

REVIEW

Open Access



Unraveling the mystery of dieback in *Dalbergia sissoo*: a review

Muhammad Zunair Latif¹, Amer Habib², ChongChong Lu¹ and Xinhua Ding^{1*} 

Abstract

The shisham tree (*Dalbergia sissoo*) is a keystone hardwood species of South Asia, highly valued in economic value in forestry, agroforestry, and landscape horticulture due to its durable, fragrant, and decay-resistant wood. However, shisham's health on both public and private lands is seriously compromised by recurrent outbreaks of dieback disease. Shisham has a history of severe dieback over the last century throughout its natural and introduced range. Since 1918, mortality associated with shisham dieback has been studied to determine its spread and underlying causes. Like most pathosystems, shisham dieback involves complex interactions among multiple biotic and abiotic factors, with certain site- and stand-level factors exacerbating disease severity across various regions and times. Recent outbreaks of shisham dieback in Pakistan have been linked to *Ceratocystis dalbergicans*. Previously, *Fusarium* was linked to wilt/dieback disease in Shisham. This disease has been differentiated from often-confusing *Fusarium* wilt/dieback on the same plant and explains dieback, a separate disease of shisham. Currently, published guidelines for managing *Ceratocystis* infections in shisham are limited. While researchers have explored potential management strategies, including identifying host resistance genes and chemical control methods, achieving sustainable disease control will require long-term, dedicated efforts due to the extended lifespan of shisham trees. This review provides a historical and updated perspective on the investigation and establishment of the pathogenic basis of shisham dieback, focusing on the role of *Ceratocystis* species. This work aims to clarify existing knowledge gaps, resolve controversies surrounding disease causation, and inform future research to enhance shisham conservation efforts.

Keywords Hardwood tree, Shisham, Tree mortality, Pathology, Dieback outbreaks, Fungal pathogens, *Ceratocystis*, Disease management

Background

Shisham (*Dalbergia sissoo*) is a moisture-loving, fast-growing, medium- to large-sized deciduous tree in the family Fabaceae (CABI 2021a), native to the Indian subcontinent (Javed et al. 2023b). This species is economically important due to its durable and decay-resistant wood, valued for construction, furniture, and

marine-grade plywood (Tewari 1994). Beyond economic uses, shisham has medicinal and industrial utility: it is a source of fuel, alkaloids, fibers, neoflavanoids, resins, and tannins (Kumar and Khurana 2016; Ijaz and Ul Haq 2021). It is used in large-scale timber production and cultivated as a landscaping tree in urban areas, parks, schools, and highways, where it acts as a vital sink for airborne pollutants (Ghosh 2018; Latif et al. 2023). In South Asian traditional medicine, the wood and bark have been recognized for their abortifacient, antipyretic, anthelmintic, aphrodisiac, and expectorant properties (Shah et al. 2010; Kumar and Khurana 2016), while the seed oil and powdered wood are used for treating skin ailments (Shah et al. 2010). Its leaves are used as animal feed and provide habitat for wildlife species such as vultures, which are

*Correspondence:

Xinhua Ding
xhding@sda.u.edu.cn

¹ College of Plant Protection, Shandong Agricultural University, Taian 271000, China

² Department of Plant Pathology, University of Agriculture Faisalabad, Faisalabad 38000, Pakistan



critically endangered in Pakistan (WWF 2021). Shisham trees form symbiotic relationships with nitrogen-fixing rhizobacteria on their roots, improving nutrient availability in the soil (Kumar and Khurana 2016).

The terms 'decline', 'dieback', and 'wilt' classify three distinct diseases based on symptoms. The term 'decline' often describes a more general set of symptoms associated with loss of tree vigor (for example, foliage death, reduced growth, or premature foliage dropping). The term 'dieback' can be defined as the 'progressive death of shoots, branches, and roots, generally starting at the tip, and associated with changes in soil moisture or virulent pathogens'. A decline is an episodic event characterized by premature, progressive loss of trees and stand health over a given period without obvious evidence of a single causal factor, such as physical disturbance or attack by an aggressive disease or insect. Despite having a distinct meaning from 'dieback', 'decline' and 'dieback' have been used interchangeably to describe tree conditions. Symptoms of dieback and decline are also often mistaken for 'wilts', which are more specifically a 'loss of rigidity and drooping of plant parts, generally caused by insufficient water in the plant' (Ciesla and Donaubauer 1994; Agrios 2005; Fraedrich 2020; Asiegbu 2022).

Shisham dieback is a growing concern in the Indo-Pak subcontinent, posing a threat to this valuable species (Naqvi et al. 2019; Ul Haq et al. 2023). Research on shisham dieback has historically focused on the immense economic importance of the host (Ijaz and Haq 2021; Javed et al. 2023a). While many pathological studies have been conducted on shisham dieback disease, they often have conflicting results. In recent years, increasing mortality due to dieback has created a need among researchers to gather information about the rate of the disease and its causes. Shisham dieback due to *Ceratocystis* infection received significant attention a decade ago.

With a focus on the emerging pathogen *Ceratocystis*, associated with shisham mortality, we gathered in-depth knowledge over the century, the related questions and controversies, and summarized the current scientific understanding of shisham dieback disease. The novelty of this document is that it describes multiple potential drivers (biotic and abiotic) that have been reported since the early 1900s and can be attributed to this disease. This review provides new insights into the pathology of shisham dieback. This study aimed to determine how pathologists perceive shisham dieback.

Shisham dieback disease

Dieback is the most important and commonly found disease on shisham across much of the Asian subcontinent. Research has primarily aimed to trace the onset and proliferation of the disease, as well as to identify its causative

agents (Naqvi et al. 2019; Ijaz and Ul Haq 2021). Since the early 1900s, successive outbreaks of shisham dieback have been observed in Bangladesh, India, Nepal, and Pakistan (Dayaram et al. 2003; Sah et al. 2003; Webb and Hossain 2005; Shakya and Lakhey 2007; Vogel et al. 2011; Mukhtar et al. 2014b). In the past 100 years, widespread dieback outbreaks and infestations have drastically reduced shisham densities and killed billions of shisham trees (Naqvi et al. 2019; Ul Haq et al. 2023). Although dieback has been present for more than 100 years and many scientific studies have been conducted, the widespread loss of shisham trees is still a problem today. The disease spreads rapidly and is present in most shisham-growing countries, causing a dramatic decline in shisham populations. The increasing prevalence of this disease indicates that it will cause significant economic losses in the future and may result in the extinction of this valuable tree species.

Shisham dieback disease symptoms

Affected shisham trees exhibit a range of symptoms, including yellowing, necrosis, thinning of leaves and crown, branch dieback at the initial and lateral stages, branch mortality, canopy loss, gummosis, vascular discoloration, and eventually tree death (Khan et al. 2000; Mukhtar et al. 2014b). Dieback-affected trees often exhibit bark cracking due to pressure pads and fungal mats growing just under the bark (Poussio et al. 2010; Latif et al. 2021). Fungal growth can block the flow of water and nutrients, causing the discoloration and wilting of leaves from the tops of trees and downward (Al Adawi et al. 2009, 2013; Latif et al. 2021; Javed et al. 2023a). Affected leaves may remain attached to the tree for some time or fall, and the crown progressively thins until the entire tree dies (Latif et al. 2021). Diseased trees show significant moisture reduction in and above the infected portion of the stem (Latif et al. 2021, 2023). Shisham trees die slowly at some locations, one to a few branches at a time, a process that can take from a few months to a few years. At other locations, there have been anecdotal reports of rapid wilting and death of the whole tree. Longitudinal bluish to grayish streaks just beneath the bark can extend several meters up the tree's stem and are a diagnostic symptom associated with shisham dieback (Figs. 1, 2; Latif et al. 2021). These symptoms distinguish dieback from *Fusarium* wilt, which typically produces pink staining in xylem vessels (Haq et al. 2023; Latif et al. 2023; Bakshi and Singh 1954).

Century-locked secrets of dieback in shisham

The earliest records of shisham mortality date back to Nepal in the early 1900s. Since then, shisham mortality has become a significant concern in many areas where



Fig. 1 Disease symptoms of shisham plants infected with *Ceratocystis* sp., and variability in disease symptoms. **a** Healthy shisham tree growing in natural conditions. **b** dieback infected tree showing thinning of leaves and crown. **c** shisham tree with partial dieback symptoms. **d** stag-headed dead tree. **e** excessive gummosis on tree stem. **f** bark splitting. **g** wilting throughout the crown of the tree, resembling physiological wilt or drought stress. **h** epicormic shoots of dieback infected tree, but eventually succumb to the infection. **i** one-sided wilting. **j** vascular discoloration (blue streaking along xylem vessels) just beneath the bark. **k** vascular blockage of xylem vessels (Latif et al. 2023)

this tree is cultivated. The first systematic research on the etiology of dying shisham was initiated in 1915 by Parker, who claimed that *Fomes lucidum* was the cause of widespread tree death (Parker 1918). This initiated widespread and significant scientific debate over dieback outbreaks and their possible causes. Although many biotic and abiotic factors may contribute to the severity of outbreaks, researchers generally agree that fungal plant pathogens are primarily responsible for dieback symptoms. Parker's work was supported by the findings of two other scientists who published similar results (Troup 1921; Sharma et al. 2000). Many researchers have identified *Fusarium solani* as the leading cause of shisham mortality. Bagchee (1944) reported that *F. solani* was involved in wilt and dieback diseases of shisham. (Bakshi and Singh 1954) studied the host-parasite relationship and behavior of associated fungi both *in vitro* and *in planta*. He also studied the cause of pink stains in dieback-affected trees. (Bakshi 1955) investigated shisham mortality in natural

and artificial plantations. He claimed that *F. solani* is comparatively more virulent under drought conditions. The fungus mainly attacks tree roots and blocks vascular bundles, ultimately leading to tree death. Bakshi (1957) reported on the correlation between edaphic factors and disease caused by *Fusarium* spp. (Bakshi and Singh 1959) concluded that *F. solani* is restricted to roots and that symptoms caused by this pathogenic fungus could be reproduced by artificial inoculation. Bakshi (1976) explained the role of *Fusarium* spp. in shisham root infections.

In 1998, a massive dieback outbreak occurred on the irrigated plains of Punjab, Pakistan, and losses of up to 70% were observed (Naz 2002). Gill et al. (2001) reported that shisham trees grown on canal sides and at other moist locations were susceptible to dieback disease caused by *Phytophthora cinnamomi*. Sah et al. (2003) explained the role of edaphic factors in shisham decline in Nepal. Various physical soil characteristics were analyzed, including pH, water-holding capacity, soil texture, soil density, soil porosity, and soil color. No correlation between the physical soil factors and shisham decline was found. (Dayaram et al. 2003) outlined the losses caused by *F. solani* f. sp. *dalbergiae*. Khan et al. (2004) investigated different fungi (*B. theobromae*, *F. solani*, and *Colletotrichum* sp.) associated with tree parts, but only *B. theobromae* was shown to be pathogenic in artificial inoculation experiments. Shakya and Lakhey (2007) confirmed that *F. solani* is the leading cause of dieback in Nepal. Javaid (2008) noted the maximum mortality of shisham plantations along bank canals and less mortality in agricultural fields. Younger trees were reportedly more resistant than older trees. Additionally, drought and high soil moisture content favor pathogen growth and disease severity. Rajput et al. (2008) reported that *F. solani* was the leading cause of dieback disease in shisham in Sindh, Pakistan.

Vogel et al. (2011) identified unknown viruses from dieback-affected trees in Bangladesh that might play an unknown role in disease. Rehman et al. (2012) reported that disease incidence is greater in irrigated plantations (53%) and lower in farmlands (8.3%). They identified *F. solani* as the most frequent fungus, followed by *B. theobromae* and *P. cinnamomi*, which were associated with roots, twigs, and bark samples. Ahmad et al. (2013) and Arif et al. (2013) suggested that *Fusarium* spp. is among the most significant genera of fungi contributing to disease. In Bangladesh, Valdez et al. (2013) described the potential role of three different strains of *Pseudomonas* in dieback disease. Mukhtar et al. (2014a) conducted comprehensive research in different ecological zones of Pakistan's Punjab and Sindh provinces and reported that dieback was prevalent at all study sites with varying



Fig. 2 Shisham dieback diagnostic signs and symptoms. **a** diseased shisham tree showing vertical bark cracking due to pressure pads/mycelial mat formation. **b** fungal mats of *Ceratocystis dalbergicans* on a recently killed shisham tree, serving as a diagnostic symptom of shisham dieback disease. **c** another diagnostic feature is vascular streaking. Photo credit: Muhammad Zunair Latif

degrees of severity. They also noted that disease incidence was greater in the rain-fed and northern irrigated plains of Punjab and was lower in sandy deserts. They concluded that environmental factors (temperature and moisture) play a crucial role in disease development and spread. Their findings confirm previous work showing that the *F. solani* complex can cause dieback in Punjab, Pakistan. According to Kumar and Khurana (2016), *F. oxysporum* and *F. solani* are pathogenic to shisham both together and alone. Poussio et al. (2010) reported that decreased shisham populations in Pakistan were due to *Ceratocystis fimbriata*. Al Adawi et al. (2009) consistently isolated *Ceratocystis* sp. from partially to wholly wilted shisham trees in Pakistan. Haq et al. (2019) summarized the associations of different isolates of *C. fimbriata* with shisham trees commonly affected by dieback disease from different districts of Pakistan. According to the latest research performed in Pakistan, shisham dieback disease prevails in different shisham-growing areas of Pakistan, and tree dieback severity varies among these dieback hotspots. Research has also concluded that environmental variables (rainfall, temperature, and relative humidity) influence disease development (Latif et al. 2021). Research indicated that 23 *Ceratocystis* sp. (Fig. 3) and 4 *Fusarium* sp. (Fig. 4) were isolated from infected tissues of shisham trees, and their potential to cause disease was examined in three shisham age groups. They found no evidence that dieback is caused by *Fusarium* sp., thus establishing that *Ceratocystis* sp. isolates are the root cause of the disease (Latif et al. 2023; Haq et al.

2023). The operational taxonomy of *Ceratocystis* isolates was explored using seven genetic loci, *ITS*, *TEF1- α* , *RPBII*, *CAL*, *MS204*, *MCM7*, and *β -tubulin*, and it was discovered that these isolates represent a new species, *Ceratocystis dalbergicans*, in the *C. fimbriata* sensu lato complex (Haq et al. 2023). However, Javed et al. (2023a) and Javed et al. (2023b) associated shisham dieback with prolonged exposure to drought, water logging, and salinity in nonnative planting sites of shisham trees in Pakistan, whereas insects and fungi were the secondary pathogens.

Taxonomy of *Ceratocystis*

Ceratocystis is among the the 11 defined genera in the *Ceratocystidaceae* family (De Beer et al. 2014, 2017; Mayers et al. 2015), comprising of 39 species (Marin-Felix et al. 2017; Barnes et al. 2003; Liu et al. 2018). These fungi typically produce black, globose ascomatal bases with long, elongated necks terminating in an ostiole, through which sticky hat-shaped ascospores exude (Lowy 1982; Seifert et al. 1993). Phylogenetic analysis revealed four clades based on geographical distribution, including the Latin American clade (LAC), the North American clade (NAC) (Johnson et al. 2005), the African clade (AFC) (Heath et al. 2009; Mbenoun et al. 2014) and the Asian-Australian clade (AAC) (Harrington 2000; Engelbrecht and Harrington 2004; Johnson et al. 2005; Thorpe et al. 2005; Li et al. 2017). The LAC clade includes species associated with diseases affecting shisham-growing regions.

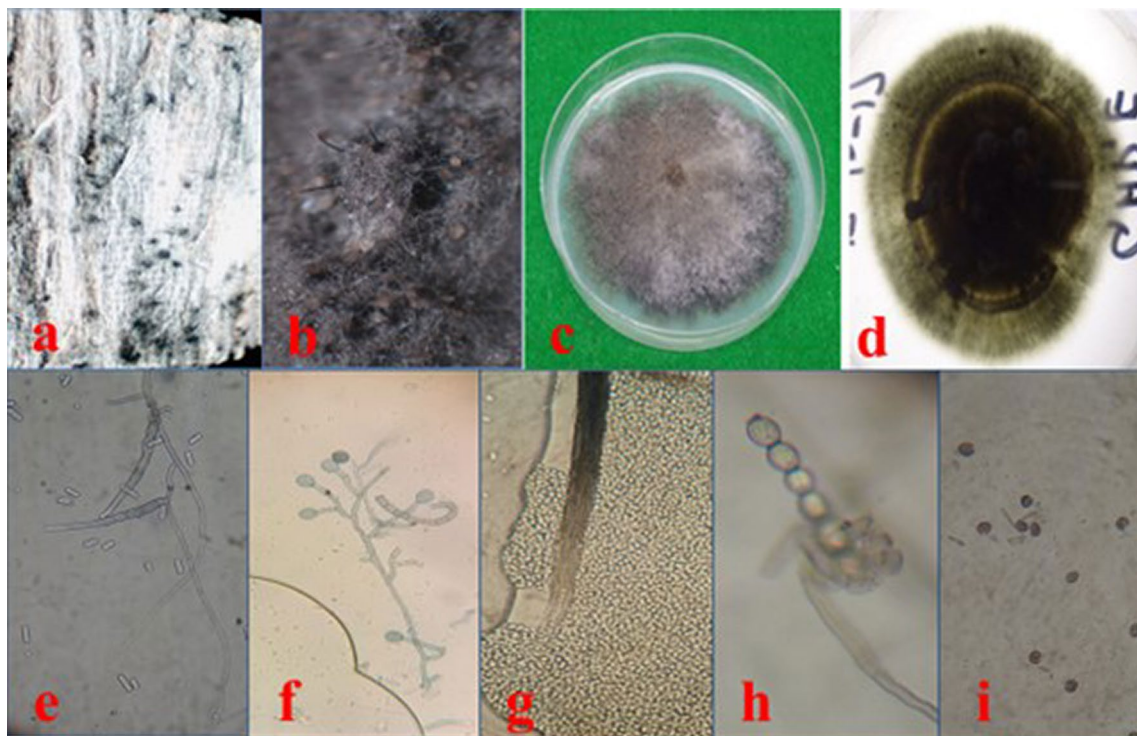


Fig. 3 Morphological features of *Ceratocystis dalbergicans* isolated from diseased shisham trees in Pakistan. **a, b** ascomata on wood chip of diseased shisham tree with masses of ascospores. **c, d** pure colonies of on PDA. **e** septate, hyaline to dark brown mycelia and cylindrical conidia. **f** aleuriconidia. **g** ascomata with masses of ascospores emerging from their necks. **h** barrel shaped conidia. **i** chlamydospores. All the pictures by Muhammad Zunair Latif, except **c, d** by Latif et al. 2023

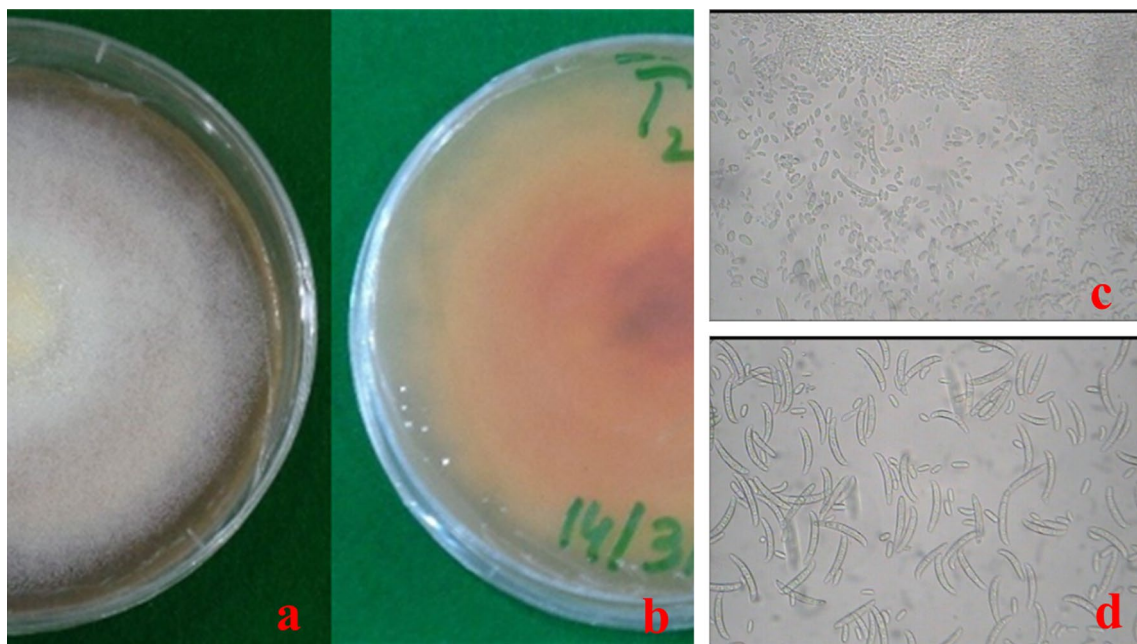


Fig. 4 Morphological features of *Fusarium* sp. isolated from shisham trees in Pakistan **a, b** pure colonies on PDA. **c, d** micro- and macroconidia. All the pictures by Muhammad Zunair Latif, except **c, d** by Latif et al. 2023

Type species: *Ceratocystis fimbriata* (Ellis & Halsted)

C. fimbriata is classified as follows: domain Eukaryota, kingdom Fungi, phylum Ascomycota, class Sordariomycetes, order Microascales, family Ceratocystidaceae, genus *Ceratocystis*, and species *fimbriata*. This species has undergone extensive taxonomic revision, initially reported from sweet potato (Harrington 2000; De Beer et al. 2014; Halsted 1890). Later, the species was transferred to *Sphaeronaema* by Saccardo (1892), to *Ceratostomella* by Elliott (1923), to *Ophiostoma* by Melin and Nannfeldt (1934), to *Endoconidiophora* by Davidson (1935), and finally to *Ceratocystis* by Bakshi (1950). In the past few decades, species identification in the genus *Ceratocystis* has continued to be a challenge for taxonomists, but with the help of molecular tools, many of these complexities have been resolved. *C. fimbriata* is a complex cryptic species that has a unique host range and geographic distribution.

***Ceratocystis* species involved in hardwood tree decline**

Ceratocystis has a broad host range and is a wound-invading pathogen of woody plants (Tarigan et al. 2011; CABI 2021b). Diseases caused by *Ceratocystis* have been frequently reported to cause cankers, declines, diebacks, and vascular wilts in trees (Table 1) (Kile 1993; Marin Montoya and Wingfield 2006; Roux and Wingfield 2009). The fungus has been reported on six continents on various hosts with varying levels of virulence (Alizadeh et al. 2024). The rise of new tree diseases caused by *Ceratocystis* spp. has led to increased concern (Ploetz et al. 2013; Tsopelas et al. 2017).

Disease management: options and challenges

C. fimbriata was reported a decade ago as a leading cause of shisham dieback, wilt, and decline in Pakistan (Al Adawi et al. 2009; Poussio et al. 2010; Latif et al. 2023). Given the increasing impact of shisham dieback caused by *Ceratocystis* spp., there is an urgent need to understand the nexus of host–interactions and the scope of existing disease management options to mitigate the impact of the fungus. At present, there are limited published guidelines for *Ceratocystis* management in shisham. Although some researchers have discussed managing shisham dieback by identifying host resistance genes or chemical controls, designing adequate control and management measures to levels deemed acceptable requires a long-term commitment, and the need to protect the host for several decades is a challenging prospect. Options for managing diseases such as oak wilt, eucalyptus wilt, and mango decline caused by *Ceratocystis* spp., however, may provide a baseline management approach for shisham dieback. As research progresses, management tactics for shisham will be refined.

In vitro chemical management of *Ceratocystis* spp.

Propiconazole (88.88%), difenoconazole (84.75%), hexaconazole (81.11%), and benzimidazole (77.73%) were found to be effective in in vitro tests against *Ceratocystis dalbergicans*. However, a decrease in the efficacy of these fungicides was observed in greenhouse trials on shisham seedlings, while these fungicides proved ineffective in preventing complete tree loss (Latif et al. 2023). Fungicides, including propiconazole (100%), hexaconazole (94.65%), difenoconazole (85.70%), thiram (74.35%), and copper oxychloride (70.52%), have shown considerable efficacy against *C. fimbriata* (Khan et al. 2017). Fungicides such as captan, carbendazim, hexaconazole, propiconazole, mancozeb, and chemicals, such as boric acid, completely inhibit *C. fimbriata* growth under controlled conditions (Sharma et al. 2010). A strong inhibitory effect on the mycelial growth of *C. fimbriata* was obtained by applying difenoconazole, thiabendazole, and fluazinam (Scruggs et al. 2017). Yang et al. (2000) reported high inhibition of *C. fimbriata* by thiophanate-methyl, carbendazim, and liguoling. As much as 4.34% mean diameter of inhibition of *C. manginecans* was achieved using Lanomyl 680 WP, Ao'yo 300SC, Carbenzim 500FL, and Ridomil Gold 68 WG fungicides (Tran et al. 2018).

In vivo management of *Ceratocystis* spp.

There are some reports on the rapid detection of *Ceratocystis* spp. from air, soil, and plant samples using real-time PCR assays, which have practical applications and can effectively be used to detect the pathogen in asymptomatic plants at much earlier stages, allowing sufficient time for the development of management practices to mitigate disease (Dharmaraj et al. 2022; Heller et al. 2023). A field study was conducted on twenty-four 3-year-old shisham trees inoculated with *C. dalbergican* to evaluate the field efficacy of propiconazole and difenoconazole. Researchers have concluded that although these fungicides cannot control tree death, they could considerably help to minimize disease severity (Latif et al. 2023). Oak wilt can be managed by intravascular injections of systemic triazole compounds, e.g., propiconazole (Juzwik et al. 2011). Compared with untreated controls, container-grown live oaks treated with propiconazole exhibited decreased disease severity and fewer diseased trees. The crown loss in naturally infected live oak plants treated with propiconazole (0–41%) was lower than that in nontreated (61–100%) plots. Furthermore, intravascular tree injection provided better disease control at the presymptomatic or preventive stage (Appel 1992). Propiconazole does not eliminate *C. fagacearum* from infected trees. However, preventive propiconazole treatments delay symptom development and tree mortality for at least two years in treated trees (Wilson

Table 1 Diseases caused by *C. fimbriata* on woody hosts and their distribution

Host	Disease(s)	Countries	References
<i>Acacia</i> spp.	Heart rot, wilt	Australia, Brazil, Indonesia, Malaysia, South Africa	Ribeiro et al. (1988); Morris et al. (1993); Barry (2002); Santos and Ferreira (2003); Farid et al. (2018)
<i>Acrocarpus fraxinifolius</i>	Dry rot	Brazil	Firmino et al. (2015)
<i>Actinidia</i> spp.	Wilt	Brazil	Piveta et al. (2016)
<i>Annona squamosa</i>	Branch blight	Brazil	Silveira et al. (2006)
<i>Carapa guianensis</i>	Seed and seedling blight	Brazil	Halfeld-Vieira et al. (2012); Valdetaro et al. (2019)
<i>Caryocar brasiliense</i>	Wilt	Brazil	Silva et al. (2017)
<i>Cassia fistula</i>	Wilt	Brazil	Morgan-Jones (1967); Ribeiro et al. (1987)
<i>Citrus</i> spp.	Dieback, canker, wilt	Argentina, Colombia, Cuba	De Alcaín and Marmelcz (1984); Mourichon (1994); Baker et al. (2008)
<i>Coffea Arabica</i>	Canker	Colombia, Venezuela	Pontis (1951); Marin et al. (2003)
<i>Conocarpus lancifolius</i>	Dieback	Pakistan	Latif et al. (2020)
<i>Dalbergia sissoo</i>	Dieback	Pakistan	Latif et al. (2023)
<i>Eriobotrya japonica</i>	Wilt	China, Pakistan	Li et al. (2014a); Alam et al. (2018)
<i>Eucalyptus</i> spp.	Canker, dieback, wilt	Brazil, China, Pakistan, South Africa, Uganda, Uruguay	Roux et al. (2000), (2001); Li et al. (2014b); Oliveira et al. (2015); Alam et al. (2017b)
<i>Ficus carica</i>	Canker	Brazil, Japan	Kato et al. (1982); Harrington et al. (2011)
<i>Ficus elastica</i>	Moldy rot	Indonesia	Nasution (1976)
<i>Gliricidia septum</i>			Morgan-Jones (1967)
<i>Gmelina arborea</i>	Stem and branch canker, wilt	Brazil	Muchovej et al. (1978); Wingfield and Robison (2004)
<i>Hevea brasiliensis</i>	Moldy rot	Brazil, Malaysia	Wastie (1975); Valdetaro et al. (2015)
<i>Lansium domesticum</i>	Dieback, Wilt	Indonesia	Irsan et al. (2016)
<i>Mangifera indica</i>	Dieback, blight, wilt	Brazil, Oman, Pakistan	Silveira et al. (2006); Galdino et al. (2016)
<i>Metrosideros polymorpha</i>	Wilt	USA (Hawaii)	Keith et al. (2015)
<i>Pimenta officinalis</i>	Canker and wilt	Jamaica	Leather (1966)
<i>Platanus</i> spp.	Canker stain, wilt	Europe, Greece, USA	Panconesi (1999); Engelbrecht et al. (2004); Tsopelas and Aggelopoulos (2004)
<i>Populus balsamifera</i>	Canker and wilt	Canada	Vujanovic et al. (1999)
<i>Populus deltoides</i>		India	Kaushik et al. (1992)
<i>Populus tremuloides</i>	Stem canker	Poland, USA	Wood and French (1963); Gremmen and De Kam (1977)
<i>Prunus</i> spp.	Canker	USA	Devay et al. (1965)
<i>Punica granatum</i>	Wilt	China, India, Pakistan	Sharma et al. (2010); Xu et al. (2011); Alam et al. (2017a)
<i>Spathodea campanulata</i>		Cuba	Isla and Ravelo (1989)
<i>Tectona grandis</i>	Wilt	Brazil	Firmino et al. (2012)
<i>Theobroma grandiflorum</i>	Wilt	Brazil	Oliveira et al. (2013)

2005; Blaedow 2009; O'Brien 2011). Blaedow et al. (2010) reported that the efficacy of propiconazole decreased by up to 69% after two years due to chemical degradation in plant roots and lower stems. Soil drenching with carben-dazim or propiconazole + chlorpyrifos was shown to be effective for the in-field management of *Ceratocystis* wilt in pomegranate (Sharma et al. 2010). Researchers in California tested the efficacy of Arbotect 20-S (thiabendazole) trunk injections in controlling *C. fimbriata* f. sp. *platani*, causing canker stain in *Platanus acerifolia* (Perry

et al. 1988). These researchers found that Arbotect 20-S provided satisfactory control of the targeted pathogen.

Plant resistance as a powerful tool for managing *Ceratocystis*-induced diseases

Plant protection, especially from fungal pathogens, is commonly achieved by resistance breeding (Vale et al. 2001). The best strategy for disease control is planting resistant hosts (Oliveira et al. 2016). The use of resistant germplasm is the most feasible disease control option for

plantation forests (Tarigan et al. 2016). In many cases, resistance can be a more effective and sustainable tool than any other IDM strategy for managing forest diseases, including diseases caused by *Ceratocystis* (Vale et al. 2001; Wingfield et al. 2001; Harrington 2013).

Plant resistance to *C. fimbriata* in woody hosts

Shisham

Genetic factors involved in shisham dieback resistance were explored by studying the NBS-LRR gene family. Transcriptomic analyses of *Ceratocystis*-inoculated shisham plants were conducted using DOP-rtPCR. Physiochemical characterization, subcellular localization, predicted protein fingerprints, in silico functional annotation, and structural modeling of identified resistance gene analogs (RGAs) suggested potential efficacy against microbial pathogens (Ijaz et al. 2022). The effects of RGAs on *Ceratocystis*-induced tree dieback in shisham were investigated by Ijaz and colleagues (2023a). They predicted that Ds-DbRCaG-02-Rga.a, Ds-DbRCaG-04-Rga.b, and Ds-DbRCaG-06-Rga.c might have contributed to the regulation of the immune response in shisham. Ijaz et al. (2023b) investigated the in silico characterization of short-nucleotide sequences. These short RGAs have been shown to play a role in stress and disease resistance.

Eucalyptus

In Brazil, 37 different four-month-old eucalyptus clones were tested for resistance to *Ceratocystis* wilt. The clones displayed a range of resistance, with most showing moderate resistance, while only one exhibited susceptibility (Tumura et al. 2012). Variation in resistance ranging from highly susceptible to highly resistant between genotypes of both *E. grandis* and *E. urophylla* to *Ceratocystis* wilt was observed in stem inoculation studies. Of the 21 parents tested, nine were susceptible, and 12 were resistant (Rosado et al. 2010). Similarly, researchers have shown that various *Eucalyptus* species are resistant to *C. fimbriata* (Mafia et al. 2011). In another study, eighteen commercial clones of hybrid eucalyptus (*E. grandis* × *E. urophylla*) were artificially inoculated with isolates of *C. fimbriata* to identify resistance genes. Six clones were highly susceptible, eight were moderately susceptible, and four were resistant, showing no discoloration on inoculated stems (Zauza et al. 2004). Five out of 20 eucalyptus genotypes showed resistance to different isolates of *Ceratocystis* (Firmino et al. 2013).

Mango

Utilizing host resistance is a common approach for managing mango wilt. In Brazil, the mango cultivars Espada, Haden, and Palmer, which were artificially

inoculated with *C. fimbriata*, exhibited greater susceptibility, whereas the cultivars Tommy and Uba exhibited moderate to complete resistance (Araujo et al. 2014). In another study, five mango cultivars were inoculated with *C. fimbriata* isolates. Significant differences in cultivar vs. isolate interactions were recorded. The 'Uba' cultivar showed the highest resistance levels, regardless of the *Ceratocystis* isolate it was challenged with (Oliveira et al. 2016). Eight-year-old mango trees from 15 different cultivars grown in the field were subjected to pathogen challenge with two different isolates of *C. fimbriata* (highly pathogenic and nonpathogenic). Four varieties (Van Dyke, Edwards, Irwin, and Sao Quirino) were resistant, one (IAC 100 Bourbon) was moderately resistant, five (Glenn, Joe Welch, Zill, and Haden) were susceptible, and two (Kent and Jasmin) were resistant to one isolate but susceptible to the other (Rossetto et al. 1996). The inheritance of resistance to *C. fimbriata* was studied by artificially inoculating commercial mango varieties. The experiment concluded that inheritance is polygenic, with greater dominance effects and possible involvement of epistatic interactions. A low frequency of alleles favorable to disease resistance was observed. In addition, a 46% reduction in disease severity was observed. The results revealed that the Keitt, Palmer, Tommy Atkins, and Van Dyke cultivars were moderately resistant, whereas the Coquinho, Espada, and Haden cultivars were susceptible (Arriel et al. 2016).

Other hosts

In Brazil, screening of kiwifruit cultivars identified 'Bruno' and 'Chieftain' as resistant, while *Actinidia arguta* and 'Ken's Red' were highly susceptible to *C. fimbriata* infection (Alfenas et al. 2017). Host plant resistance to *C. fimbriata* has also been used to successfully control disease in Citrus (Paez and Castano 2001), Coffee (Castro Caicedo et al. 2013), Cocoa (Nunez et al. 1992) and poplar (Przybyl 1984) plants.

Conclusions

This review highlights three key points: (1) shisham dieback is widespread in both native and nonnative regions; (2) it is predominantly caused by fungal pathogens, with abiotic factors possibly influencing symptom severity; and (3) current management guidelines are limited and insufficient as a comprehensive strategy.

Shisham dieback has become a textbook example of one of the most destructive and widespread diseases. It has been estimated that billions of mature shisham trees have been destroyed by outbreaks of this disease in Bangladesh, India, Pakistan, and Nepal within 100 years. Shisham dieback disease is usually described as a complex pathosystem that involves complex interactions

among several biotic and abiotic factors. Abiotic factors can influence the development of symptoms in diseased trees.

Several studies have been conducted on shisham dieback, but most have reported conflicting results. Many questions remain unanswered about the key aspects of shisham dieback: is this disease truly a dieback, or is it a decline or wilt? What is causing it? Abiotic factors or biotic factors? Could it be caused by more than one organism? Finding answers to these questions is critical: it is impossible to inform management strategies without an understanding of these key disease features.

Several information gaps and scientific uncertainties limit the conclusions that can be drawn about trends in shisham mortality. Several researchers are unable to determine whether biotic or abiotic stresses are triggering factors. They differ in terms of their knowledge level, expertise in isolating fungi, and pathological background. Some researchers misunderstood and tried to make the correlation that abiotic factors might have contributed to this disease because shisham is a tropical species that demand high amounts of water and good drainage. Therefore, plants are vulnerable to acute drought or

waterlogged conditions that can damage roots and attract different weak fungal pathogens. They also reported that shisham stands did not show any mortality in the Besham, Himalayan valleys (Fig. 5), one of the regions known as the center of shisham origin. In contrast, many scientists have established that shisham dieback is also present in Besham (Fig. 5), caused mainly by fungal pathogen(s), and some predisposing factors can accelerate this disease. Forest fungal pathogens, especially *Ceratocystis* species, are usually more aggressive under stressful conditions such as drought and rainfall. Furthermore, environmental variables can enhance or decrease pathogen(s) activity. Moreover, a closely related species, *Ophiostoma ulmi* (formerly known as *Ceratocystis ulmi*), likely originated in Asia near the foothills of the Himalayan Mountains. This supports evidence suggesting that both the host, shisham, and the pathogen, *Ceratocystis*, may also have originated in the Himalayan valleys, remaining undetected until recently.

Ceratocystis can only be found in published research from the last decade linked to shisham dieback, suggesting that the pathogen has a relatively recent history with shisham hosts. There is a clear association between



Fig. 5 Surveys and sampling in the Himalayan region of Pakistan. **a, b** healthy shisham plantation along the Sindh River in Basham, KPK. **c, d** collection of wood samples from the stem portion of infected shisham trees. Photo credits: All the pictures by Muhammad Zunair Latif, except **a** by Javed et al. (2023b)

Ceratocystis and dieback symptoms in shisham, and *C. dalbergican* has been established as the causal organism. Previously, *Fusarium* was linked to wilt/dieback disease in Shisham. This disease has been differentiated from often-confusing *Fusarium* wilt on the same plant and explains dieback, a separate disease of shisham (Latif et al. 2023; Ul Haq et al. 2023).

At present, there are limited published guidelines for *Ceratocystis* management in shisham. Chemicals, such as propiconazole, difenoconazole, hexaconazole, thiabendazole, and benzimidazole, have yielded valuable results in the laboratory but are not as promising in greenhouse/field trials. Molecular studies have identified resistance gene analogs (RGAs), Ds-DbR-CaG-02-Rga.a, Ds-DbRCaG-04-Rga.b, and Ds-DbR-CaG-06-Rga.c. These short RGAs play a role in stress and disease resistance in shisham. These management options have been evaluated on a limited scale and can only help provide baseline information, but they can not be considered a solid management plan to mitigate this disease.

While researchers have explored potential management strategies, including identifying host resistance genes and chemical control methods, achieving sustainable disease control will require long-term, dedicated efforts due to the extended lifespan of shisham trees. Hopefully, fast-evolving technologies and advances in data analysis will soon lead to breakthroughs in our understanding of this complex pathosystem and in ways in which we can improve the resistance of susceptible host germplasm.

We hope this literature review will provide a scientific consensus regarding the name and etiology of the disease. Future research must emphasize (1) developing rapid detection tools to identify disease at early stages so that tree loss can be minimized and (2) identifying and propagating resistant trees for the sustainable production of shisham.

Acknowledgements

We Thank Dr. Carmen M. Medina-Mora, Katherine Minix, and Rebecca Harkness (Forest Pathology Lab, MSU, USA) for their critical review, insights, and comments on the earlier version of this manuscript.

Author contributions

MZL, AH, and XD conceived the presented idea; CL and MZL collected relevant material; MZL prepared the original draft. AH and XD critically reviewed and provided feedback. CL and MZL addressed the comments with input from AH and XD; all authors read and approved the final manuscript.

Funding

The work was supported by the US-Pak Centre of Advance Studies in Agriculture and Food Security and Punjab Agricultural Research Board (CAS-PARB#952), National Natural Science Foundation (32272557, 32072500), Major Basic Research Project of Natural Science Foundation of Shandong Province (ZR2022ZD23, ZR2024ZD07), Shandong Province Key Research and Development Plan (2024CXGC010908, 2024LZGCQY009), Taishan Scholar Program of Shandong Province (tstp20221117), Zaozhuang major scientific and technological innovation project (2023GH12).

Availability of data and materials

Not applicable.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Received: 10 March 2024 Accepted: 19 November 2024

Published online: 09 January 2025

References

- Agrios GN. Plant pathology. 5th ed. San Diego: Elsevier Academic Press; 2005.
- Ahmad BI, Khan RA, Siddiqui MT. Incidence of dieback disease following fungal inoculations of sexually and asexually propagated shisham (*Dalbergia sissoo*). For Pathol. 2013;43:77–82. <https://doi.org/10.1111/efp.12001>.
- Al Adawi AO, Barnes I, Khan IA, Al Subhi AM, Al Jahwari AA, Deadman ML, et al. *Ceratocystis manginecans* is associated with a serious wilt disease of two native legume trees in Oman and Pakistan. Australas Plant Pathol. 2013;42:179–93. <https://doi.org/10.1007/s13313-012-0196-5>.
- Al Adawi AO, Barnes I, Al Jahwari AA, Deadman ML, Wingfield BD, Wingfield MJ (2009) Discovery of a *Ceratocystis* sp. associated with wilt disease of two native leguminous tree hosts in Oman and Pakistan. Australian Plant Pathology Society meeting (APPS). Plant health management: An integrated approach.
- Alam MW, Rehman A, Iqbal M, Saira M, Aslam S, Muhammad S, et al. First report of *Ceratocystis fimbriata* causing Eucalyptus wilt in Pakistan. Plant Dis. 2017a;101:1050. <https://doi.org/10.1094/PDIS-12-16-1703-PDN>.
- Alam MW, Gleason ML, Saira M, Riaz K, Rehman A. First report of *Ceratocystis fimbriata* causing pomegranate wilt in Pakistan. Plant Dis. 2017b;101:251. <https://doi.org/10.1094/PDIS-06-16-0835-PDN>.
- Alam MW, Rehman A, Haider MS, Gleason ML, Rosli H, Saira M, et al. First report of *Ceratocystis fimbriata* causing wilt of loquat in Pakistan. Plant Dis. 2018;102:2034. <https://doi.org/10.1094/PDIS-03-18-0408-PDN>.
- Alfenas AC, da Silva Guimaraes LM, Pimenta LVA. Evaluation of *Actinidia* spp. cultivars' resistance to *Ceratocystis* wilt. Viçosa - Minas Gerais, Brazil. 2017.
- Alizadeh M, Azaryan A, Ghaleh MK, Roshanroo M, Graily-Moradi F. Host and geographical distribution of the plant pathogenic fungus *Ceratocystis fimbriata* (Ascomycota) worldwide. Nova Hedwigia. 2024;118:41–71. https://doi.org/10.1127/nova_hedwigia/2024/0890.
- Appel DN. Intravascular injection with propiconazole in live oak for oak wilt control. Plant Dis. 1992;76:1120. <https://doi.org/10.1094/PD-76-1120>.
- Araujo L, Silva Bispo WM, Cacique IS, Cruz MFA, Rodrigues FA. Histopathological aspects of mango resistance to the infection process of *Ceratocystis fimbriata*. Plant Pathol. 2014;63:1282–95. <https://doi.org/10.1111/ppa.12208>.
- Arif M, Zaidi NW, Haq QMR, Singh YP, Khan S, Singh US. Molecular phylogeny and pathotyping of *Fusarium solani*: a causal agent of *Dalbergia sissoo* decline. For Pathol. 2013;43:478–87. <https://doi.org/10.1111/efp.12060>.
- Arriel DAA, da Silva Guimaraes LM, de Resende MDV, Neto FPL, Silva DFSHS, de Siqueira DL, et al. Genetic control of resistance on *Mangifera indica* to *Ceratocystis* wilt. Sci Hortic. 2016;211:312–8. <https://doi.org/10.1016/j.scienta.2016.09.001>.
- Asiegbu FO. Basic concepts and principles of forest pathology. In: Asiegbu FO, Kovalchuk A, editors. For Microbiol. 2022. p. 3–15. <https://doi.org/10.1016/B978-0-323-85042-1.00015-X>.
- Bagchee KD. Wilt and dieback of Shisham, Babul, and Khair in the artificial regeneration under agriculture-cum-forestry management. Indian for. 1944;71:20–4.

- Baker R, Caffier D, Choiseul JW, De Clercq P, Dormannsné-Simon E, Gerowitt B, Karadjova OE, Lövei G, Oude A, Lansink DM, Manceau C. Pest risk assessment made by France on *Ceratocystis fimbriata* considered by France as harmful in French overseas departments of French Guiana, Guadeloupe, Martinique and Réunion Scientific Opinion of the Panel on Plant Health. EFSA J. 2008;6(5):703. <https://doi.org/10.2903/j.efsa.2008.703>.
- Bakshi BK. Fungi associated with ambrosia beetles in Great Britain. Trans Br Mycol Soc. 1950;33:111. [https://doi.org/10.1016/S0007-1536\(50\)80054-2](https://doi.org/10.1016/S0007-1536(50)80054-2).
- Bakshi BK. Wilt disease of shisham (*Dalbergia sissoo* Roxb.). Indian for. 1955;81:276–81.
- Bakshi BK. Wilt disease of Shisham (*Dalbergia sissoo* Roxb.). IV. The effect of soil moisture on the growth and survival of *Fusarium solani* in the laboratory. Indian for. 1957;83:505–11.
- Bakshi BK. Forest pathology: principles and practice in forestry. 1st ed. India: Scientific Publisher; 1976.
- Bakshi BK, Singh S. Wilt disease of shisham (*Dalbergia sissoo* Roxb.). Indian for. 1954;80:316–22.
- Bakshi BK, Singh S. Root diseases of shisham (*Dalbergia sissoo* Roxb.). Indian for. 1959;85:415–21.
- Barnes I, Roux J, Wingfield BD, O'Neill M, Wingfield MJ. *Ceratocystis fimbriata* infecting *Eucalyptus grandis* in Uruguay. Australas Plant Pathol. 2003;32:361–6. <https://doi.org/10.1071/AP03032>.
- Barry KM. Heartrots in plantation hardwoods in Indonesia and Australia. Australian Centre for International Agricultural Research. 2002.
- Blaedow RA. Use of the systemic fungicide propiconazole for oak wilt management: an assessment of uncharacterized host-fungicide interactions. Minnesota: University of Minnesota; 2009.
- Blaedow RA, Juzwik J, Barber B. Propiconazole distribution and effects on *Ceratocystis fagacearum* survival in roots of treated red oaks. Phytopathology. 2010;100:979–85. <https://doi.org/10.1094/phyto-01-10-0008>.
- CABI. 2021a. *Dalbergia sissoo*. Available at <https://www.cabi.org/isc/datasheet/17808>. Accessed 17 May 2021.
- CABI. 2021b. *Ceratocystis fimbriata*. Available at <https://www.cabi.org/isc/datasheet/12143>. Accessed 17 May 2021.
- Castro Caicedo BL, Cortina Guerrero HA, Roux J, Wingfield MJ. New coffee (*Coffea arabica*) genotypes derived from *Coffea canephora* exhibiting high levels of resistance to leaf rust and *Ceratocystis* canker. Trop Plant Pathol. 2013;38:485–94. <https://doi.org/10.1590/S1982-56762013000600004>.
- Ciesla WM, Donaubaue E. Decline and dieback of trees and forests: a global overview. FAO. 1994.
- Davidson EW. Fungi causing stain in logs and lumber in the southern States, including five new species. J Agric Res. 1935;50:789–807.
- Dayaram MK, Sharma S, Chaturvedi OP. Shisham mortality in Bihar extent and causes. Indian Phytopathol. 2003;56:384–7.
- De Alcain JC, Marmelcz LA. *Ceratocystis fimbriata*—Ellis and Halst. A new lemon tree pathogen. Proc Int Soc Citricult. 1984;1:432–5.
- De Beer ZW, Duong TA, Barnes I, Wingfield BD, Wingfield MJ. Redefining *Ceratocystis* and allied genera. Stud Mycol. 2014;79:187–219. <https://doi.org/10.1016/j.simyco.2014.10.001>.
- De Beer ZW, Marinowitz S, Duong TA, Wingfield MJ. *Bretziella*, a new genus to accommodate the oak wilt fungus, *Ceratocystis fagacearum* (Microascales, Ascomycota). MycoKeys. 2017;27:1. <https://doi.org/10.3897/mycokeys.27.20657>.
- Devay J, Lukezic F, English W, Moller W, Parkinson B, et al. Controlling: *Ceratocystis* canker of stone fruit trees. Calif Agric. 1965;19:2–4.
- Dharmaraj K, Merrill AM, Pattermore JA, Mackie J, Alexander BJR, Toome-Heller M. A new real-time PCR Assay for detecting fungi in genus *Ceratocystis*. Plant Dis. 2022;106:661–8. <https://doi.org/10.1094/PDIS-08-21-1639-RE>.
- Elliott JA. The ascigerous stage of the sweet potato black rot fungus. Phytopathology. 1923;13:56.
- Engelbrecht CJB, Harrington TC, Steimel J, Capretti P. Genetic variation in eastern North American and putatively introduced populations of *Ceratocystis fimbriata* f. platani. Mol Ecol. 2004;13:2995–3005. <https://doi.org/10.1111/j.1365-294x.2004.02312.x>.
- Farid AM, Syazwan SA, Azrul WAWM, Patahayah M, Salleh SM, Ong SP. *Ceratocystis fimbriata*: A white listed invasive alien species (IAS) causing wilt disease on *Acacia mangium* plantation. 2018.
- Firmino AC, Tozze HJ Jr, Furtado EL. First report of *Ceratocystis fimbriata* causing wilt in *Tectona grandis* in Brazil. New Dis Rep. 2012;25:588–2044. <https://doi.org/10.5197/j.2044-0588.2012.025.024>.
- Firmino AC, Tozze HJ Jr, de Souza ICG, Furtado EL. Resistance of *Eucalyptus* genotypes to *Ceratocystis* sp. Sci for. 2013;41:165–73.
- Firmino AC, de Moraes WB, Furtado EL. First record of *Ceratocystis fimbriata* causing dry rot in *Acrocarpus fraxinifolius* in Brazil. Summa Phytopathol. 2015;41:160–160.
- Fraedrich BR. Dieback and Decline. Research laboratory technical report. Bartlett tree expert. <https://www.bartlett.com/resources/dieback-and-decline.pdf>.
- Galdino TVDS, Kumar S, Oliveira LS, Alfenas AC, Neven LG, Al-Sadi AM, Picanco MC. Mapping global potential risk of mango sudden decline disease caused by *Ceratocystis fimbriata*. PLoS ONE. 2016;11(7):e0159450. <https://doi.org/10.1371/journal.pone.0159450>.
- Ghosh S. 2018. Greening with pollution-gobbling trees doubles benefits. Available at <https://india.mongabay.com/2018/11/world-environment-day-greening-with-pollution-gobbling-trees-doubles-benefits/>. Accessed 7 October 2021.
- Gill MA, Imtiaz A, Khan AU, Muhamamd A, Shaukat A, Rafique RM, et al. *Phytophthora cinnamomi*? a cause of shisham decline in Punjab, Pakistan. Integrated plant disease management. Proceedings of 3rd National Conference of Plant Pathology, NARC, Islamabad, 1-3 Oct. 2001. Pakistan Phytopathology Society. 2002:33–37.
- Gremmen J, De Kam M. *Ceratocystis fimbriata*, a fungus associated with poplar canker in Poland. Eur J for Pathol. 1977;7:44–7. <https://doi.org/10.1111/j.1439-0329.1977.tb00558.x>.
- Halfeld-Vieira BA, Zilli JE, Nechet KL, Pereira GMD, Souza GR. First record of *Ceratocystis fimbriata* on *Carapa guianensis*. New Dis Rep. 2012;26:13. <https://doi.org/10.5197/j.2044-0588.2012.026.013>.
- Halsted BD. Some fungous diseases of the sweet potato. New Jersey Agricultural College Experiment Station. 1890.
- Haq IU, Ijaz S, Latif MZ. Multilocus sequence typing (MLST) based genetic variation analysis of shisham dieback associated strains of *Ceratocystis fimbriata* sensu lato species complex in Pakistan. Appl Ecol Environ Res. 2019;17:12573–82.
- Haq IU, Ijaz S, Latif MZ. Diseases of *Dalbergia sissoo*: etiology and integrated management of economically important diseases. In: Ijaz S, Haq IU, editors. *Dalbergia sissoo* biology, ecology and sustainable agroforestry. CRC Press; 2021. p. 63–87.
- Haq IU, Ijaz S, Latif MZ, Khan IA, Ali HM, Kaur S. Phylogenomics resolves the etiology of dieback disease and deciphers *Ceratocystis dalbergicans* sp. Nov., causal agent of *Dalbergia sissoo* decline. Front Genet. 2023;14:1136688. <https://doi.org/10.3389/fgene.2023.1136688>.
- Harrington TC. Host specialization and speciation in the American wilt pathogen. Fitopatol Bras. 2000;25:262–3.
- Harrington TC, Thorpe DJ, Alfenas AC. Genetic variation and variation in aggressiveness to native and exotic hosts among Brazilian populations of *Ceratocystis fimbriata*. Phytopath. 2011;101:555–66. <https://doi.org/10.1094/phyto-08-10-0228>.
- Harrington TC (2013) *Ceratocystis* diseases. In: Gonther P, Nicolotti G, editors. Infectious forest diseases. CABI pp 230–55. <https://doi.org/10.1079/9781780640402.0230>.
- Heath RN, Wingfield MJ, Wingfield BD, Meke G, Mbaga A, Roux J (2009) *Ceratocystis* species on *Acacia mearnsii* and *Eucalyptus* spp. in eastern and southern Africa including six new species
- Heller WP, Harrington TC, Brill E, Keith LM. High-sensitivity ITS Real-Time PCR assays for detection of *Ceratocystis lukuohia* and *Ceratocystis huliohia* in soil and air samples. PhytoFrontiers. 2023;3:148–55. <https://doi.org/10.1094/PHYTOFR-09-22-0091-FI>.
- Ijaz S, Haq IU. *Dalbergia sissoo* biology, ecology and sustainable agroforestry. 1st ed. Boca Raton: CRC Press; 2021. <https://doi.org/10.1201/978103175940>.
- Ijaz S, Haq IU, Khan IA, Ali HM, Kaur S, Razzaq HA. Identification of resistance gene analogs of the NBS-LRR family through transcriptome probing and in silico prediction of the expressome of *Dalbergia sissoo* under dieback disease stress. Front Genet. 2022;13:1036029. <https://doi.org/10.3389/fgene.2022.1036029>.
- Ijaz S, Haq IU, Malik R, Nadeem G, Ali HM, Kaur S. In silico characterization of differentially expressed short-read nucleotide sequences identified in dieback stress-induced transcriptomic analysis reveals their role as antimicrobial peptides. Front Plant Sci. 2023a;14:1168221. <https://doi.org/10.3389/fpls.2023.1168221>.

- Ijaz S, Ul Haq I, Razzaq HA, Nasir B, Ali HM, Kaur S. In silico structural functional characterization of three differentially expressed resistance gene analogs identified in *Dalbergia sissoo* against dieback disease reveals their role in immune response regulation. *Front Plant Sci.* 2023b;14:1134806. <https://doi.org/10.3389/fpls.2023.1134806>.
- Irsan C, Suwandi AKD, Umayah A, Hamidson H. *Ceratocystis* wilt of Lansium tree: new disease and threat to duku fruit production in Indonesia. Workshop Proceedings: *Ceratocystis* in tropical hardwood plantations. 2016;15–6.
- Isla HL, Ravelo HG. *Spathodea campanulata* Beauv., new host plant of *Ceratocystis fimbriata* Hell & Halst and *Xyleborus* spp. *Cent Agricola.* 1989;16:91–3.
- Javaid A. Research on shisham (*Dalbergia sissoo* Roxb) decline in Pakistan: a review. *Pak J Phytopathol.* 2008;20:134–42.
- Javed MA, Ul Haq I, Ghafoor N, Ur Rehman F. Climate change exacerbated *Dalbergia sissoo* dieback under water stress and *Ceratocystis fimbriata* infection. *Agri Res Tech: Open Access J.* 2023a;27(4):556376. <https://doi.org/10.19080/ARTOAJ.2023.27.556376>.
- Javed MA, Atif A, Ghafoor N, Ul Haq I, Zia MB. Environmental variation at non-native ecological regions exacerbated *Dalbergia sissoo* dieback outbreaks in Pakistan. *J xi'an Shiyu Univ Nat Sci Ed.* 2023b;19(11):573–94.
- Johnson JA, Harrington TC, Engelbrecht CJB. Phylogeny and taxonomy of the North American clade of the *Ceratocystis fimbriata* complex. *Mycologia.* 2005;97:1067–92. <https://doi.org/10.3852/mycologia.97.5.1067>.
- Juzwik J, Appel DN, MacDonald WL, Burks S. Challenges and successes in managing oak wilt in the United States. *Plant Dis.* 2011;95:888–900. <https://doi.org/10.1094/PDIS-12-10-0944>.
- Kato K, Hirota K, Miyagawa T. A new disease, *Ceratocystis* canker of fig caused by *Ceratocystis fimbriata* Ellis et Halsted. *Shokubutsu Boeki.* 1982.
- Kaushik JC, Toky OP, et al. *Ceratocystis fimbriata* Ell. and Halst: a new record on poplar (*Populus deltoides* Marsh) from India. *Myforest.* 1992;28:79–80.
- Keith LM, Hughes RF, Sugiyama LS, Heller WP, Bushe BC, Friday JB. First report of *Ceratocystis* wilt on Ohia (*Metrosideros polymorpha*). *Plant Dis.* 2015;99:1276. <https://doi.org/10.1094/PDIS-12-14-1293-PDN>.
- Khan SH, Idrees M, Muhammad F, Mahmood A, Zaidi SH. Incidence of shisham (*Dalbergia sissoo* Roxb) decline and in vitro response of isolated fungus spp. to various fungicides. *Int J Agric Biol.* 2004;6:611–4.
- Khan HSI, Indra HR, Ekbote S, Narayanaswamy H, Narayanaswamy P, Deep SP. Bio efficacy of fungicides and bio agents against *Ceratocystis fimbriata* Ell. and Halst. causing wilt disease of Pomegranate. *Int J Curr Microbiol Appl Sci.* 2017;6:2902–7. <https://doi.org/10.20546/ijcmas.2017.606.343>.
- Khan MM, Khan MH, Appanah S, Allard G, Amatya S. Die-back of *Dalbergia sissoo* in Pakistan. Die-back of *Dalbergia sissoo* in Pakistan. 2000;51–6.
- Kile GA. Plant diseases caused by species of *Ceratocystis* sensu stricto and Chalara. *Ceratocystis Ophiostoma* Taxon. *Ecol Pathog.* 1993;173–83.
- Kumar N, Khurana SMP. Bio management of wilting of a valuable timber and medicinal plant of shisham (*Dalbergia sissoo* Roxb): a review. *Int J Curr Microbiol Appl Sci.* 2016;5:32–54.
- Latif MZ, Haq IU, Ijaz S, Khan NA, Faraz A, Yasin O. First report of *Ceratocystis fimbriata* causing dieback in *Conocarpus lancifolius*. *New Dis Rep.* 2020;41:27. <https://doi.org/10.5197/j.2044-0588.2020.041.027>.
- Latif MZ, Haq IU, Ijaz S, Habib A, Khan IA. Assessment of the distribution, incidence, and severity of shisham (*Dalbergia sissoo*) dieback disease in Pakistan. *Pak J Agri Sci.* 2021;58:1819–26. <https://doi.org/10.21162/PAKJAS/21.132>.
- Latif MZ, Haq IU, Ijaz S, Habib A, Khan IA. Etiology and management of shisham die-back disease in Pakistan forests. *Pak J Agri Sci.* 2023;60:407–18. <https://doi.org/10.21162/PAKJAS/23.103>.
- Leather RI. A canker and wilt disease of pimento (*Pimenta officinalis*) caused by *Ceratocystis fimbriata* in Jamaica. *Trans Br Mycol Soc.* 1966;49:213. [https://doi.org/10.1016/S0007-1536\(66\)80055-4](https://doi.org/10.1016/S0007-1536(66)80055-4).
- Li J, Gao JM, Han YH, Sun YX, Huang Q. First report of *Ceratocystis fimbriata*-caused wilt of *Eriobotrya japonica* in China. *Plant Dis.* 2014a;98:1270. <https://doi.org/10.1094/pdis-12-13-1290-pdn>.
- Li J, Zhang Y, Xu KC, Yang JY, Han YH, Sun YX, et al. First report of wilt of Eucalyptus caused by *Ceratocystis fimbriata* in China. *Plant Dis.* 2014b;98:1744. <https://doi.org/10.1094/pdis-06-14-0580-pdn>.
- Li Q, Harrington TC, McNew D, Li J. *Ceratocystis uchidae*, a new species on Araceae in Hawaii and Fiji. *Mycoscience.* 2017;58:398–412. <https://doi.org/10.1016/j.myc.2017.06.001>.
- Liu FF, Barnes I, Roux J, Wingfield MJ, Chen S. Molecular phylogenetics and microsatellite analysis reveal a new pathogenic *Ceratocystis* species in the Asian–Australian clade. *Plant Pathol.* 2018;67:1097–113. <https://doi.org/10.1111/ppa.12820>.
- Lowy B. A monograph of *Ceratocystis* and *Ceratocystiopsis*. *Econ Bot.* 1982;36:175. <https://doi.org/10.1007/BF02858713>.
- Mafia RG, Alfenas AC, Ferreira EM, Binoti DHB. Screening method and identification of resistance sources to eucalyptus wilt caused by *Ceratocystis fimbriata*. *Rev Arvore.* 2011;35:817–24. <https://doi.org/10.1590/S0100-67622011000500007>.
- Marin M, Castro B, Gaitan A, Preisig O, Wingfield BD, Wingfield MJ. Relationships of *Ceratocystis fimbriata* isolates from Colombian coffee-growing regions based on molecular data and pathogenicity. *J Phytopathol.* 2003;151:395–405. <https://doi.org/10.1046/j.1439-0434.2003.00738.x>.
- Marin Montoya M, Wingfield MJ. A review of *Ceratocystis* sensu stricto with special reference to the species complexes *C. coerulea* and *C. fimbriata*. *Rev Fac Nac Agron.* 2006;59:3045–375.
- Marin-Felix Y, Groenewald JZ, Cai L, Chen Q, Marincowitz S, Barnes I, et al. Genera of phytopathogenic fungi: GOPHY 1. *Stud Mycol.* 2017;86:99–216. <https://doi.org/10.1016/j.simyco.2017.04.002>.
- Mayers CG, McNew DL, Harrington TC, Roeper RA, Fraedrich SW, Biedermann PHW, et al. Three genera in the Ceratocystidaceae are the respective symbionts of three independent lineages of ambrosia beetles with large, complex mycangia. *Fungal Biol.* 2015;119:1075–92. <https://doi.org/10.1016/j.funbio.2015.08.002>.
- Mbenoun M, Wingfield MJ, Boyogueno ADB, Wingfield BD, Roux J. Molecular phylogenetic analyses reveal three new *Ceratocystis* species and provide evidence for geographic differentiation of the genus in Africa. *Mycol Prog.* 2014;13:219–40. <https://doi.org/10.1007/s11557-013-0907-5>.
- Melin JBE, Nannfeldt JA. Researches into the blueing of ground wood-pulp. Studies into the blueing of ground wood-pulp. *Sven Skogsvaardsfoeren Tidskr.* 1934;32:397–616.
- Morgan-Jones, G. 1967. *Ceratocystis fimbriata*. In: Descriptions of Fungi and Bacteria. CABI, UK. 1967. <https://doi.org/10.1079/DFB/20056400141>. Accessed 22 Feb 2024
- Morris MJ, Wingfield MJ, De Beer C. Gummosis and wilt of *Acacia mearnsii* in South Africa caused by *Ceratocystis fimbriata*. *Plant Pathol.* 1993;42:814–7. <https://doi.org/10.1111/j.1365-3059.1993.tb01570.x>.
- Mourichon X. Serious citrus dieback in Colombia caused by *Ceratocystis fimbriata*. *Fruits.* 1994;49:415–6.
- Muchovej JJ, de Albuquerque FC, Ribeiro GT. *Gmelina arborea*: a new host of *Ceratocystis fimbriata*. *Plant Dis Report.* 1978;62:717–9.
- Mukhtar I, Bajwa R, Nasim G. Trees survival exposed to dieback disease implies evolutionary modulation resistance in shisham (*Dalbergia sissoo* Roxb) In various agro ecological zones of punjab (Pakistan). *Pak J Phytopathol.* 2014a;26(2):289–300.
- Mukhtar I, Bajwa R, Nasim G, Hafeez FY. Evaluation of genetic diversity among phytopathogenic isolates of *Fusarium solani* complex causing shisham dieback disease in Pakistan. *J Anim Plant Sci.* 2014b;24:1724–8.
- Naqvi SAH, Mushtaq S, Malik MT, Rehman AU, Fareed S, Zulfikar MA. Factors leading toward *Dalbergia sissoo* decline (Syndrome) in Indian subcontinent: a critical review and future research agenda. *Pak J Agric Res.* 2019;32:302. <https://doi.org/10.17582/journal.pjar/2019/32.2.302.316>.
- Nasution U. Degradation in the effectivity of Benomyl (benlate) against moldy rot disease (*Ceratocystis fimbriata* Ell. et Halst.) in rubber plants and the new fungicides. 4 Kongres Nasional Perhimpunan Fitopatologi Indonesia, Gamburg, Bandung (Indonesia). 1976.
- Naz SI. The vanishing shisham tree. 2002. Available at <https://www.dawn.com/news/1062509>. Accessed 11 Feb 2021.
- Nunez S, Galindo JJ, Phillips Mora W. Method of inoculation of *Ceratocystis fimbriata* Ell. & Halst. and evaluation of resistance in cocoa. *Turrialba.* 1992.
- O'Brien JG. How to identify, prevent, and control oak wilt. In: Forest Service Northeastern Area State and Private Forestry. USDA. 2011. <https://woodlandinfo.org/wp-content/uploads/sites/383/2017/09/NA%E2%80%9393FR%E2%80%939301%E2%80%939311.pdf>. Accessed 15 Jan 2024.
- Oliveira MI, Niella ARR, Silva VR, Lima LC, et al. *Ceratocystis* wilt, a new disease of the cupuassu tree, in Brazil. *Agrotrópica.* 2013;25:33–8.
- Oliveira LSS, Guimaraes LMS, Ferreira MA, Nunes AS, Pimenta LVA, Alfenas AC. Aggressiveness, cultural characteristics and genetic variation of

- Ceratocystis fimbriata* on *Eucalyptus* spp. For Pathol. 2015;45:505–14. <https://doi.org/10.1111/efp.12200>.
- Oliveira LSS, Damacena MB, Guimaraes LMS, Siqueira DL, Alfenas AC. *Ceratocystis fimbriata* isolates on *Mangifera indica* have different levels of aggressiveness. Eur J Plant Pathol. 2016;145:847–56. <https://doi.org/10.1007/s10658-016-0873-2>.
- Paez AR, Castano JZ. Respuesta de patrones y copas cítricos a *Ceratocystis fimbriata* Ell. Y Halst agente causal del secamiento o muerte subita. Fitopatol Colomb. 2001;25:71–8.
- Panconesi A. Canker stain of plane trees: a serious danger to urban plantings in Europe. J Plant Pathol. 1999;3–15.
- Parker RN. A forest flora for the Punjab with Hazara and Delhi. 1918. Superintendent, Government Printing, Punjab; 1918.
- Perry E, McCain AH. Incidence and management of canker stain in London plane trees in Modesto, California. J Arboric. 1988;14:18–9.
- Piveta G, Ferreira MA, Fb Muniz M, Valdetaro D, Valdebenito-Sanhueza R, Harrington T, et al. *Ceratocystis fimbriata* on kiwifruit (*Actinidia* spp.) in Brazil. New Zeal J Crop Horticult Sci. 2016;44:13–24. <https://doi.org/10.1080/01140671.2016.1143020>.
- Ploetz RC, Hulcr J, Wingfield MJ, De Beer ZW. Destructive tree diseases associated with ambrosia and bark beetles: black swan events in tree pathology? Plant Dis. 2013;97:856–72. <https://doi.org/10.1094/pdis-01-13-0056-fe>.
- Pontis RE. A canker disease of the coffee tree in Colombia and Venezuela. Phytopathology. 1951;41:178–84.
- Poussio GB, Kazmi MR, Akem C, Fateh FS. First record of *Ceratocystis fimbriata* associated with shisham (*Dalbergia sissoo*) decline in Pakistan. Australas Plant Dis Notes. 2010;5:63–5. <https://doi.org/10.1071/DN10023>.
- Przybyl K. Disease of poplar caused by *Ceratocystis fimbriata* Ell. et Halst. I. Isolation of *C. fimbriata*, symptoms of the disease and evaluation of resistance of poplar clones resulting from artificial infection. Arbor Kornickie. 1984;29:89–103.
- Rajput NA, Pathan MA, Jiskani MM, Rajput AQ, Arain RR. Pathogenicity and host range of *Fusarium solani* (mart.) sacc., causing dieback of shisham (*Dalbergia sissoo* roxb.). Pak J Bot. 2008;40:2631–9.
- Rehman A, Sahi ST, Khan MA, Mehboob S. Fungi associated with bark, twigs and roots of declined Shisham (*Dalbergia sissoo* Roxb.) trees in Punjab, Pakistan. Pak J Phytopathol. 2012;24:152–8.
- Ribeiro IJA, Ito MF, Rossetto CJ. *Cassia renigera* Wall.: new host of *Ceratocystis fimbriata* Ell. & Halst. Bragantia. 1987;46:417–23.
- Ribeiro IJA, Fumikoito M, Paradelo Filho O, de Castro JL. Gummosis of *Acacia decurrens* Willd. Caused by *Ceratocystis fimbriata* Ell. & Halst. Bragantia. 1988;47:71–4.
- Rosado CCG, da S Guimaraes LM, Titon M, Lau D, Rosse L, De Resende MDV, et al. Resistance to ceratocystis wilt (*Ceratocystis fimbriata*) in parents and progenies of *Eucalyptus grandis* x *E. urophylla*. Silvae Genetica. 2010;59:99–106. <https://doi.org/10.1515/sg-2010-0012>.
- Rossetto CJ, Ribeiro IJA, Igue T, Gallo PB. Mango wilt: XV. Varietal resistance against two isolates of *Ceratocystis fimbriata*. Bragantia. 1996;55:117–21. <https://doi.org/10.1590/S0006-87051996000100013>.
- Roux J, Wingfield MJ. *Ceratocystis* species: emerging pathogens of nonnative plantation *Eucalyptus* and *Acacia* species. South for a J for Sci. 2009;71:115–20. <https://doi.org/10.2989/SF.2009.71.2.5.820>.
- Roux J, Wingfield MJ, Bouillet JP, Wingfield BD, Alfenas AC. A serious new wilt disease of *Eucalyptus* caused by *Ceratocystis fimbriata* in Central Africa. For Pathol. 2000;30:175–84. <https://doi.org/10.1046/j.1439-0329.2000.00202.x>.
- Roux J, Coutinho TA, Mujuni Byabashajja D, Wingfield MJ. Diseases of plantation *Eucalyptus* in Uganda: research in action. S Afr J Sci. 2001;97:16–8.
- Saccardo PA. Patavii. Sylloge Fungorum. 1892;10(1):964.
- Sah SP, Sharma CK, Sehested F. Possible role of the soil in the *sissoo* forest (*Dalbergia sissoo* Roxb.) decline in the Nepal Terai. Plant Soil Environ. 2003;49:378–85. https://doi.org/10.1007/0-306-47624-X_453.
- Santos AFD, Ferreira FA. *Ceratocystis* wilt of black wattle in Brazil. Fitopatol Bras. 2003;28:325. <https://doi.org/10.1590/S0100-41582003000300020>.
- Scruggs AC, Basaiah T, Adams ML, Quesada-Ocampo LM. Genetic diversity, fungicide sensitivity, and host resistance to *Ceratocystis fimbriata* infecting sweet potato in North Carolina. Plant Dis. 2017;101:994–1001. <https://doi.org/10.1094/pdis-11-16-1583-re>.
- Seifert KA, Wingfield MJ, Kendrick WB. A nomenclator for described species of *Ceratocystis*, *Ophiostoma*, *Ceratocystiopsis*, *Ceratostomella* and *Sphaeronaemella*. St. Paul, Minnesota: American Phytopathological Society; 1993.
- Shah MH, Mukhtar I, Khan SN. Medicinal importance and association of pathological constraints with *Dalbergia sissoo*. Pak J Phytopathol. 2010;22:135–8.
- Shakya DD, Lakhey PB. Confirmation of *Fusarium solani* as the causal agent of die-back of *Dalbergia sissoo* in Nepal. Plant Pathol. 2007;56:1041. <https://doi.org/10.1111/j.1365-3059.2007.01637.x>.
- Sharma MK, Singal RM, Pokhriyal TC. *Dalbergia Sissoo* in India. 2000;18:5–16.
- Sharma KK, Sharma J, Jadhav VT. Etiology of Pomegranate wilt and its management. Fruit Veg Cereal Sci Biotechnol. 2010;4:96–101.
- Silva AC, Candido TS, Sales NLP, Harrington TC, Alfenas AC. First report of *Ceratocystis* wilt caused by *Ceratocystis fimbriata* on *Caryocar brasiliense* trees in Brazil. Plant Dis. 2017;101:1822. <https://doi.org/10.1094/PDIS-03-17-0376-PDN>.
- Silveira SF, Harrington TC, Mussi-Dias V, Engelbrecht CJB, Alfenas AC, Silva CR. *Annona squamosa*, a new host of *Ceratocystis fimbriata*. Fitopatol Bras. 2006;31:394–7. <https://doi.org/10.1590/S0100-41582006000400010>.
- Tarigan M, Roux J, Van Wyk M, Tjahjono B, Wingfield MJ. A new wilt and die-back disease of *Acacia mangium* associated with *Ceratocystis manginecans* and *C. acaciivora* sp. nov. in Indonesia. South African J Bot. 2011;77:292–304. <https://doi.org/10.1016/j.sajb.2010.08.006>.
- Tarigan M, Yuliarto M, Gafur A, Wong CY, Sharma M. Other *Acacia* species as a source of resistance to *Ceratocystis*. Workshop *Ceratocystis* in tropical hardwood plantations. 2016;31–2.
- Tewari DN. A monograph on *Dalbergia sissoo* Roxb. India: International Book Distributors; 1994.
- Thorpe DJ, Harrington TC, Uchida JY. Pathogenicity, internal transcribed spacer-rDNA variation, and human dispersal of *Ceratocystis fimbriata* on the family Araceae. Phytopathol. 2005;95:316–23. <https://doi.org/10.1094/phyto-95-0316>.
- Tran TTT, Pham TQ, Barber PA, Nguyen CM. Control of *Ceratocystis manginecans* causing wilt disease on *Acacia mangium* seedlings. Australas Plant Pathol. 2018;47:579–86. <https://doi.org/10.1007/s13313-018-0594-4>.
- Troup RS. The silviculture of Indian trees. Oxford: Clarendon Press; 1921. p. 1–3.
- Tsopelas P, Aggelopoulos A. First report of canker stain disease of plane trees, caused by *Ceratocystis fimbriata* f. sp. platani in Greece. Plant Pathol. 2004;53:531. <https://doi.org/10.1111/j.1365-3059.2004.01021.x>.
- Tsopelas P, Santini A, Wingfield MJ, Wilhelm de Beer Z. Canker stain: a lethal disease destroying iconic plane trees. Plant Dis. 2017;101:645–58. <https://doi.org/10.1094/PDIS-09-16-1235-FE>.
- Tumura KG, De Pieri C, Furtado EL. *Ceratocystis* wilt in eucalyptus: evaluation of resistance and epidemiological analysis. Summa Phytopathol. 2012;38:54–60. <https://doi.org/10.1590/S0100-54052012000100009>.
- Valdetaro DCOF, Oliveira LSS, Guimaraes LMS, Harrington TC, Ferreira MA, Freitas RG, et al. Genetic variation, morphology and pathogenicity of *Ceratocystis fimbriata* on *Hevea brasiliensis* in Brazil. Trop Plant Pathol. 2015;40:184–92. <https://doi.org/10.1007/s40858-015-0036-6>.
- Valdetaro DCOF, Harrington TC, Oliveira LSS, Guimaraes LMS, McNew DL, Pimenta LVA, et al. A host specialized form of *Ceratocystis fimbriata* causes seed and seedling blight on native *Carapa guianensis* (andiroba) in Amazonian rainforests. Fungal Biol. 2019;123:170–82. <https://doi.org/10.1016/j.funbio.2018.12.001>.
- Valdez N, Karlovsky P, Dobrindt L, Hoque MI, Sarker RH, Tantau H, et al. Role of bacteria in dieback disease of *Dalbergia sissoo* Roxb. Bangladesh J Bot. 2013;42:1–16. <https://doi.org/10.3329/bjb.v42i1.15710>.
- Vale FXR, Parlevliet JE, Zambolim L. Concepts in plant disease resistance. Fitopatol Bras. 2001;26:577–89. <https://doi.org/10.1590/S0100-4158001000300001>.
- Vogel S, Tantau H, Mielke-Ehret N, Hoque MI, Sarker RH, Saha ML, et al. Detection of virus particles and double-stranded RNA in dieback affected *Dalbergia sissoo* Roxb. from Bangladesh. Bangladesh J Bot. 2011;40:57–65.
- Vujanovic V, St-Arnaud M, Charlebois D, Fortin E. First report of *Ceratocystis fimbriata* infecting balsam poplar (*Populus balsamifera*). Plant Dis. 1999;83:879. <https://doi.org/10.1094/pdis.1999.83.9.879a>.
- WWF P Vultures. 2021. Available at https://www.wwfpak.org/our_work_wildlife_2/vultures/. Accessed Jan 2020.
- Wastie RL. Diseases of rubber and their control. PANS Pest Artic News Summ. 1975;21:268–78.

- Webb EL, Hossain SMY. *Dalbergia sissoo* mortality in Bangladesh plantations: correlations with environmental and management parameters. For Ecol Manage. 2005;206:61–9. <https://doi.org/10.1016/j.foreco.2004.10.055>.
- Wilson DA. Recent advances in the control of oak wilt in the United States. Plant Pathol J. 2005;4:177–91.
- Wingfield MJ, Robison DJ. Diseases and insect pests of *Gmelina arborea*: real threats and real opportunities. New for. 2004;28:227–43. <https://doi.org/10.1023/B:NEFO.0000040950.01256.ed>.
- Wingfield MJ, Roux J, Coutinho T, Govender P, Wingfield BD. Plantation disease and pest management in the next century. South Afr for J. 2001;190:67–72. <https://doi.org/10.1080/20702620.2001.10434117>.
- Wood FA, French DW. *Ceratocystis fimbriata*, the cause of a stem canker of quaking aspen. For Sci. 1963;9:232–5. <https://doi.org/10.1093/forestscience/9.2.232>.
- Xu B, Zheng XH, Guo WX, Zhou XP, He P. First report of pomegranate wilt caused by *Ceratocystis fimbriata* in Sichuan Province. Plant Dis. 2011;95:776. <https://doi.org/10.1094/PDIS-02-11-0146>.
- Yang X, Chen F, Zhang L. Screening of fungicides for control of *Ceratocystis fimbriata* Ellis et Halsted. Plant Prot. 2000;26:38–9.
- Zauza EAV, Alfenas AC, Harrington TC, Mizubuti ES, Silvai JF. Resistance of Eucalyptus clones to *Ceratocystis fimbriata*. Plant Dis. 2004;88:758–60. <https://doi.org/10.1094/pdis.2004.88.7.758>.