ONLINE ISSN: 3007-3197 | PRINT ISSN: 3007-3189

http://amresearchreview.com/index.php/Journal/about

Annual Methodological Archive Research Review

http://amresearchreview.com/index.php/Journal/about

Volume 3, Issue 5 (2025)

Sugarcane Whip Smut: A Comprehensive Review of Pathogen Biology, Epidemiology, and Control Measures

[1]Ameer Jan, [2]Tariq Ali, [3]Naveed Khan, [3]Abdul Latif, [1]Talha, [1]Bahadeen Peer Bakhsh, [4]Zubair Ahmed, [5]Atta Ullah, [6]Zahid Hussain, [7]Mushtaq Ahmed.

Article Details

Keywords: sugarcane, Sporisorium scitamineum, management, epidemiology, Control.

[1]Department of Plant Pathology, University of Agriculture Faisalabad, Pakistan. Ameer.jeehand143@gmail.com

[2]Department of Plant Protection, University of Sargodha, Pakistan.

[3]Southwest University of Science and Technology China.

[4]Department of Agronomy, University of Agriculture Faisalabad, Pakistan.

[5]Department of Plant Pathology, Faculty of Agriculture Lasbela University of Agriculture Water And Marine Sciences, Pakistan.

[6]Department of Forestry, University of Agriculture Faisalabad, Pakistan.

[7]Department of Plant Pathology, Sindh Agriculture University Tandojam, Pakistan.

ABSTRACT

Sugarcane whip smut, caused by the biotrophic fungus Sporisorium scitamineum, poses a significant threat to global sugarcane production, leading to yield losses of 10–50% or more and substantial reductions in sucrose content. This comprehensive review synthesizes current knowledge on the pathogen's biology, epidemiology, and control measures. The fungus undergoes a complex life cycle involving diploid teliospores, haploid sporidia, and dikaryotic mycelia, with infection primarily occurring through buds and meristematic tissues under warm (25–30°C) and humid conditions. Whip smut is spread via windborne teliospores and contaminated planting material, with high spore concentrations exacerbating disease severity. Epidemiological factors, including environmental conditions, cultivar susceptibility, and cultural practices, significantly influence disease dynamics. Economically, whip smut reduces crop quality and increases production costs, impacting growers, sugar mills, and related industries. Management strategies encompass cultural practices (rouging, hot water treatment), resistant cultivars, chemical fungicides (tebuconazole, azoxystrobin), and biological controls (*Trichoderma spp.*, plant extracts). Integrated pest management, quarantine programs, and sanitation measures are critical for sustainable disease control. This review highlights the need for continued research into molecular host pathogen interactions and eco-friendly control methods to mitigate the global impact of whip smut on sugarcane production.

Introduction

Sugarcane (*Saccharum officinarum* L.) is a C4 plant an agro-industrial crop belonging to the family Poaceae (Sugiharto *et al*., 2023). Because of its high sugar content, sugarcane is a major cash crop that is planted all over the world (Que et al., 2024). Sugarcane (*Saccharum* sp.) is cultivated in tropical and subtropical regions globally, thriving in warmer climates. It undergoes processing to yield sugar, alongside valuable byproducts like molasses and bagasse (Hewawansa et al., 2024). It provides over 85% of the world's sugar, with tropical and subtropical regions hosting the majority of sugar cultivation activities (Afghan et al., 2023). Around the world, 107 different countries grow it (Hess et al., 2016). Its entire area is 20.420 million hectares. Global sugarcane production is 1333.35 million tonnes (Adami et al., 2012). Numerous diseases that can seriously lower the crop's quantity and quality can affect sugarcane. Whip smut, red rot, viral infections, leaf rust, red stripe, and pokkah boeng are among the common illnesses (Tiwari et al., 2017). Between 10% and 77% in cane yield and 4% to 74% in sugar recovery, these diseases have the potential to significantly reduce sugarcane crop productivity (Afghan et al., 2022). There have been reports of around 100 diseases in sugarcane crops, with fungi, bacteria, and viruses being the main culprits. According to Habib et al. (2016), the two most common diseases affecting the sugarcane crop in Pakistan are red rot and sugarcane whip smut. While Whip smut can result in yield losses ranging from 39% to 56% in planted sugarcane crops and 52% to 73% in ratoon crops in Pakistan (Khan et al., 2009). Sugarcane is susceptible to various diseases that can significantly reduce both the quantity and quality of the crop. Red rot, caused by the fungus *Colletotrichum falcatum*, penetrates the sugarcane's vascular system and obstructs the water and nutrition supply (Hossain et al., 2020). This causes the leaves to wilt, dry out, and develop a characteristic red tint on the internodes (Viswanathan, 2021). After it has spread, the fungus can linger in crop waste and soil, endangering future plants. This disease can be controlled by using resistant types and appropriate crop rotation (Chona, 1980). The rust-causing *Puccinia melanocephala* colonises sugarcane leaves, rupturing the leaf surface with rust-colored pustules (Comstock et al., 1992). This lowers the plant's overall vigour and potential yield because it impairs the leaf's capacity to photosynthesize efficiently. Due to rust spores' ease of dispersal by wind and water, illness can spread quickly both inside and between fields (Tai et al., 1981). Rust outbreaks can be reduced by fungicidal sprays applied in conjunction with routine monitoring and early identification (Selvakumar and Viswanathan, 2019). Wilt infiltrating the plant's vascular system and obstructing water uptake, Fusarium species mainly *Fusarium moniliforme* and *Fusarium oxysporum* cause wilting, yellowing, and stunted growth (Viswanathan, 2013). These infections typically enter by cuts or naturally occurring root apertures, then move upward through the xylem tissue (Viswanathan et al., 2011). Rotating crops, sterilising the soil, and using resistant cultivars are essential elements of wilt control techniques (Poongothai et al., 2014). Set rot, also known as pineapple disease, is caused by the fungus *Ceratocystis paradoxa* and causes sugarcane sets to deteriorate, which prevents healthy plants from germinating and establishing (Rahman et al., 2009). Because diseased sets either don't sprout at all or produce poor seedlings, the disease is especially problematic during planting (Hema and patil, 1999). The spread of this illness can be stopped by following procedures including treating sets with hot water and making sure planting material is properly sanitized (Kalaimani et al., 1996). Ratoon Stunting disease is linked to the bacteria Leifsonia xyli subsp. xyli, causes sugarcane ratoons to grow more slowly, which lowers their vigour and eventual yield potential (Chakraborty et al., 2024). Plant health is negatively impacted when the pathogen invades the vascular tissue, causing disruptions in the flow of nutrients (Hoy et al., 1999). The application of disease-free planting material and cultural techniques that reduce crop stress are essential components of effective disease management (Johnson and Tyagi, 2010). The three most common diseases affecting sugarcane globally are sugarcane smut, grassy shoot disease (GSD), and yellow leaf disease (YLD). Sugarcane yellows phytoplasma (SCYP) and Sugarcane yellow leaf virus (ScYLV) are the causes of YLD (kumar et al., 2022). Sugarcane grassy shoot phytoplasma (SCGSP) is the cause of GSD (Nithya et al., 2020). *Sporisorium scitamineum* is the fungus that causes sugarcane smut. These diseases have a major financial impact since they lower sugarcane yield and factors that affect yield (Viswanathan et al., 2021). In India, another significant disease impacting sugarcane is red rot, which is brought on by Colletotrichum falcatum. Insect vectors like *Melanaphis sacchari* and *Delphacid planthoppers* are responsible for the spread of diseases (Hameed et al., 2024). Attempts have been undertaken to create management plans and diagnostic instruments for these diseases, such as tissue culture-based pathogen elimination and disease resistance screening (Huang et al., 2018). Sporisorium scitamineum is the cause of sugarcane whip smut disease (Maurya et al., 2024). Which is thought to be one of the main barriers to sugarcane's productive growth. A decrease in crop quantity and quality could result from the pathogen infection (Rajput et al., 2022). The main ways that Smut disease is spread are through airborne spores and contaminated sugarcane buds. The fungus that causes smut is a biotrophic pathogen called a basidiomycete. This fungus has three unique stages in its life cycle: diploid teliospores, dikaryotic hyphae, and haploid sporidia (Bhuiyan et al., 2021). When teliospores come into contact with sugarcane in ideal humidity and temperature conditions typically between 25 and 30 °C they germinate quickly. After then, the infectious mycelium spreads throughout the plant systemically. This inhibits stem elongation, resulting in short internodes, increased tillering, and eventual plant death (Jacques-Edouard et al., 2021). The severity of whip smut disease directly affects the productivity and quality of sugarcane, resulting in significant losses. The higher the incidence of smut, the greater the losses experienced (Schaker et al., 2017). Smut formation has a direct impact on reducing sucrose content, negatively influencing purity, and ultimately leading to decreased sugar yield. The extent of yield losses is also related to the number of infected whips present in a particular region (Wada et al., 2016). Infection occurs early when diseased sets or teliospores present in the soil are planted, while secondary infection can occur when airborne fungal spores infect a healthy standing crop (Rajput et al., 2021). A peculiar black whip forms when the virus enters a healthy sugarcane plant through the growth points in a certain way (Schaker et al., 2017). Which can begin to produce spores about 42 days after they first begin to grow and can survive for up to 90 days. Every whip is thought to produce one billion spores every day (Ong'Ala et al., 2015). The formation of lateral and apical shoots encourages growth, and the smut fungus mostly infects buds and sprouting shoots. When the fungus is activated, a unique fruiting body that resembles a hunter is generated. The whip is composed of both plant and fungus tissues (Rajinder et al., 2019). The production of hunter-like bodies begins 6–8 weeks after planting or ratooning and continues all season long on new tillers or from side shoots on mature stalks (Schaker *et al*., 2016). The whip smut can persist from one season to another when propagative materials or disease propagules are present in the soil (Rajput et al., 2021). Quarantine and certification programs play a pivotal role in safeguarding agricultural productivity and biodiversity by preventing the introduction and spread of pests and diseases into new areas (Vidalakis et al., 2010). In order to guarantee that plant material satisfies requirements and is free of dangerous infections, these programmes adhere to a stringent routine of inspection, testing, and certification. This facilitates worldwide trade while shielding agricultural economies from catastrophic losses (Sushil et al., 2022). Similar to this, whip smut and other diseases in sugarcane must be controlled by putting sanitation and hygiene measures into place. Farmers may control the spread of diseases, maintain crop health, and guarantee the best possible yield and quality by adhering to field hygiene, cleaning equipment, and securing contaminated areas (Yirefu et al., 2013). These measures not only serve as preventive strategies but also contribute to sustainable agriculture by reducing the reliance on chemical controls and promoting long-term disease management (Mollov and malapi, 2016). Globally Controlling whip smut in sugarcane requires coordinated disease management. The use of resistant cultivars and keeping crops free of diseases are crucial elements. According to Bhuiyan et al. (2018), eradicating crops that are highly affected is essential for effective whip smut management and low output loss. According to Sing et al. (2014), fungicides have been assessed as a useful management strategy for whipping the smut of sugarcane because they shield seed cane from soilborne teliospores and successfully reduce infections in their early stages. The best eco-friendly way to contain the illness is to use bioagents and plant extracts. It has been demonstrated that a number of plants effectively inhibit the pathogen's mycelial proliferation in vitro (Abreu et al., 2012). Whip smut of sugarcane disease is present in nearly every region that grows sugarcane including Pakistan (Rajput et al., 2019). It is brought on by the fungus *Sporisorium scitamineum* and causes major financial losses in the production of sugarcane (Marques et al., 2016). In 1887, Natal, South Africa, was where the first case of the disease was reported (Braithwait et al., 2004). It was initially present on the equator's eastern side until it was discovered in Argentina. The disease was a serious problem only in Asia and Argentina until the 1950s, when, it expanded to other parts of Africa, It later expanded to Hawaii, the Caribbean, Southern Brazil, and Central America (Daniels, 1987). Since whip smut was introduced in Pakistan, sugarcane growers and the sugar industry has been facing economic problem due to losses (Mansoor et al., 2016).

Pathogen Biology

Sporisorium scitamium goes through three different stages in its life cycle causing whip smut of sugarcane diseases: diploid teliospores, haploid sporidia, and dikaryotic mycelia respectively (Agisha et al., 2021). Smut spores germinate on the intermodal surface, and then appressoria develops on newly emerging leaves and the inner scales of immature buds. Between 6 and 36 hours following teliospore deposition, entry into the bud meristem takes place (Alexander and Ramakrishnan, 1980). Hyphae are present in the entire plant, primarily in the lower internodes of the parenchymatous cells. At every node, infectious mycelia pass through the buds and systematically colonize the apical meristem. Infected buds in mature plants may manifest as a whip at the end of the stalk or remain dormant in buds (Agnihotri, 1983). A high spore concentration (106–107 spores/ml) is needed for the occurrence of severe diseases. Rainfall and the high inoculum concentration both help to increase the incidence of smut. High temperatures (25–30 °C) have been linked to an increase in the spread of this disease (Bock, 1964). Fungal spores are usually introduced into susceptible sugarcane tissues through natural holes or wounds. This is how the infection cycle starts. The spores sprout and infiltrate the plant's outer layer, typically via stomata or fissures in the cuticle (Marques et al., 2017). After entering the plant, the fungus spreads throughout its tissues and forms haustoria—specialized structures. These haustoria let the virus absorb nutrients from the host and give it a way to change the metabolism of the host (Schaker et al., 2016). Whip smut symptoms emerge as the illness worsens. The development of whip-like structures, which frequently emerge from the top of the sugarcane stalks, is one of these signs. Masses of dark-colored spores are found inside these structures, and they act as a mechanism of spreading to new host plants (Maurya et al., 2024). When fungi invade sugarcane plants, a number of defence mechanisms are triggered. These include the synthesis of antifungal substances, the fortification of cell walls, and the initiation of signaling cascades linked to defense reactions (Sikazwe et al., 2024). But *Ustilago scitaminea* has developed defense mechanisms to withstand or subdue these defences, which enables it to colonies the host successfully (Guo et al., 2024).

Studies on the molecular relationships between *Ustilago scitaminea* and sugarcane are still in progress (Thushari and de cosra, 2024). Studies on the patterns of gene expression in the pathogen and the host during infection are included in this, along with the identification of certain genes and proteins involved in the interaction (Hu et al., 2024). Gaining knowledge of these molecular processes may help identify possible targets for the management of disease (Yin et al., 2024). Compared to other sugarcane diseases, whip smut is unique in that it is caused by the fungus *Ustilago scitaminea* (Chen et al., 2024). In contrast to other diseases including pokkah boeng, ratoon stunting disease, red rot, and sugarcane smut, whip smut causes whip-like formations made of dark spores to sprout from afflicted stalks (Thite et al., 2024). The defence systems of sugarcane are triggered by fungal invasion; however, *Ustilago scitaminea* has developed tactics to circumvent or weaken these defenses, making management endeavours more challenging. In addition to chemical control techniques, cultural practices including planting resistant types and removing sick material are frequently used strategies (Reddy et al., 2024).

Symptom Development, And Detection

The most recognizable diagnostic sign of infected plants is the appearance of a distinctive structure known as the "smut whip" in sugarcane (Schaker et al., 2016). The sugarcane plants that have been infected typically have stunted development and produce thin, slender canes with wide-spaced nodes and whip-like soruses at the apex of the affected stalks or on the side shoots of standing canes (Sundar et al., 2012). It specifically affects meristematic tissues where more than billion of teliospore are produced (Schaker et al., 2017). The affected sugarcane plants often produce numerous tillers, and the shoots are spindlier and more upright with narrower, smaller leaves (Comstock., 1992). The severely stunted plants that are afflicted may have yield losses of 12–75%. However, if sensitive cultivars are produced and the climate is conducive to infection, a complete crop failure may be possible. Relative humidity of 65-70% and temperature of 25–30 C favor the development of illness (Farooq et al., 2014). By closely examining young shoots of a sick plant, sugarcane smut is easily identified, and the symptoms of any other condition cannot be mistaken for those of the smut whip (Magarey et al., 2006). Sori formed on side shoots are less noticeable. The crop canopy frequently conceals these side shoot sori since they are significantly smaller. Depending on the cultivar, primary shoot sori may emerge above or below the crop canopy (Magarey et al., 2010). Unusual symptoms include the massive spread of side branches sori appearing on portions of flowering panicles. Shoots emerging from panicles with sori and the inflorescence going dormant have both been observed (Ghareeb et al., 2011). Under a microscope, teliospores can be immediately detected, or they can serve as the starting point for DNA tests. *S. scitamineum* teliospores are minute (5.5 to 7.5 m) (Hu et al., 2024). Microscopical examination of these teliospores, which are dark brown, round, and microscopically punctate, typically suffices to establish the disease's presence. Crop symptoms and teliospore morphology are frequently used to confirm the disease's presence (Braithwaite et al., 2004).

Spread

Whip smut of sugarcane disease is mostly spread by wind when the whip smut fungus spores are conveyed by storms and air currents and infect surrounding sugarcane plants (Bhuiyan et al., 2021). Due to their small size, teliospores can be carried by wind over quite great distances, another main method of disease transmission is using infected plants for vegetative plating material. These are the primary mechanisms proposed for the global transmission of smut (Ferreira and Comstock, 1989). Infested areas experience extremely high air spore densities as a result of teliospores discharged by sick-sensitive crops. According to estimates, smut sori release 108 to 109 teliospores daily, and a single sorus can produce up to £1014 teliospores in its lifetime (Lee-Lovick, 1978).

Teliospores can survive for up to 6 months in dry soil, but only for 2 to 3 months when the soil is damp (Bhuiyan et al., 2009). Within the first three to six months of crop growth, the pathogen enters an active growth phase at that point and infests the growing point to generate a sorus (Fazliarab et al., 2023). The spread of disease is impacted by the weather. Smut teliospores are typically removed from the atmosphere by rainy conditions (Magarey et al., 2010).

Epidemiology

The intensity and spread of whip smut, a fungal disease that affects sugarcane, are influenced by a number of factors. The environment is very important; warm temperatures and high humidity are ideal for the growth of fungi and the development of diseases (Mansoor et al., 2016). Sugarcane cultivars differ in their susceptibility to diseases, and cultural measures including crop rotation, appropriate spacing, and drainage management can influence the severity of the illness (Amrate et al., 2019). Disease dynamics are also influenced by the existence of alternative hosts, pathogen survival and dissemination strategies, insect vectors, and stressors like nutrient shortages or drought (Srivastava et al., 2016). The growth of whip smut in sugarcane is facilitated by warm temperatures and high humidity levels (Waller, 1969). The ideal temperature range for the fungus *Ustilago scitaminea* to thrive and spread is normally between 20 and 30°C (68 and 86°F) (Rajput et al., 2019). Furthermore, circumstances that are favorable for spore germination and disease progression are produced by relative humidity levels greater than 70%. These conditions are common in tropical and subtropical areas, where the cultivation of sugarcane is widely practiced (Sreeramulu et al., 1972). If not properly controlled, the fungus can grow quickly in these conditions, resulting in severe yield losses and extensive infection (Cox et al., 2010). A number of variables, including weather patterns, crop growth stages, cultural techniques, pathogen biology, host plant physiology, and pest and disease pressure, affect the seasonal fluctuation in sugarcane disease incidence (Marques et al., 2017). Seasonal variations in temperature, humidity, and rainfall have a direct effect on the emergence and dissemination of diseases such as whip smut; warm, humid weather generally promotes the growth of fungi (Schaker et al., 2017). In addition, the growth stage of sugarcane affects how susceptible it is to diseases, and agricultural practices like planting dates and watering schedules can further affect the dynamics of disease (El-Dawy et al., 2023). To accurately predict and manage seasonal disease patterns, one must have a thorough understanding of the seasonal biology of pathogens, changes in host plant physiology, and oscillations in pest and disease pressure (Sumedha et al., 2021). By considering these factors and implementing targeted management strategies, growers can mitigate the impact of seasonal variation on disease incidence in sugarcane crops, thus safeguarding yields and economic sustainability (Bhuiyan et al., 2021).

Economic challenges of whip smut

The severity of illness, the vulnerability of the sugarcane variety, and the efficacy of disease control techniques are some of the variables that might affect the yield losses in sugarcane that are related to whip smut infection (Fazliarab et al., 2023). When whip smut infection is severe, the afflicted stalks may completely disappear, which would significantly lower yield. Studies on seriously impacted fields have shown yield losses of 10% to 50% or more. The quantity of sugarcane collected is affected by these losses, but they also affect the quality of the remaining crop because diseased stalks may have less sucrose and be worth less overall (El-Dawy et al., 2023). Whip smut's financial impact on sugarcane production is further exacerbated by the expenses related to disease control techniques (Fazliarab et al., 2023). Infection with whip smut causes yield losses in sugarcane as well as negative quality effects on the harvested crop, namely on the sucrose content and juice quality. The fungus *Ustilago scitaminea* alters the normal physiology of plants, causing changes in sucrose buildup and sugar metabolism (Hoepers et al., 2023). When compared to healthy plants, infected stalks frequently have lower sucrose contents, which lowers the total amount of sugar produced per hectare. Furthermore, juice produced by whip smut-infected plants may have different chemical makeup, including variations in pH, purity, and mineral content. These changes may have an adverse effect on the quality of the finished sugar product and the efficiency with which sugarcane is processed in sugar mills, which could result in financial losses for both producers and processors (van et al., 2021). For sugarcane planters and related sectors, whip smut infestation can have serious financial repercussions. First, because of the disease's negative impact on crops, growers suffer immediate financial losses (Rajput et al., 2021). Whip smut has the potential to significantly impair sugarcane productivity, which would mean lower profits for farmers who depend on the crop for their main source of income. Production costs are additionally increased by the expenses related to disease management techniques, such as labor, fungicide sprays, and other inputs (Sundar et al., 2012). Whip smut also affects industries like sugar mills and ethanol factories that use sugarcane as a raw material. Disease-related reductions in sugarcane availability and quality can cause production plans to be disrupted, which can diminish throughput and reduce processing plants' efficiency (Sharma et al., 2022). This can result in increased operational costs, reduced profitability, and potentially lower competitiveness in the market. Fluctuations in sugarcane supply and quality may affect product quality and consistency, leading to potential losses in market share and consumer trust (Sharma et al., 2020). Decreased agricultural output and earnings may have a negative impact on the whole agricultural economy of whip smut-affected regions (Croft et al., 2008). A network of auxiliary businesses and services, such as labourers, transporters, and suppliers of inputs, are frequently supported by the growth of sugarcane (Agnihotri, 2002). Whip smut can cause a reduction in sugarcane production, which can have a knock-on effect on these industries and result in lower revenues, job losses, and economic downturns in rural areas that depend on sugarcane farming (Li et al., 2023).

Management

Cultural control

Smut is mostly disseminated by teliospores; hence it is essential to eradicate strongly infected crops as soon as possible to reduce inoculum production and teliospore dissemination (Kishore et al., 2020). Rouging of diseased sugarcane crops is a technique that is occasionally utilized in IDM in nations with inexpensive labor, particularly with high-yielding crops or nursery stock (Bailey, 1979). Employing hot water treatment on sugarcane seedlings proves to be an efficient method in averting diseases spread by contaminated seedlings (Huang et al., 2013). Thermotherapy is also effective, which involves heating sugarcane planting material to 50°C for two or three hours and for a shorter thermotherapy treatment (50°C for 45 min) is used to eradicate *S. scitamineum* from sugarcane (Bhuiyan, 2013). It is advised to avoid planting sugarcane in soil that has recently been exposed to smut since the seed cane's sprouting shoots may pass through the infected soil and infect the system (Co et al ., 2008).

Resistance varieties

Whip smut disease's effects can be considerably diminished by growing sugarcane varieties that are resistant to it. Resistant sugarcane cultivars have little to no smut infection, but susceptible types can have more than 40% of their plants infected (Bhuiyan et al., 2022). The sugarcane cultivars GT42, GT44, GT49, GT55, LC05-136, and ROC22 are among those that are prone to whip smut disease (Shuai et al., 2023). Only in LC05-136 did these varieties exhibit floral structural symptoms, suggesting that *S. scitamineum's* induction of flowering is variety-specific (Bhuiyan et al., 2022). According to a study comparing the metabolomic differences between a susceptible variety (G160) and a smut-resistant variety (Zhongzhe 1), Zhongzhe 1 exhibited a higher accumulation of lipids, terpenoids, flavonoids, and tannins, which could perhaps explain its resistance to smut disease (Hidayah et al., 2021). Furthermore, a correlation has been demonstrated between various resistance categories and the yield loss resulting from sugarcane smut, whereby susceptible varieties exhibit yield losses exceeding 40%, while resistant varieties demonstrate yield losses of less than 6% (Wu et al., 2022). Smut disease occurs more frequently and is more severe in successive regrowth crops, resulting in greater output losses (Chao, 1988). Up to 756 kg of cane per hectare and 128 kg of sugar per hectare may be lost for every 1% increase in smut occurrence and severity (Zhou, 2022). However, yield loss can be decreased to less than 6% by using resistant types (Wu et al., 2022).

Application of Fungicide

If other control methods were not available chemical fungicides are frequently required to fight harmful plant diseases and stop financial losses fungicide sprays on planting materials before sowing eliminate the infection inside the tissues of the plant (Singh, 2014). To effectively manage the sett-transmitted sugarcane smut disease, sett dip with Bavistan Tilt and Bayletan (0.15%) is advised (Rajput et al., 2019). To combat whip smut disease, fungicides have both therapeutic and preventative effects (Wada et al., 2016). Tebuconazole, Hexaconazole, Metalaxyl 8% + Mancozeb 64% WP, are the most effective fungicides for preventing whip smut in sugarcane (Thushari et al., 2022). While in both plant and ratoon crops Azoxystrobin + Tebuconazole, Trifloxystrobin + Tebuconazole, Fungicides have been shown to lower the incidence of whip smut disease and to prevent the germination of smut teliospores (Kishore et al., 2020). Additionally, it has been noted that applying fungicides as a hot water fungicidal dip rather than an ambient fungicidal dip boosts their efficacy (López-Prieto et al., 2020).

Biological control

Biological management of plant diseases holds significant importance which minimizes the environmental impact compared to chemical pesticides and provides alternative management for diseases that are sustainable and safe for Farmers, and consumers (Prajapati et al., 2020). The research showed that several *Trichoderma* isolates were present in the sugarcane rhizosphere and had clear antagonistic behaviors and had greater growth-suppression capability for *S. scitaminea*. This demonstrated *Trichoderma's* potential as a biocontrol agent for the pathogen (Tegene et al., 2021). Endophytic bacteria like Pseudomonas aeruginosa have been demonstrated to successfully control *S. scitamineum* in-vitro and glasshouse testing (Singh et al., 2021). Plant extracts have a substantial ability to combat plant diseases. Research indicates that natural compounds derived from these extracts possess antifungal properties effective against a wide range of fungal strains (De Almeida et al., 2021). The nanoparticles synthesized through biosynthesis demonstrated in-vitro antifungal properties against the *S. scitamineum* fungus, *Carissa spinarum* and *Melia azedarach* displayed the most potent antifungal activity (Nkhabindze et al., 2022). Set treatment of sugarcane treated with *Cymbopogon citratus* oil at doses of 500 ppm and 1000 ppm enhanced germination, height, tillering, stem diameter, internode length, number of internodes, and biomass. The prevalence of whip smut was reduced when *C. citratus* essential oil was present at 500 ppm (Jacques-Edouard et al., 2021). The in-vitro testing of the smut pathogen (*S. scitamineum*) against different plant species revealed that the leaf extracts of *Calendula officinalis*, *Eclipta* alba, and *Solanum nigrum* reduced >90% teliospore germination. Teliospore germination was postponed by 48 hours by *Lantana camara* and *Azadirachta indica*, respectively (Lal et al., 2009). In an experiment, 25 plants were selected to evaluate their antifungal potential against *S. scitamineum*. Among these, five plant species, namely, *Lantana camara* L., *Cinnamomum* spp, Tagetes *erecta*

L., *Zingiber officinale Roscoe*, and *Kaempferia spp*, exhibited significant effectiveness in inhibiting the growth of *S. scitamineum* (Piyathunga et al., 2013).

Conclusion

Sugarcane whip smut, caused by *Sporisorium scitamineum*, remains a formidable challenge to sugarcane agriculture, causing significant economic losses through reduced yields and compromised sucrose quality. Its complex life cycle, efficient dispersal mechanisms, and environmental adaptability necessitate a multifaceted approach to management. Effective control integrates resistant cultivars, cultural practices, judicious fungicide use, and promising biological agents like *Trichoderma* and plant derived antifungals. Quarantine and sanitation measure further curb disease spread, promoting sustainable agricultural practices. Advances in understanding molecular interactions between the pathogen and sugarcane offer potential for targeted interventions, while eco-friendly strategies reduce reliance on chemical controls. Continued global collaboration and research are essential to develop resilient cultivars and innovative management practices, ensuring the long-term productivity and economic viability of sugarcane cultivation in the face of whip smut and other diseases.

References

Abreu, A.C., A.J. McBain and M. Simões. 2012. Plants as sources of new antimicrobials and resistance-modifying agents. Natural product reports 29:1007-1021.

Afghan, S., W.R. Arshad, M.E. Khan and K.B. Malik. 2022. Sugarcane breeding in Pakistan. Sugar Tech 24:232-242.

Agisha, V., N. Ashwin, R. Vinodhini, K. Nalayeni, A. Ramesh Sundar, P. Malathi and R. Viswanathan. 2021. Protoplast-mediated transformation in Sporisorium scitamineum facilitates visualization of in planta developmental stages in sugarcane. Mol. Biol. Rep. 48:7921-7932.

Agnihotri, V. 2002. PRESIDENTIAL ADDRESS-Current sugarcane disease scenario and management strategies. Indian Phytopathol. 49:107-126.

Alexander, K. and K. Ramakrishnan. 1980. Infection of the bud, establishment in the host and production of whips in sugarcane smut (Ustilago scitaminea) of sugarcane. In: Proc Int Soc Sugar Cane Technol. p 1452-1455.

Amrate, P.K., A. Choudhary, A. Chatterjee and D. Bajoriya. 2019. Epidemiological investigations on whip smut of sugarcane and elucidation of sugarcane genotypes for possible resistance. J Mycol Plant Pathol 49:374-384.

Bailey, R. 1979. assessment of the status of sugarcane diseases in South Africa. In: Proceedings... annual congress

Bhuiyan, S. A., Croft, B. J., Deomano, E. C., James, R. S., & Stringer, J. K. (2013). Mechanism of resistance in Australian sugarcane parent clones to smut and the effect of hot water treatment. *Crop and Pasture Science*, *64*(9), 892-900.

Bhuiyan, S., M. Cox and B. Croft. 2018. How do current ratings of sugarcane varieties for resistance to smut relate to natural infection. Sugar research Australia

Bhuiyan, S.A., B.J. Croft, M.C. Cox and G. Bade. 2009. Some biological parameters of the sugarcane smut fungus, Ustilago scitaminea. In: Proceedings of the Australian Society of Sugar Cane Technology. p 125-134.

Bhuiyan, S.A., J.K. Stringer, B.J. Croft and M.E. Olayemi. 2022. Resistance of sugarcane varieties to smut (Sporisorium scitamineum), development over crop classes, and impact on yield. Crop and Pasture Science 73:1180-1187.

Bhuiyan, S.A., R.C. Magarey, M.D. McNeil and K.S. Aitken. 2021. Sugarcane smut, caused by

Sporisorium scitamineum, a major disease of sugarcane: A contemporary review. Phytopathology® 111:1905-1917.

Bock, K. 1964. Studies on sugar-cane smut (Ustilago scitaminea) in Kenya. Transactions of the British Mycological Society 47:403-417.

Braithwaite, K., G. Bakkeren, B. Croft and S. Brumbley. 2004. Genetic variation in a worldwide collection of sugarcane smut fungus Ustilago scitaminea. In: PROCEEDINGS-AUSTRALIAN SOCIETY TECHNOLOGISTS. p 48-48.

Chakraborty, M., N. Soda, S. Strachan, C.N. Ngo, S.A. Bhuiyan, M.J. Shiddiky and R. Ford. 2024. Ratoon Stunting Disease of Sugarcane: A Review Emphasizing Detection Strategies and Challenges. Phytopathology® 114:7-20.

Chao, C.-P. 1988. Nature and heritability of resistance to sugarcane smut caused by Ustilago scitaminea. Louisiana State University and Agricultural & Mechanical College.

Chen, C., S.A. Bhuiyan, E. Ross, O. Powell, E. Dinglasan, X. Wei, F. Atkin, E. Deomano and B. Hayes. 2024. Genomic prediction for sugarcane diseases including hybrid Bayesian-machine learning approaches. Frontiers in Plant Science 15:1398903.

Chona, B. 1980. Red rot of sugarcane and sugar industry--a review. Indian phytopathology 33:191-207.

Co, O., K. Ngugi, H. Nzioki and S. Githiri. 2008. Evaluation of smut inoculation techniques in sugarcane seedlings. Sugar Tech 10:341-345.

Comstock, J., J. Shine Jr and R. Raid. 1992. Effect of rust on sugarcane growth and biomass. Plant Disease 76:175-177.

Comstock, J.C., S.A. Ferreira and T.L. Tew. 1983. Hawaii's Approach to Control c. Plant Disease:453.

Cox, M., B. Croft, R. Magarey, N. Berding and S. Bhuiyan. 2010. Sugarcane smut in Australia: history, response and breeding strategies.

Croft, B., R. Magarey, P. Allsopp, M. Cox, T. Willcox, B. Milford and E. Wallis. 2008. Sugarcane smut in Queensland: arrival and emergency response. Australasian Plant Pathology 37:26-34.

de Almeida, A.R., I.C. da Silva, C.A.F. de Souza, J.R.L. Avelino, J.E.C.C. Santos, E.V. de Medeiros and K.M.S. Pinto. 2021. Plant extract as a strategy for the management of seed pathogens: a critical review. Research, Society and Development 10:e174101421846-e174101421846.

El-Dawy, E.G., Y.A. Gherbawy, O. Salamah, R. Alian, S. Ahmed, S. Aoud, R. Mosa, A.E. Ahmed, N. Ali and M. Ahmed. 2023. Diagnosis and Biocontrol of Sporisorium scitamineum Associated with Whip Smut Sugarcane. Asian Journal of Biochemistry, Genetics and Molecular Biology 15:31-40.

Farooq, M.A., A. Rasool, M. Zubair, A. Bahadar, S. Ahmad and S. Afghan. 2014. Loss of resistance in HSF-240 against whip smut of sugarcane over consecutive ratoons. Pakistan Sugar Journal 29

Fazliarab, A., R. Farokhinezhad, M. Mehrabi-Koushki, K. Mehdikhanlou and K. Taherkhani. 2023. Morphological and Phylogenetic Characterization of Whip Smut on Commercial Sugarcane Cultivars and Assessing the Resistance to Sporisorium scitamineum. Journal of Genetic Resources 9:205-214.

Ghareeb, H., A. Becker, T. Iven, I. Feussner and J. Schirawski. 2011. Sporisorium reilianum infection changes inflorescence and branching architectures of maize. Plant Physiology 156:2037-2052.

Guo, F., J. Meng, J. Huang, Y. Yang, S. Lu and B. Chen. 2024. An efficient inoculation method to evaluate virulence differentiation of field strains of sugarcane smut fungus. Frontiers in

Microbiology 15:1355486.
Habib, A., A. Mahmood, W.R. Arshad, M. Umer, M. Bilal, F. Rasul, Imran-ul-Haq and M. Usman. 2016. Crop losses and varietal response of sugarcane against red rot disease in Pakistan's Punjab province. International Sugar Journal 118:522-526.
Hema, S. and A. Patil. 1999. Biochemical changes in sugarcane due to infection by Ceratocystis paradoxa. Sugar Cane:9-13.
Hameed, M., Shahzadi, I., Kaleri, A, A., Manzoor, D., Jamali, A., Jogi, T, M., Akhtar, A., Pervaiz, R., Ali, S., Ashraf, M. (2024). Exogenous Application of Iron and zinc Nanoparticles on Germination and Growth Characteristics of Sugarcane (*Saccharum officinarum* L.) Budnode. *Pakistan Journal of Biotechnology*, *21*(2),445-456.
Hewawansa, U.H., M.J. Houghton, E. Barber, R.J. Costa, B. Kitchen and G. Williamson. 2024. Flavonoids and phenolic acids from sugarcane: Distribution in the plant, changes during processing, and potential benefits to industry and health. Comprehensive Reviews in Food Science and Food Safety 23:e13307.
Hidayah, N., M. McNeil, J. Li, S. Bhuiyan, V. Galea, K. Aitken and A. Sofo. 2021. Resistance mechanisms and expression of disease resistance-related genes in sugarcane (Sacchrum officinarum) to Sporisorium scitamineum infection. Functional Plant Biology 48:1302-1314.
Hoepers, L.M.L., L. Ruaro, J.C. Bespalhok Filho, R.A.d. Oliveira and H.d.S.S. Duarte. 2023. Screening of Brazilian sugarcane genotypes for smut reaction. Ciência Rural 54:e20220611.
Hossain, M.I., K. Ahmad, Y. Siddiqui, N. Saad, Z. Rahman, A.O. Haruna and S.K. Bejo. 2020. Current and prospective strategies on detecting and managing colletotrichumfalcatum causing red rot of sugarcane. Agronomy 10:1253.
Hoy, J.W., M.P. Grisham and K. Damann. 1999. Spread and increase of ratoon stunting disease of sugarcane and comparison of disease detection methods. Plant disease 83:1170-1175.
Hu, X., Z. Luo, C. Xu, Z. Wu, C. Wu, M.H. Ebid, F. Zan, L. Zhao, X. Liu and J. Liu. 2024. A Comprehensive Analysis of Transcriptomics and Metabolomics Revealed Key Pathways Involved in Saccharum spontaneum Defense against Sporisorium scitamineum. Journal of Agricultural and Food Chemistry
Huang, Y., W. Li, W. He, Z. Luo, X. Wang, J. Yin, J. Xue and H. Zhang. 2013. Production techniques of disease-free sugarcane seedlings with hot water treatment. Southwest China J Agric Sci 26:2150-2157.
Huang, Y.-K., W.-F. Li, R.-Y. Zhang and X.-Y. Wang. 2018. Color illustration of diagnosis and control for modern sugarcane diseases, pests, and weeds. Springer.
Jacques-Edouard, Y.K., K. Martial, K.K. Didier, K. Gaston, B. Antoine and K. Daouda. 2021. Sustainable control of the sugarcane smut disease caused by Sporisorium scitamineum Piep. using an essential oil of Cymbopogon citratus. J. Plant Sci 9:77 83.
Johnson, S. and A.P. Tyagi. 2010. Effect of ratoon stunting disease (RSD) on sugarcane yield in Fiji. The South Pacific Journal of Natural and Applied Sciences 28:69-73.
Kalaimani, T., S. Natarajan and P. Parameswaran. 1996. Effect of some chemicals, fertilizers and FYM on the control of sugarcane sett rot caused by Ceratocystis paradoxa. Plant Disease Research 11:153-155
Khan, H., A. Chattha, M. Munir and Z. Amjad. 2009. Evaluation of resistance in sugarcane promising lines against whip smut. Pakistan Journal of Phytopathology 21:92-93.
Kishore Varma, P., V. Chandrasekhar and M. Bharathalakshmi. 2020. Field evaluation of fungicides for the management of whip smut in sugarcane caused by Sporisorium scitamineum. IJCS 8:223-226.

Lal, R.J., O. Sinha, S. Bhatnagar, S. Lal and S. Awasthi. 2009. Biological control of sugarcane smut (Sporisorium scitamineum) through botanicals and Trichoderma viride. Sugar Tech 11:381-386.

Li, A.-M., F. Liao, M. Wang, Z.-L. Chen, C.-X. Qin, R.-Q. Huang, K.K. Verma, Y.-R. Li, Y.-X. Que and Y.-Q. Pan. 2023. Transcriptomic and proteomic landscape of sugarcane response to biotic and abiotic stressors. International Journal of Molecular Sciences 24:8913.

López-Prieto, A., X. Vecino, L. Rodríguez-López, A.B. Moldes and J.M. Cruz. 2020. Fungistatic and fungicidal capacity of a biosurfactant extract obtained from corn steep water. Foods 9:662.

Magarey, R., B. Croft, K. Braithwaite and A. James. 2006. A smut incursion in the major eastern-Australian sugarcane production area. In: Proceedings of the International Symposium on Technologies to Improve Sugar Productivity in Developing Countries (IS-2006). p 333-336.

Magarey, R., J. Bull, T. Sheahan, D. Denney and R. Bruce. 2010. Yield losses caused by sugarcane smut in several crops in Queensland. In: Proc Aust Soc Sugar Cane Technol. p 347-354.

Mansoor, S., M. Aslamkhan, N.A. Khan and I.R. Nasir. 2016. Effect of whip smut disease on the quantitative and qualitative parameters of sugarcane varieties/lines. Agricultural Research and Technology 2:555588.

Mansoor, S., M. Khan and N. Khan. 2016. Screening of sugarcane varieties/lines against whip smut disease in relation to epidemiological factors. J Plant Pathol Microbiol 7:2.

Marques, J.P.R., B. Appezzato-da-Glória, M. Piepenbring, N.S. Massola Jr, C.B. Monteiro Vitorello and M.L.C. Vieira. 2017. Sugarcane smut: shedding light on the development of the whip-shaped sorus. Annals of Botany 119:815-827.

Maurya, S.K., P. Vandana, S. Kumar, V. Singh, S. Kumar and D. Singh. 2024. Screening of Varieties Resistant to Sugarcane Smut Disease Caused by Sporosorium scitamineum under Sub-tropical India. Journal of Experimental Agriculture International 46:131-139.

Mollov, D. and M. Malapi-Wight. 2016. Next Generation Sequencing: a useful tool for detection of sugarcane viruses in quarantine programs. In: Proceedings of the International Society of Sugar Cane Technologists. p 1631-1635.

Nithya, K., B. Parameswari, A. Bertaccini, G.P. Rao and R. Viswanathan. 2020. Grassy shoot: the destructive disease of sugarcane. Phytopathogenic Mollicutes 10:10-24.

Nkhabindze, B.Z., H.N. Wanyika, D.M. Earnshaw and E.M. Ateka. 2022. Synthesis of silver nanoparticles using crude leaf extracts of Acacia nilotica, Azadirachta indica, Carissa spinarum, Melia azedarach, Senna didymobotrya and Warburgia ugandensis, and their antifungal activity against Sporisorium scitamineum. Afr. J. Biotech 21:305-313.

Ong'Ala, J., B. Mulianga, N. Wawire, G. Riungu and D. Mwanga. 2015. Determinants of sugarcane smut prevalence in the Kenya Sugar Industry.

Piyathunga, A., G. Chandrassena and A. Thushari. 2013. Study on the Effects of Selected Plant Extracts on Sugarcane Smut Pathogen (Ustilago scitaminea). In: Proceedings of the Research Symposium of Uva Wellassa University

Poongothai, M., R. Viswanathan, P. Malathi and A. Ramesh Sundar. 2014. Sugarcane wilt: Pathogen recovery from different tissues and variation in cultural characters. Sugar Tech 16:50-66.

Prajapati, S., N. Kumar, S. Kumar and S. Maurya. 2020. Biological control a sustainab le approach for plant diseases management: A review. Journal of Pharmacognosy and Phytochemistry 9:1514-1523.

Que, Y., Q. Wu, H. Zhang, J. Luo and Y. Zhang. 2024. Developing new sugarcane varieties suitable for mechanized production in China: principles, strategies and prospects. Frontiers in Plant Science 14:1337144.

Rahman, M., M. Begum and M. Alam. 2009. Screening of Trichoderma isolates as a biological control agent against Ceratocystis paradoxa causing pineapple disease of sugarcane. Mycobiology 37:277-285.

Rajinder, K., K. Parminder, K. Lenika, G. Sanghera and S. Paramjit. 2019. Survey and surveillance of sugarcane diseases in Punjab, India. Agricultural Research Journal 56:345-347.

Rajput, M., N. Rajput, R. Syed, A. Lodhi and Y. Que. 2021. Sugarcane Smut: Current Knowledge and the Way Forward for Management. J. Fungi, 7, 1095.

Rajput, M.A., I.A. Khan, R.N. Syed and A.M. Lodhi. 2019. Optimization of inoculation technique of Sporisorium scitamineum for the induction of smut disease in sugarcane propagative material. Pak. J. Agric. Res 32:275-281.

Rajput, M.A., R.N. Syed, F.N. Khoso, J.-U.-D. Hajano, N.A. Rajput, M.A. Khanzada and A.M. Lodhi. 2022. Impact of Sporisorium scitamineum infection on the qualitative traits of commercial cultivars and advanced lines of sugarcane. Plos one 17:e0268781.

Reddy, A.V., R. Thiruvengatanadhan, M. Srinivas and P. Dhanalakshmi. 2024. Region Based Segmentation with Enhanced Adaptive Histogram Equalization Model with Definite Feature Set for Sugarcane Leaf Disease Classification. International Journal of Intelligent Systems and Applications in Engineering 12:428-442.

Schaker, P.D., A.C. Palhares, L.M. Taniguti, L.P. Peters, S. Creste, K.S. Aitken, M.-A. Van Sluys, J.P. Kitajima, M.L. Vieira and C.B. Monteiro-Vitorello. 2016. RNAseq transcriptional profiling following whip development in sugarcane smut disease. PLoS One 11:e0162237.

Schaker, P.D., L.P. Peters, T.R. Cataldi, C.A. Labate, C. Caldana and C.B. Monteiro Vitorello. 2017. Metabolome dynamics of smutted sugarcane reveals mechanisms involved in disease progression and whip emission. Frontiers in Plant Science 8:264892.

Selvakumar, R. and R. Viswanathan. 2019. Sugarcane rust: changing disease dynamics and its management.

Sharma, G. and J. Singh. 2020. Current Status of Smut Disease of Sugarcane and Its Management in India. Diseases of Field Crops Diagnosis and Management:321 344.

Sharma, N., V. Gandhi and V. Chauhan. 2022. Sugarcane Diseases: An Overview. Emerging Trends in Agriculture Sciences:87.

Shuai, L., H. Huang, L. Liao, Z. Duan, X. Zhang, Z. Wang, J. Lei, W. Huang, X. Chen and D. Huang. 2023. Variety-Specific Flowering of Sugarcane Induced by the Smut Fungus Sporisorium scitamineum. Plants 12:316.

Sikazwe, G., D. Mark, E. Chiunga, J. Massawe, G. Nguvu and J. Ndunguru. 2024. Sugarcane Smut Pathogenic Races in Tanzania: Current Knowledge of Resistance, Characterization, Detection, and Management Strategies. Characterization, Detection, and Management Strategies (April 17, 2024)

Singh, P., B. Kumar, J. Meeta and R. Rani. 2014. Management of sugarcane smut (Ustilago scitaminea) with fungicides and bio-agents. African Journal of Microbiology Research 8:3954-3959.

Singh, P., R.K. Singh, D.-J. Guo, A. Sharma, R.N. Singh, D.-P. Li, M.K. Malviya, X.-P. Song, P. Lakshmanan and L.-T. Yang. 2021. Whole genome analysis of sugarcane root-associated endophyte Pseudomonas aeruginosa B18—A plant growth promoting bacterium with antagonistic potential against Sporisorium scitamineum. Frontiers in Microbiology 12:628376.

Sreeramulu, T. and B. Vittal. 1972. Spore dispersal of the sugarcane smut (Ustilago scitaminea). Transactions of the British Mycological Society 58:301-312.

Srivastava, S., A. Kumar, V.P. Singh and J. Rastogi. 2016. Epidemiology & detection of smut disease. Biog-An Int J 3:24-32.

Sugiharto, B., R. Harmoko and W.D. Sawitri. 2023. Biotechnological Approaches to Improve Sugarcane Quality and Quantum Under Environmental Stresses, Agro industrial Perspectives on Sugarcane Production under Environmental Stress. Springer. p. 267-300.

Sumedha Thushari, A., A. Wijesuriya, B. Wijesuriya, A. Perera and D. De Costa. 2021. Identification of sugarcane germplasm in Sri Lanka for breeding of varieties resistant to smut disease (ca Sporisorium scitamineum). Sugar Tech 23:1025-1036.

Sundar, A.R., E.L. Barnabas, P. Malathi, R. Viswanathan, A. Sundar and E. Barnabas. 2012. A mini-review on smut disease of sugarcane caused by Sporisorium scitamineum. Botany 2014:226.

Sushil, S., D. Joshi, S. Roy, G. Rao and A. Pathak. 2022. Plant quarantine regulations with reference to sugarcane in India: strengths and challenges. Sugar Tech 24:1319 1329.

Tai, P., J. Miller and J. Dean. 1981. Inheritance of resistance to rust in sugarcane. Field Crops Research 4:261-268.

Tegene, S., M. Dejene, H. Terefe, G. Tegegn, E. Tena and A. Ayalew. 2021. Evaluation of native Trichoderma isolates for the management of sugarcane smut (Ustilago scitaminea) in sugar plantations of Ethiopia. Cogent Food & Agriculture 7:1872853.

Thite, S., Y. Suryawanshi, K. Patil and P. Chumchu. 2024. Sugarcane Leaf Dataset: A Dataset for Disease Detection and Classification for Machine Learning Applications. Data in Brief:110268.

Thushari, A.N.W.S. and D.M. De Costa. 2024. Determining morphological and biochemical indices to select for smut-resistant sugarcane varieties. Journal of Crop Improvement 38:73-94.

Tiwari, A.K., A. Singh, S.P. Singh, A. Dagar, K. Kumari, D. Kumar, N. Pandey and P. Kumar. 2017. An overview of major fungal diseases of sugarcane in India: detection and management strategies. Molecular Markers in Mycology: Diagnostics and Marker Developments:275-304.

Van der Linde, K. and V. Göhre. 2021. How do smut fungi use plant signals to spatiotemporally orientate on and in planta? Journal of Fungi 7:107.

Vidalakis, G., J. Da Graca, W. Dixon, D. Ferrin, M. Kesinger, R. Krueger, R. Lee, M. Melzer, J. Olive and M. Polek. 2010. Citrus quarantine sanitary and certification programs in the USA, prevention of introduction and distribution of citrus diseases. Part 1:26-35.

Viswanathan, R. 2013. Status of sugarcane wilt: one hundred years after its occurrence in India. Journal of Sugarcane Research 3

Viswanathan, R. 2021. Red rot of sugarcane (Colletotrichum falcatum Went). CABI Reviews

Viswanathan, R., M. Poongothai and P. Malathi. 2011. Pathogenic and molecular confirmation of Fusarium sacchari causing wilt in sugarcane. Sugar Tech 13:68-76.

Wada, A., A. Anaso and M. Bassey. 2016. Sugar cane whip smut (Sporisorium scitamineum Syd) caused field sucrose and juice quality losses of two sugar cane varieties in Nigeria. Int. J. Plant Soil Sci 10:1-11.

Waller, J. 1969. Sugarcane smut (Ustilago scitaminea) in Kenya: I. Epidemiol. Trans. Br. Mycol. Soc. 52:139-151.

Wu, Q., Y. Su, Y.-B. Pan, F. Xu, W. Zou, B. Que, P. Lin, T. Sun, M.P. Grisham and L. Xu. 2022. Genetic identification of SNP markers and candidate genes associated with sugarcane smut resistance using BSR-Seq. Frontiers in Plant Science 13:1035266.

Yin, K., G. Cui, X. Bi, M. Liang, Z. Hu and Y.Z. Deng. 2024. Intracellular polyamines regulate redox homeostasis with cAMP–PKA signalling during sexual mating/filamentation and pathogenicity of Sporisorium scitamineum. Mol. Plant Pathol. 25:e13393.

Yirefu, F., A. Tafesse and Y. Zekarias. 2013. Quarantine Activities in Sugarcane Variety Exchange: Challenges and Future Directions in Ethiopia. In: Proc. Ethiop. Sugar. Ind. Bienn. Conf. p 141-149.

Zhou, M. 2022. Location and seasonal effects on sugarcane smut and implications for resistance breeding in South Africa. S. Afr. J. Plant Soil.39:1-9.