Soilborne Diseases of Red Currant

A.(Asmaa)Youssef and M.(Marcel) Wenneker

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How can you recognize them? What are the control strategies?

A. (Asmaa) Youssef and M. (Marcel) Wenneker

Wageningen University & Research, Open Teelten Randwijk, Postbus 200, 6670 AE Zetten

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Summary

Red currant (*Ribes rubrum*) and other small fruit species are important fruit crops in the Netherlands. Red currant, along with other small fruits are affected by a wide range of soilborne pathogens (SBPs) and nematode-transmitted viruses (NTVs) causing severe yield losses if not diagnosed and managed properly. Fusarium and Verticillium wilts are serious SBPs affecting red currant. *Fusarium* and *Verticillium* spp. are associated with the death of red currant bushes. Currant cane dieback or stem blight is another serious soilborne disease affecting red currant, which is associated with cane dieback symptoms. Canker or stem blight of red currant is caused by the fungus *Botryosphaeria ribis* (syn. *Neofusicoccum ribis*). The NTVs; *Arabis mosaic virus* (ArMV*), Strawberry latent ringspot virus* (SLRSV), *Raspberry ringspot virus* (RpRSV), *Tomato black ring virus* (TBRV), *Tomato ringspot virus* (ToRSV), and *Tobacco rattle virus* (TRV) infect red currant. ArMV, SLRSV, RpRSV, TBRV and ToRSV are transmitted by nematode species from the family Longidoridae; *Paralongidorus*, *Longidorus*, and *Xiphinema*. TRV is transmitted by numerous species of the nematode genera *Trichodorus* and *Paratrichodorus.* The NTVs; ArMV, RpRSV, SLRSV, TBRV, ToRSV and TRV are controlled through growing virus-free plant materials and controlling their nematode vectors. Accurate diagnosis of plant diseases is crucial for developing efficient and cost-effective disease management strategies. There are several control methods of SPBs. The key factor in controlling SBPs is resistant rootstocks. Planting pathogen-free bushes is important for minimizing the primary source of inoculum of SBPs. Developing suppressive soil may be a good management strategy against SBPs. Organic soil amendments and biofungicides may be used for suppressing SBPs. In addition, anaerobic soil disinfestation using biobased products is a control method of SBPs, which has been shown under experimental conditions to be effective against SBPs*.* Chemical control only is not effective in managing SBPs. All mentioned management strategies of SBPs have limited efficiencies, as single control methods, in managing SBPs. Therefore, an integrated pest management program is required to effectively control SBPs.

Keywords: soilborne, *Fusarium*, *Verticillium*, *Botryosphaeria*, dieback, canker, stem blight, red currant, currant, virus, nematode-transmitted

1 Introduction

Red currant (*Ribes rubrum*) and other small fruit species are important fruit crops in the Netherlands. The harvested area of red currant, raspberry, and blackberry in the Netherlands was estimated to be 610 hectares (ha) and the harvested area of black currant was estimated to be 180 ha in 2021 (https://www.cbs.nl/). Red currant, along with other small fruits are affected by a wide range of soilborne pathogens (SBPs) and nematode-transmitted viruses (NTVs) causing severe yield losses if not diagnosed and managed properly. SBPs, such as *Fusarium* spp. and *Verticillium* spp., are routinely diagnosed using selective growing media (used for selecting targeted bacterial or fungal pathogens) (Anne van Diepeningen, Wageningen Plant Research, personal communication, 2021). Currently, various molecular-based methods are applied for the identification and characterization of plant pathogens, including SBPs, such as polymerase chain reaction (PCR), quantitative PCR (qPCR), and microbiome analyses based on sequencing of fungal ITS regions (Malarczyk *et al*., 2019; Anne van Diepeningen, personal communication, 2021). This report aims to present the most important SBPs and NTVs infecting red currant and their control strategies.

Fusarium and Verticillium wilts are serious SBPs affecting red currant. *Fusarium* and *Verticillium* spp. are associated with the death of red currant bushes (Johan Sonneveld, Proeftuin Randwijk, personal communication, 2021). Several *Fusarium* spp. affect numerous species of small fruits causing root rot and wilt, where *F. solani* is associated with both of these symptoms (Pérez *et al*., 2007; Valiuškaitė *et al*., 2008; Pérez and Berretta, 2011). *F. oxysporum* is associated with wilt and bush failure in red currant in the Netherlands (Harteveld, 2020) **(Table 1)**. *Verticillium* spp. attack various species of fruits, vegetables, flowers, and forest trees, including red currant. Most *Verticillium* species are not host-specific, and symptoms of infection vary among host species. Thus, there are no universal signs of the disease on the plant (Malarczyk *et al*., 2019). *Verticillium dahliae* and *V. alboatrum* were found to be associated with Verticillium wilt in red currant, black currant (*R. nigrum*), and gooseberries (*R. grossularia*). *V. dahliae* causes Bangert disease in red currant. Verticillium wilt or Bangert disease induces verticilliosis symptoms. Verticilliosis is characterized by spongy and watery tissue exudates from the cortex of infected canes and stems, in addition to discoloured wood vessels (van der Meer, 1925) **(Table 1, Appendices Fig. 1)**. The association of *V. alboatrum* with Verticillium wilt in red currant was not reported in the Netherlands. Verticillium wilts easily spread via contaminated plant material, soil, and equipment. Conidiospores of *V. dahliae* and *V. alboatrum* are also spread via wind. *Verticillium* spp. produce microsclerotia, tiny resting structures, which can survive in the soil for more than 25 years (Wilt & Hartman, 1996; Goicoechea, 2009; Malarczyk *et al*., 2019). Currant cane dieback, canker or stem blight is another serious soilborne disease affecting red currant, which is associated with cane dieback symptoms **(Appendices Fig. 2)**. Stem blight of red currant is caused by the fungus *Botryosphaeria ribis* (syn. *Neofusicoccum ribis*) (Singer and Cox, 2010) **(Table 1)**.

The NTVs; *Arabis mosaic virus* (ArMV*), Raspberry ringspot virus* (RpRSV), *Strawberry latent ringspot virus* (SLRSV), *Tomato black ring virus* (TBRV), *Tomato ringspot virus* (ToRSV), and *Tobacco rattle virus* (TRV) infect red currant (van der Meer, 1987a; 1987b; 1987c; EFSA PLH Panel, 2013). The *Spoon leaf virus* (SLV) is an isolate of RpRSV and closely related to the Scottish RpRSV (van der Meer, 1965), and the *Currant ringspot virus* is a strain of ToRSV (Hildebrand, 1942). Infections with this group of viruses are usually symptomless if they have been present in the plant for a long time. Recent infections often cause symptoms **(Appendices Fig. 3, 4, 5, 6, 7 & 8)**. Large outbreaks of these NTVs lead to considerable economic losses. These six NTVs are also mechanically transmitted through wounds, grafting, and vegetative propagation. In addition, ArMV, SLRSV, RpRSV, TBRV, ToRSV, and TRV were reported to be seed and pollen transmissible in other small fruit species, *e.g*., raspberry (CABI & EPPO, 2001; EFSA PLH Panel, 2013; Špak *et al*., 2021).

ArMV, SLRSV, RpRSV, TBRV and ToRSV are transmitted by nematodes species from the family Longidoridae (syn. Longidorids); *Paralongidorus*, *Longidorus*, and *Xiphinema*. Longidorids are migratory root ectoparasites as they feed on the outer part of plant roots. Longidorids cause enormous damage to a wide variety of plants, in addition to being vectors for plant viruses. ArMV and SLRSV are transmitted by *X. diversicaudatum. X. diversicaudatum* is present in the Netherlands (CABI & EPPO, 2001; EFSA PLH Panel, 2013). ToRSV is transmitted by *X. americanum sensu lato* (CABI & EPPO, 2001). Other *Xiphinema* species are suggested to be possible vectors of ToRSV, for instance, *X. americanum* (Fry & Wood, 1978; CABI & EPPO, 2001)*, X. californicum, X. incognitum, X. occidium, X. pachtaicum, X. rivesi, X. thornei,* and *X. utahense* (CABI & EPPO, 2001). RpRSV is transmitted by *L. ematodes, L. elongatus, L. macrosoma,* and *P. maximus* (van der Meer, 1965; Richter *et al*., 1966). *L. elongatus* is present in the Netherlands and was associated with red currant bushes infected with the Scottish RpRSV (van der Meer, 1965). *L. macrosoma* is also widespread in the Netherlands (van der Meer, 1965; EFSA PLH Panel, 2013). *P. maximus* is also present in the Netherlands. Moreover, TBRV is transmitted by *L. attenuatus* and *L. elongatus* (CABI & EPPO, 1992; EFSA PLH Panel, 2013). *L. attenuatus* is endemic in several European countries, including the Netherlands (EFSA PLH Panel, 2013). TRV is transmitted by numerous species of the nematode genera *Trichodorus* and *Paratrichodorus* (Špak *et al*., 2021). Remarkedly, elevated infections with ArMV and TBRV were associated with increased nematode populations (EFSA PLH Panel, 2013). ArMV, SLRSV, RpRSV, and TBRV are transmitted by the same nematode species. Consequently, these viruses are often found in mixed infections. SLRSV, RpRSV, and TBRV are present in the Netherlands with limited distribution, meanwhile, ArMV is widely spread. Furthermore, the nematode vectors of these soilborne viruses are also present in the Netherlands, and two of these nematode vectors, *L. attenuatus* and *L. macrosoma*, are widely spread in the Netherlands (EFSA PLH Panel, 2013). The presence of TRV is reported in the Netherlands (van der Meer, 1987b), along with its nematode vector (Ploeg, 1992). ToRSV is present in the Netherlands with limited distribution (EFSA PLH Panel, 2013; NVWA, 2020). In the Netherlands, the spread of ToRSV is restricted to the occurrence of vegetatively propagated ToRSV-infected plants and it is not transmitted to other plant species (NVWA, 2020). This is due to the absence of its nematode vector, *i.e*., *X. americanum sensu lato.* We have not found any reports regarding its spread in red currant cultivations.

2 Control methods

Accurate diagnosis of plant diseases is crucial for developing efficient and cost-effective disease management strategies (Scarlett *et al.*, 2019). There are several control methods of SPBs. The key factor in controlling SBPs is resistant rootstocks. Planting pathogen-free bushes is important for minimizing the primary source of inoculum of SBPs (Franken-Bembenek, 2008). The NTVs; ArMV, RpRSV, SLRSV, TBRV, ToRSV and TRV are controlled through growing virus-free plant materials and controlling their nematode vectors (EFSA PLH Panel, 2013). In the Netherlands, most starting materials of fruit crops are tested for these viruses as standard.

Fusarium wilt could be controlled through growing resistant cultivars, soil solarization, applying organic amendments, applying chemicals, and applying antagonistic microorganisms, *e.g., Streptomyces griseoviridis* (Valiuškaitė *et al*., 2008; Pérez and Berretta, 2011). Crop rotation for at least five years could control or minimize pathogen populations of Verticillium (Goicoechea, 2009) and Fusarium wilts. Rovada is the prevalent cultivar of red currant in The Netherlands. Rovada is very susceptible to *V. dahliae* and *V. alboatrum* (Balkhoven-Baart and Van Zuidam, 2002). Consequently, growing Rovada in *Verticillium*-infested areas will lead to frequent replanting due to wilting. Thus, grafting on *Verticillium*-resistant or -tolerant rootstocks may help with avoiding this problem (Balkhoven-Baart and Van Zuidam, 2002). Moreover, growing red currant in pots using pathogen-free plant material and potting soil is suggested to be an alternative solution to grafting on *Verticillium*-resistant rootstocks. Verticillium wilt could be controlled through pruning dead twigs and branches, applying high nitrogen fertilizer to promote tree vigour as soon as the pathogen is detected, not overwatering bushes, and eradicating symptomatic bushes (Wilt and Hartman, 1996). Controlling *Verticillium* spp. with chemicals only is not effective. Stem blight of red currant caused by *B. ribis* is controlled by pruning of infected plants. In addition, applying 11.2 kg/ha copper hydroxide (Kocide DF: 40% metallic copper equivalent) and 6.72 kg/ha sulfur (Kumulus DF) at 50% bud break and after about 14 days at 100% bud break reduced the incidence of dieback by > 80% compared with nontreated bushes (Singer and Cox, 2010). According to our best knowledge, this application is not permitted in red currant treatment in the Netherlands. The fungicides captan and trifloxystrobin were reported to be effective in controlling *Verticillium* spp. (Goicoechea, 2009). Although, to our knowledge, these fungicides are not permitted in red currant treatment in the Netherlands, moreover the efficiencies of these fungicides in practical application are thought to be disappointing (Heino van Doornspeek, Vlamings, personal communication, 2021).

Developing suppressive soil may be a good management strategy against SBPs. Organic soil amendments (OSAs) may be used for suppressing SBPs. Suppressiveness using organic soil amendments is often pathogen-specific, *i.e*. more effective for pathogens with a limited saprophytic ability (*e.g. V. dahliae*), and also dependent on the composition of organic matter with C-to-N ratio < 15. Examples of organic amendments that were proposed to suppress SBPs are animal manure, composts, crop residues, organic wastes, and peats (Bonanomi *et al*., 2007; 2010). OSAs are arranged based on their phytotoxicity as follows: peats < composts < organic wastes ≤ crop residues (Bonanomi *et al*., 2007). OSAs were effectively controlled: *Phytophthora* spp., *Fusarium* spp., and *V. dahliae* (Bonanomi *et al*., 2007; 2010). OSAs include crop residues, organic wastes, composts, and peats. OSAs differ in their effectiveness in suppressing or controlling different SBPs and in their phytotoxicity. Application of compost suppressed 74% of *Fusarium* spp., followed by crop residues 56%, and organic waste 46%. Application of compost reduced *Fusarium* spp. population by 67%, followed by organic waste 54%, and crop residues 50%. Comparatively, application of organic waste suppressed 81% of *V. dahliae* followed by crop residue 74%, and compost 61%. Application of organic waste reduced *V. dahliae* population by 82%, followed by crop residue by 78%. On the other hand, the application of peats did not result in significant disease suppression nor reduction in the pathogen population of *Fusarium* spp. and *Verticillium* spp. (Bonanomi *et al*., 2007). Mohamed *et al*. (2017) present promising results from the disease suppressive compost for suppressing *V. dahliae*. The genera of antagonistic bacteria found in the suppressive compost and were associated with pathogen suppression were: *Bacillus, Brevibacillus, Paenibacillus, Rummeliibacillus, Arthrobacter,* and *Pseudomonas*. Lipopeptide extracts from *Bacillus subtilis* and *Pseudomonas moraviensis* isolates were the most effective in inhibiting conidial germination of *V. dahliae* with an average of 91%. Extracts from *B. subtilis* and *B. megaterium* isolates inhibited the mycelial growth of *V. dahliae* by an average of 41% (Mohamed *et al.*, 2017). Application of *Pseudomonas fluorescens* strain P60 and *Talaromyces flavus* isolate Rl significantly inhibited mycelial growth and the formation of microsclerotia of *V. dahliae.* Combined application of *P. fluorescens* strain P60 and *T. flavus* isolate Rl reduced the number of *V. dahliae* microsclerotia by 26 fold for one of the tested *V. dahliae* isolates and 44 fold for the other tested isolate. Meanwhile, separate applications of both bio-antagonists reduced the number of microsclerotia by about 8 and 4 fold, respectively (Soesanto, 2000).

Trichoderma (formerly *Gliocladium*) spp. are opportunistic plant symbionts with multiple beneficial effects, including stimulation of plant growth and nutrient acquisition, induced resistance against root and foliar pathogens, and direct biological control of pathogenic fungi (Harman 2006). *Trichoderma asperellum* is supplied commercially for the control of root pathogens and nematodes in *Rubus* (Dolan *et al*., 2018). *Trichoderma* spp. can be effective for controlling root and wilt diseases by outcompeting or suppressing pathogenic fungi (Dolan *et al*., 2018). There are a wide range of *Trichoderma*-based products available in the EU market for suppressing and/or controlling SBPs, *e.g*., *Botryosphaeria* spp., *Fusarium* spp. and *Verticillium* spp. **(Table 2)**. These *Trichoderma*-based products have *Trichoderma* spp. as the main active substance or in combination with *Glomus* spp. and/or bacteria (Woo *et al.*, 2014) **(Table 2)**. Mycostop® is a biofungicide containing *Streptomyces griseoviridis* strain K61*,* which is an antagonistic microorganism that colonizes the rhizosphere of host plants and competes for nutrition and space with other soil microbes, in addition to producing antibiotics. Based on *in vitro* results, Mycostop® successfully suppressed numerous plant pathogens, such as *Fusarium* spp., *Pythium* spp., *Phytophthora* spp., *Phomopsis* spp., *Botrytis cinerea*, and *Rhizoctonia solani.* Mycostop® was aggressive against *F. oxysporum,* and *F. solani* in peat mulch substrate (Valiuškaitė *et al.*, 2008) **(Table 2)**. Another biofungicide used for controlling Fusarium wilt is Rootshield® that is based on *Trichoderma harzianum* strain KRL-AG2 (Islam *et al*., 2019) **(Table 2)**. Interestingly, pre-planting treatment of raspberry roots with *B. subtilis* M3, *B. subtilis* OSU-142 + M3 or co-inoculation of *B. subtilis* RCAM B-10641, *B. amyloliquefaciens* RCAM B-10642 and *B. licheniformis* RCAM B-10562 promoted plant growth and improved fruit productivity (Orhan *et al*., 2006; Islam *et al*., 2019). We have not found any reports yet regarding using the previously mentioned biocontrol agents and biofungicides in controlling SBPs in red currant, however, the available results about their suppression efficiencies against *Fusarium* spp. and *Verticillium* spp. are promising. Hence, there is a research need for testing the efficiencies of these biocontrol agents in controlling SBPs of red currant. According to our best knowledge, Trianum **(Table 2)** is the only biofungicide that is allowed to be used in red currants in the Netherlands.

Anaerobic soil disinfestation (ASD) using biobased products is a control method of SBPs, which has been shown under experimental conditions to be effective against SBPs, *e.g., V. dahliae* (Blok *et al.*, 2000). ASD requires incorporating fresh organic matter, *e.g*., crop residues, after wetting the soil to field capacity, then covering with plastic foil for several weeks. Blok *et al*. (2000) investigated that soil treatment with perennial ryegrass (as soil amendment) covered with plastic sheets strongly reduced *F. oxysporum* and *V. dahliae* inoculum after 15 weeks under field conditions. Herbie is a plant-based and protein-rich biodegradable product that was found to speed up the ASD process from six to two to three weeks (Runia *et al.*, 2014). Herbie 82 is a plant-based bioproduct, which has been developed for controlling SBPs in organic farming (https://thatchtec.nl/en/soil-resetting/soil-desinfection-with-herbie/). Herbie 82 was applied into sandy silt soil infested with *Verticillium* sclerotia at ~14% moisture, followed by sealing it in pots for eight weeks at an average temperature of 16°C resulted in a significant reduction in viability of microsclerotia *V. dahliae.* A significant reduction in viability of microsclerotia of *V. dahliae* was reported after Herbie 82 application (Xu *et al.*, 2017). ASD was effective in suppressing *Verticillium* under soil temperature of <16°C when higher crop residue rates were applied for a relatively long incubation period of 10 to 25 weeks, and under soil temperature of >16°C, the incubation period can be minimized to <3 weeks (Shrestha, 2016).

Table 1 *Soilborne diseases of red currant, their causal agents, symptoms, and control strategies.*

Disease name	Causal agent (s)	Symptoms	Control strategies	Reference (s)
Fusarium wilt	*F. oxysporum*	▪ Marginal leaf burn, ▪ brown discolouration, and ▪ wilt symptoms on plants	○ Growing resistant cultivars ○ Crop rotation, applying OSAs, soil solarization ○ Chemical control ○ Biofungicide application, *e.g.*, Mycostop® and/ or Rootshield® ○ Applying ASD	(Blok *et al.*, 2000: Valiuškaitė *et al.*, 2008; Islam *et al.*, 2019)
Verticillium wilt, Bangert disease	*Verticillium dahliae* *V. alboatrum*	▪ Spongy and watery tissue exudates from the cortex of infected canes and stems ▪ Discoloured wood vessels	○ Growing wilt-resistant rootstocks ○ Pruning dead twigs and branches ○ Do not overwater bushes ○ Applying high nitrogen fertilizer to promote tree vigour as soon as the pathogen is detected ○ Symptomatic bushes should be eradicated ○ Applying suppressive compost ○ Applying biofungicides and/or ASD	(van der Meer, 1925; Wilt & Hartman, 1996; Blok *et al.*, 2000; Mohamed *et al.*, 2017)
Cane blight/ dieback	*Botryosphaeria ribis* (syn. *Neofusicoccum ribis*)	Limb and cane wilting followed by the death of whole bushes.	○ Pruning infected, declining, and dead canes ○ Applying biofungicides and/or ASD	(Cox *et al.*, 2008; Singer and Cox, 2010)
Mosaic of strawberry, the yellow dwarf of raspberry	*Arabis mosaic virus* (ArMV)	▪ Symptomless ▪ Stunted plants ▪ Mosaic symptoms ▪ Chlorotic mottling ▪ Plant death	○ Growing virus-free bushes ○ Controlling the nematode vectors ○ Destruction of infected bushes	(van der Meer, 1987a; EFSA PLH Panel, 2013)
Latent ringspot of strawberry	*Strawberry latent ringspot virus* (SLRSV)			
Spoon leaf disease of red currant, ringspot of red currant	*Raspberry ringspot virus* (RpRSV = RRV; syn. *Spoon leaf virus;* SLV)	▪ Newly planted bushes are symptomless till the second year of planting ▪ Yellowish mosaic ▪ Spoon leaf symptoms and leaf deformation	Same as for ArMV and SLRSV	(van der Meer, 1960; 1965; 1987b; Richter *et al.*, 1966; Jones & McGavin, 1996; EFSA PLH Panel, 2013)
Black ring of tomato, ringspot of lettuce, the yellow vein of celery	*Tomato black ring virus* (TBRV)	▪ Symptomless ▪ Mosaic and mottling ▪ Chlorotic ringspots ▪ Leaf deformation and distortion	Same as for ArMV, SLRSV, and RpRSV	(CABI & EPPO, 1992; Jones & McGavin, 1996; EFSA PLH Panel, 2013)
American currant mosaic, ringspot of beet	*Tomato ringspot virus* (ToRSV; syn. *Currant ringspot virus*)	▪ Mosaic	Same as for ArMV, SLRSV, RpRSV, and TBRV	(Fry & Wood, 1978; CABI & EPPO, 2001)

Continue Table 1 *Soilborne diseases of red currant, their causal agents, symptoms, and control strategies.*

Disease name	Causal agent (s)	Symptoms	Control strategies	Reference (s)
Leaf pattern of red currant	*Tobacco rattle virus* (TRV)	▪ Oak leaf patterns in new leaves ▪ Light-green mosaic ▪ Not all leaves and not all branches are symptomatic	Same as for ArMV, SLRSV, RpRSV, TBRV and ToRSV	(van der Meer, 1987c)

3 Conclusion

Chemical control only is not effective in managing SBPs. All mentioned management strategies of SBPs have limited efficiencies, as single control methods, in managing SBPs. Therefore, an integrated pest management program (IPM) is required to effectively control SBPs. An IPM includes growing pathogen-free plant materials, selecting resistant cultivars, good agricultural practices, sanitation, applying OSAs and/or suppressive compost, ASD, and biological control. Chemical control could also be included when it is strictly necessary. Growing red currants in pots using pathogen-free plant material and potting soil is suggested to be a good strategy for avoiding problems with soilborne diseases.

The NTVs; ArMV, RpRSV, SLRSV, TBRV, ToRSV and TRV are controlled through growing virus-free plant materials and controlling their nematode vectors (EFSA PLH Panel, 2013). Fortunately, ArMV, SLRSV, RpRSV, and TBRV, in addition to TRV (van der Meer, 1987a; 1987b; 1987c) are of little economic importance and no recent reports claim the opposite. If a symptomatic bush or plant is observed, it should be sent for diagnosis as soon as possible or should be simply eradicated. Once the bushes are infected, there is no cure.

Table 2 *Commercial biobased fungicides, their active substances, intended use, product registration, and producer/ distributor.*

Biobased Fungicides	Active Substances	Intended Use	Producer/ Distributor	Product Registration
Binab T P	*T. atroviride* IMI206040 (formerly *T. harzianum* IMI206040) + *T. polysporum* IMI206039	Controls wilts and root rot of fruit trees	Binab bio-innovation eftr ab	R[1] in EU
Bioplantguard	*Trichoderma* spp., mycorrhiza, bacteria, fermentation products	Antagonistic to foliar and SBPs: *Fusarium, Verticillium*	Saipan SRL, Italy	NR[2], available for use
Bioten	*T. asperellum* ICC 012 + *T. gamsii* ICC080	Controls SBPs, such as *V. dahliae*	Isagro Spa, Spain	NR[2], available for use
Eco-T	*T. harzianum* strain kd	Controls *Fusarium* spp. and enhances plant growth	Plant Health Products(Pty) Ltd - http://www.plant-health.co.za/	R[1] in France, UK, South Africa, Zambia, Morocco, Tunisia, India
Esquive Wp	*T. atroviride* 1237	Controls dieback caused by *Botryosphaeria* spp.	Agrauxine, ZA de Troyalac'h (http://www.agrauxine.com/)	R[1] in EU, France
Gliomix	*T.* spp.	Prevention and control of SBPs	Verdera Oy (Formerly Kemira Agro Oy; https://verdera.fi/en/products/horticulture/gliomix/)	R[1] in Germany & Finland
Lycomax	*T. harzianum*	Suppresses SBPs	Russelli PM, UK (http://www.russellipm.com)	NR[2], available for use
Micosat F	*T. harzianum TH01,* + spp. of *Glomus* (3), *Agrobacterium, Bacillus, Streptomyces, Beauveria, Pichia*	Suppresses SBPs	C.C.S Aosta S.R.L., Italy	NR[2], available for use
Micover Gold Eplus	*T. harzianum, Glomus intraradices, Pseudomonas*	Suppresses SBPs	Agrifutur (http://www.agrifutur.com/)	R[1] in EU
Mycofungicyd (Trichodermin)	*T. viride*	Verticillium wilt and root rots	Bizar-agro LTD, Uktaine	R[1]
Mycostop[3]	*Streptomyces griseoviridis* strain K61	Suppresses SBPs, such as *Fusarium* spp.	Kemira Agro (https://www.kemira.com/company/)	R[1] in EU, including The Netherlands
Roots (Soil) Boost	*T. harzianum* T-22	Suppresses SBPs	Dragonfli, UK (http://www.dragonfli.co.uk/product/ps-02)	NR[2], available for use
Rootshield Plus Wp	*T. harzianum* Rifai strain T-22 (KRL-AG2)	Controls SBPs, such as *Fusarium* spp.	Bioworks inc (http://www.bioworksinc.com/)	R[1] in EU
Supresivit	*T. harzianum*	Controls SBPs, such as *V. dahliae* Controls SBPs, such as *Fusarium oxysporum*	Fytovita, Ltd. Biocontrol Technologies S.L., Fargro Ltd, UK.	R[1] in Czech Republic R[1] in EU & UK

[1]Registered. [2]Not registered. [3](Valiuškaitė *et al.*, 2008).

Cont. Table 2 *Commercial biobased fungicides, their active substances, intended use, product registration, and producer/ distributor.*

Biobased Fungicides	Active Substances	Intended Use	Producer/ Distributor	Product Registration
T34 Biocontrol	*T. asperellum* T34	Controls SBPs, such as *Fusarium oxysporum*	Biocontrol Technologies S.L., Fargro Ltd, UK.	R[1] in EU & UK
***T. Harzianum* Iab-32**	*T. harzianum*	Controls SBPs, such as *Fusarium* spp.	IAB S.L., Spain (Investigaciones y Aplicaciones biotecnológicas) http://www.iabiotec.com	NR[2], available for use
Tifi	*T. atroviride* 898G + *Glomus* spp.+ Bacteria	Controls SBPs, such as *Fusarium* spp. and *Verticillium* spp.	Italpollina (https://www.hello-nature.com/int/product/tifi/)	NR[2], available for use
Trianum-P	*T. harzianum* strain T-22 (Item108)	Suppresses SBPs, such as *Fusarium* spp.	Koppert B.V. (http://www.koppert.com/diseases/overview/)	R[1] in EU
Trichodermas Bioflower	*T. harzianum*	Controls SBPs, such as *Fusarium* spp.	Terranaturale, Spain	NR[2], available for use
Trifender	*T. asperellum*	Controls SBPs, such as *Fusarium* spp.	Bioved, Hungary	NR[2], available for use
Tusal WG	*T. harzianum* + *T. viride*	Protects against and controls SBPs, such as *Fusarium* spp.	New Biotechnic SA (NBT) Spain (http://www.nbt.es); Certis Europe http://www.certiseurope.com	R[1] in EU (Spain)

[1]Registered. [2]Not registered.

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5 Appendices

Figure 1. **Symptoms of Fusarium and Verticillium wilt on wood vessels of redcurrant.** Left: Fusarium wilt. Taken by: WUR, Asmaa Youssef. Right: Verticillium wilt. Source: University of Wisconsin-Madison Plant Diseases Diagnostics Clinic. Link: https://hort.extension.wisc.edu/articles/verticillium-wilt-of-trees-and-shrubs/

Figure 2. **Symptoms of currant cane dieback on redcurrant canes.** Sources: left: https://alanbuckingham.photoshelter.com/image/I0000ANlWbkD4xWU. Right. Singer & Cox (2010)

Figure 3. **Symptoms of *Arabis mosaic virus* (ArMV) on a grape leaf.** Source: https://alchetron.com/Arabis-mosaic-virus

Figure 4. **Symptoms of *Strawberry latent ringspot virus* (SLRSV) on rose leaves.** Source: Plant Protection Service, Wageningen (NL) via EPPO. Link: https://gd.eppo.int/taxon/SLRSV0/photos

Figure 5. **Symptoms of *Raspberry ringspot virus* (RpRSV) on redcurrant leaves.** Source: van der Meer (1987b). USDA.

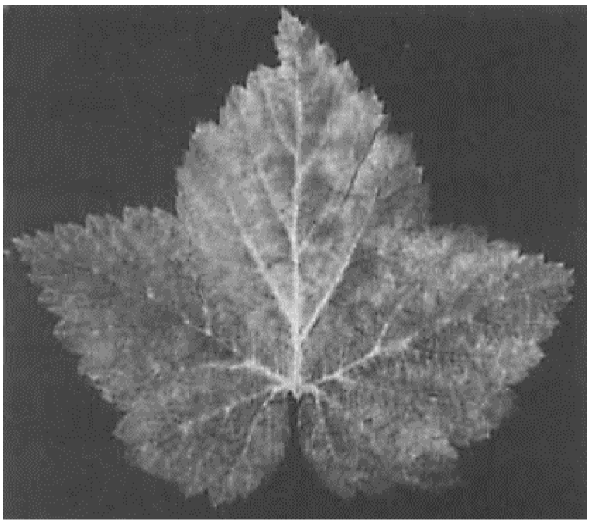

Figure 6. **Symptoms of *Tomato black ring virus* (TBRV) on a redcurrant leaf.** Source: Jones and McGavin (1996). The James Hutton Institute, Dundee, UK.

Figure 7. **Symptoms *of Tomato ringspot virus* (ToRSV) on redcurrant leaves.** Source: USDA. Link: https://www.thedailygarden.us/garden-word-of-the-day/tomato-ringspot

Figure 8. **Symptoms of *Tobacco rattle virus* (TRV) on redcurrant leaves.** Source: van der Meer (1987c). USDA.

Corresponding address for this report:
P.O. Box 200
WUR – Open Teelten Randwijk
6670 AE Zetten
The Netherlands
T +31 (0)320 29 11 93
www.wur.eu/plant-research

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