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Grapevine trunk disease in European and Mediterranean vineyards: occurrence, distribution and associated disease-affecting cultural factors

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Abstract. A survey was carried out in 22 European and some non-European Mediterranean countries in 2015 and 2016, to gain insights into the main fungal grapevine trunk diseases (GTDs) in Europe. Information was obtained from 105 viticulture regions, representing approx. four million ha of vineyards. Vintage and table wines are the main industry products, followed by nursery plants and table grapes. Diverse scion cultivars are grown, with 13 cultivars providing 50% of survey respondent production, and Riesling Italico, Chardonnay, Cabernet Sauvignon and Merlot predominating. The five most used rootstocks are SO4, 110R, K5BB, 41B and 1103P, together representing about 50% of survey respondent production. Despite the diversity of grapevine training, Guyot and cordon remain the most widespread methods, and grapevines are mainly hand-pruned. The use of pneumatic shears and mechanical pruning is becoming more common in some countries. The survey questionnaire proposed a simplified set of symptoms or diseases occurring in mature vineyards [apoplexy, esca complex leaf symptoms (including Grapevine Leaf Stripe Disease, GLSD), dead cordon, Eutypa related dieback, Botryosphaeria or unidentified agent dieback, Phomopsis cane and leaf spot]. Apoplexy and esca/GLSD, defining the esca complex, were the most frequent and increasing syndromes in almost all countries, except Israel and the United Kingdom, where these diseases are not present or not recorded in the survey. Dead cordon and Phomopsis cane and leaf spot were mentioned as occurring in a large number of regions but not frequently. Within individual countries, the profile of GTDs varied according to the region, and to pedo-climatic and production conditions. GTDs on young vines were uncommon, but remain a subject of concern in some of European countries with large nursery production. This overview on spread and relevance of GTDs in Europe and related aspects will be a useful starting point for policy makers and for collaborative research on factors contributing to the increasing disease incidence of GTDs.

Keywords. Esca complex, Botryosphaeriaceae, *Phomopsis*, *Eutypa*, dieback.

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INTRODUCTION

Europe has the greatest concentration of vineyards in the world. In 2016, Continental European vineyards covered approx. 4 million ha, which is more than the half the world vineyard area (Fontaine *et al.*, 2016). Between 2009 and 2014, the average annual production of wine was 167 million hectolitres (hL), representing 65% of world production and 70% of global wine exports (https://ec.europa.eu/agriculture/wine/statistics_en). The world wine market, considered by the sum of exports for all producing countries, is 104.3 million hL, valued at 28.3 billion euro. These production data reflect the economic importance of the wine industry in Europe. European vineyards also embody strong cultural heritage, demonstrated by the diversity of grapevine cultivars and viticultural practices (Black and Ulin, 2013).

Increasing reports of damage caused by grapevine trunk diseases (GTDs) in the last 20 years have raised concerns about these diseases affecting the culturally and economically important grapevine industries. These diseases, causing decline and plant death, are one of the greatest threats to the wine industry (Fontaine *et al.*, 2016). Increased disease incidence and severity are commonly attributed to different factors, including expanded planted area and increased productivity in the 1990s, and changes in cultural practices (Surico *et al.*, 2004). The ban of sodium arsenite in the beginning of this century for disease management in the European Union, has also been suggested as a factor, but it is well known that the upsurge of symptoms was recorded throughout Europe much earlier, at end of the 1980s (Graniti *et al.*, 2000; Surico *et al.*, 2004; Bertsch *et al.*, 2013).

GTDs cause reduced yields, they decrease the longevity of vineyards and reduce wine quality (Calzarano *et al.*, 2004, 2018; Lorrain *et al.*, 2012). In France, for example, about 13% of French vineyards are affected by wood diseases (Grosman and Doublet, 2012). In Sicily, Sidoti *et al.* (2000) reported a case where 15% of young vines in a vineyard showed signs of decline. Decline of young vines associated with black foot agents has been reported in different countries (Rego *et al.*, 2000; Halleen *et al.*, 2006, 2007; Cardoso *et al.*, 2013; Dos Santos *et al.*, 2014; Carlucci *et al.*, 2017; Úrbez-Torres *et al.*, 2014; Langenhoven *et al.*, 2018). Consequently, large disease management efforts are required to limit the spread and damage of these diseases, and to maintain the high levels of quality and productivity of European viticulture and wine production, as a major industry in Europe (Gramaje and Di Marco 2015; Gramaje *et al.*, 2018; Mondello *et al.*, 2018a).

Establishment of GTD control methods must consider the present socio-economic situation and new challenges. The increase in vineyard area in Europe is probably due to new European Union regulations making it easier to plant new vineyards (Reg. EU 1308/2013, AA.VV., 2013). Climatic changes also permit expanded geographical distribution of vineyards. The boundary of European viticulture has shifted northwards with new viticulture regions in the United Kingdom and Belgium (Mozell and Thach, 2014). In southern European countries, adapted cultural practices, such as irrigation, are developing to compensate water stress (Songy *et al.*, 2019).

Knowledge of the distribution of GTDs and the main factors associated with their development is essential to predict their spread, and to improve disease management. Data on some GTDs is sparse and incomplete through national or regional surveys, and a comprehensive inventory of GTD occurrence and frequency in Europe and Mediterranean regions is urgently required. Therefore, the European Cooperation in Science and Technology (COST) Action FA1303 "Sustainable Control of Grapevine Trunk Disease" (Fontaine and Armengol, 2014) created a network of multidisciplinary scientific institutes and companies to improve understanding of GTDs. A specific objective of this COST Action was to develop an overview of the occurrence of the different GTDs in each of the main viticulture regions of the European Union and neighbouring Mediterranean countries.

GTDs include several diseases, all defined as syndromes associated with or caused by pathogenic fungi growing in woody tissues of the vine.

Esca disease, previously called "apoplexy" or "folletage", was the first GTD reported in many European and Mediterranean countries (Viala, 1926; Mugnai *et al.*, 1999; Larignon, 2016). Esca was the original name given to a grapevine wood symptom, white rot, associated with symptoms in the crowns, causing sudden vine death (apoplexy). Typical leaf stripe symptoms were later associated with the same wood degradation. Consequently, the esca disease, was extended to the whole set of these symptoms, and from them, was described as chronic or mild forms and severe or acute forms, also named apoplectic forms or apoplexy. The leaf stripe symptom was characterized by multiple banding discoloration surrounding dry, brittle, light brown or red-brown necrotic tissues bordered by narrow red or yellow borders. These external foliar symptom were proposed by Surico (2009) to be treated as the external expression of a probably tracheomycotic disease, i.e. a separate disease from internal stem white rot ("esca", as originally proposed by French researchers). Surico (2009) defined the concept of the "esca complex", comprising different

diseases according to the stage of vine life and the types of symptoms. Among them, the "Grapevine Leaf Stripe Disease", corresponding to the external specific symptom "tiger stripe" not associated to the internal white rot (Edwards *et al.*, 2001), could be seen more clearly in young diseased vines than in older vines. When GLSD is associated with white rot in the same plant, the name of esca or esca proper is used. During the present study, external visible symptoms on vines with characteristic leaf stripe patterns and sudden wilting were considered under the names, respectively, esca/GLSD and apoplexy. Apoplexy corresponds to a sudden wilting of entire vines or of one vine arm, including drying, shrivelling and leaf fall, and this can be caused by many factors, included root rots, not all of which have been described. Apoplexy and leaf stripe symptoms can both occur from late spring to the end of the growing season.

The causes of the external symptoms in the esca complex remain to be fully clarified, and Koch's postulates for these symptoms have not been completed. Two Ascomycetes, *Phaeomoniella chlamydospora* and *Phaeoacremonium minimum* (syn. *P. aleophilum*), are the most common vascular pathogens in GLSD and related diseases (brown-wood streaking, Petri disease). Present in vines alone or in combination, these fungi produce localized necrosis in wood xylem, such as black spots, eventually surrounded by pink to brown wood discoloration, and produce a range of phytotoxins that can be translocated to the leaves (Andolfi *et al.*, 2011). On older vines in European and Mediterranean regions, beside the Ascomycete fungi, it is common to find lignin-degrading Basidiomycete fungi (usually *Fomitiporia mediterranea*, and occasionally other Basidiomycetes) responsible for white rot. Other species of Ascomycetes from the Botryosphaeriaceae or Diatrypaceae (i.e *Eutypa lata*) can also be isolated from wood necroses from vines exhibiting typical leaf stripe foliar symptoms (Bruez *et al.*, 2014) without direct relationships between their presence and the foliar symptoms.

Eutypa dieback, also called "eutypiosis" or "dying-arm disease" was first described on apricot, and then on grapevine in the 1970s (Carter, 1991). Eutypa dieback has been reported in numerous countries from European and Mediterranean vineyards (Péros and Berger, 2003, Berraf-Tebbal *et al.*, 2011). In spring, new vine shoots are stunted with short internodes, the leaves are small chlorotic with marginal necroses and sometimes have dead interveinal tissues with the development of small fruit clusters (Rolshausen *et al.*, 2014). Foliar symptoms are associated with sectorial wood necroses or wedge-shaped cankers in perennial vine organs. The causal agent of Eutypa dieback is mainly the Ascomycete fungus *Eutypa lata*. Since the early 2000s, many other species in the Diatrypaceae have been isolated from necroses associated with Eutypa dieback symptoms (Trouillas *et al.*, 2010; Luque *et al.*, 2012, Pitt *et al.*, 2013, Rolshausen *et al.*, 2014), but *E. lata* remains the most common and virulent fungus causing the typical necrosis and foliar symptoms (Trouillas and Gubler, 2010). This fungus enters vines through pruning wounds, and colonizes the xylem tissues. There it produces phytotoxic compounds that may be transported by transpiration stream towards the aerial vine parts, producing stunting of new shoots (Molyneux *et al.*, 2002).

Botryosphaeria dieback of grapevine includes different symptoms and involves various Botryosphaeriaceae species (Úrbez-Torrez, 2011). The main symptoms include wedge-shaped cankers, dark streaking of grapevine wood, elongated black lesions on the shoots (cane cankers), progressive bud-break failure and plant dieback, and fruit rot in some hosts. At least 21 Botryosphaeriaceae species have been associated with Botryosphaeria dieback of grapevines (Úrbez-Torres, 2011), including *Diplodia seriata, Neofusicoccum parvum* and *Botryosphaeria dothidea* which are the most frequently isolated fungi (Úrbez-Torres, 2011). These pathogens may be present in asymptomatic tissues as latent infections (Gonzalez and Tello, 2011; Bruez *et al.*, 2014). The transition from the endophytic latent infection to active pathogen colonization could be related to factors such as host water stress (Luque *et al.*, 2010). Since the early 2000s, research on Botryosphaeriaceae on grapevine increasingly showed that species in this family play important roles in decline of vines (Larignon *et al.*, 2015). An overview of this decline in Europe is needed to identify the risk factors associated with Botryosphaeriaceae as wood pathogens.

The final GTD included in the present study was Phomopsis cane and leaf spot caused by *Diaporthe ampelina*, often associated with other less virulent species, which can also induce grapevine canker. Vines with Phomopsis cane and leaf spot have characteristic black necrotic irregular-shaped lesions on the cane internodes, occurring in spring and winter, and bleaching and cane cankers and sometimes branch dieback (Ravaz and Verge, 1925; Bugaret, 1984). Rachis necrosis and brown, shrivelled berries on fruit bunches occur near to harvest. The disease, still frequently named ''excoriose'' in many European viticulture regions, is caused by *Diaporthe* spp., particularly *Diaporthe ampelina* (previously called *Phomopsis viticola*) (van Niekerk *et al.*, 2005; Guarnaccia *et al.,* 2018). In internal wood tissue, *Diaporthe* spp. may cause perennial cankers and vascular discoloration similar to that observed in Botryospha-

eria and Eutypa diebacks (Úrbez-Torres *et al.*, 2013; Baránek *et al.*, 2018).

On young grapevines, Petri disease and black-foot are the most damaging wood diseases (Rego *et al.*, 2000; Agustí-Brisach and Armengol, 2013; Carlucci *et al.*, 2017). The foliar symptoms of both diseases are similar, including typical decline symptoms such as leaf chlorosis with necrotic margins, stunting, budbreak delay, decreased growth and vigour, and wilting of leaves or shoots. In longitudinal stem section, vines affected by Petri disease have brown or black streaking in the xylem vessels, often with necroses at the graft unions. Various fungi have been isolated from the altered wood tissues, including *P. chlamydospora* and, less frequently, various species of *Phaeoacremonium* (Mugnai *et al.*, 1999; Gubler *et al.*, 2015) and *Cadophora* (Gramaje *et al.*, 2010).

Black-foot also manifests as necrotic root lesions, rootstock wood necroses, and gradual decline leading to vine death. The fungi causing black-foot are mainly *Cylindrocarpon*-like species belonging to the genera *Ilyonectria, Neonectria, Campylocarpon* in the Nectriaceae (Agusti-Brisach and Armengol, 2013). Decline of young vines may also be caused by other fungi or nematodes, alone or in pathogen complexes, including Botryosphaeriaceae, *Phomopsis*, *Pythium, Phytophthora*, which have also been isolated from declining vines in young vineyards (Halleen *et al.*, 2007; Agustí-Brisach and Armengol, 2013).

The above descriptions of the main GTDs shows the diversity of syndromes and associated pathogenic agents that are involved. For each GTD, incidence and symptom profiles may greatly vary according to regional or local factors such as climate, soil and cultural practices.

The species composition of grapevine trunk pathogen communities may be affected by environmental factors. Climate plays an important role in pathogen distribution (Merrin *et al.*, 1995; van Nierkerk *et al.*, 2011). For instance, geographical distribution of Botryosphaeriaceae species is strongly linked to climatic conditions. *Lasiodiplodia theobromae* is tolerant to high temperatures, while some species, such as *Diplodia seriata*, are very adaptable to different temperatures (Úrbez-Torres, 2011; Songy *et al.*, 2019). In Europe and Mediterranean regions, various pedo-climatic conditions, "terroirs", are associated with a large number of local varieties of *Vitis vinifera* subsp. *vinifera*, cultivated for mainly for wine, but also for fresh fruit and juice production. Vine training and cultural practices are also diverse, and these result from long grapevine-growing traditions.

Considering the wide diversity of viticulturists, the present study addressed the following questions on GTDs: (1) What is the distribution of each GTD disease on young or mature vines in European and Mediterranean countries? (2) Can information be obtained on the most proliferating or economically important GTDs? and (3) Can GTD occurrence and frequency be explained by regional or local factors? To provide answers to these questions, a large survey was carried out using a qualitative questionnaire. The survey included sets of questions to gather information on the occurrence of GTDs, cultural practices and terroir characteristics.

MATERIALS AND METHODS

Survey questionnaire

The questionnaire was designed to gather information about the occurrence and frequency of the main symptoms associated to GTDs on mature and young vines, and data on grapevine production and agronomic practices that could be related to disease occurrence, from the main grape production regions of European and Mediterranean countries. The questionnaire comprised two parts to obtain information on: 1) GTDs occurring in mature and young vineyards at regional scale; 2) vineyard production and agronomic practices at regional scale; 3) regional climate type in the seasons influencing disease and pathogen cycles, i.e. spring and summer; and 4) reference person(s) who collected the data in each surveyed country/ region.

The questionnaire included open and closed questions. For occurrence of GTDs on adult vines, six types of syndromes were included: (1) apoplexy, (2) esca/ GLSD, ''dead cordon'', (i.e. the result of dieback caused by wood canker agents observed in vineyard. Dead cordon is an non-specific symptom that may be related to (3) Eutypa dieback; (4) Botryosphaeria dieback; and (5), when the causal agent of cankers and dieback was not identified "dead cordon agent not identified" was reported. A sixth possible syndrome was also listed as Phomopsis cane and leaf spot.

On young vines, three types of declining symptoms were proposed: (1) Petri disease, (2) black foot and (3) decline caused by undetected agent, physiological factor or other agents. For each described syndrome, a scale that rated the frequency of the syndrome was defined as: 0, not present or not recorded (with 'not recorded' indicated with a code); 1, present but not frequent; or 2, frequent. Three other closed questions on the perception of importance were included: Is the syndrome perceived to increase in the region? Is the syndrome perceived to be worrying in the region? What is the susceptibility of the main cultivars? The questionnaire also included knowledge about the amount of GTD investi-

gation in the country: Did laboratory or extension services carry out GTD diagnoses and detection? If yes, is this at regional or national level? The second part of the survey included questions on the range of production types within region or country, including: vintage wine, table wine, table grapes, grapevine nursery. Information was also requested on the main scion and rootstock cultivars, and on the relevant cultural practices linked to GTDs, including details of the common vine training, trellising systems, and pruning methods applied at regional scale.

Questionnaire dissemination and analysis

The questionnaire, formalized as tables on Excel sheets, was distributed in 2015, by email to each National corresponding researcher, as members of the COST Action FA1303 group. The COST Action included all the European countries with relevant grapevine cultivation plus some representative Mediterranean countries. In each country a reference person selected representative grape cultivation areas through collaboration with the most competent respondents in the area, and co-ordinated the data gathering from each respondent. These groups included researchers, extension staff and field technicians. The returned questionnaires with missing data or non-adapted responses were sent again. Focus respondents were surveyed in order to obtain feedback on the response accuracy and to validate some questionnaire responses. All participant responses were gathered in a database filing system. The descriptive analysis of the data was set up using simple calculations of proportions, rates and variable distributions. The analysis of contextual data developed a general view of the characteristics of the surveyed viticulture regions.

RESULTS

General information on grape production and grapevine growing methods

The questionnaire responses were received from 22 countries, including 19 European countries, one Maghreb country (Algeria) and two Middle East countries (Lebanon and Israel) (Table 1). Data from 105 viticulture regions, corresponding to the main regions of the surveyed countries, were recorded. The number of regions by country varied from one (England) to 12 (Italy). The vineyard areas in the surveyed countries totaled about 4 million ha, and varied greatly according to country, from 1,000 ha (England) to approx. one million ha (Spain). Among the surveyed countries, Spain, Italy, France and Turkey represented the main producers, with approx. 75% of the total vineyard area. Among the different types of production, Quality Wine ["Quality Wines Produced in Specified Regions" (QWPSR)] and Table Wine (TW) represented, respectively, the first and second ranges in almost all the surveyed countries, for 87 and 79% of reports (Table 2). Only in Algeria and Turkey Table Grape (TG) was reported as the main production. Table grape production was the second or third type of production in eight countries when rated for relevance, totaling 33 regions (Tables 1 and 2). Dried Raisin (DR) production was not commonly mentioned within the surveyed countries, but represents a major grape production component in Algeria and Turkey. Significant nursery plant production was reported in 16 countries, and generally this was rated as the third most important sector (77% of reports). Nursery production was reported as the 1st or 2nd type of production in importance only in six regions of five countries: Bulgaria, France, Hungary, Italy and Romania.

Eighty-six different scion cultivars were reported in the questionnaire responses. Eighteen were reported from at least four regions in different countries, including 66% of the reports (Figure 1). However, Chardonnay, Cabernet Sauvignon and Merlot were the most frequently grown varieties in the surveyed regions. Table 3 lists the other varieties recorded, as major ones in particular regions. The diversity of rootstock varieties reported in the regions surveyed was much less than that for scion variety. Twenty-four rootstock varieties were mentioned by respondents as the main rootstock planted varieties, but only eight rootstock varieties were mentioned in 89% of the reports (Figure 2). These were dominated by S04, 110R and K5BB. Three main training methods were reported, as Guyot (42% of reports), Cordon (33%) and Gobelet (14%). Three other training methods reported were: Pergola, especially in Italy, Lebanon and Algeria; Chablis, in France; and Sylvoz, in Hungary, Italy and Germany. The respondents generally noted that grapevines were mostly hand-pruned, but that pneumatic pruning shears for hand pruning and mechanical pruning were becoming increasingly used in some countries.

Distribution and frequency of GTDs

In 18 of 22 countries, GTD diagnoses and detection were carried out by laboratory or extension services at national (in ten countries) or regional (eight countries) levels (Table 1).

Table 1. General characteristics of grapevine production in surveyed European and Mediterranean countries.

Country	Country code	No. of surveyed vine cultivation regions	Vineyards area (× 1,000 ha)[b]	Type of production (in order of importance)[a]	Wine production (× 1,000 hL)[b]	GTD investigation diagnosis and detection (yes or no), regional or national level
European Union Mediterranean Countries						
Austria	AT	4	45	QW/TW/N	1,999	No
Bulgaria	BG	5	63	QW-TW/TG/N	745	No
Croatia	HR	2	29	QW/TW/N	842	Yes, national
Czech Republic	CZ	3	17	QW/TW/N	536	Yes, regional
France	F	7	789	QW/TW/N	46,534	Yes, regional
Germany	DE	4	102	QW/TW/N	9,202	Yes, regional
Greece	EL	3	110	QW/TG/N	2,800	Yes, regional
Hungary	HU	6	62	QW/TW/N	2,427	Yes, regional
Italy	IT	12	690	QW/TW/TG/N	44,229	Yes, national
Montenegro	ME	2	9	QW/TW/N	161	Yes,national
Portugal	PT	5	224	QW/TW/N	6,206	Yes, regional
Romania	Ro	5	192	QW/TW/N/TG	3,750	Yes, national
Serbia	RS	4	54	TW/TG	2,332	No
Slovakia	SK	6	16	QW/TW/TG	258	Yes, national
Slovenia	SI	3	16	QW/TW/N	494	Yes, national
Spain	SP	7	975	QW/TW/N	39,494	Yes, national
Switzerland	S	6	15	QW/TW/N	934	Yes, national
United Kingdom	UK	1	2	QW/TW	47	Yes, national
Non-European Union Mediterranean Countries						
Algeria	AL	71	74	TG/R/QW/TW	507	No
Israel	Il	8	8	QW/TW/TG/N	246	Yes, national
Lebanon	Le	3	14	QW/TG/TW	80	Yes, national
Turkey	T	6	502	TG/R/QW/TW	615	Yes, regional
Total	22	105	4066	-	1644,483	-

[a] QW (Quality wine); TW (Table wine); TG (Table grape), R (raisin), N (Nursery)
[b] 2014 data in OIV, 2014.

Table 2. Estimates of the relevance of grapevine production types, based on frequency of reports from the all viticultural regions surveyed.

Production type range	Quality wine (QW)		Table wine (TW)		Table grape (TG)		Nursery plants (N)		Raisins (R)		Total for production range
	No. Reports[a]	%[b]	No. Reports	%	No. Reports	%	No. Reports	%	No. Reports	%	
1st Production type	80	87.1	14	17.3	6	15.4	3	5.1	3	75	106
2nd Production type	11	11.8	64	79	19	48.7	3	7.7	1	25	98
3rd or 4th Production type	1	1.1	3	3.7	14	35.9	35	89.4	0	0	53
Total for type of production	93		81		39		41		4		258

[a] Number of reports over 105 regions surveyed.
[b] Percentage over total No. of reports for each production type.

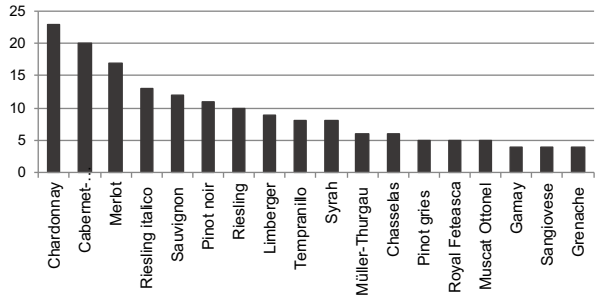

Figure 1. Numbers of reports of the main scion cultivars recorded in 105 surveyed regions.

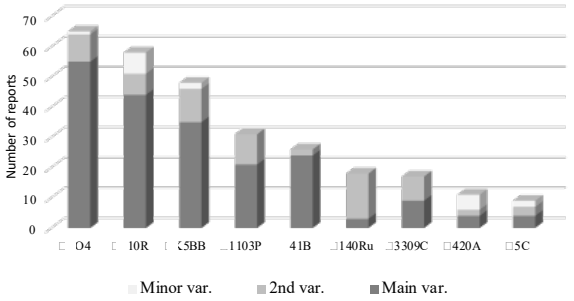

Figure 2. Number of reports of occurrence of the main rootstock varieties and their range in the regions where the survey was carried out.

Table 3. Grapevine scion varieties infrequently identified in survey questionnaire responses, with one to three mentions.

Scion variety	Report No.	Scion variety	Report No.
Furmint	3	Loureiro	1
Gamaret	3	Malvasia istriana	1
Grüne Veltliner	3	Mavrodaphni	1
Macabeu	3	Melon	1
Touriga Nacional	3	Meunier	1
Zweigelt	3	Montepulciano	1
Bobal	2	Montepulciano	1
Colombard	2	Montonico	1
Gewurztraminer	2	Muscat d'Alexandrie	1
Harslevelu	2	Negoska	1
Pinot blanc	2	Nuragus	1
Primitivo	2	Parellada	1
Yellow muscat	2	Passerina,	1
Agiorgitiko	1	Pecorino,	1
Airén	1	Plavac mali	1
Alfrocheiro preto	1	Portugais bleu	1
Aligoté	1	Prokupac	1
Alvarinho	1	Rebula	1
Arvine	1	Refosco	1
Baga	1	Rkatziteli	1
Bombino bianco	1	Saint-Laurent	1
Cabernet franc	1	Tamnjanika	1
Calabrese	1	Tinta Amarela	1
Carignan	1	Touriga Franca	1
Castelão	1	Trebbiano	1
Catarratto	1	Trebbiano romagnolo	1
Chenin	1	Treixadura	1
Dimiat	1	Ugni blanc	1
Fernão Pires	1	Vermentino	1
Garganega	1	Vernaccia	1
Glera	1	Vranac crni	1
Glera	1	Xarello	1
Grillo	1	Xinomavro	1
Jaen N	1	Zizak	1

GTDs on mature vines

Data on GTD occurrence in all the surveyed regions were combined. This revealed different frequency profiles for the different GTD syndromes reported in adult vines (Figure 3). The records of apoplexy and esca/GLSD showed similar profiles with a greater proportion of records for ''frequent'' occurrence , reaching 59% for apoplexy and 55.2% for esca/GLSD. These two syndromes were the most widespread and the only diseases reported in all the surveyed countries. They were present in most of the regions (apoplexy in 91% and esca/GLSD 86% over the 105 regions) (Table 4). In contrast, the frequency profiles of the three types of ''dead cordon", caused by canker agents, Eutypa dieback, Botryosphaeria dieback, or "agent not identified", showed less occurrence, and were reported as frequent, respectively, in only 20, 30.5 and 27.6% of the regions. These diseases were not observed (or not reported), respectively, from 22, 27.6 and 22% of the regions. Phomopsis cane and leaf spot was present in 60.9% of the regions, but was usually not frequent.

The syndromes surveyed had different occurrences in different countries, although all syndromes highlighted in the questionnaire were widespread in Continental European and Mediterranean countries (Table 4). There was a similar frequency profile for both syndromes, apoplexy and esca/GLSD within a country, except in Hungary, where esca/GLSD is more frequent than apoplexy and in Romania and Serbia, where apoplexy is more frequent than esca/GLSD. Dead cordon, caused by Eutypa dieback, was always reported less frequently than apoplexy and esca/GLSD. It was actually reported as frequent only in 7 countries, even if it was present in all countries except Israel. Dead cordon caused by other pathogens (Botryosphaeriaceae or not identified agent) were frequently recorded in almost all countries, except from Austria, probably because of lack of observation.

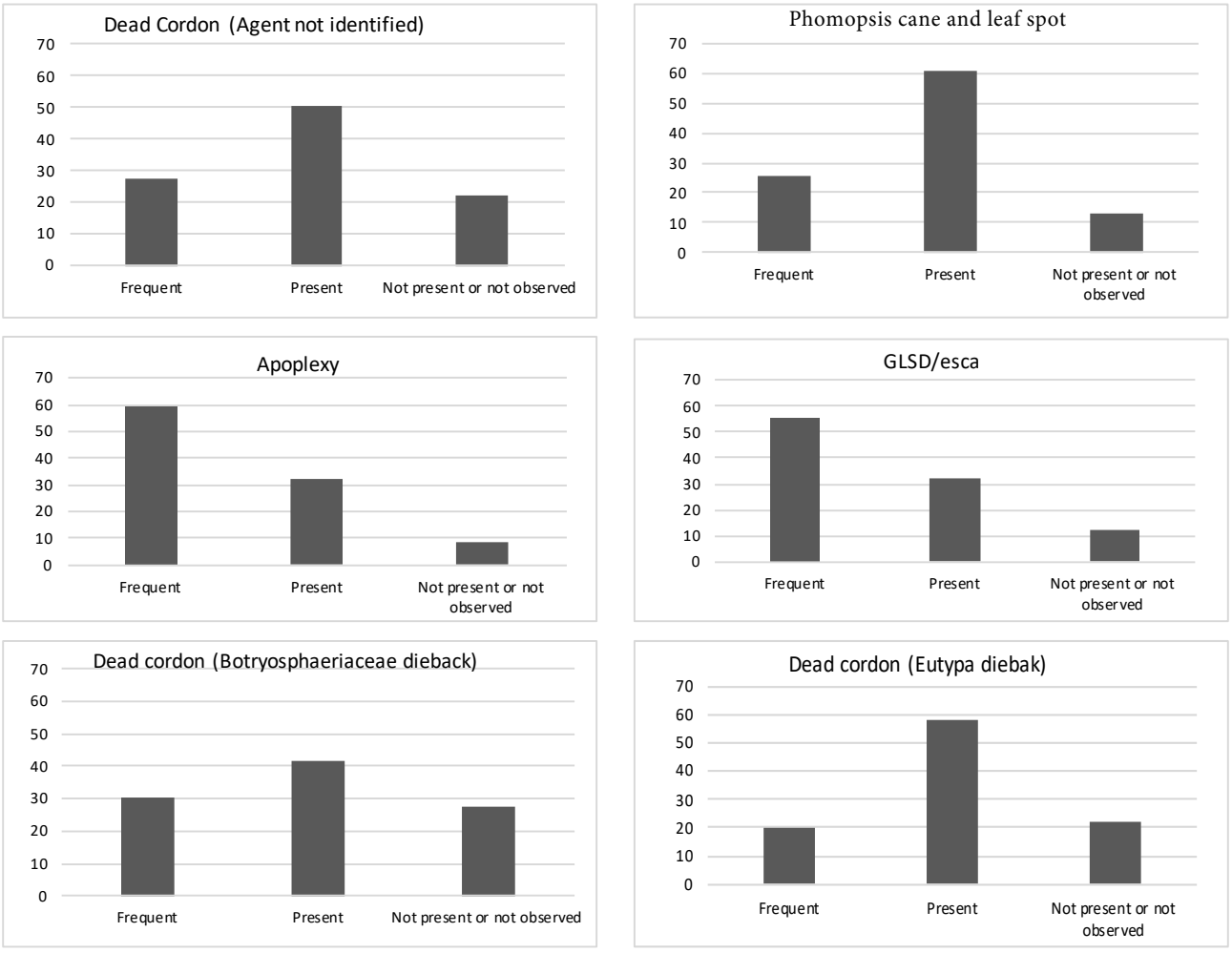

Figure 3. Reports (%) for all surveyed countries of the different GTDs on adult vines.

The level of occurrence of both of these syndromes varied according to the country and the region.

Cabernet Sauvignon was the most frequently recorded of the 18 main reported varieties (Figure 4) as the most susceptible variety to esca complex. Fourteen other varieties were cited at least once. Fewer reports concerned the susceptibility to the other GTDs. Some varieties like Ugni Blanc, Cabernet, Cabernet Sauvignon and Chasselas were reported as susceptible to Eutypa dieback in France and Germany. In Portugal, the varieties Touriga National, Loureiro, Alvarinho, Aragonez, Touringa Franca and Syrah were reported as susceptible to both esca complex disease and Botryosphaeria dieback. In Turkey, the variety Sultana Seedless was also noted as susceptible to these two disease syndromes.

GTDs on young vines

The occurrence of GTDs on young vines (Petri disease, black foot and general decline) is shown in Figure 5. The three forms on young vines were reported less frequently than the syndromes on adult vines. Decline diseases on young vines caused by Petri disease or unknown agent were mainly reported as "present but not frequent" (Petri disease, 44% and unknown agent, 61%). Petri disease was mentioned as frequent in nine regions from five countries (Hungary, Spain, Slovenia, Italy and Slovakia) (Table 5), and present in 14 countries, of the 22 surveyed countries. In seven other countries (Czech Republic, Romania, Austria, France, Lebanon, Algeria, Serbia), this decline was not observed (or not recorded). Black foot was mentioned as "frequent" only in two countries: Hungary and Spain, while it was noted "present", but not frequent, in nine other countries.

Table 4. Reported level of occurrence of Grapevine Trunk Diseases on adult vines in each surveyed European or Mediterranean country.

Country	No. of regions surveyed	Apoplexy/esca acute form						Esca/GLSD[a]						Dead cordon (Eutypa dieback)					
		Frequent		Present		Not present or not observed		Frequent		Present		Not present or not observed		Frequent		Present		Not present or not observed	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Algeria	6	3	50	0	0	3[b]	50	3	50	0	0	3[b]	50	3	50	0	0	3[b]	50
Austria	4	4	100	0	0	0	0	4	100	0	0	0	0	4	100	0	0	0	0
Bulgaria	5	0	0	5	100	0	0	1	20	4	80	0	0	0	0	5	100	0	0
Croatia	2	2	100	0	0	0	0	2	100	0	0	0	0	2	100	0	0	0	0
Czech Republic	3	1	33.3	2	66.7	0	0	0	0	3	100	0	0	0	0	3	100	0	0
England	1	0	0	1	100	0	0	0	0	1	100	0	0	0	0	1	100	0	0
France	7	6	85.71	1	14.29	0	0	7	100	0	0	0	0	1	14.29	6	85.71	0	0
Germany	4	3	75	0	0	1[b]	25	3	75	0	0	1[b]	25	0	0	3	75	1[b]	25
Greece	3	0	0	3	100	0	0	0	0	3	100	0	0	3	100	0	0	0	0
Hungary	6	2	33.3	4	66.7	0	0	5	83.3	1	16.7	0	0	0	0	5	83.3	1	16.7
Israel	5	0	0	5	100	0	0	0	0	5	100	0	0	0	0	0	0	5	100
Italy	12	10	83.3	2	16.7	0	0	11	91.7	1	8.3	0	0	0	0	11	91.7	1	8.3
Lebanon	3	3	100	0	0	0	0	3	100	0	0	0	0	0	0	3	100	0	0
Montenegro	2	1	50	1	50	0	0	2	100	0	0	0	0	0	0	1	50	1	50
Portugal	5	5	100	0	0	0	0	3	60	2	40	0	0	0	0	1	20	4	80
Romania	5	5	100	0	0	0	0	0	0	5	100	0	0	3	60	0	0	2	40
Serbia	5	4	80	1	20	0	0	0	0	1	20	4	80	5	100	0	0	0	0
Slovakia	6	0	0	6	100	0	0	0	0	6	100	0	0	0	0	6	100	0	0
Slovenia	3	3	100	0	0	0	0	3	100	0	0	0	0	0	0	3	100	0	0
Spain	6	6	100	0	0	0	0	6	100	0	0	0	0	0	0	6	100	0	0
Switzerland	6	4	66.7	2	33.3	0	0	4	66.7	2	33.3	0	0	0	0	6	100	0	0
Turkey	6	0	0	1	16.7	5[b]	83.3	1	16.7	0	0	5[b]	83.3	0	0	1	16.7	5[b]	83.3
Total	105	62		34		9		58		34		13		21		61		23	
%	100	59		32.4		8.6		55.2		32.4		12.4		20		58.1		21.9	

(Continued)

Table 4. (Continued).

Country	No. of regions surveyed	Dead cordon (Botryosphaeria dieback)						Dead cordon (agent not identified)						Phomopsis cane and leaf spot					
		Frequent		Present		Not present or not observed		Frequent		Present		Not present or not observed		Frequent		Present		Not present or not observed	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Algeria	6	1	16.7	0	0	5[b]	83.3	3	50	0	0	3[c]	50	0	0	3	50	3[b]	50
Austria	4	0	0	0	0	4	100	0	0	0	0	4	100	0	0	4	100	0	0
Bulgaria	5	1	20	1	20	3	60	2	40	3	60	0	0	0	0	5	100	0	0
Croatia	2	2	100	0	0	0	0	0	0	2	100	0	0	2	100	0	0	0	0
Czech Republic	3	0	0	3	100	0	0	3	100	0	0	0	0	0	0	3	100	0	0
England	1	0	0	1	100	0	0	0	0	1	100	0	0	1	100	0	0	0	0
France	7	1	14.3	1	14.3	5	71.4	2	28.6	4	57.1	1	14.3	0	0	7	100	0	0
Germany	4	0	0	3	75	1[b]	25	0	0	3	75	1[b]	25	0	0	3	75	1[b]	25
Greece	3	0	0	3	100	0	0	0	0	3	100	0	0	3	100	0	0	0	0
Hungary	6	3	50	2	33.3	1	16.7	3	50	3	50	0	0	0	0	4	66.7	2	33.3
Israel	5	0	0	5	100	0	0	0	0	5	100	0	0	0	0	5	100	0	0
Italy	12	6	50	3	25	3	25	5	41.7	5	41.7	2	16.	3	25	9	75	0	0
Lebanon	3	3	100	0	0	0	0	3	100	0	0	0	0	0	0	2	66.7	1	33.3
Montenegro	2	1	50	0	0	1	50	1	50	1	50	0	0	1	50	1	50	0	0
Portugal	5	3	60	2	40	0	0	0	0	1	20	4	80	1	20	4	80	0	0
Romania	5	0	0	4	80	1	20	3	60	0	0	2	40	5	100	0	0	0	0
Serbia	5	5	100	0	0	0	0	1	20	4	80	0	0	4	80	1	20	0	0
Slovakia	6	0	0	6	100	0	0	0	0	6	100	0	0	0	0	6	100	0	0
Slovenia	3	0	0	3	100	0	0	0	0	3	100	0	0	0	0	3	100	0	0
Spain	6	5	83.3	1	16.7	0	0	3	50	2	33.3	1	16.7	1	16.7	3	50	2	33.3
Switzerland	6	0	0	6	100	0	0	0	0	6	100	0	0	5	83.3	1	16.7	0	0
Turkey	6	1	16.7	0	0	5[b]	83.3	0	0	1	16.	5[b]	83.3	1	16.7	0	0	5[b]	83.3
Total	105	32		44		29		29		53		23		27		64		14	
%	100	30.5		41.9		27.6		27.6		50.5		21.9		25.7		60.9		13.3	

[a] Grapevine Leaf Stripe Disease.
[b] Not surveyed region.

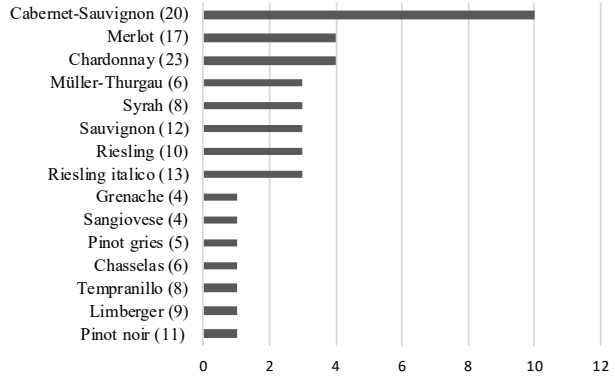

Figure 4 Numbers of survey response reports on cultivar susceptibility to esca complex (Total report number in brackets).

Focus on five sample countries

In order to give more details in specific situations, GTD distribution was analysed within five countries: Hungary, Bulgaria, Portugal, France and Italy.

Hungary

The profile of GTDs on adult vines varied according to the wine region (Table 6A). Apoplexy was recorded as "frequent and increasing" in two regions (Pécsi and Villány), characterized by dry spring and dry and hot summer weather, which may correspond to a sub-Mediterranean climate. The GTD profile in the Balat wine region differed from the other regions, with few recorded diseases or low levels of occurrence of GTD symptoms, such as apoplexy, esca/GLSD and dead cordon, in comparison with the five other regions. The Balaton area is characterised by the proximity of Lake Balaton and volcanic soils that create a peculiar environment. In the Egri region, the respondent reported frequent and increasing esca/GLSD and dead cordon caused by Botryosphaeria dieback. Dead cordon related to Eutypa dieback and Phomopsis cane and leaf spot were mentioned less frequently. They were recorded as "occasionally present" in three regions and "not recorded" in five regions.

Bulgaria

Contrasting GTDs profiles on adult vines were observed according to region (Table 6B). Esca/GLSD was recorded as "frequent" in the only region of the "sub-Balkan" area, the Rose Valley region. All the other disease syndromes on mature vines were recorded as

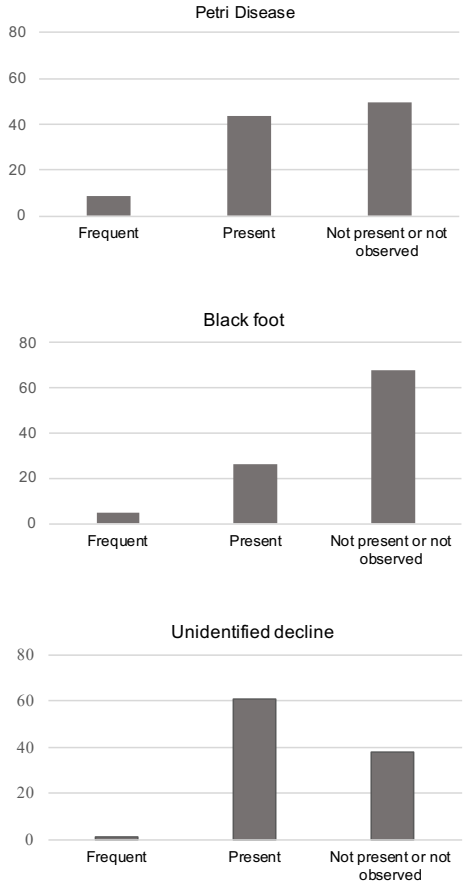

Figure 5. Proportions (%) of survey reports from all countries of different grapevine decline syndromes on young vines.

"present" or "frequent" in this region. In the Northern region, characterized by a wet and cold spring weather, dead cordon related to Botryosphaeria dieback or to an unidentified canker agent were recorded as "frequent". In contrast, only in the South-Western region were all GTDs on mature vines rarely or never observed.

Portugal

Apoplexy, esca/GLSD and dead cordon related to Botryosphaeria dieback and Phomopsis cane and leaf spot were recorded as "frequent" in Portugal (Table 6C). In contrast, dead cordon related to Eutypa dieback was recorded as "absent". In Vinho verde, in the northern Portugal, apoplexy and Phomopsis cane and leaf spot were recorded as "frequent and worrying". The climate of that region is characterized by cool and wet springs and a cool summers. In Dao and Alentejo, apoplexy and esca/GLSD were recorded as "frequent and increasing"

Table 5. Reported levels of occurrence of GTD on young vines in surveyed European and Mediterranean countries.

Country	Region No.	Petri disease						Black foot[a]						Unidentified decline[b]					
		Frequent		Present		Not present or not observed		Frequent		Present		Not present or not observed		Frequent		Present		Not present or not observed	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Algeria	6	0	0	0	0	6[c]	100	0	0	0	0	6[c]	100	0	0	0	0	6[c]	100
Austria	4	0	0	0	0	4	100	0	0	0	0	4	100	0	0	4	100	0	0
Bulgaria	5	0	0	5	100	0	0	0	0	3	60	2	40	0	0	5	100	0	0
Croatia	2	0	0	2	100	0	0	0	0	0	0	2	100	0	0	0	0	2	100
Czech Repu-blic	3	0	0	0	0	3	100	0	0	0	0	3	100	0	0	3	100	0	0
England, UK	1	0	0	1	100	0	0	0	0	1	100	0	0	0	0	1	100	0	0
France	7	0	0	0	0	7	100	0	0	3	42.9	4	57.1	0	0	2	28.6	5	71.4
Germany	4	0	0	3	75	1[c]	25	0	0	3	75	1[c]	25	0	0	3	75	1[c]	25
Greece	3	0	0	3	100	0	0	0	0	3	100	0	0	0	0	3	100	0	0
Hungary	6	2	33.3	2	33.3	2	33.3	2	33.3	2	33.3	2	33.3	0	0	5	83.3	1	16.7
Israel	5	0	0	5	100	0	0	0	0	0	0	5	100	0	0	5	100	0	0
Italy	12	1	8.3	8	66.7	3	25	0	0	0	0	12	100	0	0	9	75	3	25
Lebanon	3	0	0	0	0	3	100	0	0	1	33.3	2	66.7	0	0	3	100	0	0
Montenegro	2	0	0	2	100	2	100	0	0	0	0	2	100	0	0	1	50	1	50
Portugal	5	0	0	4	80	1	20	0	0	5	100	0	0	1	20	4	80	0	0
Romania	5	0	0	0	0	5	100	0	0	0	0	5	100	0	0	1	20	4	80
Serbia	5	0	0	0	0	5	100	0	0	0	0	5	100	0	0	5	100	0	0
Slovakia	6	1	16.7	0	0	5	83.3	0	0	0	0	5	83.3	0	0	1	16.7	5	83.3
Slovenia	3	2	66.7	1	33.3	0	0	0	0	0	0	3	100	0	0	3	100	0	0
Spain	6	3	50	3	50	0	0	3	50	2	33.3	1	16.7	0	0	5	83.3	1	16.7
Switzerland	6	0	0	6	100	0	0	0	0	4	66.7	2	33.3	0	0	0	0	6	100
Turkey	6	0	0	1	16.7	5[c]	83.3	0	0	1	16.7	5[c]	83.3	0	0	1	16.7	5[c]	83.3
Total	105	9		46		52		5		28		71		1		64		40	
%	100	8.6		43.8		49.5		4.8		26.7		67.6		0.9		60.9		38.1	

[a] Ascertained presence of *Cylindrocarpon*-like spp.
[b] Undetected agent, physiological and other agents or cause excluded.
[c] Not surveyed regions.

and/or "worrying". The spring and summer climate in Dao is wet-warm and in Alentejo is dry-hot. Apoplexy, esca/GLSD and dead cordon related to Botryosphaeria dieback were recorded as "frequent and increasing" in Bairrada, located in the western Portugal, an area with mild climate with abundant rainfall (Vinho verde, Bairrada).

France

The seven surveyed regions showed contrasting profiles of GTD occurrence on mature vines (Table 6D). Apoplexy and esca /GLSD were reported as "frequent" in almost all the regions, and were considered as "increasing" and/or "worrying" in five of of seven regions. In contrast, Eutypa dieback and Phomopsis cane and leaf spot were recorded in all the regions but not as frequently occurring. Eutypa dieback was recorded as "frequent" in Charente, a region with Oceanic climate and where the susceptible cultivar Ugni Blanc (used for distilled wines) is widespread. In the Languedoc Roussillon area, GTDs were reported as "present" or "not observed", except for esca/GLSD. Dead cordon related to Botryosphaeria dieback was reported as "present" or "frequent" only in two regions, Champagne and Rhône.

Italy

In Italy, esca/GLSD and apoplexy have high and increasing importance in all regions (Table 6E). Eutypa dieback is also widespread, being reported as "present" in all regions except Sicily (probably linked to low

Table 6. Reported levels of occurrence of GTD on adult grapevines in surveyed regions in five selected countries: Hungary (A), Bulgaria (B), Portugal (C), France (D), Italy (E). i, increasing incidence; w, worrying presence; iw, increasing and worrying P, present; PO, present occasionally. Legend: light grey : present but not frequent; medium grey: frequent; dark grey: absent or not recorded.

A. Hungary

Spring climate[a]	Summer climate[b]	Region	Apoplexy	Esca /GLSD	Dead cordon (Eutypa dieback)	Dead cordon (Botryosphaeria dieback)	Dead cordon (causal agent not identified)	Phomopsis cane and leaf spot
uf	DHsu	Tokaj			PO			
WCsp	DHsu	Balat	PO	PO				
WWsp	DHsu	Egri		i	PO	i		PO
Dsp	DHsu	Pécsi	i				PO	
WWsp	DHsu	Neszmélyi						PO
Dsp	DHsu	Villány	i				PO	PO

B. Bulgaria

Spring climate[a]	Summer climate[b]	Region	Apoplexy	Esca /GLSD	Dead cordon (Eutypa dieback)	Dead cordon (Botryosphaeria dieback)	Dead cordon (causal agent not identified)	Phomopsis cane and leaf spot
WCsp	DHsu	Northern region (Danube plain)			PO			
WWsp	DHsu	Black sea region		PO	PO			PO
WWsp	DHsu	Sub-Balkan region (Rose valley)			PO	PO		
WWsp	DHsu	Southern region (Thracian Lowland)				never	PO	
WWsp	DHsu	South-west region (Struma River Valley)	PO	PO	PO	never	PO	PO

C. Portugal

Spring climate[a]	Summer climate[b]	Region	Apoplexy	Esca /GLSD	Dead cordon (Eutypa dieback)	Dead cordon (Botryosphaeria dieback)	Dead cordon (causal agent not identified)	Phomopsis cane and leaf spot
WWsp	DHsu	Dão	iw	i				PO
WWsp	Csu	Bairrada	i	i				PO
WCsp	Csu	Vinho Verde		PO				w
WCsp	DHsu	Douro			PO		w (PO)	
WWsp	DHsu	Alentejo	w	i				

D. France

Spring climate[a]	Summer climate[b]	Region	Apoplexy	Esca /GLSD	Dead cordon (Eutypa dieback)	Dead cordon (Botryosphaeria dieback)	Dead cordon (causal agent not identified)	Phomopsis cane and leaf spot
WCsp	Csu	Bourgogne	w					
WCsp	Csu	Champagne	i	iw				
WCsp	Csu	Pays de Loire	iw	iw			iw	
WCsp	DHsu	Charentes	i	i				
WCsp	DHsu	Bordeaux						
WWsp	DHsu	Languedoc-Roussillon						
WCsp	WHsu	Rhône	w	w				

(Continued)

Table 6. (Continued).

E. Italy

Spring climate[a]	Summer climate[b]	Region	Apoplexy	Esca /GLSD	Dead cordon (Eutypa dieback)	Dead cordon (Botryosphaeria dieback)	Dead cordon (causal agent not identified)	Phomopsis cane and leaf spot
WWsp	DHsu	Sardinia				i		
WWsp	Csu	Friuli Venezia Giulia	w	w			w	
Dsp	DHsu	Sicily		i				
WWsp	DHsu	Apulia		w		w		
WWsp	DHsu	Tuscany		w				
WWsp	WHS	Veneto		w				
WCsp	DHsu	Abruzzi	w	w				
WWsp	DHsu	Romagna						
WWsp	DHsu	Emilia		w				
WWsp	DHsu	Lombardy		w				
WCsp	DHsu	Piedmont						
WWsp	Csu	Trentino		w				

[a] Wet and cool spring (WCsp), wet warm spring (WWsp), dry spring (Dsp), uncertainty factor (uf).
[b] Dry and hot summer (DHsu),Wet and Hot summer (WHsu), cool summer (Csu).

amounts of rain, which is important for Eutypa inoculum spread. Eutypa dieback was responsible for limited damage. Cankers leading to dead cordon were also recorded in all regions, but were reported as "highly relevant" only in Sardinia, Friuli, Sicily, Apulia, Tuscany, Lombardy and Trentino. Phomopsis cane and leaf spot was also reported from all regions, was more widespread in Apulia, Veneto and Piedmont than elsewhere.

Increasing and/or "worrying" GTD occurrence

The GTDs were recorded as "increasing" and/or "worrying" by the correspondents in numerous countries in Europe and some of the Mediterranean area (Table 7). These diseases were reported as more important in old than in young vineyards, mainly due to the spread of apoplexy and esca complex/GLSD, respectively, in ten and 11 surveyed countries ("increasing" or/and "worrying" occurrence), particularly in the main grape-producing countries (France, Italy, Spain and Turkey). This represents about a third of recorded regions. Dead cordon related to Botryosphaeria dieback was the third disease problem, reported to be "increasing" and/or worrying in seven countries, and 16 of the 105 surveyed regions.

Dead cordon related to Eutypa dieback was recorded as "increasing" and/or "worrying" in ten regions of Serbia, Romania and Algeria. Dead cordon caused by unknown agents was "increasing" or "worrying" in five countries. Like Eutypa dieback, Phomopsis cane and leaf spot had more local importance, being reported as "increasing" or "worrying in eight regions within Romania, Portugal, Turkey and Montenegro.

The presence of decline diseases is perceived as a problem even in young vineyards: as "increasing" (three reports) or "increasingly worrying" (five reports) in some regions, particularly in Hungary and Spain.

On young vines, black foot was reported as "increasing" and/or "worrying" only in three regions of Spain, and Petri disease was considered as "increasing" in two regions of Spain and two regions of Hungary.

DISCUSSION

This study reports the first large-scale survey of GTDs in European and closeby Mediterranean countries, which aimed to determine the spread and severity of the main grapevine wood diseases, i.e. the disease syndromes associated with, or caused by, pathogenic fungi colonizing the woody tissues of grapevines. The diseases included in the survey are summarized in the Introduction. Some are included in "esca complex", i.e. a complex of interrelated diseases differently designated according to the stage of vine life when they occur and the type of symptom they cause.

The surveys carried out showed that apoplexy and esca/GLSD (i.e. often esca proper, as white rot in wood is frequently present with GLSD leaf symptoms) occurred in all the surveyed countries, and were

Table 7. Number of the surveyed regions in European and Mediterranean countries where alarming situations of GTD spread was reported.

Disease	Increasing OR worrying			Increasing AND worrying			Total	
	Surveyed Region		Country	Surveyed Region		Country	Surveyed Region	
	No.	%		No.	%		No.	%
Symptoms on adult vine								
Apoplexy	30	28.6	Hungary, Spain, Switzerland, Romania, Portugal, France, Italy, Algeria, Serbia, Germany	4	3.8	Portugal , France, Algeria	34	32.4
Esca /GLSD	29	27.6	Hungary, Portugal, France, Italy, Algeria,Turkey, Spain, Germany, Lebanon, Montenegro, Romania	11	10.5	Portugal, Czech, Spain, Austria	40	38.1
Dead cordon (Eutypa dieback)	8	7.6	Serbia, Romania	2	1.9	Algeria	10	9.5
Dead cordon (Botryosphaeria dieback)	14	13.3	Hungary, Romania, France, Italy, Spain, Serbia	2	1.9	Portugal, Spain	16	15.2
Dead cordon (causal agent not identified)	7	6.7	Algeria Romania Serbia, Portugal	2	1.9	Algeria, France	9	8.6
Phomopsis cane and leaf spot	8	7.6	Romania, Portugal, Turkey, Montenegro	0	0	-	8	7.6
Symptoms on young vine								
Petri disease	4	3.8	Hungary, Spain, Portugal	0	0	-	4	3.8
Black foot [a]	3	2.7	Spain, Portugal	0	0	-	3	2.7

[a] Ascertained presence of *Cylindrocarpon*-like spp.

generally recorded as the most frequently occurring GTDs. Both syndromes are related to esca complex, and they were also noted as increasing and worrying in many countries, in a large vineyard area in Europe. In mature vines, the other disease syndromes such as dead cordon related to *E. lata*, Botryosphaeriaceae or to unknown origin, and Phomopsis cane and leaf spot, were also recorded in almost all the surveyed countries. These diseases were often recorded as not frequent but increasing in several surveyed countries. In contrast, decline of young vine was less widespread and less important than decline of adult vines. Only a few viticulture regions were concerned about Petri disease or black foot, reporting it as frequently present only in a few countries.

Apoplexy and esca/GLSD are both very easily identifiable syndromes due to their characteristic symptoms, respectively, of sudden wilting and leaf stripe. The extensive occurrence of esca complex in the surveyed regions supports the endemic behaviour of this GTD, and its increasing presence, since the end of the 20th Century (Fischer and Kassemeyer, 2003; Surico, 2009). In contrast, if all responses on dead cordon syndromes are pooled, these occur as frequently as the esca complex. Among the diseases leading to dead cordon, Eutypa dieback was the most studied, and this disease is also easily detectable when foliar symptoms are visible (Munkvold *et al.*, 1994; Dubos, 1999). The situation is similar for Phomopsis cane and leaf spot, with typical symptoms on the canes (Úrbez-Torres *et al.*, 2013). Mixed infection makes it difficult to sharply separate the different dieback diseases. GTD diagnoses in vineyards may be difficult without specific foliar symptom expression, as is the case for Botryosphaeria dieback. In this survey, reports of Botryosphaeria dieback, probably based on previous etiological studies, were very likely to be underestimated due to the lack of specific surveys in many regions and countries. The significant number of reports "dead cordon" "agent unidentifed" supports this finding. Numerous pathogenic Botryosphaericeae species, presenting

different life traits, may be involved in vine decline in European and Mediterranean countries (van Niekerk *et al.*, 2006; Bellée *et al.*, 2017). Their distribution and prevalence are related to many factors, such as climatic and agronomic influences. Some fungi are widespread in Europe, such as *Diplodia seriata*, reported in Spain (Armengol *et al.*, 2001; Martin and Cobos, 2007), Portugal (Phillips, 2002; Rego *et al.*, 2009), Hungary (Kovács *et al.*, 2017), Italy (Cristinzio, 1978; Burruano *et al.*, 2008; Spagnolo *et al.*, 2011**,** Carlucci *et al.*, 2009, 2015), France (Larignon *et al.*, 2001), Turkey (Akgül *et al.*, 2014), Germany (Fischer and Kassemeyer, 2003), Croatia (Kaliterna and Miličević, 2014), and Bulgaria (Nikolova, 2010). Similarly, *Neofusicoccum parvum* is reported from Croatia (Kaliterna *et al.*, 2013), in Turkey (Akgül *et al.* 2014), Portugal (Phillips, 2002), Spain (Luque *et al.*, 2009), Czech Republic (Baránek *et al.*, 2018) and Italy (Spagnolo *et al.*, 2011). Another virulent pathogen, *Lasiodiplodia theobromae*, was frequently isolated in Southern European and Mediterranean regions (El-Goorani and El Meleigi, 1972; Burruano *et al.*, 2008, Carlucci *et al.*, 2009), and recently was isolated from declining vines in France (Comont *et al.*, 2016).

The results of the survey showed that dead cordon related to Botryosphaeria dieback is increasing and worrying in more countries than those reporting Eutypa dieback. This could be related to the broad range of the Botryosphaeriaceae pathogenic species, characterised by various traits (endophytic, saprophytic, pathogenic) in numerous hosts. Furthermore, water stress has been reported to increase the severity of Botryosphaeria dieback on grapevine (van Nierkerk *et al.*, 2011; Amponsah *et al.*, 2014; Lawrence *et al.*, 2017). Incidence of disease caused by Botryosphaericeae in various plant hosts has increased in Europe during the last decades (Desprez-Loustau *et al.*, 2006; Slippers and Wingfield, 2007; Fabre *et al.*, 2011; Piškur *et al.,* 2011; Mehl *et al.*, 2014), and this may be related with climatic evolution towards more variable conditions, with increasing incidence and intensity of droughts over continental Europe and the Mediterranean region (Spinoni *et al.*, 2017). Further research on the group of pathogens implicated in grapevine decline is needed to better assess the distribution of the different pathogen species in European and Mediterranean countries, and to determine their life traits in relation with grapevine physiological status.

Results from this questionnaire also demonstrated occurrence of Phomopsis cane and leaf spot disease. This is not a wood disease and so not usually included among the Grapevine Trunk Diseases. Nevertheless, its main agents, *Diaporthe ampelina* and other *Diaporthe* species, are also recognized causes of cankers and dieback on grapevine (Úrbez-Torres *et al.*, 2013; Dissanayake *et al.*, 2015; Guarnaccia *et al.*, 2018). In the survey, the reports of Phomopsis cane and leaf spot, based on the typical easily visible symptoms on the basal internodes of canes, gave information on the disease spread in Europe. This highlights the need for accurate pathogen identification to analyse the involvement of *Diaporthe ampelina* (=*Phomopsis viticola*) and other *Diaporthe* species in perennial cankers and vine dieback in European vineyards.

Eutypa dieback was considered a menacing and spreading disease in Europe at the end of the 20th Century in Europe (Munkvold *et al.*, 1994; Dubos, 1999). However, the present survey has shown this diease is present, but not frequent, in a majority of regions. Increased knowledge of Eutypa dieback epidemiology and on efficient disease management (infected wood removal, wound protection and trunk renewal) may have contributed to decreased incidence of the disease (Dubos, 1999; Lecomte *et al.*, 2006). Nevertheless, Eutypa dieback is still present in 20% of the monitored region and was recorded as increasing or worrying in three countries, Serbia, Romania and Algeria.

In addition to the questions on the main GTDs diseases on vines, the survey also included an open question on other causes of decline observed in vineyards. Beside virus and phytoplasma diseases, that are widespread in Europe, *Verticillium* and *Fusarium* diebacks were also mentioned a few times.

The reports of increase of esca complex and other forms of decline on adult plants reported for numerous surveyed countries corroborated previous observations. Several hypotheses were advanced for this increase. In the 1960s–1970s there was a large increase in grapevine planted area, which often required intensive plant production methods, due to the large demand for of low-priced mass market grape products. This significant production led to increased vulnerability of vines to fungal agents of wood diseases (Surico *et al.*, 2004; Gramaje and Armengol, 2011). Domestic grape varieties well-adapted to local pedoclimatic conditions were still grown for inexpensive table or wine production, but were largely replaced by easily available international commercial varieties that better meet commercial needs. Cultural practices also changed, including the training systems, which have direct impacts on incidence of wood diseases incidence (Lecomte *et al.*, 2018), and use of mechanical pruning tools. Another factor leading to the increase in GTDs spread may be climatic change, which would affect plant disease prevalence and have impacts on the complex interactions between pathogens and hosts (Gregory *et al.*, 2009). Account should be taken of the increased awareness of these diseases,

which leads to increased numbers of reports. The reported GTDs increasing in the surveyed viticulture regions matched the new wave of forest decline observed in European countries and around the world (Surico et al, 2004; Allen *et al.*, 2010). For instance, the results of this survey showed an increase in the apoplexy observed in different countries that might be related to the summer climatic conditions more favourable for expression of this syndrome, such as drought during summer coming after rain (Dubos, 1999, 2002; Surico *et al.*, 2000). Some studies have considered the relationships between GTDs and climate (Marchi *et al.*, 2006; van Niekerk *et al.* 2011; Calzarano *et al.*, 2018). The present survey results indicated the need for further study on these relationships, and Bois *et al.* (2017) proposed a methodology to address the relationships between grapevine pests and diseases and climate. The present survey has shown variation in GTDs occurrence among the regions within individual country. This variation could be explained by different climatic regimes. For instance, in Hungary, a higher level of occurrence for apoplexy was reported in two regions characterized by dry springs and hot/dry summers, compared to other regions of this country. Similarly, in Bulgaria, "Rose Valley" region showed a higher level of occurrence for esca complex/GLSD in comparison with other regions. This region is characterized by frequent rain during spring over a long period (pers. comm.), quite different from the south-eastern region (Struma), characterized by a continental Mediterranean climate, where GTDs were observed only occasionally. However, beyond these two examples, the data from this survey showed that climate did not always drive the occurrence of GTDs in a region.

Other factors, such as soil type, cultural practices, the rootstock and variety used and vine age may influence the host plant physiology, and hence the level of vulnerability to GTDs. Systematic monitoring and increased GTD research on epidemiology and host/pathogen interactions are needed to better predict the distribution and incidence of GTDs, in the context of climatic changes. Widespread monitoring has been instigated in many regions in Europe. For instance, in France, the National Observatory of GTDs shows large variations in disease incidence among particular grapevine plots (Bruez *et al.*, 2013).

The results of the present survey showed great diversity of grapevine varieties planted in the European and Mediterranean countries, probably reflecting only a small part of the diversity of cultivated varieties. However, this provides evidence of a long wine-producing tradition in these countries. The homogenization given by widespread planting of the same international varieties co-exists with increasing interest in renewal of vintage varieties that are well-adapted to local environments, and also new population variability selected to enlarge genetic backgrounds. In this survey, among the recorded varieties, the six most frequently cited (Cabernet Sauvignon, Merlot, Chardonnay, Riesling, Sauvignon and Pinot Noir) correspond to those commonly grown in the European vineyards (OIV, 2017). Among these varieties, Cabernet Sauvignon was the most reported as susceptible to esca. Cabernet Sauvignon has also been reported in the literature as susceptible to other GTDs, such as Botryosphaeria dieback (Larignon *et al.*, 2001, Quaglia *et al.*, 2009, Bruez *et al.,* 2013) and Eutypa dieback (Dubos, 1999). However, the cv. Merlot, also one of the main reported cultivars in the survey, was indicated as moderately susceptible, presenting less disease incidence in vineyards than Sauvignon blanc and Riesling (Murolo and Romanazzi, 2014), or than Cabernet Sauvignon (Christen *et al.*, 2007). From the National French GTD vineyard survey, Bruez *et al.* (2013) also showed that Merlot presented low esca complex incidence. This cultivar was considered to be tolerant to Eutypa dieback (Dubos, 1999). Regarding Chardonnay, Andreini *et al.* (2014) observed lower percentage of GLSD ("esca symptoms") on Chardonnay vines than on Cabernet Sauvignon or Trebbiano vines, and Bruez *et al.* (2013) reported different level of incidence according to the surveyed region. The number of studies on Chardonnay was less than those on Merlot and Cabernet Sauvignon. For the four other predominating cultivars, Riesling Italico, Pinot noir, Limberger and Riesling, few studies of their susceptibilities to GTDs have been reported. From a mature vineyards survey of 64 cultivars, Murolo and Romanazzi (2014) reported the greatest esca incidence for Riesling, and no symptoms present for Limberger. Pinot noir has been evaluated as moderately affected by Botryosphaeria dieback (Larignon *et al.,* 2001). Trebbiano and Sangiovese were reported as less susceptible to GLSD ("esca") than Cabernet Sauvignon (Andreini *et al.*, 2014), while Sangiovese showed lower percentage of esca symptomatic vines in comparison with Trebbiano in a separate study.

The behaviour of a particular cultivar may vary according to the environmental conditions. Li *et al.* (2017) showed for Cabernet Sauvignon vines of similar age that disease incidence varied from 0.10 to 11.7 in vineyards from one region. The cultivation of resistant or tolerant grapevine cultivars to diseases has been suggested as a major challenge for the 21st Century, to decrease pesticide use against foliar pathogens. Results of the present survey show it is also relevant to select cultivars less susceptible to GTDs. Evaluation of the dif-

ferent responses of the cultivars in particular environments remains essential.

The main varieties of rootstocks used for grafted vines reported in this study were SO4, 110R, K5BB and 1103P. It was generally accepted that rootstock mother plants can also be a source of infections by pathogenic fungi associated to Petri disease and esca complex. Gramaje *et al.* (2010) compared the response to infection of different rootstock varieties to Petri disease pathogens. They found that the rootstocks 140 Ru and 110R were the most greatly affected. Both were among the commonly reported rootstocks in our survey, and 110R was the second most frequently reported. Liminana *et al.* (2009) reported that the 16 year-old trunks of rootstocks 140Ru, 11R, Fercal and 101-14MG presented the most extensive necrosis. The susceptibility of rootstocks to pathogenic fungi associated to GTDs may be considered as well as the susceptibility of scion varieties conferred by the rootstock used. For instance, in an Italian vineyard, Marchi (2001) showed that vines cv. Trebbiano grafted on rootstocks 1103P, 420A or K5BB expressed more esca symptoms than those grafted on S04 or 140RU. In contrast, when two other varieties (cv. Fiano and Sauvignon blanc) were grafted on S04 they had greater esca incidence compared with the same cultivars grafted on 1103P (Murolo and Romanazzi, 2014). These authors explained their results by the greater drought resistance of 1103P than other rootstocks. Environmental conditions must be considered to explain the results, as well as the roles of other internal or external factors (Marchi *et al.*, 2006; Calzarano *et al.*, 2018) to explain these differences.

GTDs on young vines were reported in the survey with a lower occurrence than for GTD on adult plants. GTDs were rarely reported as "increasing" and/or "worrying" on young vines. Petri disease and black foot diseases were only reported to be increasing in Spain, and Petri disease, in Hungary. These diseases are characterized by general decline symptoms, but the diseases were reported only where where plant pathologists have made specific observations and diagnoses to identify the pathogens involved. Therefore, the lack of monitoring of young vineyards, resulting in an underestimation of the problems, cannot be discounted for this result. To our knowledge, this survey was the first to evaluate occurrence of decline diseases in young vines on a large geographical scale.

The large number of survey responses, from a total of 105 viticulture regions in 22 countries, allowed us to draw an overall picture of GTDs spread in Continental European and Mediterranean countries. Some countries with relevant grapevine production were missing from the survey including Tunisia, Morocco, and some Balkan and Central European countries (e.g. Poland). The survey data were based on correspondent declarative responses and not on formally recorded information. Differences between countries may be important: in 15 countries out of 22, GTD surveys or observatories were established at regional or national levels.

In other cases, the responses may be based on expert knowledge on the phytosanitary state, depending on personal perceptions. For some countries, the lack of information or correspondent response may have led to underestimation of occurrence of the disease syndromes. Therefore, the results presented in this paper need to be taken with some caution. Nevertheless, the survey data showed that almost all the surveyed countries (except four), had laboratories or extension services based on GTD survey or/and diagnostic/detection at regional or national levels. That information favoured validity of the collected data, even if the etiological complexity of dieback diseases requires more detailed investigations, such the recording of data from plots and etiological evidence provided by identification of the involved pathogenic fungi, especially for the dead cordon syndrome.

CONCLUSIONS

Taking account of the results of this survey with caution, all findings from this large-scale European consultation, extended to several Mediterranean countries and producers, highlighted the important roles of GTDs, particularly esca complex, in vine decline in European and Mediterranean grape-producing regions. Furthermore, the survey has emphasized the need to accurately determine the occurrence and distribution of the causes of grapevine decline, such as the involvement of Botryosphaericeae and *Diaporthe* species in dieback and vine death. Etiological and epidemiological studies should be conducted to identify and quantify the environmental and agronomic factors associated with GTDs. Also urgent is the need to share and disseminate all nursery and vineyard management practices that have proved useful for GTD prevention, or for limiting the damage resulting from these diseases. The recently established European Winetwork project was set up to increase knowledge transfer on current and innovative strategies for grapevine disease management in Europe (Mondello *et al.*, 2018b, www.winetwork.eu). This initiative needs to be maintained and promoted.

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