

FUSARIUM WILT OF SUGARCANE IN LOWER SINDH, SPATIAL RISK MAPPING, AND INTEGRATED DISEASE MANAGEMENT A REVIEW

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ABSTRACT

Sugarcane (*Saccharum officinarum* L.) is a globally important crop that contributes nearly 85% of the world's sugar and supports numerous industries through its byproducts. In Pakistan, it is the second-largest cash crop, but its productivity is frequently constrained by diseases, among which Fusarium wilt, caused mainly by *Fusarium sacchari*, is a major threat. This disease reduces germination, tillering, cane yield, and juice quality, with losses reported up to 65%, making it second only to red rot in economic importance.

This review synthesizes current knowledge on the prevalence, symptoms, and yield impacts of

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Fusarium wilt, with a focus on South Sindh. Disease expression is most severe during monsoon and post-monsoon periods, and its soil- and sett-borne nature complicates control. While chemical fungicides such as carbendazim and difenoconazole provide partial suppression, they are not sustainable as stand-alone solutions. Alternative approaches, including biological control with *Trichoderma* spp., use of plant extracts, and micronutrient amendments, offer eco-friendly options but show variable field efficacy.

The most effective strategy lies in Integrated Disease Management (IDM), combining resistant varieties, clean seed systems, cultural sanitation, sett treatment, biocontrol agents, and soil health improvements. Mapping disease prevalence and identifying risk factors in South Sindh can guide localized interventions. Ensuring access to clean seed, strengthening extension services, and promoting farmer adoption of IDM are essential for reducing losses, stabilizing yields, and supporting the long-term sustainability of the sugarcane industry.

Keywords: Sugarcane, Fusarium Wilt, Fusarium Sacchari, Prevalence, South Sindh, Integrated Disease Management, Resistant Varieties, Trichoderma.

Introduction

Sugarcane (*Saccharum officinarum* L.) is a crop of global importance, providing about 85% of the world's sugar. Beyond sugar, it is increasingly cultivated for biofuel and other byproducts, making it a key agricultural commodity with nutritional, economic, environmental, and industrial significance (Raza et al., 2018; Manzoor et al., 2023). Currently, sugarcane is grown in more than 105 countries.

The main food products derived from sugarcane are jaggery, brown sugar, and refined sugar. In recent years, research has also focused on developing “energy canes” with high fiber and fermentable sugar content for bioenergy production. Bagasse, the fibrous residue left after juice extraction, is an important byproduct used in boilers for steam and electricity generation. In Pakistan, sugar mills recycle about 3.5 million metric tons of bagasse annually (Wani et al., 2023).

Globally, Brazil, India, Thailand, China, and Pakistan contribute about 70% of sugar production. In Pakistan, sugarcane is the second-largest cash crop, cultivated on 1.06 million hectares with an average yield of 55 tons/ha, producing about 5.5 tons of sugar/ha. The sugar sector contributes 3.6% to GDP, with domestic demand of 4.5 million tons against an installed capacity of 7.5 million tons, leaving an export potential of around 3 million tons annually (Qureshi et al., 2020; FAOSTAT., 2023).

Sugarcane juice contains 65% water, various sugars (sucrose, glucose, fructose), organic acids, vitamins (B-complex, C, D), and minerals (K, Ca, Mg, Fe, Zn). It also carries bioactive compounds such as polyphenols and flavonoids with health benefits (Panigrahi et al., 2021). These qualities, along with its industrial versatility, make sugarcane vital for both local economies and global trade.

Despite its resilience, sugarcane is highly vulnerable to diseases caused by more than 100 fungi, bacteria, and viruses. Major diseases include red rot, smut, ratoon stunting, mosaic virus, and Fusarium wilt. These can reduce yields by 10–50%, threatening farmer income and industry sustainability (Rajput et al., 2021).

Fusarium wilt, caused mainly by *Fusarium sacchari*, is particularly damaging, second only to red rot in economic impact (Poongothai et al., 2014). The disease reduces tillering, stunts

growth, and causes yellowing, drying, and wilting of the canes. Yield losses range between 2–10 tons/ha, with symptoms most visible during monsoon and post-monsoon seasons (Viswanathan., 2013; Paul et al., 2022). Because the pathogen is soil- and sett-borne, therefore eradication is extremely difficult.

Conventional fungicides provide partial relief but are not always cost-effective or sustainable (Sharma et al., 2011; Moosa et al., 2017). Alternative strategies, such as plant extracts with antifungal compounds, have shown potential in suppressing *Fusarium* due to their eco-friendly and low-cost nature (Sana et al., 2017; Rafiq et al., 2021). Integrated disease management, combining resistant varieties, clean seed, soil management, biocontrol (e.g., *Trichoderma*), and selective fungicide use, is currently the most practical approach (Gupta et al., 2011).

Managing *Fusarium* wilt is not just an agricultural necessity but also an economic and social imperative. Yield stability ensures farmer livelihoods, supports export potential, and strengthens food security. Sustainable management practices are critical for maintaining long-term productivity without harming future generations (Shoaib et al., 2018).

The origin and history of Sugarcane

About 8000 BC, sugarcane was first domesticated in New Guinea. From then, it expanded to Southeast Asia and India. A unique sugar crystallization method was created by an Indian scientist around the fifth century AD, greatly aiding in the storage and transportation of crystallized sugar. After this breakthrough, sugarcane farming, juice refining, and granulated sugar manufacturing expanded throughout China, Persia, and the Mediterranean area. Asia, Europe, and the Arab world were among the regions where sugarcane production spread as a result of the conquest of Egypt, where it was widely planted. During the sixteenth and seventeenth centuries, a number of nations, notably Spain, Portugal, Italy, Cyprus, and the Azores, attempted to stabilize their economies through the cultivation of sugarcane. Sugarcane was first introduced to Spain in 715 AD (Nisa et al., 2022). A perennial plant of the Poaceae family, sugarcane is indigenous to Southeast Asia's tropical climates. To generate sugar, several types of sugarcane are grown all over the world in warm, humid climates, roughly between 30°S and 35°N latitude. The plant's stem, which has a diameter of 2 to 6 cm, normally reaches a height of 1.5 to 4 meters, but under ideal circumstances, it may grow as high as 7 meters. Sugar is extracted from the stalk, which has a blooming head on top and no leaves (Varga et al., 2022). With its origins in Southeast Asia and its expansion around the world via commerce, colonization, and technical improvements, sugarcane has a long and varied history. It has had a major impact on civilizations, economies, and cultures across several continents (Voora et al., 2023).

Economic Importance of Sugarcane

Every year, the world's demand for cane sugar increases, propelling the sugarcane industry and agriculture toward a prosperous future. Sugarcane is not only the preferred crop for producing sugar, but also for bioenergy and bioethanol. A large number of member states of the European Union (EU) are already blending bioethanol or biodiesel into diesel and gasoline fuels. Bioethanol is often blended with gasoline in different ratios, ranging from 10 to 85%, which frequently requires vehicle modifications. In Norway, for example, about 7% of bioethanol is blended with regular octane gasoline (Sundvor & Lopez-Aparicio., 2014). In developing nations, sugarcane is especially important to the economy since it generates billions of rupees

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in taxes and fees for the government. Since the crop needs a lot of water to thrive, it is critical to use creative, sustainable, and water efficient production techniques (Raza et al., 2023). Sugarcane's uses have grown beyond the manufacturing of sugar due to recent technological breakthroughs; it is now used as a raw material for many other businesses in the nation (Farooq et al., 2019). Furthermore, there are significant financial difficulties associated with the encroachment of pollutants or mycotoxins into agricultural food chains (Agriopoulou et al., 2020). Millions of people throughout the world rely on the enormous employment that sugarcane farming and processing provide for their livelihoods. In many areas, this labor-intensive business reduces poverty and promotes employment in rural areas. Sugarcane farming greatly enhances farmers' financial security by providing them with a source of income. Farmers receive income from selling sugarcane to processing mills, which boosts rural economies (Iwuzor et al., 2023).

International commerce helps sugarcane producing nations gain foreign cash and fortify their economic bonds with one another. This interaction is essential to international trade. The production of sugarcane also yields important byproducts, such as filter cake, molasses, and bagasse, all of which have a variety of industrial uses and raise the crop's overall economic worth. Moreover, sugar is an essential component of the food and beverage business, having a big influence on the industry's profitability. Many food items use sweeteners derived from sugarcane (Maitah et al., 2024).

Major diseases of sugarcane

The diseases are a major challenge for sugarcane growers worldwide. These diseases can cause significant losses in sugarcane yield and quality, leading to economic losses for farmers and industry. Fungal diseases in sugarcane are caused by various pathogenic fungi that attack different parts of the plant, including leaves, stems, and roots. Approximately 100 fungal, 10 bacterial, 50 nematodes, and 10 viral diseases have been identified in sugarcane crops worldwide (Sharma & Tamta., 2015). The most common fungal diseases in sugarcane are wilt, red rot, smut, and set rot. The fungal disease is mainly causing a loss in sugarcane production in the field. Fungal diseases in sugarcane spread through several mechanisms, including wind, water, and infected seed material. Once established, these diseases can be challenging to control, and management strategies must be carefully developed and implemented to prevent their spread (Manjula et al., 2023).

The precise diseases that impact sugarcane might differ depending on the environment and locale. Yield is greatly impacted by phytoplasma, viral diseases such sugarcane streak mosaic, sugarcane mosaic virus, and yellow leaf syndrome, and fungal diseases like brown spot, wilt, rust, red rot, and smut. Reduced sugar yield is also a result of pests like the white woolly aphid and sugarcane borer (Thilagavathi et al., 2020). Furthermore, hazardous compounds from *Fusarium*, *Aspergillus*, *Alternaria*, *Penicillium*, and other fungus contaminate around 25% of the world's crops (Kagot et al., 2019; Abdallah et al., 2020).

Wilt disease of Sugarcane

In many sugarcane producing places, wilt is one of the most damaging fungal disease that affect the productivity of sugarcane (*Saccharum officinarum* L.), (Bao et al., 2020). Wilt is a dangerous stalk disease that seriously reduces sugarcane yield and output. On rare occasions, the illness breaks out in the field as a major epidemic, which has a disastrous impact on the

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production of sugarcane (Viswanathan et al., 2020). The illness was initially identified as "wilt" by (Sarma et al., 1976), who also identified *Cephalosporium sacchari* as the causative culprit. The ailment was originally reported in India. Nonetheless Bourne et al., (1922) identified a kind of *Fusarium* in Barbados that they linked to rot disease in the basal sections of unwounded sugarcane stems. At about the same time, a *Fusarium* spp linked to ratoon rot and dry rot of sugarcane in Argentina was also discovered by (Fawcett et al., 1922). Nowell et al. (1920) had already observed that wilt disease was common in Barbados and had little effect on the crop, but in the island of Nevis, the illness caused more damage and had symptoms like red rot. In addition, Sen et al., (1975) reported a stem disease in Florida that produced sugarcane wilt in seedling kinds that were comparable to the illness that Butler and Khan had first reported in India. Rands & Abbott., (1938) found that purple and white strains of *Fusarium* were present in seed cuttings and that a purple species of the disease was often linked to infected cuttings in Louisiana. *Fusarium* in its purple form was also frequently found on developing stalks after borer damage.

Fusarium is responsible for the purple rotting of seed cane and standing crops in Louisiana, according to (Rands & Abbott., 1938). They discovered that cuttings planted in low, moist places, banked cane, and seed canes with poor bore were more prone to the illness. *Fusarium* stem rot was seen by (Ayson et al., 1938) in stubbles, standing canes, and seed canes, indicating that this was the same disease that Butler and Khan had reported in India. In the Everglades area of Florida, *Fusarium* stem rot was common between 1949 and 1952, as reported by (Singh., 1955). The authors stressed the significance of breeding cane that is resistant to both red rot and this disease.

Symptoms of Sugarcane wilt disease

The interior damage caused by sugarcane wilt disease results in recognizable pith cavities and discolored stalk tissue. PITHY caverns planting wilt affected setts causes poor crop establishment; sprouting seedlings either die or produce weak plants with discolored leaves. Plants cultivated from disease-free setts, on the other hand, have a healthy phenotype. The disease affects the crop at three different stages: germination, young crop, and maturity. However, symptoms are most noticeable in mature harvests, when yellowing is followed by leaf drying and affected plants withering. Disease signs are also present in germinating setts or germinated seedlings; however, these instances are frequently disregarded (Viswanathan et al., 2020).

Typically, the monsoon and post-monsoon seasons are when wilt symptoms appear. But in extreme circumstances, the illness might appear in crops that are just 4-5 months old. At first, all of the canes in a clump or only the diseased canes inside it will have a vivid yellow discoloration of the leaves in the crown. The diseased canes are readily recognized by their discolored leaves and slowed development. Healthy canes are unaffected by the illness, but diseased canes gradually dry up and wither as they worsen. In extreme situations, the young crop exhibits wide spread drying due to considerable leaf yellowing. The field may only include dry canes by the time the growing season ends. Wilt affected canes can occasionally continue to be somewhat turgid with discolored leaves and may not completely dry until harvest. According to (Viswanathan et al., 2013) in certain plants, the crown may stay green while the other leaves clearly show signs of fading.

Disease Life Cycle of Sugarcane Fusarium Wilt (*Fusarium sacchari*)

The life cycle of sugarcane Fusarium wilt is soil- and sett-borne, involving both survival structures and active infection stages:

Survival Phase

The pathogen persists in the soil and crop residues through chlamydospores, mycelium, and infected setts. These structures can remain viable for extended periods, ensuring survival between crop cycles (Leslie & Summerell., 2006).

Primary Infection

Infection begins when setts or roots come into contact with contaminated soil or infected planting material. The fungus penetrates through wounds or natural openings, establishing itself in the root cortex and vascular tissues (Viswanathan., 2013; Bao et al., 2020).

Vascular Colonization

The pathogen rapidly invades and colonizes xylem vessels, producing mycelium and spores that block water transport. This leads to water stress in the plant, disrupting physiological functions (Poongothai et al., 2014).

Symptom Expression

External symptoms appear gradually: leaf yellowing at the crown, drying of foliage, stunting, poor tillering, and wilting of canes. Internally, stalk tissues show reddish-brown discoloration and pith cavity formation (Viswanathan et al., 2020). Symptoms are most severe during monsoon and post-monsoon seasons and often unnoticed until mid-growth stages (Parthasarathy., 1972; Agnihotri & Rao., 2002).

Secondary Spread & Sporulation

Infected tissues harbor sporodochia and macroconidia of *F. sacchari*. These propagate through irrigation water, wind, ratoons, and infested setts, facilitating field-to-field dissemination (Rands & Abbott., 1938; Rajput et al., 2021).

Persistence and Re-infection

After harvest, infected residues and ratoon crops continue to harbor inoculum. If ratooning is practiced, disease incidence intensifies, creating hotspots for the next crop cycle (Viswanathan & Rao., 2006).

Cycle Renewal

The survival of pathogen propagules ensures that the cycle repeats in subsequent plantings, perpetuating field infestation if no management practices are applied. Figure-1

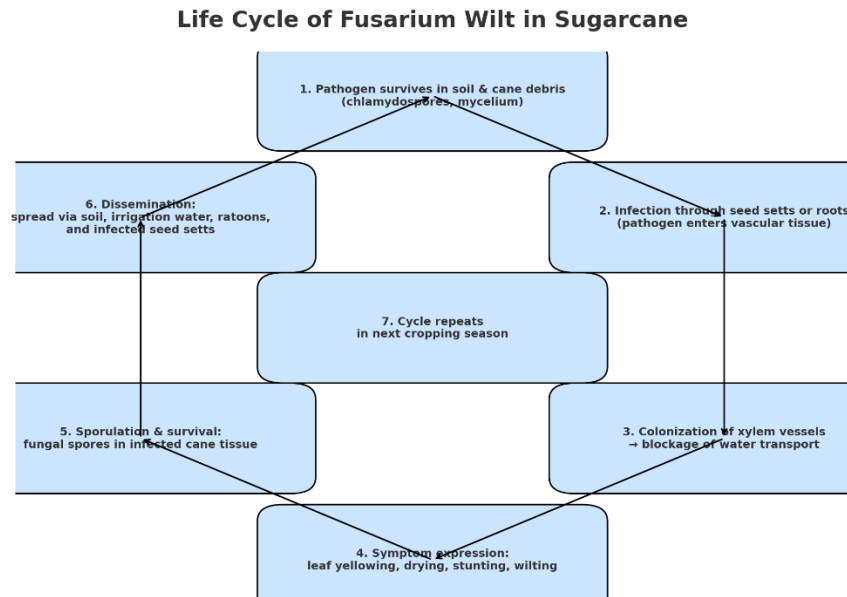


Figure.1 Disease Life Cycle of Sugarcane Fusarium Wilt (*Fusarium sacchari*)

Losses Sugarcane wilt disease

Sugarcane wilt disease has a detrimental effect on the crop and its juice, resulting in large losses in terms of both quantitative and qualitative metrics. There seems to be a clear correlation between the cane types of resistance level and the impact's intensity. The disease reduces the following: moisture content in cane (49.6-58.4%), sett germination ability (40.2-50.1%), number of mill able canes (39.9-50.9%), number of tillers (40.0-49.0%), cane yield (45.2-51.2%), juice content (42.8-59.2%), protein content in leaf (19.9-23.9%) and juice (18.8-34.5%) (Kumar et al., 2015).

Wilt losses are often measured in terms of the amount of dead or dry canes found in the field following harvest losses have been reported to range from 2 to 10 tons per hectare (Parthasarathy., 1972). According to Sharma et al., (2011) yield losses can be as high as 65%, and the illness is more common in ratoon crops than in plant crops. In general, plants with diseases yield fewer tillers than those that are healthy (Agnihotri & Rao., 2002). In the cultivar Co 1148, (Longvah et al, 2017) observed a high frequency of wilt (90%) linked to stalk borer infestations, making the crop almost unfit for milling. According to Viswanathan & Rao., (2006) the disease may cause yearly losses of around 12.7 to 25.4 million tons in different years, with conservative estimates of loss ranging from 3 to 6 tons per hectare. This might have an economic effect of Rs. 1250 to 2500 crores annually. The sugar business and farmers are equally impacted by these losses. Furthermore, the effect on recoverable sugar in the mill is frequently underestimated, resulting in annual unreported financial losses for sugar mills.

Management of Sugarcane wilt disease

Management of wilt is a serious issue in the country as the disease is a soil borne and diseased setts carry the pathogen. The use of different chemical fungicides, plant extracts and wilt resistant varieties are economical and ecologically sustainable. Viswanathan et al., (2020)

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worked on the assessment of wilt resistance parental clones and found resistance up to 22.3%. Apart from the use of wilt resistant varieties other methods for disease management are also required like biological control, cultural methods and chemical methods, which can be integrated to manage the disease. In recent times there has been considerable national and international focus on the sustainability and productivity of the world's sugarcane growing industries (Kingston et al., 2007).

A number of factors, such as land size, education, slow extension services, and insufficient training delivery, have an influence on sugarcane productivity. Farmers frequently struggle with money problems and lack access to the newest agro technical techniques. Adopting contemporary practices is hesitant because of issues with irrigation water, pesticides, high quality seed types, modern technology, and little information about agricultural inputs and their unavailability. Farmers also confront a plethora of additional difficulties, such as limited marketing expertise, government disarray, political meddling, and a lack of information sources (Bassey et al., 2024). Healthy seed canes are very important for disease management. This exercise prevents the entry of the pathogen into new areas. Disease severity increases in ratoon crops. So, wilted plants should be harvested early, and ratooning should be avoided. After harvest the residue should be burned and proper sugarcane sett treatment with suitable fungicide (Goswami et al., 2020). Table .1.

Host resistance & clean seed

Use resistant/tolerant varieties; screen parents/lines where possible (Viswanathan et al., 2020). Establish clean seed systems: certified nurseries, hot-water treatment, and strict rouging to prevent pathogen movement in setts.

Cultural measures

Prefer plant crop over ratoon where wilt is established; avoid ratooning in affected fields. Early removal of wilted clumps; destroy residue post-harvest; rotate with non-host crops. Improve drainage and avoid low, waterlogged pockets that predispose to wilt-borer complexes. Optimize soil health (organic matter, EC/pH management) and irrigation quality.

Biological control

Employ *Trichoderma* spp. (e.g., *T. viride*, *T. harzianum*) as sett dips or soil applications; combine with organic amendments for establishment (Moosa et al., 2017; Nanjundaswamy et al., 2020).

The uses of plant extracts

By preventing the growth of pathogens, in particular, natural plant extracts have a major impact on controlling plant growth and improving defensive responses. These extracts, which are made from different plant parts, have active ingredients that work as antimicrobial agents against a wide range of fungi that cause plant disease (Sagar et al., 2007). They are a sustainable substitute for chemical fungicides due to their eco friendliness and absence of harmful effects on people and the environment (Khalikar et al., 2011). Plant extracts from *Aloe vera*, *Zingiber officinale*, *Datura stramonium*, *Allium cepa*, *Thea sinensis*, *Cynara cardunculus*, *Glycyrrhiza glabra*, and *Nepeta* spp are among the promising ones that have been documented in review studies. These extracts have proven to be effective in reducing plant diseases and supporting environmentally friendly farming methods (Madavi et al., 2005). Numerous plant-produced

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chemicals have demonstrated a great deal of promise in regulating the growth and spread of *Fusarium* infections. Important substances with antifungal qualities, such as tannins, flavonoids, and phenols, stop the growth and metabolism of harmful fungus. For example, tannins, saponins, and flavonoids are present in eugenol, which makes up about 70–85% of the essential oil that is extracted from clove leaves. This substance is useful as an organic fertilizer since it not only has antifungal action but also has high concentrations of vital elements including calcium (Ca), iron (Fe), magnesium (Mg), phosphorus (P), potassium (K), and nitrogen (N). Additionally, it has been observed that aqueous extracts from plants such as *Salvia guaranitica*, *Oxalis latifolia*, *Azadirachta indica*, *Punica granatum*, and *Solanum indicum* efficiently limit the development of *Fusarium oxysporum* (Şesan et al., 2015). These organic extracts present a viable substitute for traditional chemical fungicides, promoting more environmentally friendly methods of controlling plant diseases.

The anti-fungal activity of ethanol extracts from *Allium sativum*, *Allium cepa*, *Ocimum sanctum*, and *Catharanthus roseus* against five pathogenic fungi *Alternaria brassicae*, *Colletotrichum capsici*, *Fusarium oxysporum*, *Rhizoctonia solani*, and *Sclerotinia sclerotiorum* was assessed in a study conducted by (Shivpuri et al., 1997). At 1000 µg/mL, *O. sanctum* and *C. roseus* leaf extracts showed the maximum toxicity against all tested fungus, according to the study. Analogously, leaf extracts from *Azadirachta indica*, *Catharanthus roseus*, *Eucalyptus globulus*, *Lantana camara*, and *Withania somnifera* were examined by (Kanherkar et al., 2007). Their results showed that these extracts successfully inhibited *Fusarium oxysporum* mycelial proliferation. On the third day of incubation, *E. globulus* showed the maximum inhibition among them, followed by *C. roseus*, *L. camara*, *A. indica*, and *W. somnifera*. This research demonstrates how plant extracts may be used as organic fungicides to treat plant diseases. In research, (Sagar et al., 2007) assessed the effectiveness of fourteen plant extracts at 5 and 10% concentrations against *Pythium aphanidermatum* and *Fusarium solani* caused ginger rhizome rot. The results of the tests indicated that the extracts from *Ferula feotida* powder and *Ocimum* leaf exhibited the greatest suppression of mycelial development against *F. solani*, at 68.51% and 60.16%, respectively. Similarly, *Alternaria lini*, the bacterium that causes linseed leaf and bud blight, was evaluated by (Singh & Singh, 2007), using aqueous leaf extracts from 15 plants at a concentration of 2.0%. The plants with the strongest inhibition were *Azadirachta indica* (67.7%), *Lawsonia inermis* (63.0%), *Datura metel* (39.2%), *Calotropis procera* (37.8%), *Lantana camara* (36.6%), and *Citrus medica* (28.1%). Twelve plant extracts were examined by (Vijaya et al., 2007) at 5 to 10% doses to see how well they worked against the sugarcane disease sett rot. They discovered that there was a substantial difference in the effectiveness of the extracts at 5 and 10% concentration. In comparison to other plant extracts, garlic extract, at 10%, showed the highest mycelial colony growth inhibition at 53.13%. This indicated that it was the most effective extract.

Chemical control

Since fungicides offer a rapid and efficient means of battling fungal infections, they are essential for controlling *Fusarium* wilt disease in sugarcane. Rapid sett treatment instruments simplify the application of fungicides by lowering treatment chamber pressure and minimizing soaking time, which improves fungicide absorption into sugarcane setts (Gandhi & Mehra., 2021). Sugarcane setts treated with 0.1% carbendazim have shown good results in preventing wilt illnesses. Furthermore, research indicates that in subtropical India, varieties such as cv.

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Co 89003 can be successfully managed for borer and wilt severity by applying chlorpyrifos 20EC or imidacloprid at 0.5 L a.i./ha and carbofuran 3G or fipronil at 1.5 kg a.i./ha in the final week of August (Viswanathan & Rao., 2006). It has been demonstrated that putting 40 parts per million boron or manganese to wilt affected soil will reduce the frequency of Fusarium wilt disease. Furthermore, disease incidence can be decreased by dipping healthy sugarcane setts in a comparable solution before to planting in diseased plots (Ganguly., 1964). By strengthening the resistance of sugarcane plants against the pathogen and boosting soil health, these treatments help lessen the consequences of wilt.

The in vitro sensitivity of *Fusarium sacchari* to five fungicides from various chemical groups was investigated by (Osti et al., 2022). Using ITS and TEF region amplification, a *Fusarium sacchari* isolate that was isolated from sugarcane plants displaying wilt symptoms was identified both visually and molecularly. Using the poison plate technique, the study assessed the effectiveness of the fungicides azoxystrobin, difenoconazole, hymexazol, cyprodinil, and thiabendazole at doses of 1, 10, 100, and 1000 $\mu\text{g mL}^{-1}$. The capacity of the fungicides to stop *Fusarium sacchari* growth was used to evaluate their efficacy, and the EC50 was calculated by contrasting the growth on fungicide-treated plates with that on untreated plates. The fungicides thiabendazole at 10, 100, and 1000 $\mu\text{g mL}^{-1}$ and difenoconazole at 1000 $\mu\text{g mL}^{-1}$ were shown to be extremely efficient in suppressing the development of *Fusarium sacchari* mycelial cells, with inhibition % of 91.4% and 89.8% and 93.5% and 92.1%, respectively, according to the research by (Osti et al., 2022). Difenoconazole (9.2 $\mu\text{g mL}^{-1}$), thiabendazole (9.9 $\mu\text{g mL}^{-1}$), and cyprodinil (10.6 $\mu\text{g mL}^{-1}$) had the lowest EC50 values. *Fusarium* wilt in sugarcane may be effectively managed by using difenoconazole and thiabendazole, as evidenced by the fact that *Fusarium sacchari* is particularly susceptible to these treatments.

Twelve fungicides were evaluated in research by (Subhani et al., 2008), to see how well they worked in preventing *C. falcatum* related sugarcane illnesses. At doses of 5, 10, 20, and 50 $\mu\text{g mL}^{-1}$, Benomyl 50 WP, Folicar, and Radomil 75 WP were able to completely (100%) suppress the development of fungal growth. 100% inhibition was like wise attained with Tilt 250 EC at doses of 20 and 50 $\mu\text{g mL}^{-1}$. On the other hand, Nimrod 25 EC demonstrated the least inhibition of mycelial development at 5 $\mu\text{g mL}^{-1}$, with an increase in inhibition noted with an increase in concentration. The growth of fungus was not entirely inhibited by other fungicides. The study emphasizes how crucial it is to use efficient fungicides and modify their dosages in order to properly manage fungal infections in sugarcane.

Both in vitro and in vivo bioassays were utilized in the research on controlling *Fusarium* wilt in peas to assess the effectiveness of various fungicides. Four fungicides were examined in the study fosetyl-aluminum, acrobat, matalyxal, and thiophanate-methyl. The minimum effective concentration of each fungicide was found to be 10 ppm. When compared to untreated controls, the use of these fungicides dramatically decreased the incidence of disease, according to the data. Acrobat responded the best to the fungicides, especially when the flooding method was used to apply it. Additionally, successful was fosetyl-aluminum, which demonstrated noteworthy efficacy in pathogen suppression whether applied as a seed treatment or during spraying. These results emphasize the necessity of specialized disease management tactics to provide the best possible crop protection and highlights the significance of choosing the right fungicides and treatment techniques to manage *Fusarium* wilt. In comparison to untreated controls, treated plants showed substantial increases in plant growth indices in research assessing management strategies for pea wilt disease. This demonstrated how fungicides may

effectively control disease when administered according to recommended procedures (Aslam et al., 2019). Many in vitro analyses were carried out in the context of sugarcane (*Saccharum officinarum* L.), an important cash and industrial crop, in order to determine appropriate treatments. It was discovered that systemic fungicides, including carbendazim 50% WP (0.15%), thiophanate-methyl 75% WP (0.15%), propiconazole 25% EC (0.15%), and hexaconazole 5% EC (0.1%), were quite effective. Promising outcomes were also shown by non-systemic fungicides as mancozeb (0.3%) and copper oxychloride 50% WP (0.2%). Furthermore, successful combinational medications included captan 70% + hexaconazole 5%, hexaconazole 18% + zineb 68%, carbendazim 12% + mancozeb 63%, and tricyclazole 18% + mancozeb 62% WP (0.05%). Plant extracts that proved efficient against the pathogen *L. Fusarium sacchari* included eucalyptus and *Azadirachta indica* leaf extracts at a 10% concentration, as well as bio agents including *Trichoderma viride* and *T. harzianum* (Nanjundaswamy et al., 2020).

Table .1 Sugarcane Wilt Management Comparison (South Sindh)

Approach	Key actions (South Sindh playbook)	Evidence strength	Typical effect on wilt	Cost level	Speed of impact	Key risks/limits	Best combined with
Resistant/tolerant varieties + Clean seed system	Adopt locally screened tolerant cultivars; establish 3-tier nurseries; hot-water treat seed (50–52°C for 20–30 min where label allows); rogue wilted stools; certify seed source.	High	Large reduction in primary infections and field incidence over seasons	Medium (setup) → Low (recurring)	Medium (one crop cycle)	Availability of clean seed; breakdown of resistance; hygiene slippage	Sett treatment; * <i>Trichoderma</i> *; rotation; drainage improvement
Sett treatment (fungicidal dips)	Dip setts in labeled systemic fungicide (e.g.,	Moderate–High (sugarcane-specific + in vitro)	Reduces sett-borne inoculum	Low–Medium per hectare	Fast (at planting)	Resistance risk; label compliance & PPE;	Clean seed; * <i>Trichoderma</i> * soil

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	carbendazim 0.1–0.15% where permitted); use rapid-sett treatment device to ensure penetration; drain/dry in shade before planting.		m; better emergence & early vigor			partial control of soil-borne inoculum	application; cultural controls
Biological control (*Trichoderma* spp.)	Apply *T. harzianum* / *T. viride* as sett dip (10^7 – 10^8 CFU/mL) and soil drench/granules at planting; incorporate with compost/press-mud to aid colonization.	Moderate (field & greenhouse)	Suppresses pathogen, promotes root health; yield stability	Low–Medium	Medium (weeks)	Quality/viability of inoculum; heat/drought; needs organic matter	Sett treatment; rotation; organic amendments
Botanicals / plant extracts	Use neem, eucalyptus, garlic, tulsi extracts as sett dips/soil sprays were validated locally; prioritize standardized products	Low–Moderate (mostly in vitro; variable field data)	Adjunct suppression; safer residue profile	Low	Fast–Medium	Inconsistent efficacy; formulation variability; short persistence	Biocontrols; cultural hygiene; resistant varieties

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	over homemade brews.						
Cultural sanitation & field hygiene	Avoid ratooning in infested fields; early removal of wilted clumps; destroy residues; sanitize tools; schedule harvest of hotspots first and last (separate).	High (epidemiological logic + field practice)	Breaks infection cycles; lowers field inoculum	Low	Medium	Labor demands; compliance over time	All other tactics
Soil & water management	Improve drainage/best planting; avoid low pockets; manage EC/pH; ensure good-quality irrigation; add organic matter; balanced nutrition.	Moderate (risk-factor based)	Reduces stress and opportunistic infection; better vigor	Medium	Medium	Infrastructure cost; water quality constraints	Resistance; biocontrol; cultural hygiene
Micronutrient amendments (site-specific)	Where soil tests indicate deficiency, trial boron/manganese corrections; small-plot validation	Low (context-specific, historical reports)	Potential reduction in incidence; improved plant defense	Low	Medium	Over-application toxicity; inconsistent benefits	Core IDM (clean seed, sett treatment , *Trichoderma*)

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	before scale-up.						
Integrated package (IDM)	Combine clean seed + sett fungicide dip + *Trichoderma* + drainage/rotation + sanitation; monitor hotspots and re-treat.	High (systems approach)	Greatest, most durable reduction and yield protection	Medium (balanced across tactics)	Medium (within one season; strengthens over cycles)	Requires coordination and training; input availability	Extension support and monitoring

Conclusion

Fusarium wilt of sugarcane, primarily caused by *Fusarium sacchari*, remains a persistent threat to cane production in South Sindh and other sugarcane-growing regions worldwide. This disease is second only to red rot in economic importance, with yield losses ranging from 10–65% depending on cultivar susceptibility, ratooning, and environmental conditions. The pathogen's soil- and sett-borne nature makes complete eradication unrealistic, necessitating integrated and location-specific management strategies.

Our review highlights that no single measure can ensure durable control. Instead, a combination of resistant/tolerant varieties, clean seed systems, cultural sanitation, targeted fungicidal sett treatments, biological control using *Trichoderma* spp., and supplementary use of botanicals or micronutrients provides the most promising framework. Among these, resistant varieties and clean seed remain the cornerstone of long-term disease management, while sett treatment and *Trichoderma* applications provide short- to medium-term protection. Improved drainage, soil health management, and farmer training further enhance resilience.

In South Sindh, prevalence mapping and risk factor analysis can guide district-specific intervention packages. Adopting an Integrated Disease Management (IDM) approach not only reduces losses but also strengthens farmer income, supports national sugar supply security, and ensures sustainability of the sugarcane industry. Moving forward, coordinated research–extension linkages, farmer access to quality inputs, and monitoring of pathogen variability will be essential to safeguard yields against Fusarium wilt and maintain the economic stability of this vital crop.

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