

SEA BUCKTHORN DISEASES CAUSED BY PATHOGENIC FUNGI

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Sea buckthorn (Hippophae rhamnoides L.) is a native species in various regions of Asia and Europe. It is cultivated as a multipurpose horticultural species in northern temperate regions of Europe, Asia, and North America with large economic potential used for food, pharmacology, cosmetics, and environmental conservation. Diseases in natural populations and managed landscapes have increased, endangering sea buckthorn growth and cultivation worldwide. This review article focuses on sea buckthorn canker, wilt and decline diseases caused by pathogenic fungi, their distribution, hosts of involved pathogenic fungi and symptoms. Published information on sea buckthorn fungal diseases is available only about a few diseases, such as wilt (Verticillium dahliae), the dried-shrink disease caused by various fungi and abiotic factors, and stem canker (Hymenopleella hippophaeicola, Cytospora spp., Stigmina sp.). Some fungi reported on sea buckthorn are poorly studied, or the sea buckthorn is a newly discovered host, as in the case of Eutypa spp. The most often reported symptoms of these diseases are cankers and cracks on trunks and main branches, dead buds and leaves, necrosis of various tissues on branches, and root necrosis, resulting in the death of the shrubs. In general, the fungal diseases on sea buckthorn are not sufficiently addressed, and more research is needed.

Keywords: Hippophae rhamnoides L., canker, decline, wilt.

INTRODUCTION

Common sea buckthorn (*Hippophae rhamnoides* L.) is a valuable, multipurpose shrub or tree (family *Elaeagnaceae*) extensively grown in Asia, Europe and North America. Products from all shrub parts are perspective for the medical, pharmaceutical, and cosmetic based industries (Kennedy, 1987; Piłat *et al.*, 2015; Ivanišová *et al.*, 2020). The strong root system of sea buckthorn safeguards against soil erosion, making sea buckthorn a well-adapted plant for soil conservation and improvement (Osipan and Martirosian, 1984; Kalia *et al.*, 2011). The wide range of applications contribute to the growing interest in sea buckthorn production, and in the last years, the area of sea buckthorn plantations has increased substantially in several countries, including in Latvia (Piłat *et al.*, 2015; Gurčik *et al.*, 2019; Lamo *et al.*, 2019; CSP, 2021). In 2020, sea buckthorn was the third-largest fruit crop species grown in plantations in Latvia after apple and blackcurrant (CSP, 2021).

There are few studies on fungal sea buckthorn diseases compared to the traditional temperate fruit and berry crop species, e.g., apple, pear, strawberry, raspberry. However, as cultivation of sea buckthorn increases, the risk for pathogen development and disease damage also increases. Scientific reports indicate that diseases in natural populations and managed landscapes have increased (Prokkola, 2003; Khovalyg and Toropova, 2017; Popp *et al.*, 2021), endangering sea buckthorn growth and cultivation worldwide. Susceptibility to pests and pathogens reduces sea buckthorn yield and quality (Prokkola, 2003; Kalia *et al.*, 2011). Sea buckthorn was previously considered free of fungal diseases or only slightly damaged by pathogens, not significantly affecting the plant or yield and its quality (Osipan and Martirosian, 1984; Khovalyg and Toropova, 2017). This opinion could be one of the reasons why there is limited research on sea buckthorn pathogens and diseases. Nowadays, experience shows that there can be a range of problems concerning plant health. Each sea buckthorn cultivation region may



Fig. 1. Observed disease symptoms on sea buckthorn in Latvia: (A, B) Cankers and cracks on stems; (C) Dieback and drying of branch; (D-F): Premature yellowing of leaves and berry damages.

have a different disease range and involved pathogens that could vary over time because of cultivar introduction, changes in climate conditions and cultivation technologies (Shalkevich *et al.*, 2015). The severity of disease damage can be periodic or long-lasting, with yield losses up to 100% in some varieties or regions (Shalkevich *et al.*, 2015; Khovalyg and Toropova, 2017).

This review aimed to summarise the published information about sea buckthorn diseases, focusing on canker, wilt and

decline caused by pathogenic fungi, their distribution, hosts of involved pathogenic fungi and symptoms.

WILT

The most widely-spread disease in sea buckthorn orchards reported from several cultivation regions worldwide is wilt, also called drying.

Pathogens. Wilt or drying of sea buckthorn is associated with several *Verticillium* and *Fusarium* species (Shamanskaya, 2009; Pilat *et al.*, 2015; Shalkevich *et al.*, 2015) depending on the cultivation region. In Romania, Belarus, Latvia and in the nurseries in the northern part of India, both *Verticillium* and *Fusarium* have been identified as causes of sea buckthorn wilt or drying (Garanovich *et al.*, 2009; Cotuna *et al.*, 2014; Shalkevich *et al.*, 2015; Singh, 2018; Moročko-Bičevska *et al.*, 2019). Both are vascular pathogens that can lead to plant death (Cotuna *et al.*, 2014). In Russia, *V. dahliae* and several *Fusarium* species caused wilt and drying together with drought (soil moisture below 70%), leading to yield losses of up to 100% (Khovalyg and Toropova, 2017).

In Canada, *V. dahliae* has been found on living and dead sea buckthorn roots and shoots (Sholberg *et al.*, 2005). *Verticillium* was identified as a severe problem in German sea buckthorn orchards, especially on cultivars of Russian origin. Increased plant wilting and death caused by *Verticillium* was observed two years after planting (Höhne, 2015).

Two species of *Verticillium*, *V. dahliae* and *V. albo-atrum*, have been associated with sea buckthorn wilt. These species are well known vascular plant pathogens (Harris, 1998; Desjardins *et al.*, 2005; Cotuna *et al.*, 2014). *Verticillium* fungi can enter the host root system directly or through the wounds formed naturally by root growth or induced by other organisms in the soil. After entering plant tissue, the pathogen produces toxins, invades the xylem and causes systemic infection of the plant (Cotuna *et al.*, 2014).

Verticillium dahliae hosts include over 400 dicotyledonous plant species, including soft and stone fruits, nuts, vegetables, herbs, root crops, oilseed crops, fibre crops, legumes, woody and herbaceous ornamentals, and different weeds (Harris, 1998; Hiemstra, 1998; Song *et al.*, 2020). *Verticillium dahliae* was identified as a cause of wilt, gradual leaf yellowing, scorching, and twig dieback on Chinese redbud (*Cercis chinensis*) plants in China, which is an essential ornamental plant in China (Lu *et al.*, 2013). It causes wilt also on avocado in several European and North American countries (Markakis *et al.*, 2014) and New Zealand spinach (*Tetragonia tetragonioides*, *Aizoaceae*) in Europe (Garibaldi *et al.*, 2013). In pathogenicity tests on sea buckthorn using different *V. dahliae* strains from sea buckthorn and strawberry, all caused wilt on sea buckthorn plants (Kennedy, 1987). However, due to the complicated taxonomic history of *Verticillium* (Inderbitzin and Subbarao, 2014), the reports about occurring species may be incomplete due to

the initial lack of knowledge and may change when more data about *Verticillium* strains on sea buckthorn is supported by phylogenetic analysis.

Fusarium species associated with sea buckthorn wilt or drying are usually identified only at the genus level. Research in Belarus (Garanovich *et al.*, 2009; Shalkevich *et al.*, 2015) showed that in plant samples with wilt symptoms, *Fusarium* fungi were dominating. *Fusarium culmorum*, *F. roseum*, *F. oxysporum*, and *F. gibbosum* were identified. However, the pathogenicity of these fungi on sea buckthorn was not further studied.

Symptoms. Because of the possible simultaneous involvement of more than one species of soil-borne pathogenic fungi from two genera, it is difficult to differentiate which damages are caused by which pathogen. Therefore, the symptoms and the disease are often reported as a complex disorder and are also considered in this way here.

Three main types of the symptoms can be observed: on leaves, it appears as wilt, discolouration, and defoliation; on wood as vascular tissue discolouration due to the production of toxins and plugging of vessels; decline as stunting and dieback (Hiemstra, 1998). In the summer, wilt symptoms are visible in the canopy of the main trunk. The trunk, branches, and shoots of severely affected sea buckthorn usually are dry, lose turgor, are bare without leaves, and easily break. The yellowing of the leaves followed by necrosis and stunting of the diseased plants compared to the healthy plants from the same variety are typical symptoms (Kennedy, 1987; Khovalyg, 2005; Fefelov, 2011; Cotuna *et al.*, 2014). In studies in Romania, the primary root cortex was softened, decayed, and brown-reddish in plants infected with *Verticillium*; 25% of roots of diseased plants had decay symptoms, and browning of the vascular tissues was noticed (Cotuna *et al.*, 2014).

The early symptoms of the disease may vary depending on the geographical origin of the sea buckthorn cultivars. Cultivars of Siberian origin in Russia initially showed wilting, yellowing leaves and falling in the lower part of the bush. The bark of branches and trunks of drying plants becomes reddish, orange and swollen. No synchronous death of all plants was observed; the observation were made in mid-June and at the end of August (Fefelov, 2011). For sea buckthorn of southern and Kaliningrad origin, two types of wilt or drying have been observed: acute and chronic. In acute wilting, leaves on individual perennial branches or the whole plant suddenly wither, turn yellowish-brown, but do not fall off until the end of the vegetation season. Chronic wilting is similar to drying and lasts for a long time; leaves of such plants have a dull sheen (Fefelov, 2011). Plants damaged by frost and exposed to drought or excessive moisture are more susceptible to the disease (Harris, 1998; Khovalyg, 2005; Khovalyg and Toropova, 2017). In Romania, the first disease symptoms appeared in the first year after planting, and the planting material was suspected to be infected already in the nurseries (Cotuna *et al.*, 2014). Development of symptoms may take some time, and the infec-

tion may be latent, as *V. dahliae* was also isolated from sea buckthorn without symptoms (Sholberg *et al.*, 2005).

One of the contributing factors to wilt development is damage of the sea buckthorn roots during the winter due to excessive soil moisture and higher temperatures when the ground is not frozen and covered with snow (Fefelov, 2011). Drought or excessive moisture weakens plants and promotes infection with soil-borne pathogens. Studies in Russia have shown that the highest mortality due to wilt was observed in three- to seven-year-old plants, reaching a maximum in the fifth year (29%) (Fefelov, 2011). The peaks of plant mortality were not weather dependent, but correlated with plant age. Plant tolerance to wilt or drying was concluded to be of great importance to the severity of disease damages, as the pathogens were present in the soil at all times, and the ecological conditions were the same. Therefore, increased attention should be paid to the selection of tolerant varieties and plant resistance or susceptibility to wilt during the first seven years (Fefelov, 2011).

Control possibilities. The possibilities for control of wilt or drying are limited because causal agents are soil-borne fungi, and fungicides are not available. Due to the presence of microsclerotia, *V. dahlia* can survive in the soil for many years and rapidly spread when susceptible hosts are present (Harris, 1998; Song *et al.*, 2020). Soil can be sterilised by heat or chemical fumigation (Gomiero, 2019). Replanting in affected soils, even with sea buckthorn varieties resistant to *Verticillium* wilt, is recommended only after soil sterilisation or not earlier than after 3–5 years (Cotuna *et al.*, 2014).

Plant genetic resistance is the most effective measure to control *Verticillium* wilt (Harris, 1998; Song *et al.*, 2020). Several varieties with high tolerance were identified in studies of sea buckthorn resistance to wilt in Belarus (Shalkevich *et al.*, 2015).

Preventive measures have an essential role in controlling soil-borne diseases; therefore, it is recommended to control weeds, apply mineral fertilisation, perform sanitary pruning, and provide plants with irrigation during drought periods (Harris, 1998; Pilat *et al.*, 2015). Recommendations for infected plantings are the cutting, removing and burning of the diseased plants from all areas affected by the pathogen (Harris, 1998; Cotuna *et al.*, 2014; Pilat *et al.*, 2015).

In the studies on *V. dahlia* pathogenicity on sea buckthorn in Canada (Sholberg *et al.*, 2005), the pathogen was also isolated from control plants, indicating that some of the cuttings used in the trial were already infected with *V. dahliae* before they were inoculated. The findings indicate that plant material in the nurseries may have latent infections; therefore, the scion wood used for cuttings should be tested for the presence of *V. dahliae* because the pathogen is widespread and can be present in branches that appear healthy (Sholberg *et al.*, 2005; Singh, 2018). A recommendation for growers is to make sure that their nursery stock is not infected and to test soil for the presence of the pathogen before planting a new orchard (Harris, 1998; Sholberg *et al.*, 2005; Singh, 2018).

DRIED-SHRINK DISEASE

The dried-shrink disease refers to the widespread overall decline of sea buckthorn in China. It is characterised by various damage symptoms on trunks, branches, drying and death of the shrubs. This disease in China has expanded on a large scale and has caused severe damages to cultivated and wild sea buckthorn populations (Luo *et al.*, 2008). The dried-shrink disease has also been reported in Sweden and Russia (Ruan *et al.*, 2010).

Pathogens. Precise information on the causes of dried-shrink disease is insufficient. The described symptoms and identified pathogens overlap with sea buckthorn wilt and drying reported from other regions. This overlap may be due to parallel studies in different sea buckthorn growing regions and naming of the disorder. Some of the symptoms of wilt and dried-shrink are the same or very similar, and identification of the pathogen in both cases reveal several species, or the pathogens are identified only at the genus level. Since it has been reported as a separate devastating sea buckthorn disease and a wider range of symptoms, and as associated pathogenic fungi have been described, we distinguish it as a separate disorder also in the current review.

In China, several pathogenic fungi, such as *Fusarium acuminatum*, *F. oxysporum*, *F. camptoceras*, *F. sporotrichioides*, and *Phomopsis*, have been identified and proved by biotests as causes of dried-shrink disease (Ruan *et al.*, 2010; Xia *et al.*, 2021). *Fusarium sporotrichioides* (as syn. *F. sporotrichiella*) in Russia has been reported as cause of wilt of fruits (Osipan and Martirosian, 1984). In northwest China (Xia *et al.*, 2021), *F. sporotrichioides* on twelve Chinese and Russian sea buckthorn cultivars caused stem wilt that resulted in high mortality (over 70%) of 5-year-old trees in late July. *Diaporthe* and *Fusarium* species were also associated with sea buckthorn decline and dieback in Latvia (Moročko-Bičevska *et al.*, 2019).

Dothidea hippophaes (as syn. *Plowrightia hippophaes*) has also been associated with dried-shrink disease in China (Sun and Hong, 2012). This fungus was also reported in Europe on dead branches of sea buckthorn collected in Switzerland (GBIF, 2021b); however, this report needs to be verified.

The pathogens associated with the dried-shrink disease are known to cause various diseases on many host plants. For example, *F. sporotrichioides* causes soybean root rot (Abdelmagid *et al.*, 2020); it is commonly found on cereals and is known as a toxin-producing pathogen (Abramson, 1999). *F. oxysporum*, *F. camptoceras* and other fungi of this genus cause vascular wilt of babaco (*Vasconcellea heilbornii* var. *pentagona* Badillo) in southern Ecuador (Robles-Carrión *et al.*, 2016). Various physiological forms of *Fusarium oxysporum* are pathogens of herbaceous and woody plants, mainly distributed in warm temperate and tropical regions (Jacob *et al.*, 2004). Fungi of the genus *Diaporthe* (syn. *Phomopsis*) cause various diseases on several host plants (Udayanga *et al.*, 2011); for example, 76 *Diaporthe* isolates

were recovered from wood cankers of cultivated grape, pear, apricot, almond and the wild host willow in four California counties (Lawrence *et al.*, 2015). Several *Diaporthe* (*Phomopsis*) species, such as *P. fukushii*, *P. amygdali*, *D. eres*, and *D. neotheicola*, were associated with the pear shoot cankers in China (Bai *et al.*, 2015). *Diaporthe* species have also been isolated from stem-end rot tissues of several mango cultivars (Lim *et al.*, 2019).

Symptoms. Described symptoms for dried-shrink disease (Ruan *et al.*, 2009a; 2010; Sun and Hong, 2012) include chlorotic and pale leaves, spots on leaves, shoot decay, branches with cracks, shrinkage, dry up, sporadic yellow dots on damaged tissues, and plant destruction. Fruits do not develop properly and retain a pre-mature colour; they may drop early at the end of June, decreasing fruit yield. The branches start to bend down, then they dry up and usually die before July. If the plant is severely infected, it dies in late summer. Some infected plants survive the winter, but the leaves do not fully develop in the following year, resulting in the infected plant's death. In China, this disease decreases fruit yield by 20–40% and leads to the destruction of sea buckthorn plantations at a large scale (over 10 000 hectares per year) (Ruan *et al.*, 2009a).

Symptoms caused by *F. sporotrichioides* were described to be massive chlorosis and drooping of leaves, dried-up stems, and irregular light-brown discolouration in the xylem of tree roots and stems (Xia *et al.*, 2021).

Long-term observations on dried-shrink disease in China (Ruan *et al.*, 2009a; Ruan *et al.*, 2010) have shown that the main damage often occurs on the tree-neck, growth vigour of infected plants gradually weakens and plants die one to two years after infection. The dried-shrink disease affects plants older than three years. Death of the stem above the infected plant part usually does not influence the normal growth of other stems. In addition, root vitality can be maintained if the infected plant parts are cut off.

Control possibilities. There are no specific control methods suggested to control dried-shrink disease; which could also be complicated because of the diverse damages described and pathogenic fungi associated with this disorder that require further detailed studies on disease epidemiology and its causes. Root vitality can be maintained if the infected plant parts are cut off, thus resulting in the regeneration of a new plant (Ruan *et al.*, 2009a; Ruan *et al.*, 2010). Some work has been started to study sea buckthorn resistance to dried-shrink disease and to develop molecular markers that could be used in breeding programmes to select plant lineages resistant to this disease (Ruan *et al.*, 2009b; Li *et al.*, 2010). In the case of sea buckthorn dried-shrink disease, it is difficult to select materials with pathogen resistance, because all plants affected by the dried-shrink disease are more than three years old (Ruan *et al.*, 2009a; 2010). Such markers could be helpful for breeders to distinguish resistant seedlings or hybrids at an early stage of sea buckthorn breeding (Li *et al.*, 2010).

STEM CANKER

Stem canker is spread worldwide and affects stems, branches and also leaves of sea buckthorn, sometimes resulting in the death of shoots and entire bushes. Similarly, as in other diseases, several fungal pathogens have been reported as causes of sea buckthorn stem canker, depending on the study region and time.

Pathogens. *Stigmina hippophaes* and *Stigmina* sp. as among the main causes of stem canker have been reported in Russia (Khovalyg, 2005), China (Luo *et al.*, 2008), and Finland (Parikka and Karhu, 1998; Prokkola, 2003). In Finland, sea buckthorn plants were found to be very susceptible to stem canker caused by *Stigmina* sp. (Parikka and Karhu, 1998; Prokkola, 2003). Pathogenicity tests on sea buckthorn leaves in Finland (Fabritius and Koponen, 2004) showed that *Stigmina* also causes leaf spots on sea buckthorn leaves (Fabritius and Koponen, 2004).

Stigmina sp. found on sea buckthorn seems to be adapted to cool climate. The optimum growth and spore production were at +15 °C to +20 °C, and maximum at +25 °C (Parikka and Karhu, 1998). *Stigmina* development was abundant at +5 °C, indicating that it is well adapted to lower temperatures. Therefore, it was suggested (Fabritius and Koponen, 2004) that *Stigmina* can reproduce on sea buckthorn leaves in the autumn and early spring before the temperature rises. *Stigmina* sp. was also suggested as the probable cause of berry damage, especially in wet summers, but is not seen as a severe problem yet (Kauppinen, 2013). *Stigmina* sp. produces spores on dead buds and cankers (Parikka and Karhu, 1998; Prokkola, 2003).

Hymenoplectra hippophaeicola (syn. *Lepteutypa hippophaes*) has been associated with cankers and dead wood of sea buckthorn in several regions of Europe (Jacklisch *et al.*, 2016; GBIF, 2021a). Several fungi obtained from diseased sea buckthorn tissues in Latvia showing canker symptoms were identified as *Lepteutypa* (Moročko-Bičevska *et al.*, 2019). It has also been reported from Armenia (Osipan and Martirosian, 1984) as the cause of sea buckthorn canker and forming numerous black perithecia on living and dead branches (as *Melanomma hippophaes*, syn. of *H. hippophaes*; for taxonomy see Jacklisch *et al.*, 2016). The fungus was reported to be widely found in Siberia, Russia on sea buckthorn branches associated with necrosis. It was reported to be in its conidial state *Monochaetia ampelophila* when causing ring necrosis (Osipan and Martirosian, 1984; Khovalyg, 2005); however, no data have been provided for teleomorph anamorph connections, and these records need to be verified.

Studies in Finland have shown that damaged sea buckthorn shoots are infected with *Lepteutypa* (Fabritius and Koponen, 2004). *Lepteutypa* and *Stigmina* have been found together several times on diseased plant parts, and it was suggested that they possibly induce the disease together. However, only *Lepteutypa* sp. was detected in some of the samples and was concluded as the main cause of sea buck-

thorn canker (Fabritius and Koponen, 2004). Leaf inoculation experiments in Finland (Fabritius and Koponen, 2004) showed that *Lepteutypa* could cause leaf spots on sea buckthorn leaves, similar to that caused by *Stigmina*. Active development of *Lepteutypa* sp. requires a higher temperature than *Stigmina* (15 °C), but like *Stigmina*, spore germination test on *Lepteutypa* showed that it also germinates well at temperatures up to +5 °C and can thus develop in spring and autumn at relatively low temperatures (Parikka and Karhu, 1998; Fabritius and Koponen, 2004).

Cytospora hippophaes was reported as a pathogen on sea buckthorn twigs and branches associated with canker (Osipan and Martirosian, 1984; Fan *et al.*, 2015). In northern China, *C. hippophaes* is associated with stem canker, and also it has been found in Australia, Spain, and Armenia (Osipan and Martirosian, 1984; Fan *et al.*, 2015). *Cytospora ambiens* has been reported as the cause of canker in Armenia (Osipan and Martirosian, 1984). *Cytospora chrysosperma* was diagnosed as the cause of stem canker on sea buckthorn in Canada (Manitoba Agriculture, Food and Rural Initiatives Crop Diagnostic Centre) (Desjardins *et al.*, 2005). *Cytospora* species are important plant pathogens causing severe canker diseases worldwide and having a broad host range (Osipan and Martirosian, 1984; Fan *et al.*, 2015). Several *Cytospora* species are known as causes of cankers on woody hosts, including various fruit crops (Fan *et al.*, 2015; Kopley and Jacobi, 2000).

Symptoms. Stem canker disease caused by *Stigmina* often starts from the buds, and lesions develop as concentric rings resulting in the death of shoots or even entire bushes (Parikka and Karhu, 1998; Prokkola, 2003). Stem canker usually destroys previous year shoots. The symptoms are purple-brown, slightly sunken lesions developing around the buds and on the branches of lateral shoots, which later darken and form pits. The shoot dies if the canker enlarges girdling it, and new stems or suckers grow when the older stems die because the roots are not affected. If the lesions do not enlarge around the shoot, the lesions develop as cankers on stems and twigs. The cankers are elliptical, 0.5 to 7 cm, in length and girdle the stems, which wilt or produce abnormal growth. The heaviest losses occur when the disease attacks young bushes. Severely infected shoots do not produce berries and usually die (Parikka and Karhu, 1998; Prokkola, 2003). On leaves (Fabritius and Koponen, 2004), *Stigmina* cause spots that are rounded and dark in colour, and gradually the leaf becomes completely almost black. The mycelium grows under the bark, and the spore mass protrudes out of the cracking surface. Wild sea buckthorn has relatively little damage caused by these fungi, while Russian origin, high-yielding varieties are very susceptible and suffer from severe stem damage (Parikka and Karhu, 1998; Prokkola, 2003).

In Russia, damage on twigs, shoots, leaves and fruits was associated with *S. hippophaes* (Khovalyg, 2005; Khovalyg and Toropova, 2017). Spots on the leaves gradually increase. Non-affected leaf parts become chlorotic, but damaged parts become necrotic. Rounded, grey spots are typical

on the berries. As the berries ripen, these spots become black, dense and have smooth edges. The flesh of the berries become black, then they curl and wither. Yield losses can reach up to 50% (Khovalyg, 2005; Khovalyg and Toropova, 2017). The pathogen overwinters in the form of mycelium in plant residues and on infected sea buckthorn. Wet weather during conidia dispersal favours the infection (Khovalyg, 2005).

The disease symptoms associated with *Cytospora* fungi are death of bark of the branches that become reddish-brown, the damaged tissues crack, and the cambium dies. In Armenia, *Cytospora* is usually observed on branches damaged by winter frosts (Osipov and Martirosian, 1984). Cankers associated with *C. ambiens* were observed on the stem bases, branches, shoots and around buds as cracks and swollen tissues at the edges of cankers due to cell hyperplasia and hypertrophy due to the fungal infection (Khovalyg, 2005; Khovalyg and Toropova, 2017). In the places of cracks, the wood is exposed (Khovalyg, 2005). Damaged parts brown and dry out. On the bark, the dark brown solid pycnidium groups are formed. Infected plants do not form or grow shoots from dormant buds. Local necrosis is also observed on the shoots. The disease contributes to premature leaf fall. Symptoms are usually seen from May to September. The pathogen asexual and sexual spores overwinter in the pycnidia and perithecia on infected plants and on fallen branches. Moisture contributes to the spread of the pathogen (Khovalyg, 2005). In Russia, the number of locally damaged plants does not exceed 10%, and they are moderate, and the loss of yield quantity and berry quality is not significant (Khovalyg, 2005; Khovalyg and Toropova, 2017).

Among fungi obtained from the diseased sea buckthorn branches in Latvia showing canker and decline symptoms, fungi belonging to *Eutypa* were also recovered (Moročko-Bičevska *et al.*, 2019). *Eutypa* species are well known as causes of dieback and canker, e.g., *Eutypa lata* is one of the major trunk pathogens of grapevines (Živković *et al.*, 2019). However, the pathogenicity of these fungi on sea buckthorns need to be further characterised.

Control possibilities. Sanitary pruning by cutting out diseased branches and shoots and destroying the remains of damaged plants is recommended to control sea buckthorn cankers. Balanced mineral fertilisation and the growing of resistant varieties are important to reduce disease impact (Khovalyg, 2005). No fungicide treatments have been recommended as sea buckthorn are grown mainly in organic farming systems.

Studies in Finland showed that climatic conditions greatly influenced stem canker development; the damage was more severe in the coastal area than inland (Parikka and Karhu, 1998). Elevated temperatures for a long time in autumn may cause heavy infections (Prokkola, 2003). It is recommended to choose varieties that are not only resistant to stem canker but also tolerant to frost, ensuring that no additional damage occurs.

LEAF AND BERRY DISEASES

Several damages are increasingly observed not only on the shoots, stems and branches but also to leaves and berries, affecting not only the yield but also the overall health of the plant. Several pathogens have been identified associated with sea buckthorn leaf diseases. Most of the studies have been done in Russia.

With *Septoria hippophaes* infection, yellow spots initially form at the top of the leaf, which later turns dark brown with a light circle around the spots. The leaves turn brown and fall early from the bush (Khovalyg, 2005; Khovalyg and Toropova, 2017).

Phyllosticta hippophaes was reported to cause irregular brown spots on leaves. The spots appear on the edges of leaves in early July. Damaged tissue crumbles and falls out, changing the shape of the leaves and resembling pest damages. The pathogen also infects stems and fruits, reducing quality (Khovalyg, 2005; Khovalyg and Toropova, 2017).

Phomopsis sarmentella (syn. *Phoma sarmentella*) damage is observed on leaves as dark brown spots with reddish-brown edges covering the entire surface of the leaf. The leaves curl, and become crumpled and whitish (Khovalyg, 2005; Khovalyg and Toropova, 2017).

Leaf scald of sea buckthorns is associated with *Rhynchosporium hippophaes* in Russia. The surface of the leaves turns brown, followed by light brown and dark brown spots with a broad light-yellow border. Photosynthesis and growth of the plants are disrupted (Khovalyg, 2005; Khovalyg and Toropova, 2017).

Coryneum elaeagni is associated with necrosis on sea buckthorn leaves, branches and shoots. The damage starts from the edges of the leaf, the spots in the centre are light, and the edges have a thin brown border with a black tinge. The fungus overwinters as mycelium in infected branches, shoots and sea buckthorn plant residues (Khovalyg, 2005).

In addition to these diseases, there are other pathogens reported to damage berries. In some years, a fruit disorder named “endomycosis” of fruits was observed but is not considered to cause significant damage. *Botrytis cinerea*, *Capnodium* sp., *Monilia altaica*, and *Penicillium hordei* have been associated with these damages (Garanovich *et al.*, 2009; Shamanskaya, 2009). *Botrytis cinerea* was reported as causing sea buckthorn fruit grey mould. Small brownish spots develop, berries shrink, and a thin grey coating appears on the cuticle. *Monilia altaica* was reported on berries, causing rounded, light spots that gradually increased and covered the whole berry. It has been reported from Russia and China (Khovalyg, 2005; Luo *et al.*, 2008). *Phyllactinia hippophaes* infection was reported on sea buckthorn fruits as white, fluffy mycelium (Khovalyg, 2005), while *P. miracula* was indicated as the cause of powdery mildew on leaves of sea buckthorn (Paul, 2003).

OTHER DISEASES

Among the diseases reported on sea buckthorn, the sea buckthorn decay disease has also been recorded. The associated pathogens were *Pythium* sp., *Alternaria* sp., *Botrytis* sp., *Valsa* sp., *Fomes* sp. (Luo *et al.*, 2008; Ming *et al.*, 2008; Garanovich *et al.*, 2009; Cotuna *et al.*, 2014). In nurseries in the northern part of India, sea buckthorn root-rot caused by *Rhizoctonia solani* has been observed (Singh, 2018).

Fomitiporia hippophaeicola (syn. *Phellinus hippophaeicola*) has been reported as a pathogen causing significant losses in sea buckthorn forests in western China (Meiqing and Yucheng, 1997). This is a bracket fungus that grows on older, living branches of sea buckthorn.

In Germany, where healthy and diseased parts of the damaged sea buckthorn branches were analysed, *Alternaria* and *Phytophthora* were found together with *Verticillium* (Höhne, 2015). When more plant parts were diseased, also more *Alternaria* and *Phytophthora* co-infection could be found (Höhne, 2015), but their role in the damage needs to be further studied.

CONCLUDING REMARKS

There are many diseases reported causing more or less significant damage to sea buckthorn worldwide. The described symptoms included necrosis, decline, wilt, cankers, root rots, leaf spots and berry damages, sometimes resulting in significant yield losses or even plant death. Damage is caused by various fungi on all parts of sea buckthorn — berries, leaves, shoots, branches, stems, and roots. The severity of the reported diseases varies among regions, age of the plants, and weather and growing conditions (e.g., soil moisture). As the damage is caused by various pathogenic fungi and often by a complex of several pathogens, preventive measures, favourable growth conditions for plants, growing of resistant and regionally adapted varieties play essential roles in disease control.

Although many symptoms and associated pathogenic fungi species have been reported, information about several diseases and their causal agents is incomplete, and studies are at an early stage. Moreover, information about the sea buckthorn diseases is mostly available in various conference proceedings and abstracts, and relatively few studies are published in peer-reviewed journals. The studies are often not continued in detail, and Koch's postulates are still not fulfilled for several reported fungi. Among many fungi listed on sea buckthorn, the pathogenicity and disease symptoms verified by bioassays have been demonstrated only in a few cases, such as *V. dahlia* as the cause of wilt in the United Kingdom (Kennedy, 1987), *F. sporotrichioides*, *F. acuminatum*, *F. oxysporum*, *F. campdoceras* as primary causes of dried-shrink disease in China (Ruan *et al.*, 2010; Sun and Hong, 2012; Xia *et al.*, 2021), and *Stigmata* sp. and *Leptotypha* sp. as causes of stem canker and leaf spot in Finland

(Parikka and Karhu, 1998; Fabritius and Koponen, 2004). In addition, new sea buckthorn pathogens are being discovered. With the increase of planting area and the age of cultivated sea buckthorn plants, new symptoms of diseases and relationships of various pathogens and damages are observed. The described symptoms overlap for various diseases, and often several pathogenic fungi are reported as causes, indicating the complex nature of the observed disorders. As sea buckthorn pathogens have been identified in different regions at different times, there are currently many synonyms in the classification. Future research is needed for precise characterisation of the pathogens, their spread in different cultivation regions, caused symptoms verified in bio-tests, and teleomorph and anamorph connections.

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PATOGĒNO SĒŅU IEROSINĀTAS SMILTSĒRKŠĶU SLIMĪBAS

Smiltsērķšķi (*Hippophae rhamnoides* L.) ir vietējā suga Āzijā un Eiropā, to audzē kā daudzfunkcionālu dārkopības augu Eiropas, Āzijas un Ziemeļamerikas reģionos. Smiltsērķšķim ir plašs ekonomiskais potenciāls, to izmanto pārtikā, farmācijā, kosmētikā un apstādījumos vides saglabāšanai. Gan dabiskajās populācijās, gan stādījumos pieaug slimību spektrs un izplatība, apdraudot smiltsērķšķu ilgtspējīgu audzēšanu visā pasaulē. Šis apskata raksts vērsts uz patogēno sēņu ierosinātu smiltsērķšķu kalšanu un vēzi, to izplatību, simptomiem un saimniekaugiem. Pieejamā informācija par sēņu ierosinātām smiltsērķšķu slimībām pārsvarā ir par vīti (*Verticillium dahliae*), kalšanu, ko ierosina vairākas sēnes līdz ar abiotisko faktoru ietekmi, un stumbra vēzi (*Hymenopleella hippophaeicola*, *Cytospora* spp., *Stigmata* sp.). Dažas literatūrā minētās sēnes kā smiltsērķšķu patogēni ir maz pētītas, vai smiltsērķšķi ir jauns saimniekaugs, piemēram, *Eutypa* spp. gadījumā. No simptomiem biežāk novēroti ir vēzis un plaisāšana uz zariem un stumbra, bojāti pumpuri un lapas, audu nekroze uz zariem un saknēm, kā rezultātā augi iet bojā. Informācija par smiltsērķšķu slimībām un to ierosinātājiem ir nepietiekama, nepieciešami padziļināti pētījumi.