage, and Nutrition

Red-rot- or wilt-affected clumps should be uprooted with stubbles and destroyed safely under local recommendations. Such fields should not supply seed or be ratooned. Smut whips should be covered and removed before rupture, followed by removal of the affected stool. Severe pokkah boeng top rot should be removed after diagnosis. Irrigation water and tools should not carry inoculum from affected fields into clean nurseries, and heavily affected sites should be rotated with a suitable non-host crop.

Drainage is a climate-adaptation measure as well as a disease-management practice. Field levelling, open drains, soil-structure maintenance, and avoidance of prolonged standing water reduce stress after intense rain. Irrigation should match crop demand and soil condition, avoiding both persistent saturation and severe drought. Excessive nitrogen can produce dense, tender growth, whereas balanced potassium and other nutrients support host resilience. Nutrition should follow soil testing and official recommendations; it cannot cure systemic infection.

Pokkah boeng management should emphasize canopy health and reduction of prolonged humidity around the spindle. Wilt risk calls for attention to soil aeration, root and stalk injury, and borers where locally important. Smut requires strict whip removal and ratoon decisions. Insect injury and mealybug or borer infestation should be recorded and managed through integrated pest management when confirmed; broad insecticide use is not justified solely by a fungal disease diagnosis.

9.5 Chemical and Biological Tools

Chemical control has a supporting and mainly preventive role. Red rot and wilt are difficult to cure once stalks are systemically infected. Approved smut sett treatments can reduce seed-borne risk, and early protective treatment may reduce pokkah boeng in some situations, but performance depends on timing, species or strain, application quality, and local registration.

Product choice must follow current labels and official advisories, and modes of action should be rotated where permitted. Blanket spraying after severe symptoms wastes inputs and delays sanitation.

Biological control is promising but evidence must be described accurately. Trichoderma, Bacillus, Pseudomonas, and endophytic bacteria have shown antagonism or defence-related effects against Fusarium or smut in laboratory, greenhouse, or selected field studies. These results do not guarantee area-wide control in a long-duration crop exposed to heat, rain, irrigation, and variable soils. Formulation quality, shelf life, compatibility with sett treatment, and replicated multi-location trials are needed. Biologicals are most credible as part of nursery hygiene and integrated soil and plant health, not as a stand-alone cure.

9.6 Weather Services and an Operational Early-warning Framework

A useful warning system should combine weather forecasts with cultivar, crop, seed, and disease information. Red rot risk indices could include susceptible-variety area, CF13 or other pathotype reports, ratoon proportion, humid or rainy days, and waterlogging. Wilt indices need soil-moisture stress, drainage, crop injury, and field history. Pokkah boeng indices should include crop age, spindle growth, minimum temperature, humidity, rain or leaf wetness, and canopy density. Smut indices should combine infected seed or whip reports, susceptible ratoons, wind conditions, and warm moist periods suitable for bud infection.

Warnings should trigger specific actions: intensified scouting, stalk splitting, whip removal, laboratory sampling, drainage inspection, seed-movement restrictions, and grower communication. They should not automatically trigger blanket pesticide spraying. Forecast performance must be tested for sensitivity, specificity, lead time, and economic value. Mobile advisories can support delivery, but mill and extension staff remain essential because they know local cultivar distribution, seed sources, ratoon fields, and access constraints.

Table 2: Climate-informed action plan for a North Indian mill zone

Stage or signal	Red rot and wilt	Smut and pokkah boeng	Shared mill-zone action
Pre-planting and seed selection	Reject cane from fields with stalk drying, red-white mottling, purplish pith, or cavities; verify nursery history.	Reject smutted source fields and cane with spindle distortion or top rot; use approved sett treatment where recommended.	Maintain traceable multi-variety nurseries; inspect and test high-value seed lots; clean cutting equipment.
Early crop and ratoon establish ment	Map previous foci; inspect gaps and weak clumps; correct drainage and injury risks.	Inspect ratoons for excess tillering or early whips and young crops for spindle symptoms.	Record cultivar, planting date, crop class, seed source, field history, and baseline disease status.
Monsoon, humid spell, or stress event	Increase stalk splitting in susceptible cultivars and ratoons; record waterlogging, drought, and borer injury.	Scout 3-7-month crops for pokkah boeng and inspect susceptible ratoons for whips before rupture.	Use forecast alerts to intensify scouting and sampling, not to trigger automatic blanket spraying.
Confirmed disease focus	Uproot clumps and stubbles; stop seed use and ratooning; inspect nearby fields, tools, and water routes.	Cover and remove smut whips and stools; remove severe confirmed top rot; assess surrounding fields.	Notify mill-zone plant-protection staff, geotag the focus, confirm diagnosis, and trace the seed source.
Post-season review	Update pathotype and Fusarium samples, cultivar ratings, and field restrictions.	Archive representative smut and pokkah isolates and review plant-versus-ratoon response.	Evaluate warning performance and revise next season's variety, nursery, drainage, and surveillance plan.

Source: Proposed framework based on Chhabra et al. (2020), Viswanathan et al. (2021, 2022, 2025a), Bhuiyan et al. (2021), Poorniammal et al. (2024), and Raj et al. (2025).

10. Research Gaps and Priorities

North India has strong disease expertise but lacks harmonized longitudinal datasets that cover all four diseases and can support climate-risk attribution or operational forecasting. The following priorities offer the greatest practical value:

Build a georeferenced surveillance network across sugar mills, state departments, ICAR institutes, and agriculture universities, using common incidence and severity scales for red rot, wilt, smut, and pokkah boeng.

Monitor C. falcatum pathotypes, Fusarium species and aggressiveness, and S. scitamineum population or race structure in major cultivar zones, linking pathogen change to variety deployment, seed movement, and epidemic history.

Validate disease-specific PCR, qPCR, and LAMP assays for asymptomatic seed PCR, qPCR, and LAMP assays for asymptomatic seed cane and define sampling intensity, detection limits, false positives, cost, and decisions triggered by a positive result.

Establish multi-year field experiments that jointly record daily weather, leaf wetness, soil moisture, crop stage, cultivar, seed source, crop class, nutrition, irrigation, injury, and disease progress.

Standardize resistance screening: representative red rot pathotypes, clear internal wilt criteria, plant-and-ratoon smut assessment, and several characterized pokkah boeng isolates with separate symptom phases.

Quantify how latent infection, sett treatment, nursery inspection frequency, ratooning, and source-field exclusion affect downstream disease at acceptable cost.

Test chemical and biological programmes in replicated, multi-location field trials that include pathogen sensitivity, formulation stability, yield, juice quality, environmental effects, and economic return.

Develop and prospectively validate disease-risk models, updating them as varieties, pathogen populations, management practices, and climate conditions change.

The most important methodological improvement is to analyse climate together with host, pathogen, seed, and management. A district model that uses rainfall and temperature but ignores susceptible-cultivar area, infected seed, ratoon proportion, drainage, or whip density may assign the wrong cause to an epidemic. Conversely, a host-pathogen study that ignores extreme rain, soil-moisture stress, wind, and crop stage may fail to explain why disease expanded in one season but not another.

Table 3: Priority questions for a climate-ready disease research programme

Theme	Priority question	Minimum evidence needed	Expected application
Attribution	Are trends in all four diseases changing after accounting for cultivar, seed source, ratoon area, pathogen population, and management?	At least 10 years of comparable multi-district disease and covariate data.	Credible estimates of climate contribution and non-climate drivers.
Forecasting	Which weather and stress sequences predict infection, whip emergence, or rapid symptom increase for each disease?	Repeated field seasons with daily weather, soil or canopy moisture, crop stage, and disease progress.	Disease-specific 7-14-day scouting and sanitation alerts.
Pathogen change	How rapidly do C. falcatum virulence, Fusarium composition, and smut pathogenicity change across mill zones?	Annual representative sampling, pathogenicity tests, and molecular population data.	Timely variety withdrawal and better resistance screening.
Seed systems	What inspection, testing, treatment, and source-field exclusion prevent most pathogen movement at acceptable cost?	Risk-based sampling trials linked to downstream plant and ratoon outcomes.	Traceable certification protocols and practical treatment thresholds.
Integrated control	Which combinations remain effective under wet, dry, windy, and heat-stressed seasons?	Multi-location factorial trials with disease, yield, quality, environmental, and economic data.	Locally adapted packages rather than single-input advice.

11. Conclusions

Red rot, wilt, smut, and pokkah boeng will remain important constraints on North Indian sugarcane, but they require different immediate responses. Red rot control depends on clean seed, rapid clump removal, diseased-ratoon avoidance, pathotype surveillance, and varietal diversification. Wilt requires reliable internal diagnosis, source-field exclusion, soil and water management, and tolerant varieties. Smut demands resistant clean seed, preventive sett treatment where recommended, and removal of whips before teliospores disperse. Pokkah boeng requires careful symptom recognition, Fusarium-level diagnosis, and surveillance of rapidly growing crops during humid periods.

Changing climate conditions may alter disease windows through warmer temperatures, irregular rainfall, intense wet spells, waterlogging, drought, wind-mediated dispersal, and host stress. Evidence is strongest for short-term weather sensitivity and biological plausibility; long-term attribution of local epidemics remains limited. This uncertainty should strengthen monitoring, not delay prevention. A climate-ready programme can already be built around traceable seed, diversified resistant varieties, pathogen surveillance, field hygiene, timely roguing, drainage, balanced nutrition, need-based registered inputs, and forecast-triggered scouting. The goal is an adaptive mill-zone system that learns from each season and acts before the next epidemic forces varietal or field-level change.

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