Grapevine Trunk Diseases (GTDs): Impact on Table Grapes and Wine Vineyards in Chile

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Additional information is available at the end of the chapter

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Abstract

This chapter involves the description and information about the main grapevine trunk diseases (GTDs) affecting *Vitis vinifera* in Chile. There is a complete description of Esca-type disease, bot canker disease affecting more than 7-year-old plants, and Petri disease affecting young plants. Symptom descriptions of GTD diseases are done, and also the principal species as causal agents and the importance of them are analyzed. The dispersal of Botryosphaeriaceae spores is considered, and finally, the principal management measures can be taken in order to avoid or control these important diseases. The information is contrasted with different researches done in the most important countries where these diseases are relevant.

Keywords: bot canker, Esca-like disease, *Diplodia seriata*, *D. mutila*, Botryosphaeriaceae, *Phaeomoniella chlamydospora*, chlorotic leaf roll

1. Introduction

In Chile, the first notice of a disease caused by Botryosphaeriaceae occurred in 1986 [1], where *Botryosphaeria dothidea* was reported causing damage to a grapevine grown in a Spanish trellis for table grape production. Since the 1960s, worldwide studies in grapevine trunk diseases (GTDs) have expanded incrementally; four important types of diseases have been recognized: Esca disease, bot canker disease, *Eutypa* dieback, and *Phomopsis* dieback [2], and actually, the reported studies had acquired an exponential curve, but up to date, there is not a satisfactory field control of these important diseases. In the study done by Fontaine et al. [2], there is an important contribution to understanding these important diseases in many countries, but the

Chilean situation was not included; therefore, this chapter contributes to understand the actual status of GTDs in Chile.

Chile is the principal fruit exporter of fresh table grapes in the world. In addition, it is important as wine producer. An analysis of the main table grapes and wine producer regions is done, with special association to GTD predisposition. The economic importance of GTDs and potential damage that it causes is described. The principal species associated to Botryosphaeriaceae canker and a disease called Esca-like, caused mainly by *Phaeomoniella chlamydospora* in Chile, are descripted in detail, analyzing previous published information [3]. The symptomatology associated to bot canker and Esca disease causal agents is detailed, and a comparison of the situation for the main wine- and table grape-producing countries is done. Furthermore, the importance of these causal agents affecting another high-value species or plants associated to natural habitats, commonly interacting with vineyard's and table grape's orchards, is considered. The factors associated to GTDs will be described, including the analysis associated to climatic conditions. A spatial analysis will be done including different stress-affecting plants and the importance of the Botryosphaeriaceae family as endophytic pathogens. The chapter includes information about the tissues commonly colonized by Botryosphaeriaceae and by *Phaeomoniella*, considering analysis of their preference and age of the colonized tissue. Finally, the chapter includes a description of a complete integrated management and future trends for control of GTDs, with special emphasis in bot canker and Esca diseases. Up to date there is no official report of *Eutypa* disease affecting *Vitis vinifera* in Chile [3, 4], and *Phomopsis* dieback was reported, but the prevalence of its causal agent, *Phomopsis viticola*, is very low [3]. So, this chapter includes an analysis of bot canker and Esca-type disease.

The ability of GTD-associated species to be endophytes is specially a threat for the quarantine programs worldwide, which can be overlooked considering its latent phase. This is particularly important because most of the causal agents have the ability to rapidly express pathogenicity when their hosts are under stress [5]. This is particularly important considering that the Servicio Agrícola y Ganadero (SAG) of Chile requires a 2-year period of quarantine when propagation material is introduced from foreign countries, and not always these types of diseases will express in this period. In addition, it is also important to consider that under the climate change, there is an increase in drought periods in many places, with an increase in stress for many plant communities and an increase of GTD-type diseases.

2. Grapevine trunk diseases (GTDs) in Chile

2.1. Chilean table grape and wine industry

Considering world table grape production, Chile is the seventh main producer worldwide, but considering the export to other countries, Chile is the first exporter, doubling the exports of the second most important country, the United States. Actually, there are 52,234 ha for table grape fresh fruit production in Chile, with vineyards developed in seven different regions, from the North in the Atacama Region and to the South up to the Bío Bío Region. In the Atacama

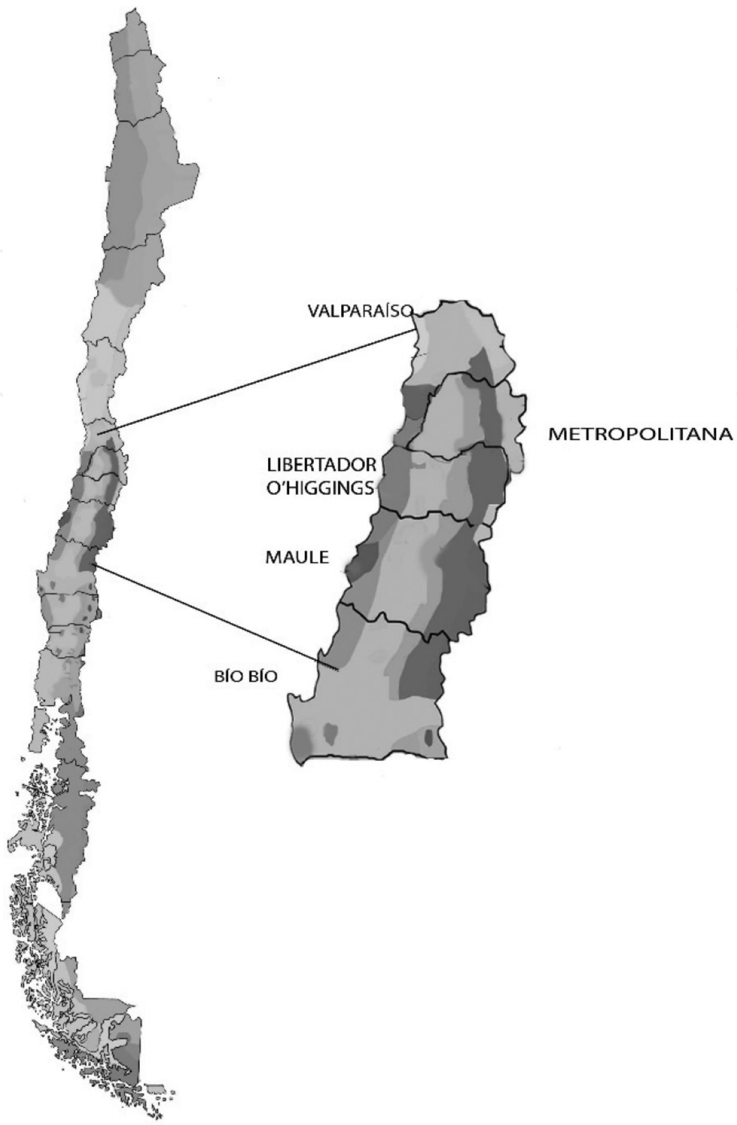

Figure 1. Map of Chile; in detail the five main producing regions with vineyards for wine.

Region, there are about 8515.9 ha, mainly grown for pisco (distilled liqueur) production. In relation to the wine industry, Chile is the sixth most important wine producer and the fourth most important wine exporter. Chile exported in 2016 about 9,100,000 hectoliters, corresponding to 8.74% of the total volume exported in the world [6]. The main wine-producing regions in Chile considering the cultivated area are Maule (37.94%), O'Higgins (32.81%), Bío Bío (10.65%), Metropolitana (9.2%), and Valparaíso (7.1%) (**Figure 1**) with a total of 141,918 ha in 2015 [7]. So, this delineates the significance of GTDs affecting vineyards and the importance of prevention, detection, diagnosis, and opportune control.

2.2. Main diseases and economic importance of GTDs in Chile

In Chile Petri disease [8] has been detected affecting young *Vitis* plants produced for the wine industry, mainly associated to *Phaeomoniella* and *Phaeoacremonium* genera. In vineyards more than 7-year-old, the main diseases affecting plants are *Botryosphaeria* dieback (or bot canker) and a disease similar to Esca found associated to Diatrypaceae fungi and with Basidiomycete fungi associated to wood spongy tissues [1, 3, 4, 8].

Pathogenicity of bot canker has been consistently proven in Chile [4] as well as necrotic strikes associated to *Phaeomoniella chlamydospora* [3, 9]. But there is an important disease called chlorotic leaf roll (*enrollamiento clorótico*) of the vines that is frequently associated to V-shaped necrosis and necrotic streaks in the xylem and also with spongy tissues mainly associated to Basidiomycetes colonization, which Koch's postulates have not been done. So, this type of disease and symptoms needed to be solved by the Chilean plant pathologists.

The economic importance of diseases affecting grapevines has been partially studied in Chile. Morales et al. [4] found that bot canker disease affects table grape vineyards and that the disease increases with the age of the plants. With an increasing incidence of the disease of 22% in an 11-year-old vineyard to 70% in the 22-year-old vineyard, and with maximum severity up to 22% of damage index in a 16-year-old table grape vineyard. In these table grape vineyards, the main species and detected prevalence (%) were *Diplodia seriata* (83.3%), *D. mutila* (8.3%), and *Spencermartinsia viticola* (8.3%). In a national survey done by Díaz et al. [3], with about 694 wood samples being analyzed obtained from 67 Chilean vineyards, from Copiapó (27° 18'S) to Los Angeles (37°42'S), a total of 1363 fungal isolates were obtained from diseased plants with different symptoms, and the most prevalent identified species were *Phaeomoniella chlamydospora* (in 85% of the samples); Botryosphaeriaceae (in 56% of the samples) with the main detected species *Diplodia seriata*, *D. mutila*, *Neofusicoccum parvum*, and *Spencermartinsia viticola*; and Diatrypaceae (in 4.8% of the samples, but *Eutypa lata* was not found). *Phomopsis viticola* and *Cylindrocarpon* sp. were only found in 0.4% of the analyzed samples. Finally, Valencia et al. [10] analyzing conidial dissemination in four vineyards from the Valparaíso Region found in the spore traps conidia from *D. seriata*, *S. viticola*, and *Neofusicoccum australe*, but the greater peaks found corresponded to *D. seriata*.

On the other hand, Torres et al. [11] reported the prevalence and damage observed in 10 vineyards cv. Cabernet Sauvignon during the 2010–2011 growing season. In the research done in 14 blocks of the O'Higgins (n = 8) and Maule (n = 6) regions, the average damages associated with bot canker were 36 and 48% for each region, respectively, with an average of production loss estimated at 5800 kg ha^{-1}. The most prevalent species detected were *Diplodia seriata* (69.2%), followed by *D. mutila* (12.8%), and *Neofusicoccum parvum* (10.2%).

GTDs are the main biotic factors affecting grapes wherever are grown and affecting vineyard productivity and longevity [12]. In France, there is a national crisis with 12% of the vineyards not economically viable, causing annual losses for about 1 billion euros [13]. In China, where *Botryosphaeria* dieback is a serious disease, Yan et al. [14] made a survey in 72 vineyards of 20 grape-growing regions; they found that dieback occurs in 18/20 provinces, and they confirmed the presence of *B. dothidea*, *D. seriata*, *L. theobromae*, and *N. parvum*. These species were spatially distributed: *L. theobromae* and *N. parvum* only occurring in subtropical monsoon climate regions, *Diplodia seriata* only occurring in temperate climatic regions, and *B. dothidea* occurring in both types of climates. Of the 25 cultivars most grown in China, none was resistant to the four (taxa) species.

Black dead arm (BDA) disease was first reported by Lehoczky [15] associated to *B. stevensii* (formerly named as *D. mutila*). This pathogen did not infect the green parts of the vines or the chesters. He reported that the phloem and xylem tissues were black discolored; therefore, he named the disease as "black dead arm disease" instead of the "dead arm disease" caused by *Phomopsis viticola*, previously described by Pine [16]. Actually, there are four major diseases in vineyards. And, their names are Esca, *Eutypa* dieback, *Botryosphaeria* canker, and *Phomopsis* dieback [2].

2.3. GTD causal agents

According to the 10th International Workshop on Grapevine Trunk Diseases (2017) taken place in Reims, France, in the introduction done by Dr. José Ramón Úrbez-Torres "Main achievements and future prospects in GTDs Pathogen Characterization and Identification," he analyzed that 133 species from 34 genera are associated to GTDs worldwide. Considering these information, the analysis of this type of diseases affecting grapevines is much complex to organize. Fortunately, in Chile the situation is more easy considering that there are only five species causing bot canker [3, 4, 8, 10, 17], two main species associated to Petri and Esca-like diseases [3, 9, 18], plus three species of Basidiomycetes [3]. *Phomopsis* dieback is very infrequently seen, and black foot also seems to be associated with problems at the plantation site of grafted material and with very low prevalence [3].

In table grape and wine vineyard research done in Chile, only five Botryosphaeriaceae species have been reported to affect these crops: *Diplodia seriata* De Not. (≡ *Botryosphaeria obtusa* (Schwein.) Shoemaker); *D. mutila* (Fr.) Mont. (= *Botryosphaeria stevensii* Shoemaker); *Neofusicoccum parvum* (Pennycook & Samuels) Crous, Slippers & A.J.L. Phillips (= *Botryosphaeria parva*) Pennycook & Samuels; *N. australe* (Slippers, Crous & M.J. Wingf.) Crous, Slippers & A.J.L. Phillips (= *Botryosphaeria australis* Slippers, Crous & M.J. Wingf.); and *Spencermartinsia viticola* (A.J.L. Phillips & J. Luque) A.J.L. Phillips, A. Alves & Crous (= *Botryosphaeria viticola* A.J.L. Phillips & J. Luque) [1, 3, 4, 8, 11, 17]. The names in parentheses are in accordance with the name and authors described by Phillips et al. [19].

In accordance with Díaz et al. [3] from a total of 694 analyzed samples obtained from different varieties grown for table grapes or wine industry, 56.3% of them were Botryosphaeriaceae species, and from 85% of these samples, the principal recovered species was *Phaeomoniella chlamydospora* (*Pa. chlamydospora*) (W. Gams, Crous, M.J. Wingf. & L. Mugnai) Crous & W. Gams, obtained from vascular streaks. But considering cankers with V-shaped form, 91% of the recovered species were Botryosphaeriaceae, and from these 68% of them was *Diplodia seriata*. From a soft-spongy canker (n = 314), the main species isolated in 96% of the samples was *Inocutis* sp. In pathogenicity tests carried out by Díaz et al. [3], *Inocutis* was able to cause damage but significantly less than that caused by Botryosphaeriaceae or *Phaeomoniella* species.

Considering Úrbez-Torres' [20] review of species affecting *Vitis vinifera*, he could recognize 21 different Botryosphaeriaceae species affecting this crop in California. In France the disease known as Esca complex is caused by *Pa. chlamydospora* and by *Phaeoacremonium* spp. plus the basidiomycete *Fomitiporia mediterranea* [2].

2.3.1. Reproductive structures

Taking into account *Botryosphaeria* dieback disease, all of the pathogens involved produce their asexual spores or conidia in pycnidia, and depending on the species, it is the shape and color of the conidia (**Figure 2A–C**). They are formed in conidiogenous cells, but some species have conidiophores [19]. In their sexual stage (if present), the ascospores are produced in a bitunicate asci, and this is inside an ascomata, most of them gregarious. In Chile, there is no report of sexual stage of Botryosphaeriaceae occurring in *Vitis*.

The *Phaeomoniella* genus produces yeast-like colonies that were olivaceous with sparse aerial mycelium and erect non-branched, smooth, and septate conidiophores [18]. The conidia are cellular, slightly pigmented, smooth, oblong to ellipsoid, and with small dimensions (3.0–4.2 μm large). Black globose pycnidia were produced on pine needles. White dense cirrus was produced on pine needles.

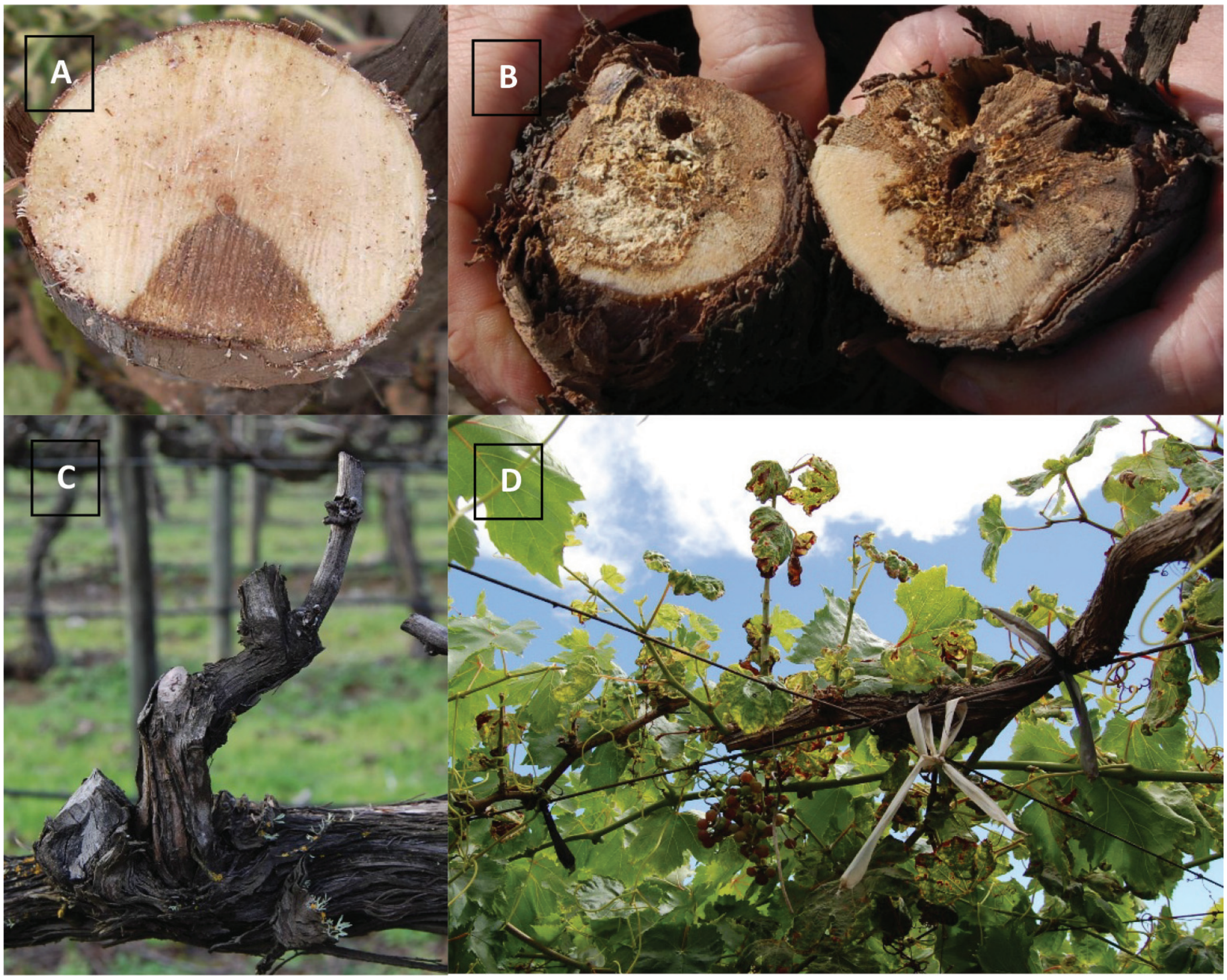

Figure 2. Grapevine trunk symptoms associated to bot canker and Esca-like disease symptoms in Chile. (A) V-shaped canker on the main branch of *Vitis*. (B) Main brunch associated with canker necrosis, yellow soft-spongy canker, and mottling in the trunk. (C) Dead spur attached to a diseased brunch with a typical grayish color. (D) Table grape vineyard with symptoms of distorted leaf and necrosis in the margin associated to chlorotic leaf roll.

2.4. Principal symptoms associated to GTDs

According to the research carried out by Díaz et al. [3, 4], Esca-like symptoms and their causal agents are associated to brown streaking in the xylem of the trunk and cordon of young grapevines (≤ 10 years old) (**Figure 2A–C**). Cordons and trunk from young grapevines showed this brown strike with the appearance of necrotic mottling in cross sections or dark brown necrotic streaking in longitudinal sections. They reproduce part of the symptoms associated to Esca in Europe [2] but not the characteristics foliar symptoms of this disease.

On the other hand, brown V-shaped cankers were consistently associated in table grape vineyards to four Botryosphaeriaceae species by Díaz et al. [3] and Morales et al. [4]. In a vast survey done along the main viticulture regions, Díaz et al. [3] found a total of 12 genera including *Diplodia*, *Dothiorella*, *Neofusicoccum*, *Spencermartinsia*, *Cryptovalsa*, *Eutypella*, *Cylindrocarpon*, *Phomopsis*, *Inocutis*, *Phaeoacremonium*, *Phaeomoniella*, and *Seimatosporium*. When the fungal isolates obtained from these genera were correlated to the principal symptoms observed in the field, these authors associated dark brown streaking symptoms to *Pa. chlamydospora* (85.2% of the samples), *D. mutila* (3.8% of samples), and *Inocutis* sp. (3.7% of samples). Symptoms of brown hard V-shaped canker (**Figure 3A**) were associated to *Diplodia seriata* (68.1% of samples), *Neofusicoccum parvum* (8.3% of samples), *Spencermartinsia viticola* (8.1% of samples), and *Pa. chlamydospora* (5.3%), and yellowish soft-spongy canker (**Figure 3B**) was associated to *Inocutis* sp. (96.2% of samples), *Diplodia seriata* (2.5% of samples), and *Pa. chlamydospora* (1.3% of samples). In vineyards, the presence of dead spurs that show a grayish color is frequently observed (**Figure 3C**).

The causal agent of leaf chlorotic roll symptom associated to decay plants of table grape and vineyard cultivars (**Figure 2D**) has not solved up to date. This symptom is frequently associated to cankers caused by Botryosphaeriaceae species, but up to date, no one has reproduced these symptoms in Chile. It consists in a leaf malformation and chlorosis of the leaf lamina, short internodes of the shoots or canes, death of spurs, and dieback commonly associated to cordon and/or trunk dieback [3, 4]. In Argentina, a similar situation was studied by Gatica et al. [21] with the disease called "hoja de malvón," where they found similar symptoms in association to mature vines with *Phellinus* sp. that prevailed over *Phaeoacremonium aleophilum*, *Pm. parasiticum*, and *Phaeomoniella chlamydospora*. In a previous study done by Gatica et al. [22], they made an in vitro pathogenicity test with *Phellinus* sp., *Botryodiplodia* sp., *Phaeoacremonium aleophilum*, and *Phaeomoniella chlamydospora*, where all these were pathogenic and cause decline and death of young plants, but the chlorotic leaf symptoms with reddish edges were produced by *Phellinus* sp. and by *P. chlamydospora*. Nevertheless, this situation needed to be studied reproducing the symptoms in mature plants.

2.5. Cultivar susceptibility

The first report of a *Botryosphaeria* species affecting the *Vitis* genus in Chile was done by Latorre et al. [1], where these authors report a severe attack of a canker disease affecting 2-year-old plants of cv. Flame Seedless grown in a Spanish trellis for fresh table grape production. Extensive cankers were found in the trunk, causing mild to moderate chlorosis and leaf necrosis and a poor seasonal growth. All that time, the authors classified the causal agent as

Figure 3. Pathogenicity tests done in shoots of 1-, 2-, and 5-year-old *Vitis* plants and the spores of different Botryosphaeriaceae. (A) Lessons and spores of *Diplodia seriata*. (B) Lessons and spores of *D. mutila*. (C) Lessons and spores of *Spencermartinsia* (= *Dothiorella*) *viticola*.

being *B. dothidea*, but with the increasing knowledge in the genera, the detected species correspond to *D. mutila*. Considering the most important table grape cultivars grown in Chile, in trials done by Morales et al. [4] with excised shoots of cvs. Thompson Seedless, Red Globe, and Flame Seedless, the most aggressive species was *D. mutila*. In a field trial done with 25-year-old plants of the cv. Flame Seedless, inoculating three different tissues, 1-, 2-, and

5-year-old shoots, the most aggressive species of the Botryosphaeriaceae tested was also *Diplodia mutila* (**Figure 3B**), and *Diplodia seriata* (**Figure 3C**) was less aggressive in all of the tested tissues considering the necrotic lesion. However, considering vascular streak length, *Diplodia seriata* was more aggressive than *D. mutila*. This is not in accordance with another pathogenicity tests reported by Úrbez-Torres and Gubler [23], where the most virulent species was *Lasiodiplodia theobromae*, followed by *Neofusicoccum luteum*, *N. parvum*, and *N. australe*, and they considered *Diplodia mutila* and *D. seriata* as weakly virulent. Maybe, the climatic conditions make the difference in the pathogenicity of the isolates or the age of the tissue done in the pathogenicity test. On the other hand, in pathogenicity field trials done in two regions, Sonoma and Colusa, employing adult plants of Chardonnay and Zinfandel, respectively, infecting nine different GTD causal agents, the most infectious were the four Botryosphaeriaceae species tested, while *Pa. chlamydospora* was in an intermediate position, and the less infective were *Togninia minima*, *Phaeoacremonium parasiticum*, *P. richardsiae*, and *Eutypa lata* [24].

In young tissue the most aggressive species are *Neofusicoccum* and *Lasiodiplodia*. Also, it is important to note that in Chile only five species of Botryosphaeriaceae have been detected affecting *Vitis vinifera* [1, 4, 8, 17]. Nevertheless, these species are capable to cause almost 50% of less yield in some regions [11]. Up to date, *Lasiodiplodia theobromae*, an important causal agent described in different countries, has not been detected or described affecting table grape vines or wine cultivars in Chile [3, 4, 10].

2.6. Botryosphaeriaceae main hosts

In order to understand how Botryosphaeriaceae species can arrive to *Vitis* plants, one way could be in the association of different species crops in a same orchard or in surrounding orchards. If we analyze the statement done by De Wet et al. [25], this authors classify different species of Botryosphaeriaceae associated to gymnosperms or angiosperms: *Diplodia* species occurred mainly in gymnosperms; *Dothiorella* species restricted to angiosperms; *Lasiodiplodia* occurred equally on gymnosperms or angiosperms, and *Fusicoccum* anamorphs occurred mostly on angiosperms with rare reports in gymnosperms. Nevertheless, in the case of *Vitis vinifera*, this species has been affected by all the different genera of the Botryosphaeriaceae family. In Chile, other important hosts for Botryosphaeriaceae are almond trees [26], loquat [27], blueberry [28], avocado trees [29], and araucaria trees [30], among others.

2.7. Plant physiology damage

In the trunk a depletion of starch reserves in woody tissues is not only associated with fungal colonization but also affects leaves (where no colonization is achieved) affecting photosynthetic rate. This can cause a decrease of plant development and vigor during the subsequent year. Also, lipid and amino acid are downregulated [2]. There is a response of the affected plants resulting in an accumulation of tyloses and gummosis, not only causing the blockage of the limiting fungal invasion but also causing disease. But, their progression in the wood is also inhibited by the formation of polyphenol-rich reaction zones and by the accumulation of pathogenesis-related (PR) proteins and the production of oxidative damage and reactive oxygen species (ROS) production.

It has been demonstrated that fresh pruning wounds are the main infection route for grape trunk disease pathogens, bot canker disease [3, 4], and Esca-like disease [3].

2.8. Endophytic species

Many authors highlight the fact that these fungi are common endophytes mainly in woody plants and that these fungi have the ability to cause serious diseases, particularly when plants are predisposing due to environmental stress [5, 31]. In general, these species have been recognized as natural opening colonizers. The first report of a forest pathogen isolated from stem and xylem healthy tissues was done by Petrini and Fisher [32]. Later, Johnson et al. [33] could recover *Fusicoccum*, *Neofusicoccum*, *Pseudofusicoccum*, and *Lasiodiplodia* from healthy mango plant parts.

Muruamendiaraz and Legorburu [34] could recover *D. seriata* from asymptomatic tissues of *Vitis* plants. This finding could agree with the endophytic character of this species. In the same work, *E. lata* was rarely found in asymptomatic vines. On the other hand, *Phaeomoniella chlamydospora* and *Phaeoacremonium* spp. were present in healthy rootstock propagation material as endophytes [35].

2.9. GTD spore's dispersion and optimal temperature

In Chile according to Valencia et al.'s [10] work, the dispersal of Botryosphaeriaceae conidia was studied in two vineyards in the Valparaíso Region of Chile, where semiarid Mediterranean conditions prevail. Due to the climate situation in this region characterized by the habitual rainy period mainly occurring in winter months, peaks of inoculum also occurred in the season associated to precipitation events equal or greater than 2 mm. The main species associated to the spore traps were *D. seriata*, *Spencermartinsia* (= *Dothiorella*) *viticola*, *Neofusicoccum*, and probably *N. australe*. In this work no association was observed between the volume of water used in the application of agrichemical products (≤1000 L ha^{-1}) and peaks of Botryosphaeriaceae.

Considering the dispersion of Botryosphaeriaceae species, there are mainly two works done in other countries: Úrbez-Torres et al.'s [36] work done in California, United States, and Amponsah et al.'s [37] work done in Canterbury, New Zealand. In California, Úrbez-Torres et al. [36] found a strong regression between the spore release and precipitation and that more spores were trapped during the winter period. Amponsah et al. [37] work on the dispersal of spores of Botryosphaeriaceae that are responsible for dieback in grapevines. They work in one vineyard, with the Vaseline-coated slide trap. During all the trapping period, 59.8% of the total species trapped were *Neofusicoccum* spp., and 40.2% of the rest were *Diplodia* spp. The spores were detected during the entire period but most abundant during December, January, and February associated to high temperatures and rainfall, where routine trimming of mature canes provides wounds for infection. Under these conditions, the main collected species were *Neofusicoccum luteum*, *N. australe*, *N. parvum*, and *Diplodia mutila*. These species infect mainly trunks, canes, green shoots, and plant debris. In this region, rainfall occurs not only in the winter period, mainly June, July, and August but also in the rest of the year.

Taking into account Díaz and Latorre's [18] work, they reported that they could not find *Pa. chlamydospora* in pruning debris samples (n = 168), sap samples (n = 82), soil samples (n = 100), or weed samples (n = 293) that were collected during 2010–2012. Maybe, infection of this species is mainly associated to young plants.

Studies carried out by Úrbez-Torres et al. [36], evaluating the conidial germination of different Botryosphaeriaceae at different temperatures found that conidia did not germinate at 5°C with the exception of *Botryosphaeria dothidea* and *Neofusicoccum parvum*. On the other hand, only *B. dothidea*, *Diplodia seriata*, and *Lasiodiplodia theobromae* germinate at 40°C. Optimum germination at 25°C was for *B. dothidea* and *Dothiorella iberica*; 25–30°C for *Spencermartinsia viticola*; 30°C for *D. corticola*, *D. mutila*, *D. seriata*, and *Neofusicoccum parvum*; and 40°C for pigmented *L. theobromae*. This is not strange considering the observations done by Yan et al. [14] that *L. theobromae* was found in *Vitis* under subtropical monsoon climatic conditions.

2.10. Disease management

Considering the recent statement done by Gramaje et al. [38] about the establishment, progress, severity, and spread of GTDs have been associated with (i) drought, (ii) limited availability of effective fungicides, (iii) pressure to increase yields, (iv) lack of pruning wound protection, and (iv) poor low-quality propagation material. All the efforts should first be done in order to avoid these types of situation.

2.10.1. Petri disease

In order to avoid early infection of grapevines by *Phaeomoniella* or *Phaeoacremonium* species, the main treatments considered are during the production of plants in the nursery. The program should start with an adequate clean mother plants and use of fungicides in the hydration process when the new plants are produced. Details of this process can be followed in Auger et al. [39]. This is complemented with the heat treatment [40].

2.10.2. Bot canker control

The disease's integrated management of this disease should start with an efficient cleaning process of all the diseased or dead shoots, arms, and trunks present in a vineyard. This material should be immediately taken out of the vineyard and efficiently destroyed in order to avoid the formation of reproductive structures such as pycnidia or ascomata of Botryosphaeriaceae and also to avoid the colonization of diseased tissues associated to Basidiomycetes like *Inocutis* spp.

A cultural management interesting to note is that the actual pruning cordon system produces many little injuries that are difficult to protect, more over if a mechanical pruning is used. Something that should be evaluated, especially in regions where GTDs are highly prevalent, the use of double Guyot pruning system should be considered.

Botryosphaeriaceae can cause cankers and dieback in grapevines, but different species affect grapevines in different grape-growing regions and countries. There are regions or countries where the rainfall period is concentrated mainly in winter time, while there are some regions or countries where rainfall conditions occur around the whole year. According to the climatic specific conditions of each area, the management will be oriented to prevent the disease mainly in the winter period or during the whole year. In Chile, according to the work published by Díaz et al. [3] and Valencia et al. [10], the main risk period for bot canker is in winter, where pruning management takes place, so the main effort should be oriented to protect pruning wounds. Nevertheless, the wine-producing area has expanded to the southern regions of Chile, where it usually rains during the summer months, so at these locations the problem probably expands to another species and attack green shoots that currently occurs in New Zealand [37] or in subtropical regions of China [14].

One of the first works done in evaluating different fungicides under in vitro conditions was the work done by Amponsah et al. [41]. They evaluate mycelial and conidial inhibition and also if they were able to protect pruning wounds against infection. In this work the tested species differed in their response to the different fungicides, and considering all the evaluated species, *N. luteum* was the least sensitive. The most effective fungicides were flusilazole, thiophanate-methyl, and mancozeb. According to the in vitro mycelial inhibition, flusilazole was the most effective (0.002 ppm) but was less effective considering conidial germination inhibition. For the in vivo trial, the best treatments were carbendazim, mancozeb, iprodione, and flusilazole. Under field conditions the best treatment was based on flusilazole active ingredient.

In the work done in Chile by Torres et al. [42], they evaluate demethylation-inhibiting (DMI) fungicides against *D. mutila*, *D. seriata*, *N. australe*, and *N. parvum*. The results demonstrate that the fungicides tebuconazole, myclobutanil, prochloraz, and prochloraz plus epoxiconazole were effective under in vitro conditions in inhibit mycelial and conidial germination for all the evaluated species.

Díaz and Latorre [18] evaluate the efficacy of benomyl, pyraclostrobin, tebuconazole, and thiophanate-methyl, applied as paste or liquid, in pre- or postinoculation. The paste application provides a better control than the sprayed form. **Table 1** shows the actual registered fungicides to be used for GTD control in Chile.

In California, USA, Rolshausen et al. [24] probed four fungicides (previously registered for use in vineyards) and their effect in the control of nine different GTD causal agents. The fungicides were Topsin M (thiophanate-methyl), Biopaste (boron), Cabrio EG (pyraclostrobin), and Garrison

Commercial product	Active ingredient	Manufacturer	Pathogens controlled
Podexal	Pyraclostrobin	BASF	Plateado, *Phaeomoniella*, and *Botryosphaeria obtusa*
Podastik Max	Tebuconazole	Arysta LifeScience	Silver leaf, *Nectria*, *Neofusicoccum* spp., and black dead arm of *Vitis*
Pasta Poda TPN-50	Chlorothalonil	Anasac	Plateado, *Phomopsis*, and European canker
Pasta Poda Full	Tebuconazole + Kresoxim-methyl	Anasac	*Neofusicoccum parvum* and *Phaeomoniella* spp.

Table 1. Commercial products actually commercialized in Chile for GTD control in vineyards.

(cyproconazole and iodocarb). All of these fungicides were effective in reducing the lessons caused by this GTD species, but the most effective according to the authors was Topsin M.

In Portugal, Rego et al. [43] in a 3-year field trial conducted in 15-year-old vineyard cv. Aragonez evaluate the efficacy of six different treatments against *Botryosphaeria* canker and *Phomopsis* dieback, applying three sprays each year, and the most efficient treatment was the application of Bion plus Score (difenoconazole).

3. Conclusion and future trends

In Chile the most important diseases affecting vineyards for table grapes and wine production are bot canker and Esca-like disease. In addition, for young plants the main problem is Petri disease. There are several studies done in determining causal agents, epidemiology, and control strategies, but there still remaining work to be done, for example, the fulfillment of Koch's postulates in order to determine the etiology of chlorotic leaf roll disease. Also, the convenience of the use of a double Guyot pruning system instead of a cordon pruning system, in order to avoid so many exposed fresh cuts during the pruning period, should be analyzed.

Something that is important to note is that some management change occurred worldwide that makes a point of inflection in the increase of GTDs. In Europe some change was that sodium arsenite was excluded in 2001 for Esca control, but in Chile sodium arsenite was not used. In the management of vineyards, a change in the gray mold control was done, mainly associated with the discontinuous use of benzimidazoles because of the increase of resistant *Botrytis cinerea* isolates. It is important to note that in many trials done in different countries, benzimidazoles were highly efficient in controlling most of the GTD agents.

These considerations are something that should be approached in an interdisciplinary work done with different researchers from different countries.

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