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REVIEW ARTICLE

Leaf blight disease: A serious threat to large cardamom cultivation in sub-Himalayan region of North-Eastern India

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Abstract

Colletotrichum gloeosporioides is a highly destructive fungal pathogen that causes significant yield losses in large cardamoms (*Amomum subulatum* Roxb.). The sexual, or teleomorphic, stage of the fungus is known as *Glomerella cingulata*. Symptoms of the disease include water-soaked lesions and necrotic spots that gradually expand and cause the affected tissue to become blighted. Infected old tillers are the main reason for the spread of the disease, serving as an inoculum for upcoming seasons. Despite the development of various biological, cultural, chemical and host resistance strategies to mitigate yield losses and limit pathogen growth, field data indicate that the disease continues to result in substantial yield reductions, emphasizing the need for further research. Therefore, the aim of this work is to provide a comprehensive review of leaf blight disease in large cardamom and the pathogen responsible for the infection.

Keywords

Colletotrichum; disease cycle; large cardamom; North-East India; plant disease

Introduction

Amomum subulatum Roxb., commonly known as large cardamom, is one of the leading cash crops in India (1). It is a perennial herb belonging to the family Zingiberaceae and the order Scitamineae. The plant prefers a shady environment and thrives in regions with an average annual rainfall between 1500 and 3500 mm, contributing to high relative humidity that remains consistently elevated within a temperature range of 6 °C to 33 °C (2). The fruit of large cardamom is typically four to 6 times larger than that of small cardamom. The dried fruit has a distinctive, stimulating flavour, taste and aroma, earning the title, the "Queen of all Spices" (3). Large cardamom is the third most expensive spice in the world, following saffron and vanilla (4).

Historical references indicate that large cardamom was used in Indian Ayurvedic preparations as early as 600 BC, according to Susrata (5, 6). The seeds of large cardamom are rich in magnesium, potassium and calcium, while the capsules provide a good source of vitamin C, niacin and riboflavin (7). The dried capsules are traditionally used to treat stomach and oral infections, diseases like malaria and as neutralizing agents for scorpions and snake venom. The seeds are also used in various treatments such as lung congestion, digestive problems, pulmonary tuberculosis and muscle spasms (6, 8).

The cultivation of large cardamom extends to countries such as Guatemala, Papua New Guinea, Sri Lanka, Nepal, Bhutan and India, with Guatemala leading in production (8). In India (Fig. 1), large cardamom is predominantly grown in Sikkim, Nagaland, Arunachal Pradesh, Assam, Manipur, Mizoram, parts of Uttarakhand, the Western Ghats and the Darjeeling district of West Bengal (4, 9). It is believed that the cultivation of the plant began in Sikkim and later spread to other northeastern states such as Arunachal Pradesh, Assam, Nagaland, Manipur and Mizoram (10, 11). State wise total production and area under cultivation of large cardamom in the financial year 2023–2024 is given in Table 1. Sikkim is estimated to contribute approximately 90% of India's total large cardamom production, making India one of the world's largest producers and exporters of the spice (12, 13).

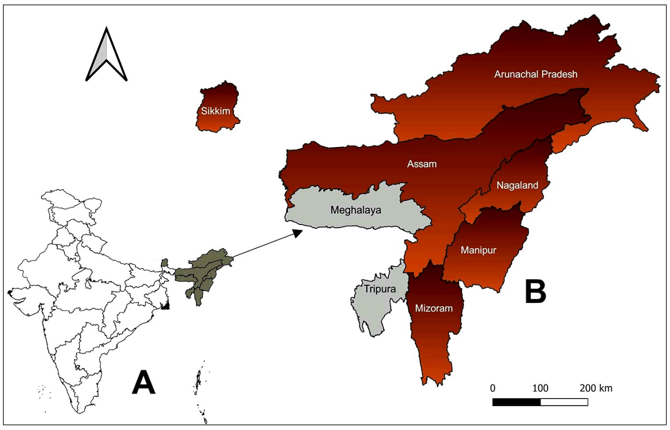

Fig. 1. Map showing distribution of leaf blight of large cardamom **A.** India; **B.** Northeast Indian states* (prepared using QGIS software; *states where disease has been reported are colored).

Table 1. State wise total production and area under cultivation of large cardamom in India in the financial year 2023–2024 (source: Spice Board of India, https://www.indianspices.com)

State	Area under cultivation (Hectares)	Production of large cardamom (Tons)
Sikkim	23312	5280
West Bengal	3305	1070
Arunachal Pradesh	12131	1806
Nagaland	6631	1128
Manipur	217	5
Total	45596	9288

However, recent studies have shown that large cardamom production is significantly impacted by various abiotic and biotic stresses (5, 14, 15). Among these, *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. {teleomorph, *Glomerella cingulata* (G. F. Atk.) Spauld. & H. Schrenk}, a notorious fungal pathogen that predominantly affected the plant (14, 16). This pathogen is also known to cause diseases in other plants, including anthracnose in peppers, mango, avocado and papaya, as well as secondary leaf falls in rubber and leaf spot in Chinese bean (17-22). Of all the diseases caused by this pathogen, leaf blight in large cardamom (Fig. 2, 3A-C) is considered one of the most significant, especially in areas with temperatures

Fig. 2. Leaf blight disease of large cardamom; **A.** Large cardamom plantation infected by leaf blight disease. **B-D.** Infected leaf showing the symptoms; **E.** Infected stems.

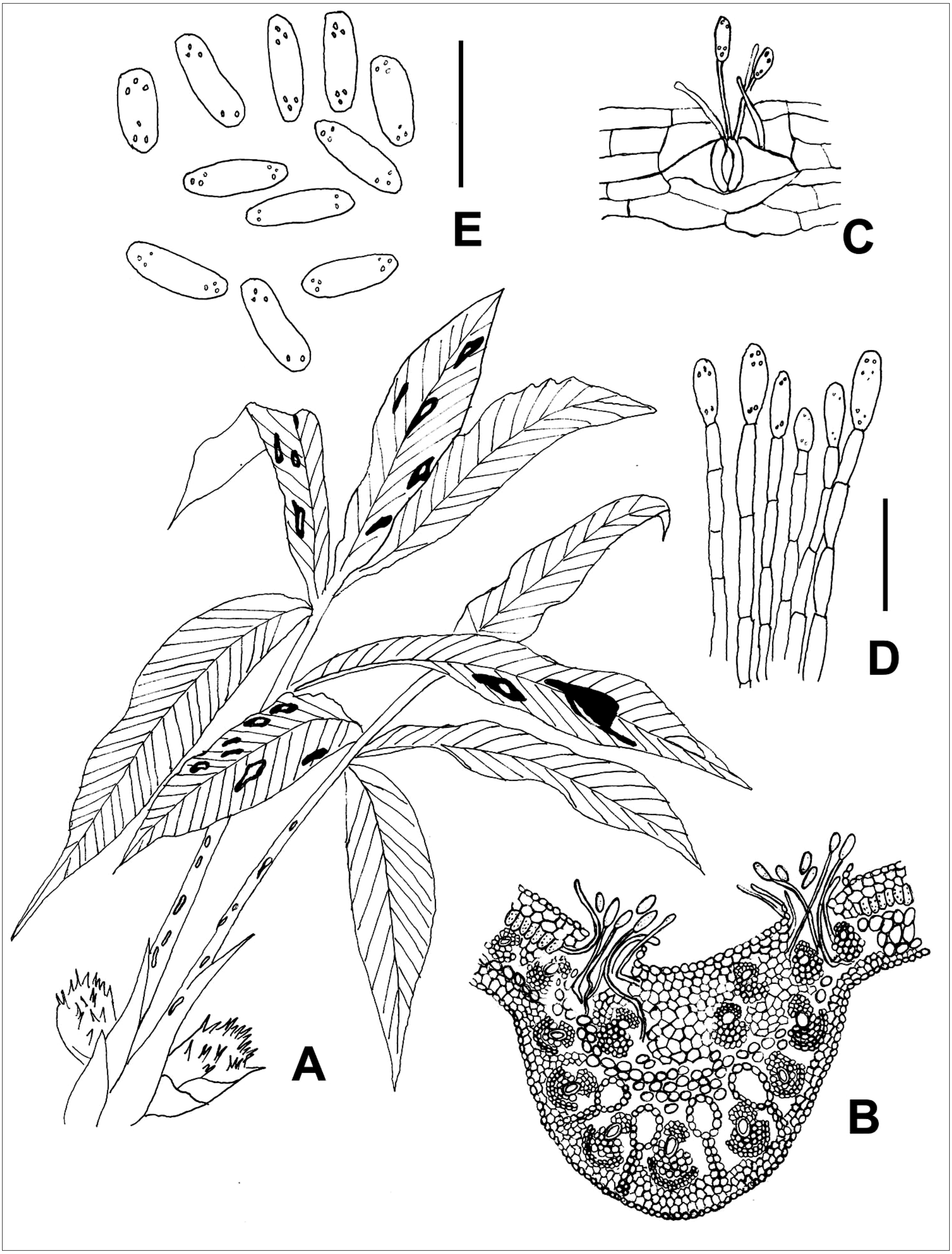

Fig. 3. A. Large cardamom plant showing leaf blight disease; **B.** TS through infected leaf; **C.** Surface view of the infected leaf; **D.** Conidiophore and **E.** Conidia of *C. gloeosporioides*, bar =20 µm.

ranging from 10 °C to 35 °C, a mean temperature between 20 °C and 25 °C, a soil pH of 5.5–7.0 and consistently high humidity (23, 24).

The initial documentation of leaf blight disease in large cardamoms was recorded in 1989 in the regions of Sikkim and Darjeeling (25, 26). A comprehensive study conducted in 59 villages, focusing on 151 large cardamom plantations, revealed that the disease was most prevalent in the southern district of Sikkim, followed by the northern, western and eastern districts (26). The Darjeeling district in West Bengal also exhibited a significant incidence of the disease. Severe infections showing leaf blight disease were reported in 30 villages in Sikkim (13).

Yield Losses

The production of large cardamoms has significantly declined over the past decade due to various factors. These include inadequate infrastructure, the lack of effective replantation techniques, several fungal, viral and insect pest infestations and water scarcity during the winter months. Among the fungal diseases, *Colletotrichum* leaf blight has emerged as a major contributor to reduced productivity and substantial crop losses in large cardamom plantations (27). Plants affected by leaf blight exhibit a decline in the dry weight of capsules and an increase in the husk weight of fresh capsules, resulting in lower-quality produce and diminished economic returns (28). In 2003, the cultivation area of large cardamom reached its peak at 22714 hectares (ha). However, disease outbreaks and prolonged dry spells between 2004 and 2007 led to a consistent decline in both productivity and cultivated area. By 2006–2007, the total cultivation area had decreased to 12500 ha (13, 29). A study highlighted the impact of leaf blight caused by *C. gloeosporioides* on 2 large cardamom cultivars, Varlangey and Sawney. The findings revealed a decrease in the number of seeds per capsule by approximately 13.9% in Varlangey and 7.2% in Sawney, illustrating the severity of the disease's impact on yield (28).

The pathogen

Taxonomic Description

Causative agent

Colletotrichum gloeosporioides (Penz.) Penz. & Sacc. (Fig. 3 D-E)

The anamorphic (asexual) stage of the fungus is *C. gloeosporioides* (Penz.) Penz. & Sacc., while the teleomorphic (sexual) stage is *Glomerella cingulata* (Stoneman) Spauld. & H. Schrenk. *G. cingulata* belongs to the phylum Ascomycota, subdivision Pezizomycotina, class Sordariomycetes, subclass Hypocreomycetidae, order Glomerellales and family Glomerellaceae. Similarly, *C. gloeosporioides* is classified under the phylum Ascomycota, class Sordariomycetes, order Glomerellales and family Glomerellaceae.

The generic name *Colletotrichum* was first proposed by Corda for *C. lineola*, which was associated with members of the family Apiaceae (30). The species *C. gloeosporioides* produces septate, branched, cottony or woolly mycelium with numerous conidiomata that are bright orange and contain abundant setae. Colonies grown on potato dextrose agar are creamy, pale grey to white in color and eventually turn black in the later stages of growth. The conidiophores are sub-cylindrical, erect, branched and occur singly or in clusters, with hyaline conidia (Fig. 3D). Brown to slightly pale septate setae is present. The conidia (Fig. 3E) measure 12.5–18.5 × 4.4–5.5 µm, are hyaline, sub-cylindrical to oblong-obtuse and have round, blunt ends (31, 32). During the asexual phase of its life cycle, *G. cingulata* can form acervuli within the host tissue. The teleomorphic stage of the fungus, which is responsible for large cardamom leaf blight, poses a severe threat to crop yields by significantly reducing overall produce (23). Globally, *Colletotrichum* species are recognized as soil- and seed-borne pathogens and are associated with one of the most widespread anthracnose diseases.

According to a study, it is suggested that APN2/MAT-IGS, the intergenic spacer between DNA lyase and the mating-type locus MAT1-2-1, along with GS (glutamine synthetase), could be used to differentiate species within the *C. gloeosporioides* species complex (17). However, the molecular identification of *Colletotrichum* in this species complex remains challenging due to the lack of sequencing of APN2 (DNA lyase) and GAP2-IGS (the intergenic spacer between GAPDH and a hypothetical protein) in many species (33). Therefore, robust genome sampling and a comprehensive phylogenomic study of *Colletotrichum* species are essential, along with the identification of appropriate markers, in order to delimit species and species recognition among *Colletotrichum* (33).

Disease symptoms

Leaf blight disease of large cardamom is identified by sunken, water-soaked lesions with necrotic regions at the tips or margins of the leaves (Fig. 2, 3A-C). The disease manifests as asymmetrically arranged yellowish-brown spots that enlarge rapidly, coalesce and eventually cover a significant portion of the lamina, giving the affected leaves a blighted or burnt appearance (8, 34–37). Initially, the blight appears as infections on the leaves; however, the most destructive stage occurs when lesions form on the pseudostem. These lesions start off as brown patches but later progress to black or grey, surrounded by brown to yellow halo margins as the disease advances (14, 26, 35, 38, 39). The entire leaf ultimately dries out due to the necrotic lesions extending onto the pseudostem (34).

The seeds, which constitute the economically significant part of the plant, remain immature and take on a light brown to white coloration (14). The leaf sheath encasing the pseudostem exhibits a dark brownish-black discoloration that spreads to the rhizome, eventually transitioning to a greyish color with brown edges. Over time, the middle portion of the pseudostem, referred to as the collar region, becomes brittle and breaks (27, 37). The disease predominantly affects the bearing tillers, while the new tillers usually remain unaffected (35). However, instances of pale-yellow discoloration have been observed in the interveinal regions of the young leaves from new tillers. Additionally, these new leaves may bend without fully opening and appear whitish. A stunted growth pattern has been reported, with rosetting of leaves observed in the diseased clumps of the Varlangey cultivar (35). Upon closer examination, brown lesions with air spaces can be identified in the rhizome of such tillers. The spike emerging from the diseased clumps develops an elongated appearance, attributed to the absence of proper fruit setting compared to healthy clumps (27). Eventually, the entire clump takes on a completely dried, burnt appearance, with the whole bush displaying a scorched look (8, 40).

Epidemiology

In recent years, there has been a significant increase in the prevalence of leaf blight disease in large cardamom, attributed to various factors, including favorable atmospheric and environmental conditions that promote fungal spore proliferation (41). The disease often originates from previously infected tillers, which exhibit numerous lesions, and the dissemination of contaminated plant material serves as a reservoir of inoculum for subsequent disease outbreaks (27, 28). The disease occurs in both normal and excessively shaded areaswas reported (26). The initial symptom involves the loosening of pseudostem sheaths, eventually leading to the development of a greyish-black mold. The optimal growth of *Colletotrichum* species is supported by a temperature range of 25–28℃ and a pH of 5.8–6.5 (24). Consequently, the monsoon season in the Eastern Himalayan hills provides ideal conditions for the rapid emergence and spread of the disease. The disease typically begins to manifest during the monsoon, coinciding with pre-monsoon showers in April-May (35). Moreover, isolated cases of the disease have been observed in certain areas between January and March (35). However, the peak incidence of leaf blight disease in large cardamom generally occurs between June and September, aligning with the mid-monsoon period characterized by high humidity levels (42). The severity of the disease often intensifies during the later months of the monsoon season, particularly in October and November, and gradually subsides in March (42). During the dry season, the pathogen survives in a dormant state but becomes active and spreads the disease when favorable conditions return (24).

Disease Cycle

The pathogen *C. gloeosporioides* survives the winter by remaining dormant on infected bearing tillers, defoliated pseudostems and dead leaf debris that accumulate at the base of the plant. Additionally, other plant species, such as canna, marigold and wild *Colocasia*, exhibit symptoms of *Colletotrichum* blight and may act as alternate hosts for the pathogen (27, 43). Disease development and sporulation of *Colletotrichum* are favored by warm, wet and humid conditions, which are ideal for infection. The phytopathogen primarily spreads through water, with its spores, known as conidia, being disseminated via rain splash and wind (44). This dispersal is facilitated under moist and warm conditions, particularly during the monsoon season (45). The conidia, embedded in a mucilaginous matrix, are carried to nearby plants by splashing water. Once settled on leaves and pseudostems, they serve as infection sites. The availability of moisture and favorable temperatures facilitate spore germination, which allows the pathogen to penetrate the host surface using an appressorium. Following this, the spores enter a dormant or quiescent stage. Dormancy, especially in fruit, is a hallmark of *Colletotrichum* infections. The fungus penetrates directly into the intact cuticle through an infection peg and subsequently colonizes plant tissues, resulting in symptom development. Under conducive conditions, lesions form, leading to the production of perithecia or acervuli. This cycle perpetuates the disease, as the fungus generates substantial inoculum (43). During rainy or humid weather, sticky masses of conidiospores produced in acervuli multiply within symptomatic tissues (46, 47). The sexual stage of *C. gloeosporioides*, identified as *G. cingulata*, produces ascospores and is commonly found on plant debris (48). However, the sexual stage is less significant as a disease-causing phase compared to the asexual stage. Moreover, seeds produced from infected capsules can contribute to the spread of the disease (Fig. 4).

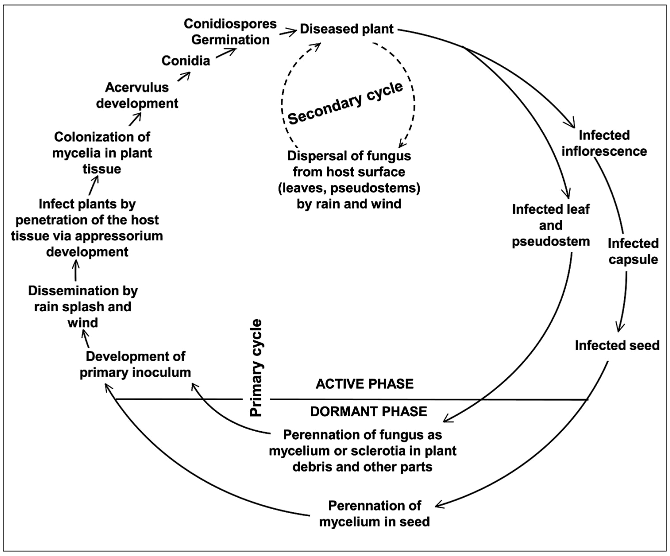

Fig. 4. Disease cycle of *C. gloeosporioides*.

Control measures

In regions where large cardamom is cultivated, there has been a notable increase in disease prevalence in recent years. This rise is primarily attributed to the lack of effective management practices, which pose a significant challenge for large cardamom growers. For example, during the cultivation process, mature stems of the plant are cut at the base after harvesting and left in the fields. These stems, often bearing numerous lesions, act as a reservoir of infection for the subsequent season, potentially leading to increased disease severity and substantial crop losses (35). To ensure the effectiveness of disease management or control methods, it is crucial to minimize the initial disease load. Furthermore, certain regions, such as Sikkim—one of the leading producers of large cardamom—have prohibited the use of chemical fungicides due to their adherence to organic farming practices. This restriction presents an additional challenge in managing and curbing the spread of the disease (27, 35). However, several practices can be adopted to effectively mitigate the occurrence and spread of the disease. These strategies are discussed below:

Biological control

The application of *Lantana camara* extract has proven to be highly effective in the biological management of leaf blight disease in large cardamom. A study has demonstrated that the use of *L. camara* extract can significantly reduce disease incidence by 68% (49, 50). This effectiveness is attributed to the phytochemicals and therapeutic properties present in *L. camara*. The antifungal properties of cyclopropane phytochemicals derived from *L. camara* play a crucial role in disease management (51). According to a study conducted by a group of researchers, the extract has the potential to inhibit the growth of *C. gloeosporioides* mycelium (13). Plant extracts at concentrations of 2.5%, 5%, 10%, and 20%, derived from *Azadirachta indica*, *Solanum torvum* and *Solanum nigrum*, have shown promising results in controlling *C. gloeosporioides*. These extracts cause deformities in fungal hyphae, such as abnormal branching, vacuolization, and hyphal tip swelling (52). For additional management, pre-treating large cardamom suckers with *Pseudomonas fluorescens*—using a solution of 5 L/ 100 L of water prior to planting in the field or nursery is recommended (35). Furthermore, spraying and drenching the clumps with *P. fluorescens* at a rate of 3 per 3-5 L/100 L of water during May, August and September have been shown to effectively reduce disease severity (35, 53). Certain antagonistic bacteria and fungi, such as *Bacillus subtilis* and *Trichoderma gamsii*, exhibit therapeutic and enzymatic activity against various microorganisms by producing enzymes, biochemicals, secondary metabolites and antibiotics. These microbial agents have been applied to manage leaf blight in large cardamom, with 40–45% of disease incidences being controlled (54). Among the treatments tested, *L. camara* extract and *B. subtilis* have emerged as particularly effective options for controlling *C. gloeosporioides*.

Cultural practices

To effectively manage leaf blight disease in large cardamom, it is essential to destroy pathogen-infected plant litter before the onset of the monsoon season. Leaves and spike residues, along with bearing tillers cut during harvest, should be composted, as the elevated temperatures during composting help to eliminate the pathogen (27). Incorporating cow dung slurry along with microbes in compost pits to enhance the composting process was recommended (35). Additionally, burning infected plant materials, along with pruned non-productive parts from the clump base, has been suggested. (34, 36). Maintaining adequate shade in plantations can significantly reduce disease intensity. Optimal shade levels, allowing 40–60% of filtered light, have been shown to effectively control disease incidence (42). Furthermore, it is crucial to remove alternative hosts, such as marigold, turmeric, *A. dealbatum*, castor, ornamental basil, wild *Colocasia*, and ginger, from the immediate vicinity of plantations (8, 35, 37). The destruction and removal of diseased plant parts or entire plants in nurseries and plantations are also beneficial for controlling the spread of the disease.

Chemical methods

A variety of fungicides, including hexaconazole, copper oxychloride (1%), Bordeaux mixture (1%), and Mancozeb (0.2%), can be applied prophylactically at intervals of 20–25 days (13, 35–37). The frequency of fungicide application may be increased to 2 or 3 times, depending on the severity of the disease. The preventive application of a 1% Bordeaux mixture on the clumps before and after the monsoon season has proven effective (35). A study was conducted to identify the most effective fungicide for controlling leaf blight in cardamom and found that a 0.2% concentration of SAAF (carbendazim + mancozeb) and 0.1% carbendazim, used in an intercropping system with Areca nuts, were the most effective (1). These findings indicated that the combination fungicide SAAF, consisting of carbendazim and mancozeb at 0.2% concentration, as well as carbendazim alone at 0.1%, were more effective than the fungicides propeconazole and difenconazole in managing cardamom leaf blight disease (1). An effective approach to disease control involves applying sprays of Difolatan, Indofil M-45, Dithane Z-78, or Lonacol at 7–10 days intervals. After seedling germination, it is recommended to apply copper oxychloride in a solution of 1 g/L of water to the soil. For treating suckers, fungicides such as Demoson or Apron 35SD, Metalaxyl 25WP at 2 g/L of water, Plantvax 75WP at 2.5 g/L of water, or Benomyl 25WP can be used (8).

Host resistance

Identifying resistant sources of large cardamom under suitable environmental conditions necessitates comprehensive screening of cardamom accessions (52). A study conducted on cardamom accessions maintained at one of the experimental farms of the Cardamom Research Centre, part of the Indian Institute of Spices Research in Kodagu District, Karnataka, India, categorized the accessions based on the percent disease index (16, 52). Among the 328 accessions of large cardamom studied, IC-349613 and IC-349588 emerged as the 2 highly resistant types, each demonstrating a resistance level of 51% was reported (52).

To confirm the durability of resistance, it is essential to evaluate these highly resistant accessions under favourable field conditions (42). Further research has investigated the resistance of cardamom germplasm to leaf blight. For instance, researchers assessed 72 accessions sourced from Kerala (Attappadi and Wagamon) at the Indian Institute of Spices Research, Indian Council of Agricultural Research, Calicut, Kerala, India (55). This study revealed that 21 of the accessions remained unaffected by *C. gloeosporioides*. Future research should focus on identifying large cardamom species that not only exhibit resistance to the pathogen but also possess resilience to changing climatic conditions.

Conclusion

Large cardamom is a highly valued cash crop renowned for its distinctive aroma and unique chemical properties. However, the fungal pathogen *Colletotrichum gloeosporioides*, responsible for causing large cardamom leaf blight disease, has led to substantial losses in capsule production in recent years. The rising incidence of this disease has significantly reduced production, emphasizing the urgent need for improved infrastructure and the adoption of replantation techniques alongside effective disease management strategies. Farmers should be trained in the latest cultivation practices and provided with disease-free planting material, which would contribute to increased production of this important cash crop. Climate change has also exacerbated the challenges associated with cardamom cultivation, with prolonged dry spells and heightened disease infestations further diminishing yields. Additionally, the cultural practice of retaining infected tillers acts as a source of inoculum for the following growing season. Thus, integrating cultural practices with biological and chemical control methods can be an effective approach to managing plant diseases. The phytopathogen *C. gloeosporioides* infects multiple hosts, underscoring the importance of screening for alternate hosts in the cultivation area and their subsequent removal to mitigate disease spread and enhance yield. Furthermore, developing disease-resistant cardamom varieties through advanced breeding techniques is essential for ensuring sustainable production and cultivation of large cardamom.

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Authors' contributions

AKD conceptualized and designed the study. TB and NR acquired the data and drafted the manuscript. AKD reviewed and edited the draft.

Compliance with ethical standards

Conflict of interest: The authors report no conflict of interest.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used QuillBot (https://quillbot.com/) in order to improve language and readability at the drafting stage of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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