Chapter

Botryosphaeria Dieback on Grapevines and Sustainable Management

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Abstract

Botryosphaeria dieback (BD) is a major trunk disease of grapevines worldwide. It is especially prevalent in Mediterranean climates. Several fungal species in the Botryosphaeriaceae family cause BD. *Diplodia seriata* and *Neofusicoccum parvum* are the most prevalent and studied. *Botryosphaeria* dieback has a latent endophytic phase. In this phase, fungi live inside plant tissues without causing symptoms. This is followed by a necrotrophic phase, during which fungi kill plant cells and feed on dead tissue. Stressors such as drought, high temperatures, and vine aging trigger the necrotrophic phase. Environmental stress and pathogen activity together drive disease development. Climate change likely intensifies this process. Current management is limited and relies mostly on pruning and fungicide treatment. Sustainable methods, such as clean materials, biological control, and induced resistance, are gaining relevance. This chapter reviews the taxonomy, symptomatology, epidemiology of BD, host–pathogen interactions, and environmental drivers associated with BD, with particular emphasis on Mediterranean viticulture. In addition, current and emerging sustainable management strategies are discussed as tools ti improve vineyard resilencie and lng-term productivity under changing climatic conditions.

Keywords: diplodia seriata, *Neofusicoccum parvum*, *Botryosphaeria dieback*, demethylation inhibitor fungicides, benzimidazoles, water stress, biocontrol, Bacillus, Trichoderma, Pseudomonas, Actinomycetes

1. Introduction

Botryosphaeria dieback (BD) is one of the main grapevine trunk diseases (GTDs). These chronic fungal diseases attack grapevine trunks and threaten the sustainability of viticulture worldwide. *Botryosphaeria* dieback reduces longevity, productivity, and quality in vineyards. It causes vascular necrosis, killing the water-conducting tissues in the plant. *Botryosphaeria* dieback also produces cankers, or dead tissue, in the cortex, the vine's outer layer. As the disease progresses, it causes dieback (progressive death) of vine arms and shoots. This inflicts significant economic losses in both table grape and winemaking systems [1–5]. Although growers and researchers have observed symptoms for decades, knowledge about the disease's etiology (causes) and epidemiology (spread and patterns) has grown significantly. Historically, researchers linked the disease to "black dead arm," which Lehoczky [6] described and later included in the GTD complex. Typically, a "V" appears in main branches as necrosis of the vascular tissues develops. When other pathogens invade, lesions expand. Molecular taxonomy, which uses genetic information to classify organisms, has advanced understanding of BD. Researchers now know BD is not caused by a single pathogen. Instead, a complex of species in the Botryosphaeriaceae family causes BD. Ongoing research continues to clarify their phylogenetic relationships, names, and biological behaviors [6–10].

Diplodia seriata and *Neofusicoccum parvum* dominate Mediterranean climates. *D. seriata* is highly prevalent and aggressive in older vineyard tissues [4, 11, 12], while *N. parvum* is among the most aggressive toward young tissues, such as recently formed shoots or green stems [12–15]. It rapidly colonizes woody tissues and often causes swift symptom progression [13, 14, 16–18]. Both species are important in Chilean vineyards and impact table and wine grapes [4, 19–21]. One of the most complex aspects of *Botryosphaeria* dieback is the causal agents' ability to persist for long periods as latent endophytes – fungi inside the plant without causing symptoms – in seemingly healthy tissues. They induce symptoms only when activated by predisposing factors such as water stress, high temperatures, vineyard aging, pruning wounds, or physiological weakening [1, 22–24]. This latency explains the chronic, progressive nature of the disease and the challenge of early detection and management.

The Mediterranean climate is characterized by wet winters and warm, dry summers. In this region, abiotic stress (such as drought or heat), host physiology (the vine's internal health and processes), and inoculum pressure (the number of disease-causing particles present) interact to favor BD (BD) development. Climate change plays a significant role, as increased drought and extreme heat events make vines more susceptible and amplify symptom expression [2, 25, 26]. *Botryosphaeria* dieback should not be viewed solely as a phytopathological issue. It results from interactions among the pathogen (the disease-causing organism), the host (grapevine), the microbiota (the microbial community), and the environment. Despite advances in understanding, BD remains challenging to manage. Fungicide-based strategies protect pruning wounds but vary in their effectiveness. Fungicides entail costs, environmental risks, and the potential for resistance development [3, 18, 27]. There is growing interest in sustainable alternatives, such as biocontrol agents (BCAs) (beneficial organisms that control pathogens), resistance induction (stimulating plant defenses), and integrated management (combining preventive and curative actions). These alternatives aim to reduce chemical dependence and enhance vineyard resilience [28–31].

This chapter provides an integrated review of BD in Mediterranean climate regions. It emphasizes the epidemiological relevance of *Diplodia seriata* and *Neofusicoccum parvum*. Topics include their incidence, prevalence, biology, nomenclature, and predisposing factors. The chapter then discusses sustainable management strategies. It highlights the importance of a systemic perspective and ensures a cohesive understanding across sections.

2. BD and sustainable control

2.1 Global relevance of viticulture in the Mediterranean climate

Viticulture, or grape cultivation, is a major agricultural activity globally, especially in countries with a Mediterranean climate (**Figure 1**). These regions have mild, humid winters and warm, dry summers. Such conditions create an ideal environment for *Vitis vinifera* L. These environmental factors enable the production of grapes for wine, fresh consumption, and export [32, 33]. However, climate also affects the plant's physiology (its functioning and growth) and interactions with the environment, influencing growth patterns, photosynthetic efficiency (the plant's ability to convert sunlight into energy), and the susceptibility to diseases [34–37].

The main wine-producing regions are found in Mediterranean climates. These include Spain, Italy, Portugal, Chile, South Africa, Australia, the United States (California), and Mexico. These areas account for much of the world's vineyard area and wine production [33, 38]. In the Southern Hemisphere, especially Chile, viticulture has grown increasingly over the decades. This growth is driven by favorable conditions and global demand [21, 39]. Worldwide, vineyards cover more than 7 million hectares [40]. Grafted plants (vines created by joining the root system of one plant, called rootstock, to the fruit-bearing portions of another) are increasingly common. Rootstock use helps address biotic (caused by living organisms) and abiotic (nonliving factors) challenges. These include phylloxera (*Daktulosphaira vitifoliae*, a root-feeding insect) and stresses from drought, salinity, or calcareous (chalky) soils [33, 41]. In most Mediterranean regions, grafted plants are the norm. Some areas with sandy soil still have nongrafted vineyards due to lower

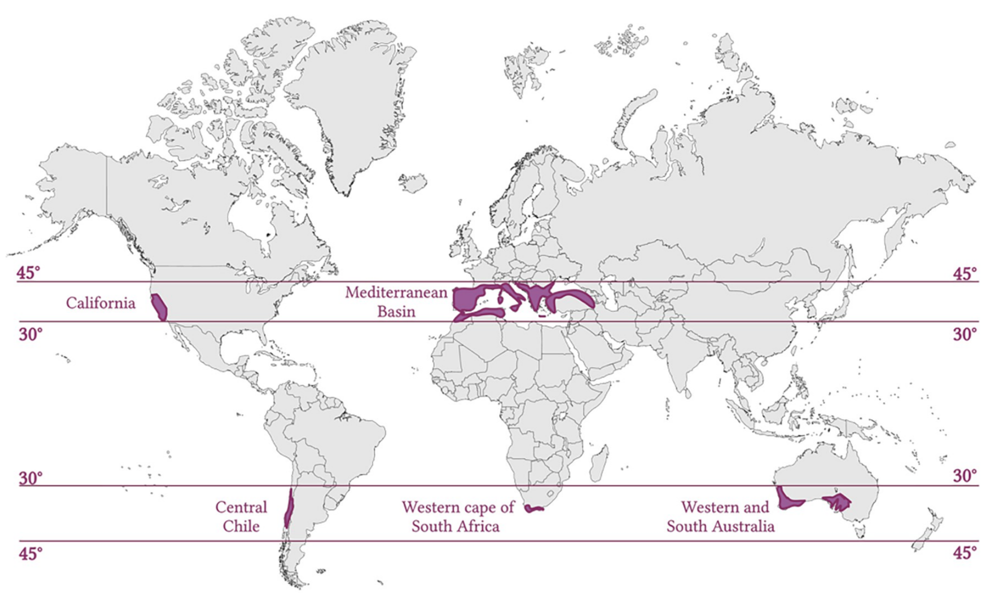

Figure 1.
Mediterranean climate regions worldwide. Source: Created in BioRender. L1, B. (2026) https://biorender.com/25j0kzb.

pest pressure. In Chile, the industry mainly relies on nongrafted vineyards, but the trend is shifting toward grafted plants.

Rootstocks provide pest resistance but also affect plant–microorganism interactions. They influence colonization by both beneficial and harmful microbes, which affects the plant's health and disease response [24, 31]. Abiotic stresses, such as water deficit, can make plants more vulnerable to infection by opportunistic pathogens, including those that cause wood diseases [1, 2, 42]. *Vitis vinifera* varieties in Mediterranean regions are diverse. Some varieties are more common due to their adaptability and market value. Red varieties include Cabernet Sauvignon, Merlot, Syrah, and Tempranillo. For white grapes, Chardonnay, Sauvignon Blanc, and Airén are prominent [33]. Variety choices depend on climate, water availability, and production goals. Disease susceptibility also influences choices, as cultivars differ in their sensitivity to trunk disease pathogens such as *D. seriata* and *N. parvum* [12, 14, 16, 18, 42].

Despite favorable conditions, Mediterranean viticulture faces water stress and climate change. There is an increased incidence of wood diseases and reliance on chemical inputs [25, 26]. Overall, viticulture in Mediterranean regions is significant but vulnerable. Climate, agronomic management, and pathogen pressure jointly determine crop sustainability. Diseases such as BD should be considered within an integrative framework. This framework must include physiological, environmental, and microbiological factors [1, 2, 12, 43].

2.2 Incidence and severity of BD

In Mediterranean climate viticulture, BD is among the most widespread and economically significant wood diseases. Estimates of incidence and severity vary considerably by vineyard age, variety, environmental conditions, and diagnostic criteria [1, 2, 5]. Infections mainly occur through pruning wounds. Symptom expression is often linked to water stress and the physiological decline of the vine [8, 23, 44]. As a result, BD is chronic and progressive. Both incidence and severity increase with vineyard age and the number of infection events [2, 3].

One of the earliest and most comprehensive studies of Mediterranean-type climates was conducted in California by Úrbez-Torres et al. [7], who analyzed 166 vineyards across 21 counties and demonstrated that Botryosphaeriaceae species were among the most frequently isolated fungi from grapevine cankers. This study confirmed the widespread distribution of pathogens associated with the disease in California's main wine regions and highlighted their central role within the trunk disease complex [7, 27]. Subsequent pathogenicity studies also showed that species such as *N. parvum* are highly aggressive and capable of causing rapid wood necrosis and drying symptoms under Mediterranean conditions [13, 14].

In Chile, where viticulture also develops under Mediterranean conditions, various studies have quantified the incidence and severity of BD in commercial vineyards. Morales et al. [16] reported that in table grape vineyards aged 11–20 years, the incidence ranged from 22% to 69%, while the severity ranged from 6% to 21.3%, demonstrating a strong association between plant age and disease development. Similarly, Díaz et al. [17, 18] confirmed the widespread presence of *D. seriata*, *N. parvum*, and other Botryosphaeriaceae species in Chilean vineyards, stressing their importance within the complex of GTDs. These findings are consistent with previous reports of *Botryosphaeria obtusa* causing cankers and decline symptoms in

Chile [20], suggesting that BD has been present and relevant in the country for decades [19–21]. More detailed epidemiological data were provided by Larach et al. [4], who evaluated BD in vineyards of *V. vinifera* cv. Cabernet Sauvignon grown in the principal two regions of central Chile over two growing seasons and the evolution of incidence and severity over two different years, 2010 and 2018. The authors reported extremely high incidence rates (84–87%) and severity levels close to 50%, along with significant yield losses. These results demonstrate that BD can reach epidemic levels in mature vineyards and confirm its strong impact under Mediterranean conditions in Chile. Additionally, the study highlighted the temporal persistence of the disease and the difficulty in reducing inoculum once vineyards are established [2, 4].

Epidemiological studies also support the high incidence observed in Chile by linking disease development to inoculum dynamics. Valencia et al. [42] demonstrated that conidia from Botryosphaeriaceae species are continuously dispersed in vineyards of the Valparaíso Region, with peaks associated with rain events typical of Mediterranean winters. These findings explain the repeated infection of pruning wounds and the progressive increase in disease incidence over the seasons [8, 42]. Additionally, studies on varietal susceptibility have shown that different grapevine cultivars exhibit variable responses to infection, influencing both the incidence and severity of the disease within vineyards [15, 16].

In other regions with a Mediterranean climate, such as Portugal, Spain, and southern Europe in general, BD is also recognized as one of the main wood diseases affecting vineyards. Reviews and field studies indicate that species of Botryosphaeriaceae are widely distributed and are frequently associated with cankers and decay symptoms, often coexisting with other trunk pathogens such as *Eutypa lata* and fungi associated with Esca [2, 5, 45]. Although quantitative incidence data are less standardized than in Chile, these studies consistently report an increase in the disease in aging vineyards and under drought stress conditions, reinforcing its importance in Mediterranean viticulture [3, 26]. Similarly, in Australia, BD is widely distributed in the wine-growing regions and is considered an important factor in vine decline. Several studies have shown that species of Botryosphaeriaceae are common colonizers of pruning wounds and woody tissues, and that their incidence increases with vine age and environmental stress [14, 44, 46]. However, as in other regions, field assessments often group BD within broader categories of 'progressive death' or "decline," which makes direct comparisons of severity difficult. Still, the available evidence clearly indicates that BD plays a central role in the epidemiology of trunk diseases under Australian Mediterranean-type conditions [2, 3].

Overall, the literature demonstrates that BD is a globally distributed disease in Mediterranean climate viticulture, with an incidence ranging from moderate to extremely high depending on vineyard conditions, and whose severity increases with plant age and accumulated infections. Studies in California established its widespread distribution and pathogenic relevance, Chilean research provided quantitative evidence of its high incidence and productive impact, and European and Australian studies confirmed its broad importance in other Mediterranean regions. These findings support the idea that BD is not a secondary disease but a structural limitation to vineyard longevity and productivity in Mediterranean environments [1–3, 5].

2.3 Prevalence of BD

The prevalence of BD is closely related to the frequency and relative abundance of Botryosphaeriaceae species that colonize grapevine wood. Unlike incidence, which reflects the proportion of symptomatic plants, prevalence is usually assessed by isolating and identifying the pathogen, providing insight into the dominant causal agents in different regions. Studies conducted in Mediterranean and similar climates consistently indicate that species such as *N. parvum*, *D. seriata*, and *Lasiodiplodia theobromae* are among the most prevalent pathogens associated with BD worldwide [2, 8, 10]. Among them, *N. parvum* stands out for its high aggressiveness and wide distribution, while *D. seriata* is often among the most isolated species across different regions, including Chile [4, 14, 16].

In Mediterranean regions such as California, Portugal, and Spain, the prevalence of Botryosphaeriaceae species is also high, though the specific composition may vary with environmental conditions and vineyard management practices. In California, *D. seriata* and *N. parvum* are among the most frequently isolated species from grapevine cankers [7, 27]. In southern Europe, studies have reported a diverse community of Botryosphaeriaceae, including species of *Diplodia*, *Neofusicoccum*, and *Spencermartinsia*, which often coexist on the same plant [2, 5, 45]. This diversity suggests that BD is not caused by a single pathogen but by a complex of species, whose relative prevalence can vary with climate and host factors.

In Australia, prevalence studies also indicate that species of Botryosphaeriaceae are widely distributed and are frequently isolated from pruning wounds and infected woody tissues. Studies have identified *D. seriata* and *N. luteum* among the most common species, although their relative prevalence varies between regions [14, 46]. As in other Mediterranean climate regions, the prevalence of these pathogens is strongly influenced by environmental conditions, particularly rainfall patterns that favor spore dispersal and infection [2, 44].

2.4 Nomenclature associated with species of *Botryosphaeriaceae*

The taxonomy and nomenclature of fungi associated with BD have undergone significant changes in recent decades, primarily due to advances in molecular phylogeny. Historically, fungal species were described using different names for their sexual (teleomorph) and asexual (anamorph) states, which caused considerable confusion in the literature, particularly within the Botryosphaeriaceae [8–10]. As a result, the same pathogen could be reported under different names depending on the observed state, complicating the interpretation of epidemiological studies and the development of management strategies. Within the family Botryosphaeriaceae, this reorganization established that several pathogens previously grouped under the genus *Botryosphaeria* belong to different genera. For example, species previously described as *Botryosphaeria parva* are now classified as *N. parvum*, while *Botryosphaeria obtusa* is now known as *D. seriata* [7, 10, 47]. These changes are not just nominal but reflect significant differences in pathogenicity, host range, and environmental adaptation [2, 8, 14].

The adoption of a unified nomenclature has been especially important in the study of BD, as it enables consistent identification of causal agents across studies and regions. However, older literature still uses outdated names, so understanding synonyms is essential when analyzing historical background [1, 45]. For example,

Specie	Teleomorph	Reference
Neofusicoccum parvum	*Botryosphaeria parva*	[7, 47]
Diplodia seriata	*Botryosphaeria obtuse*	[7]
Neofusicoccum australe	*Botryosphaeria australis*	[48]
Lasiodiplodia theobromae	*Botryosphaeria rhodina*	[49]
Diplodia mutila	*Botryosphaeria stevensii*	[47]
Neofusicoccum luteum	*Botryosphaeria lutea*	[50]
Spencermartinsia viticola	*Botryosphaeria viticola*	[51]
Dothiorella Iberica	*Botryosphaeria Iberica*	[51]
Diplodia corticola	*Botryosphaeria corticola*	[49]
Neofusicoccum mediterraneum	*Botryosphaeria mediterranea*	[9]

Table 1.
The main species of Botryosphaeriaceae associated with grapevines and their nomenclature.

early reports of "*Botryosphaeria* canker" in grapevines included species now classified in genera such as *Diplodia*, *Neofusicoccum*, and *Lasiodiplodia* [7, 19, 20]. **Table 1** summarizes the main species of Botryosphaeriaceae associated with wood diseases in grapevines, including their currently accepted names and corresponding teleomorphs, according to modern taxonomy. The listed species represent the most frequently reported pathogens associated with BD in Mediterranean climate wine regions [2, 5, 8].

2.5 Endophytic and necrotrophic phases of the causal agents

The species of the family Botryosphaeriaceae exhibit complex biological behavior, widely described as a continuum between a latent endophytic phase and a necrotrophic pathogenic phase. Various authors agree that many of these fungi can colonize grapevine tissues without causing visible symptoms for long periods, behaving as endophytes [1, 7, 22]. This ability to remain latent in plant tissues is a key characteristic in the epidemiology of BD. Species such as *D. seriata* and *N. parvum* have been widely reported as endophytes in apparently healthy vine tissues [7, 14, 22]. Studies conducted in different wine-growing regions have shown that these pathogens can be isolated from wood without symptoms, suggesting that their presence does not always immediately correlate with disease [1, 52]. In this context, Abreo et al. [53], working in vineyards in Uruguay, isolated *D. seriata* and *N. parvum* from both symptomatic and asymptomatic tissues, confirming their endophytic behavior and latent potential in the host plant.

However, the transition from this endophytic phase to an active necrotrophic phase remains a complex process and is not fully understood. It has been proposed that abiotic and biotic stress factors, such as water deficit, extreme temperatures, pruning wounds, or physiological weakening of the plant, can trigger pathogen activation [23, 26, 44]. Under these conditions, the fungi change their life strategy, actively colonizing woody tissues, producing toxins, and causing vascular necrosis and regressive death [54, 55]. These processes result in visible symptoms at both the canopy and wood levels, including dieback, vascular discoloration, and internal

Figure 2.

Symptoms and internal wood necrosis associated with Botryosphaeria dieback *in grapevines (*V. vinifera *cv. Cabernet Sauvignon). (a–b) Vineyard showing pruning stage under Mediterranean conditions; (c) external symptoms on pruning wounds, including vascular discoloration and wood necrosis; (d) cross-section of infected wood showing internal necrosis and sectorial discoloration; and (e–g) longitudinal sections of grapevine wood illustrating internal vascular necrosis: (e) control (T0), (f) inoculated with* N. parvum*, and (g) inoculated with* D. seriata*. Red lines indicate the extent and pattern of vascular necrosis associated with each pathogen. Source: The detailed description of this experiment and its methodological approach is presented in Castillo-Novales et al. [12].*

necrosis, as illustrated in **Figure 2**. In this regard, recent reviews have proposed that the causal agents of BD should be considered organisms with a hemibiotrophic lifestyle, that is, organisms that exhibit an initial endophytic or biotrophic phase followed by a destructive necrotrophic phase [5, 24]. This behavior explains the chronic and progressive nature of the disease and the difficulty in managing it, as the pathogen can establish itself in the plant long before visible symptoms appear [2, 3].

2.5.1 Phenolic compounds associated with BD

Phenolic compounds play a central role in the interaction between the vine and pathogens of the Botryosphaeriaceae family. These secondary metabolites are part of the plant's defense mechanisms and can act as antimicrobial agents, antioxidants, or signaling molecules in the stress response [56, 57]. In the context of grapevine diseases, it has been observed that infection by species such as *N. parvum* induces significant changes in the vine's phenolic metabolism.

Lambert et al. [57] demonstrated that phenolic compounds present in the vine's wood can exhibit antifungal activity against Botryosphaeriaceae species, suggesting a direct role in limiting pathogen development. However, these defense mechanisms are not always sufficient to halt disease progression, especially under stress. Additionally, the accumulation of phenolic compounds may be associated with lignification processes and the formation of structural barriers in the xylem, contributing to the restriction of fungal colonization [1, 58]. However, some pathogens can tolerate or even metabolize these compounds, allowing them to persist in woody tissues [54].

2.5.2 Main defense compounds

The vine's defense against BD pathogens involves a complex network of compounds and biochemical mechanisms. Among the main defense compounds are pathogenesis-related proteins (PR), phenolic compounds, antioxidant enzymes, and various signaling molecules [59, 60]. During infection, reactive oxygen species (ROS) accumulate, acting as signals to activate defense responses but also causing cell damage if not properly regulated [61, 62] In response to this oxidative stress, the plant increases the activity of antioxidant enzymes such as catalases, peroxidases, and superoxide dismutase [62].

Likewise, the participation of compounds such as proline has been described, which act as an osmoprotectant and stress regulator, contributing to the plant's tolerance to adverse conditions [63, 64]. At the molecular level, infection by Botryosphaeriaceae also induces the expression of defense-related genes, including those involved in phytoalexin and PR protein synthesis [15, 65]. On the other hand, recent studies have highlighted the role of the grapevine microbiome in modulating these defensive responses. Endophytic and rhizospheric microorganisms can induce systemic resistance and help limit the development of wood pathogens, opening new perspectives for the biological management of BD [29–31].

2.6 Microbiota associated with BD

The study of the microbiota associated with diseases of the grapevine trunk, including BD, has gained increasing interest in recent years; however, there are still relatively few studies that comprehensively address the composition and function of the fungal, bacterial, and viral microbiomes in grapevine woody tissues [3, 30, 66]. One of the pioneering studies in this area was conducted by Bruez et al. [66], who analyzed fungal communities in symptomatic and asymptomatic grapevine tissues using molecular techniques. Their results showed no significant differences in fungal community composition between the two tissue types, suggesting that the presence of pathogens alone does not determine symptom appearance. This finding supports the hypothesis that Botryosphaeriaceae pathogens can behave as latent endophytes, and an additional factor, such as plant stress, is necessary for disease expression [1, 22].

In addition to fungi, recent studies have highlighted the importance of the bacterial microbiota associated with the vine. Endophytic and rhizospheric microorganisms can play key roles in modulating plant responses to pathogens, including inducing systemic resistance, competing for nutrients, and producing antimicrobial compounds [29, 31]. In this context, bacteria from the genera *Pseudomonas* and *Bacillus* have been widely described as potential BCAs against wood pathogens [28, 30].

2.7 Fungal dispersion

The dispersal of pathogens associated with BD is a key process in the epidemiology of the disease and is strongly influenced by the typical environmental conditions of Mediterranean climates. Species of Botryosphaeriaceae mainly produce conidia (asexual spores), which are released from reproductive structures (pycnidia) present in infected tissues and pruning debris [2, 8]. The release and dispersal of these spores mainly occur during rain events, where water acts as a dispersal agent, transporting conidia to recent wounds on the plant, especially pruning wounds [42, 44]. Studies conducted in Chile have shown that Botryosphaeriaceae conidia disperse year-round, with peaks coinciding with winter rainfall, which occurs during the pruning period in many production systems [42].

In addition to splash water dispersal, conidia have been reported to be transported by the wind over short distances and via contaminated pruning tools, contributing to the pathogen's spread within the vineyard [14, 27]. Once deposited on fresh wounds, the spores germinate rapidly and colonize vascular tissues, initiating the infection [23]. The persistence of inoculum in the vineyard, particularly in infected pruning debris, constitutes an important source of reinfection year after year, making disease control difficult [2, 3]. Therefore, understanding fungal dispersal patterns is essential for designing management strategies, such as protecting pruning wounds and eliminating sources of inoculum.

2.8 Nutritional aspects

Nutritional factors play an important role in both the pathogen's development and the host plant's response. Species of Botryosphaeriaceae can colonize woody tissues thanks to their ability to degrade structural components such as cellulose, hemicellulose, and lignin through the production of hydrolytic and oxidative enzymes [54, 55]. This ability enables them to use wood as a carbon and energy source, facilitating their growth and expansion within the host. On the other hand, the plant's nutritional status may greatly affect its susceptibility to the disease. Deficiencies or imbalances in essential nutrients can weaken the vine's defense mechanisms, promoting colonization by pathogens [1, 2]. Nutritional stress, combined with water stress, has been identified as a factor that increases the severity of symptoms associated with BD [3, 44].

Few studies have been conducted on the nutritional aspects of Petri diseases, their causal agents, and potential biocontrollers of BD. Focus on *D. seriata* and *N. parvum*; the former uses 100% pentoses, tri- to tetrasaccharides, and polysaccharides, while *N. parvum* uses 0% pentoses and only tri-to tetrasaccharides. Another difference was that *D. seriata* used fewer amino acids (47%) than *N. parvum* (64%) and fewer tripeptides (64%) than *N. parvum* (100%). Among biocontrollers, those that used more C and N nutrients were *Trichoderma harzianum* and *T. lecanii*, which were considered competitive for the biocontrol of *D. seriata* and *N. parvum* [67].

Likewise, soil nutrient availability influences the composition of the plant-associated microbiome, which, in turn, can indirectly affect disease dynamics. Soils with high microbial activity may promote the presence of antagonistic microorganisms that limit pathogen development [28, 31]. Finally, it has been suggested that management practices, such as balanced fertilization and the use of biostimulants, may help improve the plant's resistance to trunk diseases, although further research is required to fully understand these effects in the context of BD [29, 30].

2.9 Predisposing factors for BD

The development and severity of BD do not depend solely on the presence of the pathogens but are strongly influenced by predisposing factors that affect the plant's physiological state. In this context, agents of Botryosphaeriaceae are considered opportunistic pathogens that can remain in an endophytic state until stress conditions favor their activation and transition to a necrotrophic phase [1, 21, 24].

Various studies have shown that factors such as water stress, high temperatures, vineyard age, pruning practices, and nutrient limitations act synergistically to predispose the vine to BD [2, 3]. These factors affect the plant's ability to activate effective defense responses, facilitating the colonization of woody tissue and the progression of the disease [23, 44]. In Mediterranean climate regions, where seasonal drought and high temperatures are common, these factors become especially relevant, helping to explain the high incidence and severity of BD observed there [8, 25].

2.9.1 Water stress

Water stress is one of the main predisposing factors associated with the development of BD. Under water-deficit conditions, the vine experiences reduced photosynthetic capacity, altered water and nutrient transport, and decreased production of defense compounds [1, 68, 69]. Various studies have shown that water stress promotes the expression of symptoms associated with Botryosphaeriaceae, even in plants previously colonized in a latent state [23–44]. In this context, water limitation can induce physiological changes that facilitate the transition of pathogens from an endophytic to an active necrotrophic phase, thereby increasing vascular necrosis and shoot dieback.

Additionally, water stress can compromise the integrity of the vascular system, promoting xylem embolism, reducing water transport capacity, and increasing the extent of pathogen damage [70–72]. This interaction between water stress and vascular dysfunction is especially relevant in the context of BD, where xylem colonization is a central component of the infectious process [1]. On the other hand, prolonged drought can reduce the activity of antagonistic microorganisms in soil and plant tissues, altering the microbiome balance and promoting the development of pathogens [28, 31]. Overall, these effects position water stress as a critical factor in the epidemiology of BD, especially in climate change scenarios in which the frequency and intensity of droughts are projected to increase in Mediterranean regions [2, 25].

2.9.2 Heat and thermal stress

Thermal stress, particularly at high temperatures, is another key factor in the vine's predisposition to BD. In Mediterranean climates, warm, dry summers create conditions that can negatively affect plant physiology, increasing their susceptibility to pathogens [5, 25]. High temperatures can disrupt the plant's metabolism, increase the production of ROS, and damage proteins and cell membranes [61, 73]. Although the plant activates antioxidant mechanisms to reduce these effects, under extreme conditions these systems can be overwhelmed, leading to a general weakening of the plant [62].

In parallel, many Botryosphaeriaceae species, including *N. parvum* and *D. seriata,* exhibit high tolerance to elevated temperatures, allowing them to maintain metabolic activity and infectious capacity under plant stress conditions [13, 14]. This physiological advantage of the pathogen over the host contributes to the progression of the disease under hot conditions. Likewise, heat stress can interact with water stress, creating a combined effect that worsens the severity of trunk diseases. Fernández et al. [69], working with *D. seriata* and *N. parvum*, found that *D. seriata* was enhanced by simultaneous heat and water stress (25%), while *N. parvum* did not change its virulence.

2.10 Varieties and rootstocks susceptible to BD

The susceptibility of the vine to BD is strongly influenced by genetic factors associated with both the variety (graft) and the rootstock. Different studies have shown significant variability in *V. vinifera*'s response to Botryosphaeriaceae species, reflected in differences in disease incidence, severity, and progression [13, 14, 16]. In general, the cultivated varieties in Mediterranean climate regions exhibit varying levels of tolerance or susceptibility, associated with physiological, anatomical, and biochemical factors, including the ability to form structural barriers, produce phenolic compounds, and respond to stress [1, 2]. Likewise, the rootstock can influence the plant–pathogen interaction by affecting vigor, water-use efficiency, and tolerance to adverse conditions [3, 41].

2.10.1 Main grapevine cultivars and their susceptibility to BD

The varieties of *V. vinifera* cultivated in Mediterranean regions are highly diverse; however, a reduced number of cultivars dominate vineyard acreage due to their agronomic performance, adaptability, and market demand. Among red varieties, Cabernet Sauvignon, Merlot, Syrah, and Tempranillo are widely planted, while Chardonnay, Sauvignon Blanc, and Airén are among the common white cultivars [33]. These international varieties have been extensively adopted across Mediterranean climate regions, including Europe, California, Chile, South Africa, and Australia, due to their enological quality and commercial value.

In addition to widely cultivated international varieties, native and autochthonous cultivars remain highly relevant, particularly in European viticulture. In countries such as Spain, Italy, and Portugal, traditional cultivars, including Tempranillo, Garnacha, Sangiovese, Touriga Nacional, and Airén, are extensively cultivated and increasingly valued due to their adaptation to local environmental conditions and their potential resilience to climate change [26, 33]. These varieties often exhibit specific physiological and structural traits that allow them to cope more effectively with water deficits and high temperatures, conditions that are characteristic of Mediterranean climates.

Recent studies suggest that both international and autochthonous grapevine varieties differ in their susceptibility to GTDs, including BD. Variability in disease expression and pathogen colonization among cultivars has been widely reported and is associated with differences in wood anatomy, phenolic composition, and physiological responses to biotic and abiotic stress [1, 2, 74]. For instance, differences in xylem structure and compartmentalization capacity can influence pathogen spread within woody tissues, thereby affecting disease severity and progression.

Furthermore, some traditional cultivars have shown lower disease severity or slower disease progression, which may be linked to enhanced tolerance to abiotic stress and a greater ability to limit pathogen colonization [24]. Similar variability has also been observed in Chilean vineyards, where cultivar-dependent differences in susceptibility to Botryosphaeriaceae species have been reported [16, 17]. These findings highlight that host genotype plays a crucial role in disease development and should be considered in integrated disease management strategies.

Therefore, incorporating both international and native grapevine varieties is essential for improving our understanding of the epidemiology of BD and for developing more sustainable and resilient viticultural systems under Mediterranean climate conditions.

2.10.2 Main rootstocks

The use of rootstocks is a widely adopted practice in modern viticulture, primarily to combat phylloxera (*Daktulosphaira vitifoliae*), but also to improve adaptation to soil and climate conditions [33]. However, its role in susceptibility to trunk diseases, including BD, has been less studied than that of the varieties. Among the most widely used rootstocks globally are 110 Richter (110 R), 140 Ruggeri (140Ru), 1103 Paulsen (1103P), SO4, 101-14 Mgt, and 3309 Couderc, which are derived from hybrids of American species such as *Vitis berlandieri, V. rupestris*, and *V. riparia* [33, 41].

Some studies have suggested that rootstocks may indirectly influence susceptibility to BD by affecting plant vigor and tolerance to abiotic stress. For example, rootstocks with greater drought tolerance may reduce the impact of water stress and, consequently, limit the activation of endophytic pathogens [41, 71]. In contrast, rootstocks that induce high vigor may produce tissues more susceptible to colonization or hinder pathogen compartmentalization.

2.11 Main fungicides used for BD control

The chemical management of BD primarily focuses on protecting pruning wounds, as these are the main entry points for *Botryosphaeriaceae* pathogens [2, 27]. Unlike foliar diseases, chemical control of BD is mainly preventive rather than curative because the pathogens can colonize internal wood tissues. Among the most used fungicides are compounds from the triazole family (DMI, demethylation inhibitors), such as tebuconazole, difenoconazole, and metconazole, which have demonstrated effectiveness in reducing conidia germination and mycelial growth in laboratory trials [75] and infections caused by *D. seriata* and *N. parvum* in field trials [75]. These compounds work by inhibiting ergosterol biosynthesis, affecting the integrity of the fungal cell membrane. Likewise, fungicides such as pyraclostrobin + boscalid (QoI + SDHI) and thiophanate-methyl have been evaluated as protectants for pruning wounds, with effectiveness varying by environmental conditions and application timing [2, 5].

In general, the efficacy of these products depends heavily on their ability to persist on the wound and prevent spore germination [76]. In Chile, studies have shown that the application of systemic and contact fungicides can significantly reduce infection by Botryosphaeriaceae pathogens, although their effectiveness depends on proper timing relative to pruning events and weather conditions [18, 42]. However, the intensive use of fungicides presents challenges related to the development of resistance, environmental impact, and regulatory restrictions (2022 Sustainability – Fungicides) [77]. In this context, chemical management of BD is considered a useful but limited tool, which should be integrated into broader management strategies.

2.12 Biocontrol agents

The use of biocontrol agents (BCAs) has emerged as a sustainable alternative for managing trunk diseases of grapevines, including BD. These microorganisms, mainly bacteria and fungi, can inhibit the growth of pathogens through various mechanisms, such as competition for space and nutrients, the production of antimicrobial compounds, and the activation of plant defenses [28, 31]. Among the most studied agents are species of the genus *Trichoderma*, which have demonstrated high efficacy in colonizing pruning wounds and inhibiting *Botryosphaeriaceae* pathogens. Studies conducted across different wine-growing regions have shown that Trichoderma spp. can significantly reduce infection incidence by directly competing with pathogens and producing lytic enzymes [78, 79].

Regarding bacteria, genera such as *Pseudomonas* and *Bacillus* have been widely described as BCAs with potential against wood pathogens. These bacteria can produce antifungal metabolites, volatile organic compounds (VOCs), and enzymes that inhibit the growth of pathogens, as well as induce systemic resistance in the plant [12, 29–31, 43, 80, 81]. Recent studies have also shown that microbial consortia can improve biocontrol efficacy through the complementarity of their mechanisms of action [28]. In this regard, the microbiome approach is gaining relevance as an innovative strategy for managing GTDs. Despite these advances, the effectiveness of BCAs in field conditions can be variable, depending on factors such as formulation, persistence on the plant, and environmental conditions [2, 3]. Therefore, integrating them with other management practices is essential.

2.13 Induced resistance

Induced resistance is a complementary strategy in disease management, leveraging the plant's ability to activate its defense mechanisms in response to biotic or abiotic stimuli. This phenomenon can be triggered by beneficial microorganisms, chemical compounds, or specific environmental conditions [82]. In the vine, different signaling pathways involved in the defensive response against pathogens have been described, including the salicylic acid (SA), jasmonic acid (JA), and ethylene (ET) pathways [1, 83]. Activation of these pathways leads to the production of PR proteins, phenolic compounds, and other secondary metabolites with antimicrobial activity.

Microorganisms associated with plants, such as plant growth-promoting bacteria (PGPR), can induce systemic resistance (ISR), preparing the plant to respond more quickly to infection [29, 31]. This mechanism has been widely described in agricultural systems and represents a promising tool for managing trunk diseases. Additionally, the use of biostimulants and elicitors has shown potential to improve grapevine resistance to wood pathogens, although their effectiveness depends on factors such as dose, timing of application, and the plant's physiological state [30]. At the molecular level, transcriptomic studies have demonstrated that infection by Botryosphaeriaceae induces the expression of genes related to defense, oxidative stress, and secondary metabolism, suggesting a complex, multifactorial response in the plant [24, 83].

2.14 Integrated management of BD

Managing BD represents one of the biggest challenges in modern viticulture due to the complex nature of the disease, the diversity of causal agents, and their ability to remain in a latent endophytic state. In this context, there is no single effective control strategy, so an integrated pest management (IPM) approach that combines preventive, cultural, chemical, and biological practices is required [2, 3]. The integrated approach is based on reducing inoculum levels, protecting pruning wounds, improving the plant's physiological state, and using sustainable tools that reduce dependence on fungicides. Within this framework, selecting less susceptible plant material is an important preventive strategy, as is using healthy and certified propagation material to prevent the early introduction of pathogens into the vineyard [1, 16, 83].

Likewise, irrigation management plays a fundamental role in Mediterranean regions, as avoiding critical levels of water stress can reduce the plant's predisposition to activate endophytic pathogens [44, 68, 71]. However, as noted by Fernández et al. [69], the most important management strategy for *D. seriata* disease is to avoid simultaneous heat and water stress. Additionally, pruning wounds need to be protected with fungicides or BCAs, depending on the adopted management strategy and the regulatory and environmental context [2, 27]. Finally, the integration of BCAs and induced resistance strategies represents a promising approach to advancing toward more sustainable management systems. Microorganisms such as *Trichoderma* spp., *Pseudomonas* spp., and *Bacillus* spp. not only directly antagonize pathogens but also strengthen the plant's defenses [28–30]. Overall, integrated disease management should be understood as a dynamic, multifactorial strategy tailored to the specific conditions of each vineyard, which is particularly relevant in the context of climate change.

In **Figure 3**, we include the most important practices that should be implemented to reduce the incidence of BD in a vineyard. Start the vineyard with healthy material, but since these pathogens have an endophytic phase, the idea is to

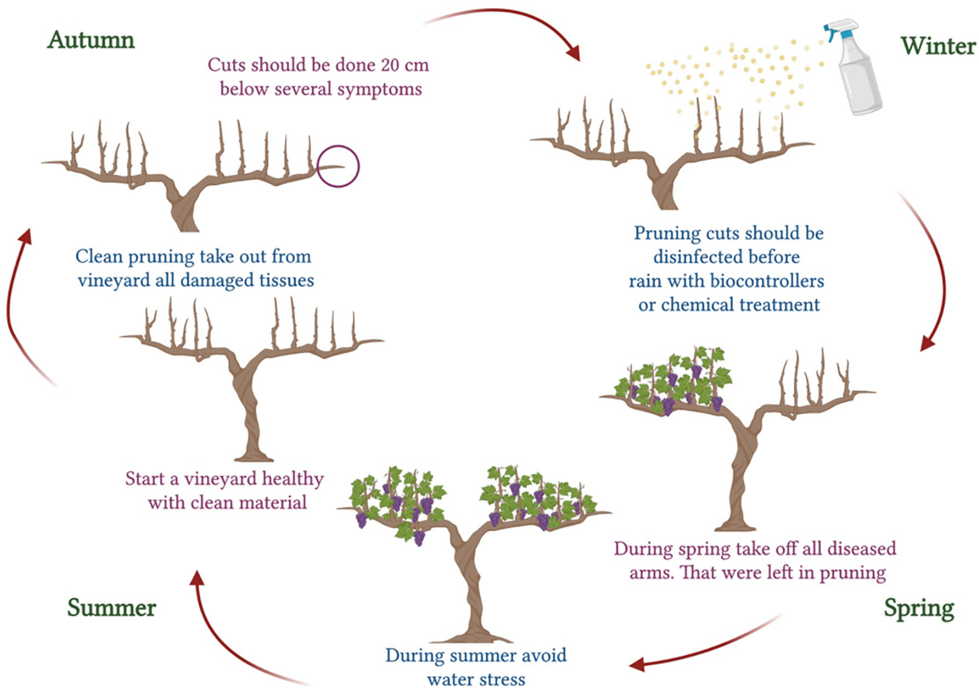

Figure 3.
Integrated management of the Botryosphaeria *dieback disease. Source: Created in BioRender. L1, B. (2026) https://biorender.com/ukan6tm*

implement proper management to avoid the necrotrophic phase. During the winter period, usually prune plants without rain, at least as pruning starts, and immediately begin using a fungicide or a biocontrol treatment to prevent the ingress of BD agents' conidia. Later in spring is a good time to do a cleaning prune, since diseased arms can be easily detected and removed. If the vineyard's main problem is *D. seriata*, avoid water stress during the heat period (summer months), especially at temperatures over 33 °C.

3. Conclusions and future perspectives

Botryosphaeria dieback has become one of the main threats to the sustainability of viticulture in Mediterranean climate regions. Its chronic nature, widespread distribution, and association with multiple species of *Botryosphaeriaceae*, particularly *D. seriata* and *N. parvum*, demonstrate that it is a complex disease whose dynamics depend on interactions among the pathogen, host, and environment. The ability of these pathogens to persist as latent endophytes and activate under stress conditions – especially water and heat stress – positions BD as a disease strongly influenced by the climate context. In this scenario, climate change could not only increase its incidence and severity but also accelerate the decline of vineyards.

Despite advances in understanding, the management of BD remains limited when based on isolated strategies. The available evidence supports the need for integrated approaches that combine pruning wound protection, the use of healthy plant material, abiotic stress management, and the incorporation of sustainable tools such as BCAs and induced resistance strategies. Future perspectives point toward a deeper understanding of the plant–pathogen–microbiome interaction, the development of early diagnostic tools, and the integration of omics approaches that enable the design of more precise and sustainable management strategies. In this context, BD should be addressed not only as a disease but also as a systemic problem in modern viticulture, requiring interdisciplinary solutions accompanied by increasingly challenging environmental conditions.

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Conflict of Interest

The authors declare no conflicts of interest.

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