REVIEW OF THE PEAR SCAB CAUSED BY *VENTURIA PYRINA*

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Abstract
European pear scab (*Venturia pyrina* Aderh.) is common and economically important disease in commercial orchards in most of the pear (*Pyrus communis* L.) growing areas worldwide. Studies on pear scab pathogen *V. pyrina* diversity in general and among different geographical regions are scars at an early stage. In the limited number of studies reported so far, some attempts have been made to characterize and define races or biotypes of *V. pyrina* and new biotypes co-adaptated to specific cultivars have been recorded recently. Despite the long history, worldwide distribution and increasing economic significance of the European pear scab, the research on control methods, and pathogen biology and disease epidemiology that could aid to develop more effective and also alternative to fungicide application control methods are still limited. Mechanisms of European pear resistance to scab remains uncertain and currently only one major resistance gene *Rvp1* has been identified and characterised. Although the disease is important in many European countries, breeding programs of pear scab-resistant varieties are still under development. In this paper we provide an overview on *V. pyrina*, its significance and distribution, control methods and current scientific progress in understaning of the pathogen and the disease.
Overview of literature on *V. pyrina* characterization, ecology, biology and diseases epidemiology from Latvia and other countries has been used for the study.
Key words: *Pyrus communis*, races, fungal diseases, control, diversity.

Introduction

The European pear is one of the most widely grown pome fruit tree species with long cultivation history (Sánchez, 2005; Sharma et al., 2010). In Latvia, pear is a second common pome fruit crop grown commercially and in home gardens, although commercial pear plantations are limited in comparison to other pear producing countries (Skrīvele et al., 2008; Lācis et al., 2012). Emphasis on integrated and organic fruit production in Europe is increasing every year due to environmental and food safety concerns. The pear production, especially in the integrated and organic production systems, is constrained by diseases, which reduce the viability of plants, fruit development and quality. Changes in production technologies, introduction of new cultivars as well as climatic changes can alter the pathogen populations resulting in the development of new and more aggressive forms adapted to the changing environmental conditions. The European pear is infected with a range of fungal, bacterial and viral pathogens, whose significance varies depending on growing reagion and particular disease (Wood, 1997; Johnson, 2000). In Europe, and also in other parts of the world where European pear is cultivated, as most significant pear diseases are considered fire blight (*Erwinia amylovora*), pear scab (*Venturia pyrina*), blossom blight (*Pseudomonas syringae pv. syringae*), powdery mildew (*Podosphaera leucotricha*) and brown spot (*Stemphylium vesicularium*) (Shabi et al., 1981; Deckers and Schoofs, 2002; Deckers and Schoofs, 2005; Postman et al., 2005; Mizuno et al., 2010).

Scab on pear is economically important disease worldwide, especially in organic orhards (Shabi, 1990; Postman et al., 2005; Lespinasse et al., 2008; Spotts and Castagnoli, 2010; Bouvier et al., 2012). Severe damages can be caused in conditions conducive to the disease and on susceptible cultivars in all main growing regions (Stehmann et al., 2001). Despite the long history, worldwide distribution and increasing economic significance of *V. pyrina*, the research on control methods, and pathogen biology and disease epidemiology that could aid to develop more effective and also alternative to fungicide application control methods are still limited.

The aim of the article is to give an overview of *Venturia pyrina* significance and distribution, control methods and current scientific progress in understaning of the pathogen and the disease.

Materials and Methods

Monographic method has been used for this study. Available literature of pathogen characterization, ecology, biology and diseases epidemiology from Latvia and other countries has been used for the study.

Results and Discussion

Distribution and significance of the disease

European pear scab for a long time was not considered as a destructive disease and was controled efficently with fungicide applications and growing of tolerant cultivars; however, in some areas severe losses were noted already for more than 80 years ago that continued to increase over the time (Bearden et al., 1976; Spotts and Covey, 1990; Spotts and Cervantes, 1994). In Israel, the European pear scab for the first time was observed in the beginning of 1960ies and after ten years due to pathogen resistance to fungicides and cultivar susceptibility (Shabi et al., 1972; Shabi and Katan, 1979; Shabi, 1989) severe losses already occurred. Nowadays, the European pear scab is common, and it is considered as an economically important disease in commercial orchards in most of the pear growing areas worldwide (Lattore et al., 1985; Shabi, 1990; Bakker, 1999; Pierantoni et al., 2007; Chevalier et al., 2008; Rossi et al., 2009; Spotts and Castagnoli, 2010; Bouvier et al., 2011). In Latvia, pear scab is considered as one of the most important fungal diseases affecting pear production (Eglītis et al., 1943; Lācis et al., 2012).

Pear scab is an especially serious problem in organic orchards causing severe crop losses (Timmermans et al., 2010; Sugar and Hilton, 2011). In the Netherlands, the scab incidence has increased only during the last few years in organic pear farms (Timmermans and Jansonius, 2012). Similarly, severe attacks of *V. pyrina* have been detected recently in French orchards overcoming resistance of pear cultivar ‘Conference’, which still is dominant cultivar in large areas in Western Europe (Chevalier et al., 2008).

The major losses caused by *V. pyrina* are due to scabbed fruits, which are not marketable. Because of the loss of commercial value, frequent use of fungicides is required (Bouvier et al., 2011). Sometimes due to the scab infection yield losses in pear orchards reached 40 – 80% (Kienholz, 1937; Liu et al., 2009). If appropriate control measures are not applied, in case of susceptible cultivars and condusive weather conditions yield losses can reach up to 100% (Shabi, 1990; Sugar and Hilton, 2011). The pear scab infects and causes disease also on ornamental pears planted in urban landscapes. *V. pyrina* causes also severe twig infections and repeated plant infections can lead to tree mortality in urban landscapes (Shabi, 1990; Percival and Noviss, 2010).

Characterization of the pathogen

The scab on European pear is caused by ascomycetous fungus *Venturia pyrina* Aderh. (Sivanesan and Waller, 1974). *V. pyrina* has been classified to *Pezizomycotina* subdivison, *Dothideomycetes* class, *Pleosporomycetidae* subclass, *Pleosporales* order, *Venturiaceae* family (Kirk et al., 2004; Lumbsch and Huhndorf, 2010). Recently, based on molecular phylogeny and morphological and ecological grounds, *V. pyrina* was re-classified and placed in the newly described order *Venturiales*, C.L. Scoch and K.D. Hyde within *Dothideomycetes* (Zhang et al., 2011). The fungus is heterothallic and similarly as other *Venturia* species is hemibiotrophic (Langford and Keitt, 1942, cit. in. Spots and Covey, 1990; Stehmann et al., 2001). *V. pyrina* develops sexual stage in leaf litter, where it overwinters as a saprotroph during the dormant season, and asexual (conidial spores) state is formed on infected plants during the season (Stehman et al., 2001). Species of *Venturia* are mostly identified based on morphology and host (Stehman et al., 2001). The detailed morphology of the fungus is summarized and described by A. Sivanesan and J.M. Waller (1974).

European pear (*Pyrus communis* L.), Syrian pear (*Pyrus syriaca* Boiss.), other *Pyrus* species and also loquat (*Eriobotrya japonica* Lindl.) are mentioned as the hosts for *V. pyrina* among which European pear is considered to be the principal host (Sivanesan and Waller, 1974). The loquat *E. japonica* as a host for *V. pyrina* is doubtful and most likely the scab reported on this plant is caused by another *Venturia* species phylogenetically closely related to *V. inaequalis* as revealed by P. Sánchez-Torres et al. (2009). As summarized by P. Zhao et al. (2012) Asian pear (*Pyrus pyrifolia* (Burn) Nak.) was considered a host for *V. pyrina* until another species *V. nashicola* was described and proved to be the causal agent for scab on this plant.

Studies on *V. pyrina* diversity in general and among different geographical regions are scars at an early stage (Shabi et al., 1972; Chevalier et al., 2008). The variation of the pathogen was shown in cultivar resistance studies, where cultivar resistance or susceptibility correlated to the origin of inoculum (Shabi et al., 1972; Zhao et al., 2011) and in multigene phylogenetic studies (Zhao et al., 2011). The first indications of diversity among *V. pyrina* populations were based on inconsistency in pear cultivar resistance in different geographical regions. Possible presence of variable *V. pyrina* biotypes in each location was concluded as the main reason for this inconsistency (Brown, 1960). In the limited number of studies reported so far some attempts have been made to characterize and define races or biotypes of *V. pyrina*. In Israel, four races were defined on European pear and one race on Syrian pear (Shabi, 1972). Among defined races in Israel only race 2 was considered as important in pear growing (Shabi, 1989). During more recent studies in France, it was found out that *V. pyrina* population is highly divergent in terms of specificity and aggressiveness on different pear cultivars and strong co-adaptation of new strains to the so far resistant cultivar ‘Conference’ was detected (Chevalier et al., 2004; Chevalier et al., 2008). Due to *V. pyrina* life cycle, each spring plant is infected by the newly released ascospores representing new genotypes, and therefore ensuring high potential for genetic diversity and adaptation ability of the pathogen. This phenomenon has been reported for apple pathogen *V. inaequalis* as one of the driving forces for diversity and formation of more aggressive races (MacHardy et al., 2001).

In those few phylogenetic studies on *Venturia* species conducted so far (Schnabel et al., 1998; Beck et al., 2005), only isolates of *V. pyrina* from New Zealand, Japan and Israel were included and phylogenetic relationships of isolates with other origin have not been studied. In the recent phylogenetic study based on rDNA-ITS, partial ß-tubulin and elongation factor 1a gene sequences using *V. pyrina* isolates originated from Japan and Israel revealed two distinct evolutionary lineages (Zhao et al., 2012). Isolates from Israel belonging to the race 2 and Japanese *V. pyrina* isolates were closely related and formed separate clade, while other isolates grouped together in another lineage (Zhao et al., 2012).

Pathogen populations differ among the regions due to the factors of host genotypes, climate conditions and management strategies. Continuous use of fungicides leads to adaptation of the pathogen populations and formation of the resistance (Koenraadt et al., 1992). Closely related to *V. pyrina*, the apple scab pathogen *V. inaequalis*, has a high ability for adaptation to the environment of continuous fungicide pressure and as a result fungicide resistance in the populations is formed (Chapman et al., 2011). Fungicide resistance and genetic bases for it in *V. pyrina* populations, particulary resistance to benomyl, was studied during 1970^{ies} to 1980^{ies} in pear orchards in Israel (Shabi and Katan, 1979; Shabi et al., 1986). During these studies it was found out that benomyl resistance of *V. pyrina* is regulated by a single gene (Shabi and Katan, 1979). Resistance remained consistant in the pathogen populations for 10 years without benomyle applications (Shabi, 1989).

Symptoms, life cycle of the pathogen and disease epidemiology

V. pyrina attacks buds, leaves, fruits and young shoots and the first symptoms appear usually within two weeks after infection (Eglītis et al., 1943; Sivanesan and Waller, 1974; Bearden et al., 1976; Shabi, 1990; Liu et al., 2009). Symptoms on leaves and fruits appear as olive green to dark brown, usually circular spots that become velvety because of pathogen conidial sporulation, and growth distortion on scabbed organs is often observed (Eglītis et al., 1943; Sivanesan and Waller, 1974; Jones and Aldwinkle, 1997). With age lesions on fruit become cracked and corky, and the velvety look disappears on infected areas (Jones and Aldwinkle, 1997). Unlike apple pathogen *V. ineaqualis*, *V. pyrina* attacks also young wood and infection appears as pale brown blister-like lesions (Kienholz and Childs, 1937; Sivanesan and Waller, 1974).

V. pyrina overwinters as a saprotroph in the litter on infected leaves and as mycelium in infected twigs (Kienholz and Childs, 1937; Eglītis et al., 1943; Bearden et al., 1976; Spotts and Covey, 1990; Rossi et al., 2009). Pseudothecia are formed on the old leaf tissue during the winter. Psedothecia are formed only from heterothallic mating, requiring two different mating types (Keitt and Palmiter, 1938; Langford and Keitt, 1942). The ascospore maturity and release usually occurs about the time when pear buds are unfolding and this is the most important source for primary infections in the spring (Shabi, 1990; Liu et al., 2009). When moisture and temperature conditions are favourable, airborne ascospores are discharged, and they are carried by air to the surrounding trees, where they germinate and cause primary infections (Latorre et al., 1985). The ascospore discharge from overwintered pseudothecia usually occurs after spring rainfals and dews in a wide range of air temperature and may last up to four months in several events when faivaroble conditions are present (Lattore et al., 1985; Spotts and Cervantes, 1994; Liu et al., 2009; Rossi et al., 2009; Rancāne et al., 2013). In the studies on *V. pyrina* epidemiology has been shown that light stimulates ascospore discharge, but some amount of ascospores was also trapped during the darkness, especially during dew periods (Spotts and Cervantes, 1994). In the spring, conidia are also formed on overwintering lessions on young wood and in some years they are important source of primary infections (Sivanesan and Waller, 1974; Timmermans et al., 2010). Because of overwintering conidia the disease was more difficult to control when twig infection has occurred (Marsh, 1933; Smith, 1905). However, the occurrence and importance of twig infections differ among geografical regions (Spotts and Covey, 1990; Rossi and Pattori, 2009).

Soon after the first infection conidial sporulation appears on the lesions, and secondary infections occur when conditions are favorable for the fungus, and in warm and humid conditions conidia are formed in great numbers (Rossi and Pattori, 2009; Liu et al., 2009). The conidia are dispersed by rain and wind (Shabi, 1990). Conidia of *V. pyrina* need free water to germinate and infect pear leaves similarly as for other closely related pathogens *V. nashicola* and *V. inaequalis* (Shabi, 1990; Li et al., 2003). During the growing season the fungus lives as a true parasite within the pear tissue (Isshiki and Yanase, 2000). The new infections from sporulating lesions may occur several times per season depending on environmental conditions (Shabi, 1990). For long distance spread picking bins with scabbed leaves have been suspected as a possible carrier of spores and suggested as possible means of spreading *V. pyrina* among orchards (Spotts and Covey, 1990).

Resistance of varieties and control possibilities of the disease

Due to the public demand and new legislation annualy banning several fungicides important for agriculture, a great demand for elaboration of alternative control methods or compounds has been raised for scientific community and growers. Studies on resistance to the pear scab pathogen *V. pyrina* in European pear are at an early stage (Postman et al., 2005; Faize et al., 2007; Pierantonie et al., 2007; Liu et al., 2009). The knowledge on pear resistance is mostly as a general description of cultivar performance in the field (Kemp et al., 2000; Fisher and Mildenberger, 2004). Only in few cases systematic field evaluation results based on wide screening of collections are published (Brown, 1960; Chevalier et al., 2011; Lācis et al., 2012). Currently grown pear cultivars have different susceptibility to pear scab, and only cultivars 'Abbé Fètel' and 'Navara' (Zhao et al., 2011; Bouvier et al., 2011) have been described as resistant. For a long time the cultivar 'Conference' remained resistant to pear scab (Bell, 1991). However, since the 1990's 'Conference' has become very susceptible in some French orchards (Chevalier et al., 2008). The pear cultivar 'Navara' was shown to be a resistant cultivar in Angers environmental conditions and several experiments have shown a pinpoint reaction and stellate necrosis indicating presence of resistance genes (Chevalier et al., 2004; Lespinasse et al., 2008).

Mechanisms of European pear resistance to scab remains uncertain and currently only one major resistance gene *Rvp1* has been identified in the cultivar 'Navara' (Bouvier et al., 2011). Development of QRL markers for *Rvp1* gene showed the synteny between apple and pear linkage groups (Pierantoni et al., 2007; Bouvier et al., 2011). Evidence of polygenic resistance of pears to *V. pyrina* has also been shown (Chevalier et al., 2004; Pierantoni et al., 2007). The importance of resistance to pear scab is highlited by several authors and some breeding programmes aimed to develop scab resistant pear cultivars are in progress (Faize et al., 2007; Chevalier et al., 2004; Lespinasse et al., 2008; Liu et al., 2009; Chevalier et al., 2011).

Despite the long history, worldwide distribution and increasing economic significance of the European pear scab, the research on control methods, and pathogen biology and disease epidemiology that could aid to develop more effective and also alternative to fungicide application control methods are still limited. Previously benzimidazole fungicides have been used extensively in some areas to control pear scab and lead to fast and stable resistance formation in the pathogen populations, which forced to switch to other type of fungicides and to find alternatives (Shabi and Katan, 1979; Shabi et al., 1981; Bakker, 1999; Washington et al., 1998; Sugar and Hilton, 2011). The salts like bicarbonates and silicon against various fungal diseases have been tested on a wide range of diseases including apple scab (Laffranque and Shires, 2005; Conway et al., 2007; Creemers et al., 2007). In case of pear scab, potassium phosphite in combination of reduced amount of fungicide myclobutanil was tested as alternative to existing control system and was found that potassium phosphate alone significantly reduced the pear scab (Percival and Noviss, 2010). Some limited efforts have also been made to control pear scab by control of the tree vigour and by applications of systemic induced resistance agents (Jansonius, 2008; Perciaval et al., 2009).

Nowadays the pear scab control basically relies on protective fungicide applications on the regular bases during the primary infection period, which is the most essential step for successful scab control (Bearden et al., 1976; Liu et al., 2009; Rossi and Pattori, 2009; Teng, 2011; Villalta et al., 2013). The number of sprays needed during the primary infection period and later in the season to control secondary infections greatly depends on infection background in the previous year, wetness periods and temperature (Bearden et al., 1976; Shabi, 1989; Rancāne et al., 2013). Combination of protective fungicide sprays with potharwest sanitation to reduce amount of pseudothecia in overwintered leaf litter have been successfully used (Eglītis et al., 1943; Spotts et al., 1997; Rancāne et al., 2013). Several sanitation methods and compounds have been evaluated for their efficency to reduce primary inoculum from leaf litter including application of dolomitic lime in autumn, beetroot Vinasse, and leaf collection with different level of succsess (Spotts et al., 1997; Timmermans and Jansonius, 2012; Timmermans et al., 2010). Among compounds used to reduce ascospore inoculum in the spring, urea applications on the leaf litter and on the tree canopy have proved as the most efficient not only for pear scab, but also for reduction of apple scab (Burchell et al., 1965; Sutton et al., 2000; Holb, 2006; Mac and tSaoir, 2010; Rancāne et al., 2013).

In order to decrease the use of pesticides due to the environmental and food safety concerns, the early warning and disease-modeling systems are developed. They are based on careful monitoring of meteorological parameters and pathogen development. Despite similarities in several aspects, including a life cycle, it was concluded that epidemiology of pear scab differs from apple scab and knowledge on pear scab is missing for development of effective warning system for pear scab control (Jansonius, 2008). Limited number of studies has been carried out to develop models for prediciting risk of primary infection (Rossi and Pattori, 2009). Need for adaptation to different growing regions and validation of existing warning models, which currently are based on limited factors (e.g. temperature and time) influencing ascospore matuaration and release have been highlited by some authors (Villalta et al., 2013). Necessity for more accurate prediction of the first ascospore release at the beginning of the season as well as integration of other factors influencing pear scab development, such as weather, tree growth and time since the last spray, has also been pointed out (Villalta et al., 2013).

Further investigations are necessary to develop the system of pear scab integrated control, which include knowledge about pathogen biology, diversity, resistance of cultivars and forecast and warning system of spores realising.

Conclusions

1. Nowadays, the European pear scab is common and considered as an economically important disease in commercial orchards in most of the pear growing areas worldwide. Pear scab is an especially serious and increasing problem in organic orchards.
2. Studies on pear scab pathogen *V. pyrina* diversity are scars at an early stage. The variation of the pathogen was shown in cultivar resistance studies and in multigene phylogenetic studies. Some attempts have been made to characterize and define races of *V. pyrina* and new biotypes co-adaptated to specific cultivars have been recorded recently indicating adaptation of the pathogen.
3. Due to environmental and food safety concerns and high adaptation capability of the pathogen to overcome resistance, need for changes in control strategies has been highlighted by pear scab research community. Deeper knowledge on the resistance mechanisms, pathogen diversity worldwide, and identification of pathotypes/races and evaluation of population diversity can provide the basic knowledge required for development of an effectively integrated pest management (IPM) system and breeding strategies of durable resistance in pear.
4. Despite the long history, worldwide distribution and increasing economic significance of the European pear scab caused by *V. pyrina*, the research on control methods, and pathogen biology and disease epidemiology that could aid to develop more effective control methods are still limited.

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