Desktop evaluation on commercially available microbial-based products for control or suppression of *Pseudomonas syringae* pv. *actinidiae*

Alison Stewart

Robert Hill

Christine Stark

Bio-Protection Research Centre

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Contents

1. Introduction

The following report presents the findings of a desktop evaluation of biocontrol agents with potential to control or suppress bacterial canker of kiwifruit caused by *Pseudomonas syringae* pv. *actinidiae* (Psa). The review identifies the most likely candidates of locally available and overseas products based on a ranking approach and discusses their suitability.

2. Background

Biological control of plant pests and diseases relies on the use of one living organism to control another through antagonistic interactions. Generally, biocontrol agents are predators, pathogens and parasites of the organism to be controlled. In the specific case of the bacterium Psa, biological control might be achieved through three different mechanisms, which include (i) amensalism, i.e. antibiosis and lysis; (ii) competition; and (iii) parasitism and predation. In addition, for the purpose of this report, we have identified the following modes of action as having potential biocontrol properties against Psa, either by themselves or in combination with other products as part of an integrated pest management strategy: (iv) induced resistance and (v) plant growth promotion or regulation.

(i) Amensalism describes an interaction in which the biocontrol organism produces metabolic substances that inhibit growth, certain metabolic pathways or multiplication (antibiosis) or even lead to the complete breakdown of the cells of the target organism (lysis, the mechanism used by bacteriophages).

(ii) Competition refers to the contest between biocontrol agent and pathogen for space and resources. A quickly growing and multiplying biocontrol organism, for example, can colonise flowers, leaves or roots to the extent that it replaces or prevents any subsequent colonisation by the pathogenic organism. However, there is evidence in some cases that if the antagonist is applied when the pathogen is already present it is not effective. This suggests that agents with competition as the sole mode of action are best used on a regular basis as a preventative measure before disease outbreak.

(iii) The third mechanism of action is hyperparasitism (i.e. the biocontrol organism is parasitic to plant parasites/ pathogens), in which case the biocontrol organism lives off the pathogen, killing it in the process.

(iv) Like elicitors or chemical / biochemical compounds, some biological organisms help promote plant resistance by exuding compounds that stimulate the defence responses.

(v) Similarly, certain metabolic compounds produced by microbial organism might promote plant growth and crop production by improving seed germination and fruit ripening, enhancing nutrient uptake and boosting protein synthesis. This will increase disease resistance and help the plant to withstand stress conditions, which might not lead to disease control by itself but could be a mechanism contributing to a successful pest management strategy.

The control of plant diseases using biological agents is an attractive prospect not just within integrated crop management. Especially in view of the ever growing number of plant pathogen strains resistant or tolerant to widely used chemical compounds, alternatives such as biocontrol have become almost an imperative to ensure the continued viability of crop production. While biological control can be very effective, it is necessary to understand that its nature makes biological control variable. Its efficacy hugely depends on environmental conditions. Just like the pathogen, the biocontrol organism requires optimum temperature and moisture conditions to proliferate and spread. Biocontrol seldom means complete eradication of the unwanted organism but rather reducing its population to levels below the economic threshold.

3. Product Evaluation

3.1. Overview

As part of this study, a range of biocontrol products (commercially available locally and / or overseas) and organisms (where no commercial product is available[1]) suitable for the control of agricultural and horticultural plant pathogens (including fungi and bacteria) were identified and ranked based on the following criteria: Target pathogen/ disease; target crop; mode of action; availability in NZ/ ease of import:

Target pathogen/ disease:

5 – *Pseudomonas*;

4 – Other bacterial diseases on fruit (e.g. *Erwinia amylovora*, fire blight);

3 – All other bacteria;

2 – Foliar diseases caused by fungi;

1 – Soil-borne diseases.

Mode of action:

5 – Several modes of action against bacterial pathogens (antibiosis, induced resistance, competition, parasitism);

4 – One mode of action against bacterial pathogens;

3 – Several modes of action against fungal pathogens;

2 – One mode of action against fungal pathogens;

1 – Plant growth promotion, if only mode of action

Target crop:

5 – Perennial vine crops (including grape and kiwifruit);

4 – Fruit trees;

[1] This might be due to a lapse of registration, where a company went out of business or because a new organism was identified to have biocontrol potential.

3 – Other perennial tree crops;
2 – Perennial vegetables / arable crops (incl. tomato);
1 – Annual vegetables / arable crops.

Availability / ease of import:
5 – Available in NZ;
3 – Most other products and organisms where species might be present in NZ and organism is not on MAF unwanted organism list;
1 – No product available, i.e. organism would need to be isolated or imported from culture collection;
0 – Organism on MAF list of unwanted organisms / regulated pest.

Table 1: Highest scoring microbial candidates for control and / or suppression of Psa.

Rank	Total Score	Product Name	Biocontrol agent/ organism*
1	20	Serenade Max	*Bacillus subtilis* strain QST 713
2	19	BacStar ™	*Bacillus subtilis* var. *amyloliquefaciens* D747
3	18	BlightBan® A506	*Pseudomonas fluorescens* A506
3	18	Blossom Bless™	*Pantoea agglomerans* P10c
5	17.5	Companion Gold	*Bacillus subtilis* GB03
6	17	Sonata®	*Bacillus pumilus* QST 2808
7	16	Bloomtime ®	*Pantoea agglomerans* strain E325
7	16	Cease®/ Rhapsody®	*Bacillus subtilis* strain QST 713
7	16	Clarity/ Subtilex® NG	*Bacillus subtilis* MBI600
10	15.5	Blossom Protect™	*Aureobasidium pullulans* DSM 14941, *Aureobasidium pullulans* DSM 14940
11	15	Ballad® Plus	*Bacillus pumilus* QST2808
11	15	Companion®	*Bacillus subtilis* GB03, other *B. subtilis, B. licheniformis, B. megaterium*
11	15	Tri-D25™	*Trichodema koningii, Trichodema hazianum*
14	14.5	Botry-Zen®	*Ulocladium oudemansii*
14	14.5	Vinevax™	*Trichoderma harzianum*
14	14.5	TripleX	*Bacillus amyloliquefaciens* BS 1b
14	14.5	Bio Sol B Sub Plus	*Bacillus subtilis* strain ATCC6051 + seaweed extract
18	14	AgriPhage™	bacteriophages
18	14	Sentinel®	*Trichoderma* LC52
18	14	Superzyme®	*Bacillus subtilis, Pseudomonas putida, Trichoderma koningii* & *T. harzianum*
18	14	Fulzyme Plus™	*Bacillus subtilis* + amino acids

* Where biocontrol organisms are the same, products will be discussed in the same section.

Twenty-one products that achieved the highest overall ranking scores are deemed the most promising to control or suppress Psa and are presented in the following section. The order of priority is based on the overall score (Table 1), which was obtained by simple addition of the individual scores (see Appendix for details). Brief comments on each product / organism are included to give a quick overview of any issues that could be important with regard to their use as biocontrol agents against Psa in NZ.

3.2. Detailed description

1) Bacillus subtilis QST 713

Product Name: Serenade Max – BASF New Zealand Ltd (score 20)

Serenade Max/ Serenade ASO – AgraQuest, Inc., USA, www.agraquest.com

Cease® – BioWorks, USA; www.bioworksinc.com (score 16)

Rhapsody® – AgraQuest, Inc., USA, www.agraquest.com (score 16)

Target pathogen/disease:

Serenade: Powdery mildew; Gray mould (*Botrytis cinerea*); Downy mildew; Early Blight (*Alternaria solani*); Late Blight (*Phytophthora infestans*); Bacterial spot (*Xanthomonas* spp.); Walnut blight (*Xanthomonas campestris*); *Monilinia* spp., *Venturia* spp., Fire Blight; *Pseudomonas syringae*.

Cease®: *Pseudomonas syringae* pv. *tomato;* Powdery Mildew, Anthracnose, Rust, *Botrytis cinerea,* Downy Mildew, Early/ Late Blight; Bacterial Soft Rot (*Erwinia, Pseudomonas*), Bacterial Leaf Spot and Speck, Anthracnose; fungal soil diseases (*Rhizoctonia* spp.; *Pythium* spp.; *Fusarium* spp.; *Phytophthora* spp.).

Rhapsody®: Powdery Mildew, Leaf Spot and Speck, Anthracnose, Rust, bacteria (*Pseudomonas, Erwinia, Xanthomonas*), Black spot of rose, *Botrytis cinerea*, Downy Mildew, Rust, Scab (*Venturia* spp.), fungal soil diseases (*Rhizoctonia* spp.; *Pythium* spp.; *Fusarium* spp.; *Phytophthora* spp.).

Mode of action:

Nutrient and niche competition, site exclusion; colonization and attachment of the bacteria to the fungal pathogen; Antibiosis through production of a class of lipopeptide antibiotics (incl. iturins) that help out-compete the pathogenic organisms by either killing them, disrupting development or reducing their growth rate. May help foster plant's natural defences by inducing natural systemic resistance or systemic acquired resistance.

Registered for use on/Target crop:

Bacillus subtilis strain QST 713 according to US Environmental Protection Agency (US EPA, 2011): wide variety of food crops, including cherries, cucurbits, grapes, leafy vegetables, peppers, potatoes, tomatoes, and walnuts.

Serenade Max in NZ: vegetables, fruit (Peach, apricot, plum, cherry, nectarine), nut and vine crops (grape vine, table grapes), tomato; kiwifruit, berries, avocado.

Cease®: foliar spray on agricultural greenhouse crops (incl. leafy vegetables, roots and tubers, herbs/ spices, fruiting vegetables; Cucurbits; bulb vegetables; brassica, strawberries).

Rhapsody®: turf, landscape areas, ornamental and greenhouse plants.

Formulation:

Serenade Max: wettable powder for spray/ foliar application; Serenade ASO: aqueous solution (lower concentration of biocontrol agent); Cease®: aqueous solution; Rhapsody®: aqueous solution.

Efficacy: (Raudales et al., 2010)

Serenade Max (US formulation): Evidence for disease control and/or yield increase when used on/against: Blueberry/Anthracnose fruit rot; Grape/Bunch rot and Powdery mildew; Hydrangea/Powdery mildew; Pansy/Cercospora leaf spot; Pumpkin, Cantaloupe, Honeydew/Powdery mildew; Lettuce/Powdery mildew; Broccoli/Downey mildew.

Evidence for disease control is mixed with some reports showing positive results and others not when used on/against: Blueberry/Mummy berry; Lettuce/Lettuce drop.

No obvious response to treatment in one or more published reports when used on/ against: Cranberry/Fruit rot; Apple/Fireblight; Apple/Flyspeck; Apple/Sooty blotch; Apple Black pox; Apple/Brooks fruit spot; Red Raspberry: Fruit rot; Turnip greens/bacterial leaf spot.

Serenade ASO: Cranberry/Cotton ball: ± (evidence for disease control is mixed); Radish/Hypocotyl root rot and Clubroot: ±; Spinach/Stemphylium leaf spot: 0 (no obvious response to treatment); Snap bean/Rhizoctonia root rot: 0.

Comments: *Bacillus subtilis* strain QST 713 achieved moderate disease reduction of *Phytophthora infestans* on media (*in vitro*) and suppression of late blight on potato but not at levels observed for chemical compounds (Olanya and Larkin, 2006). Similarly, Gilardi *et al.* (2009) found that suppression of leaf spot (*Pseudomonas syringae* pv. *syringae*) on tomato was only partially effective. On the other hand, mixed or alternate applications of *Bacillus subtilis* QST 713 with chemical fungicides showed very good results in the control of *Alternaria* leaf blight on ginseng (Li et al., 2008).

Testing a range of biocontrol agents individually (incl. preparations of *Bacillus subtilis* QST 713 (Serenade Max), *Pseudomonas fluorescens* A506 (BlightBan® A506), *Pantoea agglomerans* C9-1 (BlightBan C9-1 – currently not registered) and *Pantoea agglomerans* E325 (Bloomtime®)) showed that they were not consistently effective in reducing fireblight in apple (average reduction between 9.1 to 36.1%, compared to 59.0 to 67.3% when using streptomycin). The main reason for this seems to be inconsistent blossom colonisation by the biocontrol organisms. However, blossom infection could be controlled more effectively when the biocontrol agents were used in combination with streptomycin as part of an integrated disease management program, thus leading to a reduction of necessary streptomycin applications while maintaining similar control levels (Sundin et al., 2009).

Serenade Max achieved the highest ranking score in our evaluation (closely followed by the other formulations of *Bacillus subtilis* QST 713) due to their wide range of target pathogens/ diseases, target crops and various modes of action. This combination makes this biocontrol agent a promising potential candidate for the control or suppression of Psa.

Serenade Max is part of the New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme.

http://www.epa.gov/oppbppd1/biopesticides/ingredients/factsheets/factsheet_006479.htm
http://www.epa.gov/oppbppd1/biopesticides/ingredients/tech_docs/tech_006479.htm
http://www.agro.basf.com/agr/AP-Internet/en/content/solutions/solution_highlights/serenade/bacillus-subtilis

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2) Bacillus subtilis var. amyloliquefaciens D747

Product Name: BacStar ™ – ETEC Crop Solutions Limited, NZ; www.elliottchemicals.co.nz (score 19)

Target pathogen/disease: Powdery mildew, *Botrytis* and sour rot, fireblight.

Mode of action:

Competition for space and nutrients; antibiosis (production of antibiotic compounds such as iturin A as observed for other *Bacillus amyloliquefaciens* strains (Yu et al., 2002)); possibly active as a plant growth regulator (as for *Bacillus subtilis var. amyloliquefaciens* strain FZB24).

Registered for use on/Target crop: Grapes, kiwifruit, pipfruit, berryfruit, persimmon, onions, avocado, citrus, lettuce, turf.

Formulation: Water dispersible granules

Comments: This formulation of *Bacillus amyloliquefaciens* (strain D747) is intended for the control of fungal pathogens, such as *Botrytis*, powdery mildew and sour rot as well as fireblight on fruit (incl. kiwifruit) and other crops. Its alleged range of target crops and target diseases together with its various modes of action make this an interesting candidate for the management of Psa. While a literature search did not reveal any evidence that the product or organism had been tested for their efficacy in rigorous scientific experiments, products based on other strains of *Bacillus amyloliquefaciens* are marketed as biocontrol and plant strengthening agents (e.g. FZB24® *Bacillus subtilis*, Bayer CropScience AG/ www.bayercropscience.com and TripleX, BioStart Limited, NZ).

BacStar™ is part of the New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme.

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3) Pseudomonas fluorescens A506

Product Name: BlightBan® A506 – NuFarm Inc., USA; www.nufarm.com/USAg/Agriculture (score 18)

Target pathogen/disease: Frost damage, *Erwinia amylovora*, and russet-inducing bacteria.

Mode of action:

Reduces/ suppresses growth of frost forming and fireblight inducing bacteria; competition for space and nutrients by colonising blossoms of apples and pears before pathogenic bacteria can get a foothold.

Active on or Registered for use on/Target crop: Almond, apple, apricot, blueberry, cherry, peach, pear, potato, strawberry, tomato.

Formulation: wettable powder

Comments: Testing a range of biocontrol agents individually (incl. *Pseudomonas fluorescens* A506 (BlightBan® A506), *Pantoea agglomerans* E325 (Bloomtime®), *Pantoea agglomerans* C9-1 (BlightBan C9-1 – currently not registered) and preparations of *Bacillus subtilis* QST 713 (Serenade Max)) showed that they were not consistently effective in reducing fireblight in apple (average reduction between 9.1 to 36.1%, compared to 59.0 to 67.3% when using streptomycin). The main reason for this seems to be inconsistent blossom colonisation by the biocontrol organisms. However, blossom infection could be controlled more effectively when the biocontrol agents were used in combination with streptomycin as part of an integrated disease management approach, thus leading to a reduction of necessary streptomycin applications while maintaining similar control levels (Sundin et al., 2009).

Vanneste *et al.* (2004) found that *Pseudomonas fluorescens* A506 has limited ability to colonise apple and pear leaves, which suggests that it might not be a suitable candidate for the control of Psa, which manifests itself in leaves, shoots and trunks.

BlightBan® A506 is part of the New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme.

http://www.nufarm.com/USAg/BlightBanrA506

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4) Pantoea agglomerans P10c

Product Name: Blossom Bless ™– AgriNova NZ Ltd, NZ; www.grochem.co.nz (score 18)

Target pathogen/disease: fire blight

Mode of action:

Nutrient competition (nectar, stigma); exclusion by pre-emptive occupation of flower infection sites (competition for space); antibiosis.

Registered for use on/Target crop: Pip fruit flowers

Formulation: wettable powder

Comments: *Pantoea agglomerans* P10c is an effective bacteria to suppress fire blight incidence on apples and pears blossoms. Under optimum conditions, experimental evidence suggests that 100% of all flowers randomly sampled in treated commercial orchards were colonised by P10c when the powder formulation was sprayed directly onto flowers or delivered to flowers using honeybees (Vanneste et al., 2002); ability of the organism to colonise apple and pear leaves, however, is low (Vanneste et al., 2004). This indicates that it might not be a suitable candidate for the control of Psa, which manifests itself in leaves, shoots and trunks.

Blossom Bless™ is part of the New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme.

http://www.grochem.co.nz/Portals%5C537%5Csds/BlossBless%20SDS.pdf
http://www.grochem.co.nz/Portals%5C537%5Clabels/BlossomBless_300g.pdf

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5) Bacillus subtilis GB03

Product Name: Companion Gold – Zelam Ltd, NZ; www.nuchem.co.nz (score 17.5)

Companion® – Growth Products, Ltd., USA; www.growthproducts.com (score 15, ranked 12th)

Target pathogen/disease:

Companion Gold: powdery mildew, sour rot and *Botrytis*; Companion®: *Rhizoctonia, Pythium, Fusarium, Phytophthora;* Bacterial leaf spot *Xanthomonas campestris*.

Mode of action:

Competition for space and nutrients; antibiosis (*B. subtilis* produces the antibiotic Iturin, which inhibits the pathogen's growth by disrupting cell wall formation); Induced Systemic Resistance (ISR) (cf. Brannen and Kenney, 1997).

Registered for use on/Target crop:

Grapes and ornamentals (Companion Gold); turf, greenhouse, nursery, ornamental crops, field grown trees (preventative) (Companion®).

Efficacy: (Raudales et al., 2010)

Evidence for disease control is mixed with some reports showing positive results and others not when used on/against: Snap beans/*Fusarium* Root rot; Pea/*Fusarium*, *Phoma*, *Pythium*.

No obvious response to treatment in one or more published reports when used on/against: Snap bean/*Rhizoctonia* root rot; Wheat/*Fusarium* crown rot; cucumber/Damping off.

Formulation: liquid suspension.

Comments: *B. subtilis* GB03 is successfully used in many crops against disease of roots caused by soil fungal pathogens, such as *Fusarium*, *Rhizoctonia* and *Pythium* (Backman et al., 1998). When used to control *Fusarium* root rot of dry beans, seed application of *B. subtilis* GB03 resulted in the promotion of plant growth by increasing biomass and in a reduction of disease severity under greenhouse conditions and in the field (yield increase of 31%). However, the biocontrol treatment did not eradicate the disease (Estevez de Jensen et al., 2002). Although Companion Gold (registered in NZ) is primarily used against fungal diseases, such as powdery mildew, sour rot and *Botrytis*, Companion®, the US product containing the same strain of *B. subtilis*, is registered for use against bacterial leaf spot. This makes *Bacillus subtilis* GB03 an interesting candidate for the control / suppression of other bacterial diseases, incl. Psa.

Companion Gold is part of the New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme.

http://www.growthproducts.com/pages/horticulture.asp?tables=featured&product=10

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6) Bacillus pumilus QST 2808

Product Name: Sonata® – AgraQuest, Inc., USA, www.agraquest.com (score 17)

Ballad® Plus – AgraQuest, Inc., USA, www.agraquest.com (score 15 due to different range of target crop)

Target pathogen/disease:

Sonata®: Several fungal and bacterial diseases, incl. rusts, powdery and downy mildew, blight, scab, brown spot, bacterial blight and streak (*Alternaria* spp., *Botrytis* spp. *Bremia lactucae, Cercospora* spp., *Cercosporidium personatum, Erysiphe* spp., *Erwinia amylovora, Oidiopsis taurica, Peronospora* spp., *Phoma cucurbitacearum, Phytophthora* spp., *Plasmopara viticola, Podosphaera leuchotricha, Pseudoperonospora cubensis, Puccinia* spp., *Sclerotinia* spp., *Sphaerotheca* spp., *Uncinula necator, Uromyces* spp., *Venturia* spp., *Xanthomonas* spp.).

Ballad® Plus: rust, powdery mildew, *Cercospora*, and brown spot, Asian Soybean Rust *Phakopsora pachyrhizi*, Bacterial Blight and Streak *Xanthomonas* spp., Bacterial Speck *Pseudomonas syringae* pv. *glycinea*.

Mode of action:

Antibiosis: antifungal amino sugar compounds disrupt the cell metabolism and destroy the cell walls of the Target pathogen; competition for space and nutrients: *Bacillus pumilus* QST 2808 acts as a physical barrier between the leaf and the pathogen spores; may stimulate plant's own defence mechanisms by inducing systemic resistance.

Registered for use on/Target crop:

Sonata®: Many food and non-food crops, including trees susceptible to sudden oak death syndrome; cucurbits, grapes, hops, vegetables, peanuts, pome fruits, stone fruits, black sigatoka in bananas, cereal. For use outdoors, including nurseries, landscapes, and rights-of-way, and in greenhouses.

Ballad® Plus: Barley, corn, millets, oat, rice, rye, sorghum, triticale, wheat and other cereal grain crops; grass seed, canola, castor, cotton, flax, oil palm, olive, peanut, rapeseed, safflower, sesame, sunflower, soybeans and other oilseed crops, sugar beets, sweet corn.

Formulation: emulsifiable concentrate

Efficacy of Sonata®: (Raudales et al., 2010)

Evidence for disease control and/or yield increase when used on/against (crop/disease): Lettuce/Powdery mildew; Broccoli/Downey mildew; Radish/Downey mildew.

Evidence for disease control is mixed with some reports showing positive results and others not when used on/against: Lettuce/Lettuce drop.

No obvious response to treatment in one or more published reports when used on/against: Lima Beans/White mould; Pumpkin/Powdery mildew; Radish/Clubroot and Rhizoctonia hypocotyl root rot.

Comments: In field experiments that compared the treatment of late blight on potato (*Phytophthora infestans*) using Sonata®, as well as a variety of other alternative products including the commercial biocontrol agents Actinovate, Serenade, Trichodex, sulphuric clays (e.g. Myco-Sin; EcoGrape, www.ecogrape.com) and

plant extracts with copper-based products none of the alternatives provided sufficient disease control on their own or in combination with each other to be an effective substitute for copper products (Dorn et al., 2007; Oregon State University, 2007; Syrovy et al., 2009). However, Sonata® is successfully used in integrated pest management to control *Botrytis* on strawberries in the United States (e.g. http://www.ipmcenters.org/pmsp/pdf/TNstrawberry.pdf).

Sonata®, Ballad® Plus or other formulations of *Bacillus pumilus* are not part of the New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme.

http://www.agraquest.com/agrochemical/products/fungicides-sonata.php
http://www.agraquest.com/docs/labels-msds/Sonata-Label.pdf
http://www.epa.gov/pesticides/biopesticides/ingredients/factsheets/factsheet_006485.htm
http://www.agraquest.com/docs/labels-msds/Ballad-Plus-Label.pdf

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7) Pantoea agglomerans strain E325

Product Name: Bloomtime ® – NorthwestAgricultural Products, USA; www.nap-chem.com (score 16)

Target pathogen/disease: fire blight in apples and pears *Erwinia amylovora*.

Mode of action:

Competition for nutrients (for nectar, on the stigma) and space (exclusion by pre-emptive occupation of potential flower infection sites); Antibiosis (by producing an antibiotic specific to *Erwinia amylovora*) (Pusey *et al.*, 2011).

Registered for use on/Target crop: Apples and pears

Efficacy:

Evidence for disease control is mixed with some reports showing positive results and others not when used on/against: Apple/Fire blight (Pusey et al., 2008; Raudales et al., 2010; Stockwell et al., 2010).

Comments: Testing a range of biocontrol agents individually (incl. *Pantoea agglomerans* E325 (Bloomtime®), *Pseudomonas fluorescens* A506 (BlightBan® A506), *Pantoea agglomerans* C9-1 (BlightBan C9-1 – currently not registered) and preparations of *Bacillus subtilis* QST 713 (Serenade Max)) showed that they were not consistently effective in reducing fireblight in apple (average reduction between 9.1 to 36.1%, compared to 59.0 to 67.3% when using streptomycin). The main reason for this seems to be inconsistent blossom colonisation by the biocontrol organisms. However, blossom infection could be controlled more effectively when the biocontrol agents were used in combination with streptomycin as part of an integrated disease management program, thus leading to a reduction of necessary streptomycin applications while maintaining similar control levels (Sundin et al., 2009).

Bloomtime® is not part of the New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme.

http://www.nap-chem.com/Product_Pages/yeoman_products.htm

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8) Bacillus subtilis MBI600

Product Name: Clarity – Gro-Chem, T/A Agrinova NZ Ltd; grochem.co.nz (score 16); **Subtilex ® NG** – Becker Underwood, Australia, www.beckerunderwood.com

Target pathogen/disease:

Clarity: *Botrytis*, Powdery Mildew and Sour Rot; *Sclerotinia*; Subtilex®: Soil borne pathogens *Fusarium* spp., *Rhizoctonia* spp., and *Pythium* spp. that cause seed and root rots.

Mode of action:

Bacillus subtilis MBI600 colonises and protects plant roots by producing a metabolite that destroys the pathogen's cell wall (antibiosis); suppressing numbers and viability of disease organisms by competition for space and nutrients.

Registered for use on/Target crop:

Clarity: grapes; kiwifruit; berryfruit; onions; citrus; lettuce; turf; Subtilex®: ornamentals, vegetable field and greenhouse crops.

Formulation: wettable powder

Comments: A field study showed that under conditions of severe disease pressure, yield increases and pathogen control could only be achieved through a combined application of *B. subtilis* MBI600 and *Rhizobium tropici* (nitrogen-fixing, root nodulating bacteria that are known to promote plant growth). The co-application of *B. subtilis* with *Rhizobium* is considered a promising strategy to control root rot on beans (Estevez de Jensen et al., 2002).

Clarity is part of the New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme.

http://www.beckerunderwood.com/en/products/subtilexng:usa

http://web.pppmb.cals.cornell.edu/resourceguide/mfs/01bacillus_subtilis.php

http://www.grochem.co.nz/Default.aspx?TabID=35618&productid=37&a=2

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9) Aureobasidium pullulans DSM 14941 and DSM 14940

Product Name: Blossom Protect™ – bio-ferm GmbH, Austria, www.bio-ferm.com (score 15.5)

Botector – bio-ferm GmbH, Austria, www.bio-ferm.com (score 12: different target pathogen) (registered in Austria since 2009)

Target pathogen/disease:

Blossom Protect: fire blight (*Erwinia amylovora*); Botector: *Botrytis cinerea*

Mode of action:

Yeasts, such as *Aureobasidium pullulans* the main active ingredient in Blossom Protect, are naturally occurring on buds, leaves, flowers and fruit. They have the ability to readily colonise these plant surfaces and successfully compete with other microorganisms for space and nutrients and have antagonistic properties against fireblight (Seibold et al., 2004). *Aureobasidium pullulans* blocks the fire blight pathogen from colonising, for example, apple blossoms.

Registered for use on/Target crop:

Citrus, pome fruit, sugarcane, Florida greenway and trail lands (Blossom Protect); grapes (Botector).

Formulation: Water dispersible granules and powder for spray/ foliar application.

Comments: In field trials, Blossom Protect™ was the most effective out of 44 products tested against fireblight achieving on average 78% disease reduction. To avoid fruit russetting in susceptible (apple) varieties, Blossom Protect™ should be applied a day before conditions become conducive to disease development and used in combination with sulphur and sulphuric clay (e.g. Myco-Sin; EcoGrape, www.ecogrape.com) to control apple scab (Kunz and Mendgen, 2009). Botector's efficacy against *Botrytis* bunch rot in grapes has been discussed but has not been established independently (Elmer and Reglinski, 2006). There is some evidence that the application of Botector might increase disease incidence (Landwirtschaftliches Versuchswesen Rheinland-Pfalz, 2011).

Blossom Protect™ is not part of the New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme. It is currently available in a range of European countries and the US; however, it's high ranking score in our evaluation, which is based on its successful control of a bacterial disease in fruit trees, suggests that this candidate has potential for control of Psa and its use in NZ should be further investigated.

http://www.bio-ferm.com/de/index.php?nav=12

http://www.bio-ferm.com/en/index.php?id=217

http://www.bio-ferm.com/en/index.php?id=211

http://www.bio-ferm.com/media/file/Blossom_Protect_Comp_A_GB_2011.pdf

http://www.bio-ferm.com/media/file/Blossom_Protect_Comp_B_GB_2011.pdf
http://orgprints.org/16515/

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10) Trichodema koningii, Trichodema hazianum

Product Name: Tri-D25™ – Roots Shoots and Fruits Ltd, New Zealand, www.rd2.co.nz (score 15)

Target pathogen / disease: *Phytophthora* spp., *Rhizoctonia* spp., *Botrytis* spp.

Mode of action:

Hyperparasitism: Mycoparasitism, improved plant health; soil and / or root inocculant to increase beneficial microbial populations

Registered for use on / Target crop:

Avocados, Macadamias, Chestnut, Pistachio, Almonds & Kiwifruit; Brassicas; Carrot, Onion & Potato; Lettuce; Tomato, Capsicum, Eggplant & Strawberries; Fruit Trees; Tropical Fruits; Grapes

Formulation: wettable powder for soil or foliar application

Comments: A literature search did not reveal any evidence that Tri-D25™ has been scientifically tested in its application as foliar spray against Botrytis on grapes and its efficacy against the root rot fungi *Phytophthora nicotianae* and *Pythium ultimum* has been reported as lacking compared to conventional chemicals . Walker and Morey found that the formulation did not reduce isolation frequency of the fungi nor did it effectively reduce the level of root rot on citrus when studied in pot and field experiments. They concluded that their findings did not substantiate the manufacturer's claims. This suggests that despite its high score Tri-D25™ is not a promising candidate for the control/suppression of Psa on kiwifruit.

Tri-D25™ is included New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme, but has not been tested.

http://www.rd2.co.nz/uploads/TriD25%20NZ(1).pdf
http://www.rd2.co.nz/uploads/TriD25%20105x100%20180907(1).pdf"

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11) Ulocladium oudemansii

Product Name: Botry-Zen® – Botryzen, New Zealand; www.botryzen.co.nz (score 14.5)

Target pathogen/disease: *Botrytis cinerea*, *Sclerotinia sclerotiorum*

Mode of action:

Competition for nutrients and space; the biocontrol organism competes with the pathogen for the same ecological niche.

Registered for use on/Target crop: Grapes, kiwifruit, blackcurrants, ornamentals

Formulation: water dispersible granules

Comments: Successful suppression of *Botrytis cinerea* on grapes using *Ulocladium oudemansii* has been reported, even under high disease pressure, however, biocontrol was much more effective when used in combination with a chemical plant defence stimulant (Reglinski et al., 2005).

Botry-Zen® is part of the New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme but has not been tested yet.

http://www.botryzen.co.nz/pdf/Botry-Zen_MSDS_v5.pdf

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12) Trichoderma harzianum

Product Name: Vinevax™– Agrimm Technologies Ltd, New Zealand; www.vinevax.com (score 14.5)

Target pathogen/disease:

Wood-infecting fungal pathogens: *Eutypa lata, Botryosphaeria* spp., *Phaeomoniella chlamydospora, Cylindrocarpon destructans, Phomopsis viticola* and *Botrytis cinerea.*

Mode of action:

Niche exclusion and competition for nutrients; mycoparasitism - degradation of other fungi; antibiosis: Production of metabolites with antifungal activity; stimulation of the plant's defence mechanism (SAR).

Registered for use on/Target crop: Pruning wound dressing in vine

Formulation: paste or spray

Comments: Experimental evidence from glasshouse and vineyard trials suggests that commercial formulations of *T. harzianum*, including Vinevax™, can reduce the recovery of a fungal pathogen (*Eutypa lata*) from pruning wounds when the biocontrol agent is applied at least 1 day before the pathogen (John et al., 2005). John et al. (2008) also found that T. harzianum has the ability to colonise and persist on vine wood for at least 20 months indicating the biocontrol agent's potential to protect vines from inoculation with the pathogen. The manual

protection of pruning wounds, though labour intensive, might therefore be warranted. Whether the biocontrol agent is effective against bacterial diseases needs to be established.

Vinevax™ is part of the New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme but has not been tested yet.

http://www.vinevax.com/vinevax.html
http://www.vinevax.com/pdfs/BrochureVinevaxPWD.pdf

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13) Bacillus amyloliquefaciens BS 1b

Product Name: TripleX – BioStart Limited, NZ; www.biostart.co.nz (score 14.5)

Target pathogen/disease: *Botrytis cinerea*

Mode of action:

Competition for space and nutrients; antibiosis (by breaking down peptide bonds of pathogen proteins).

Registered for use on/Target crop: Grapes, top fruit, vegetables, e.g. onions.

Formulation: liquid

Comments: This formulation of *Bacillus amyloliquefaciens* (strain BS 1b) is intended for use against *Botrytis*, a fungal pathogen, on fruit. Literature search did not reveal any evidence that this product/ organism has been tested for its efficacy in rigorous scientific experiments; all current knowledge is based on manufacturer's claims. However, products based on other strains of *Bacillus amyloliquefaciens* are also used as biocontrol and plant strengthening agents (e.g. FZB24® *Bacillus subtilis*, Bayer CropScience AG/ www.bayercropscience.com and BacStar™, ETEC Crop Solutions Limited/ www.elliottchemicals.co.nz) and have been suggested to be effective on other crops and diseases.

TripleX is part of the New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme.

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14) Bacillus subtilis strain ATCC6051 + seaweed extract

Product Name: Bio Sol B Sub Plus – Biological Solutions Ltd., NZ; www.biosolutions.co.nz (score 14.5)

Target pathogen / disease: Powdery Mildew, Botrytis, Sour rot

Mode of action:

Competition for nutrients and space; antibiosis through production of antifungal products; improved plant nutrient status and resistance.

Registered for use on / Target crop: grapes, fruits, vegetables, potatoes, ornamentals

Comments: A literature search did not reveal any independent evidence of the efficacy of this product based on rigorous scientific testing (only manufacturer's information). This suggests that despite its high score this product is not a promising candidate for the control/suppression of Psa on kiwifruit.

Bio Sol B Sub Plus is part of the New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme.

http://www.biosolutions.co.nz/b-sub-plus
http://www.biosolutions.co.nz/assets/pdfs/bol-sol-b-sub.pdf

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15) Bacteriophages

Product Name: AgriPhage™ – Omnilytics , USA; www.omnilytics.com (score 14)

Target pathogen/disease:

Bacterial diseases (*Xanthomonas campestris* pv. *vesicatoria* or *Pseudomonas syringae* pv. *tomato*).

Mode of action:

Predation: Bacteriophage destroy bacteria through lysis. Lysing begins the moment a phage comes in contact with a bacterium and results in a release of additional phages within 30 minutes. Over four billion phages are included in every ml of AgriPhage™. Each phage is capable of destroying bacteria, and can replicate as many as 100 additional phage.

Registered for use on/Target crop: Tomato, pepper (capsicum)

Formulation: concentrated liquid

Comments: The possibility of phage therapy in plants is of growing interest as phages are host specific viruses that destroy the pathogenic bacteria. The use of bacteriophages to treat Psa could therefore be an attractive and promising possibility.
For the existing Omnilytics product Agriphage™ there is scientific evidence for disease control when used on/against Bell Pepper/bacterial spot (Raudales et al., 2010). However, a specific phage type needs to be isolated from the location the product will be applied to (in order to guarantee its viability and effectiveness under prevailing environmental conditions) and, just as pathogens can develop resistance to chemical products and antibiotics, bacteria can become resistant to bacteriophages, which might lead to an uncontrolled spread of the disease (Goodridge, 2004; Evans et al., 2010; Mahony et al., 2011).

http://www.omnilytics.com/documents/infosheet.pdf
http://www.omnilytics.com/documents/AgriPhage,%20T&P%20Xanth%20MSDS.pdf

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16) Trichoderma atroviride LC52

Product Name: Sentinel® – Agrimm Technologies Ltd, New Zealand; www.vinevax.com (score 14)

Target pathogen/disease: *Botrytis cinerea*

Mode of action:

Colonises the foliage, flowers and fruit competing with disease organisms for space and nutrients thus preventing invasion by *Botrytis.*

Registered for use on/Target crop: Grapes and tomatoes

Formulation: wettable powder

Comments: Experiments under controlled environmental conditions showed that the efficacy of Sentinel® was very good and that the use of biocontrol product significantly reduced disease levels of *Botrytis cinerea* in strawberry plants (Robinson-Boyer et al., 2009).

Sentinel® is not part of the New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme.

http://www.vinevax.com/sentinel.html
http://www.vinevax.com/pdfs/BrochureSentinel.pdf
http://www.vinevax.com/pdfs/MSDSSentinel.pdf

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17) Bacillus subtilis, Pseudomonas putida, Trichoderma koningii & Trichoderma harzianum

Product Name: Superzyme® – Roots Shoots and Fruits Ltd, New Zealand, www.rd2.co.nz (score 14)

Target pathogen/disease: plant growth promoter

Mode of action:

The mixture of selected fungi, bacteria and enzyme complexes provides beneficial microbes to the root zone, stimulates plant growth and reduces the risk of disease. Competition for space and nutrients might help suppress pathogen numbers.

Registered for use on/Target crop:

All crops; including all vegetables, potatoes, carrots, onions, all berries and strawberries, all brassicas, all fruit trees, avocados, persimmons, citrus, all nut

trees, vineyards, kiwifruit, tropical fruit, lettuce, asparagus, all melons, beans, ginger, ornamentals, cut flowers and pastures.

Formulation: wettable powder for soil or foliar application

Comments: Although literature search did not reveal any independent evidence of the efficacy of this product based on rigorous scientific testing (only manufacturer's information), it is known that many saprotrophic fungi, such as isolates of Trichoderma species, positively influence plant growth similar to plant growth promoting rhizobacteria; and healthier, stronger plants might be able to better withstand pathogen attack. The plant growth promoting effect is most effective in the absence of any major pathogens (Whipps, 2001).
There is also evidence that mixtures of fungi and bacteria can provide better biocontrol than individual control agents (Duffy et al., 1996; Mao et al., 1998; Duijff et al., 1999). For instance, suppression of take-all in wheat was greater when using a combination of *Trichoderma koningii* with *Pseudomonas* species compared to applying *T. koningii* by itself (Duffy et al., 1996).
Based on the information available, soil application of Superzyme® might be useful in combination with other biocontrol agents as part of an integrated control strategy of Psa.

Superzyme® is part of the New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme.

http://www.rd2.co.nz/uploads/MSDS%20Superzyme%20NZ.pdf
http://www.rd2.co.nz/uploads/Superzyme%20105x100%20180907(1).pdf

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18) Bacillus subtilis (+ amino acids)

Product Name: Fulzyme Plus™ – Roots Shoots and Fruits Ltd, New Zealand; www.rd2.co.nz (score 14)

Target pathogen/disease: Biological plant growth promoter.

Mode of action:

According to manufacturer's claims, Fulzyme Plus™ helps solubilise nutrients, incl. phosphorus, calcium, potassium, magnesium, to make them readily available for plant uptake; it aids in decomposing organic matter and plant material; and it produces natural and beneficial substances essential for plant productivity. These properties might assist in increasing the plant's natural resistance and help the plant to withstand stress conditions as experienced during pathogen attack.

Registered for use on/Target crop: All crops

Formulation: liquid

Comments: Even though this product achieved a ranking score amongst the top 20 products based on the criteria chosen, no reports could be found of the product's efficacy or whether it had been tested in a methodologically rigorous experiment.

Fulzyme Plus™ is part of the New Zealand Kiwifruit Industry's *in vitro* & greenhouse testing programme.

http://www.rd2.co.nz/uploads/Fulzyme%20Plus%20100x100%20180907(1).pdf
http://www.rd2.co.nz/uploads/MATERIAL%20SAFETY%20DATA%20SHEET-%20FULZYME-PLUS.doc

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4. Conclusions and Recommendations

According to the New Zealand Kiwifruit Industry 'Psa-Actives Screening Status List' from 02 September 2011[2], 13 of our top 20 promising products/ biocontrol organism have already been tested as part of the New Zealand Kiwifruit Industry's screening programme: Serenade Max (=Cease®/Rhapsody®), BacStar™, BlightBan® A506, Blossom Bless™, Companion Gold (=Companion®), Clarity, Vinevax™, TripleX, Bio Sol B Sub Plus, Superzyme® and Fulzyme Plus™).

The glasshouse screening tests indicate that Serenade Max (active ingredient: *Bacillus subtilis*), BlightBan® A506 (*Pseudomonas fluorescens*) and Blossom Bless™ (*Pantoea agglomerans* P10c) are the best microbial products tested so far. These also featured amongst the highest ranked on our list.

Products with the same active ingredients to those already tested (i.e. *Bacillus subtilis, Pseudomonas fluorescens* and *Pantoea agglomerans* P10c) are unlikely to provide substantially greater control than that already observed. Our evaluation and the screening test results suggest that there is limited value in screening other products based on *Bacillus subtilis* as Serenade Max is likely to be the best performer with this active ingredient and it is already being evaluated by Zespri.

Similarly, other *Pseudomonas fluorescens* or *Pantoea agglomerans*-based products are unlikely to perform differently to or better than BlightBan® A506 and Blossom Bless™, which both came out as the No 3 priority in this evaluation and are currently being assessed by Zespri.

We, therefore, recommend to focus further screening efforts on those priority products with different biocontrol organisms. The following products would be worthwhile including in the screening programme and/or bringing into NZ for testing since they are distinct microorganisms with a range of different mechanisms of actions that ranked in our top 20:

- Sonata®/ Ballad® Plus (*Bacillus pumilus* QST 2808);
- Botry-Zen® (*Ulocladium oudemansii*);

[2] http://www.kvh.org.nz/vdb/document/378

- Blossom Protect™ (A*ureobasidium pullulans* DSM 14941, *Aureobasidium pullulans* DSM 14940);
- Sentinel® (*Trichoderma* LC52).

Of the products not rated amongst the top 20 in this evaluation the following could also be included in future screening tests as there is a limited chance of efficacy against Psa:

- Actinovate® / Microplus (*Streptomyces lydicus* WYEC 108);
- Prestop® Biofungicide WP (*Gliocladium catenulatum* strain J1446);
- Bio-save® 10LP (*Pseudomonas syringae* strain ESC-10).

Of these products *Bacillus pumilus* QST 2808 (Sonata®/ Ballad® Plus), *Pantoea agglomerans* strain E325 (Bloomtime®), *Aureobasidium pullulans* (Blossom Protect™), Prestop Biofungicide WP (*Gliocladium catenulatum* strain J1446) and Bio-save 10LP (*Pseudomonas syringae* strain ESC-10) are currently not commercially available in New Zealand according to the ACVM register (Registered Veterinary Medicines, Agricultural Chemicals and Vertebrate Toxic Agents[3]). The organisms, however, are recorded as being present in the country and are non-regulated [4]. As agrichemicals, importation of the formulated products should thus be subject to approval under the Hazardous Substances and New Organisms (HSNO) Act [5].

To date, there is no strong evidence that commercial, microbial products will deliver standalone control or suppression of Psa. They are more likely to be successful when used as part of an integrated pest management strategy which incorporates tolerant kiwifruit cultivars, judicious crop hygiene and targeted pesticide applications.

It is possible that mixtures or combinations of two or more biocontrol products might be able to offer better disease suppression/control and greater reliability than individual products/organisms. However, compatibility issues would need to be addressed to ensure that individual agents in the mixture did not inhibit each other or interfere with the existing, non-pathogenic microbial community of the plant.

Similarly, integration of biological and chemical control systems could also lead to increased efficacy and better disease control.

We recommend that both approaches should to be considered when selecting biocontrol products for further evaluation of their potential to control Psa.

[3] https://eatsafe.nzfsa.govt.nz/web/public/acvm-register
[4] http://www.maf.govt.nz/biosecurity-animal-welfare/pests-diseases/boric.aspx
[5] http://www.epa.govt.nz/hazardous-substances/importing-manufacturing/Pages/Pesticide-Products.aspx

References

Backman, P.A., Wilson, M., Murphy, J.F., 1998. Bacteria for biological control of plant diseases. In: Rechcigl, N.A., Rechcigl, J.E. (Eds.), Environmentally safe approaches to plant disease control, CRC/Lewis Press, Boca Raton, FL, pp. 95-109.

Brannen, P.M., Kenney, D.S., 1997. Kodiak® - a successful biological-control product for suppression of soil-borne plant pathogens of cotton. Journal of Industrial Microbiology & Biotechnology 19, 169-171.

Bull, C.T., Stack, J.P., Smilanick, J.L., 1997. *Pseudomonas syringae* strains ESC-10 and ESC-11 survive in wounds on citrus and control green and blue molds of citrus. Biological Control 8, 81-88.

Bull, C.T., Wadsworth, M.L., Sorensen, K.N., Takemoto, J.Y., Austin, R.K., Smilanick, J.L., 1998. Syringomycin E produced by biological control agents controls green mold on lemons. Biological Control 12, 89-95.

Dorn, B., Musa, T., Krebs, H., Fried, P., Forrer, H., 2007. Control of late blight in organic potato production: evaluation of copper-free preparations under field, growth chamber and laboratory conditions. European Journal of Plant Pathology 119, 217-240.

Duffy, B., Simon, A., Weller, D., 1996. Combination of *Trichoderma koningii* with fluorescent pseudomonads for control of take–all on wheat. Phytopathology 86, 188–194.

Duijff, B.J., Recorbet, G., Bakker, P.A.H.M., Loper, J.E., Lemanceau, P., 1999. Microbial antagonism at the root level is involved in the suppression of *Fusarium* wilt by the combination of nonpathogenic *Fusarium oxysporum* Fo47 and *Pseudomonas putida* WCS358. Phytopathology 89, 1073-1079.

Elmer, P.A.G., Reglinski, T., 2006. Biosuppression of *Botrytis cinerea* in grapes. Plant Pathology 55, 155-177.

Estevez de Jensen, C., Percich, J.A., Graham, P.H., 2002. Integrated management strategies of bean root rot with *Bacillus subtilis* and *Rhizobium* in Minnesota. Field Crops Research 74, 107-115.

Evans, T.J., Trauner, A., Komitopoulou, E., Salmond, G.P.C., 2010. Exploitation of a new flagellatropic phage of *Erwinia* for positive selection of bacterial mutants attenuated in plant virulence: Towards phage therapy. Journal of Applied Microbiology 108, 676-685.

Gilardi, G., Gullino, M.L., Garibaldi, A., 2009. Evaluation of spray programmes for the management of leaf spot incited by *Pseudomonas syringae* pv. *syringae* on tomato cv. Cuore di bue. Crop Protection 29, 330-335.

Goodridge, L.D., 2004. Bacteriophage biocontrol of plant pathogens: fact or fiction? Trends in Biotechnology 22, 384-385.

Hýsek, J., Vach, M., Brožová, J., Sychrová, E., Civínová, M., Neděelník, J., Hrubý, J., 2002. The influence of the application of mineral fertilizers with the biopreparation Supresivit (*Trichoderma harzianum*) on the health and the yield of different crops. Archives Of Phytopathology And Plant Protection 35, 115-124.

John, S., Wicks, T., Hunt, J., Lorimer, M., Oakey, H., Scott, E., 2005. Protection of grapevine pruning wounds from infection by *Eutypa lata* using *Trichoderma harzianum* and *Fusarium lateritium*. Australasian Plant Pathology 34, 569-575.

John, S., Wicks, T.J., Hunt, J.S., Scott, E.S., 2008. Colonisation of grapevine wood by *Trichoderma harzianum* and *Eutypa lata*. Australian Journal of Grape and Wine Research 14, 18-24.

Koch, E., 1999. Evaluation of commercial products for microbial control of soil-borne plant diseases. Crop Protection 18, 119-125.

Kunz, S., Mendgen, K., 2009. Entwicklung von Strategien zur Feuerbrandbekämpfung im ökologischen Obstbau (Development of a strategy for fire blight control in organic fruit growing). Universität Konstanz, Lehrstuhl für Phytopahtologie, Konstanz, Germany. pp. 48.

http://orgprints.org/16515/1/16515%2D06OE524_06OE336%2Duni_konstanz%2Dkunz%2D2009%2Dfeuerbrandbekaempfung.pdf (Last accessed 29/08/2011).

Landwirtschaftliches Versuchswesen Rheinland-Pfalz, 2011. Versuche und Erhebungen im ökologischen Landbau 2010. Ministerium für Wirtschaft, Verkehr, Landwirtschaft und Weinbau, Speyer. pp. 67. http://www.am.rlp.de/Internet/global/themen.nsf/7c7312e7401a695bc12571250029f3d2/84B2C133B4E22530C125785E00238A9B/$FILE/Versuchsbericht_%20Oeko_2010_Endfassung.pdf (Last accessed 29/08/2011).

Lee, J.P., Lee, S.-W., Kim, C.S., Son, J.H., Song, J.H., Lee, K.Y., Kim, H.J., Jung, S.J., Moon, B.J., 2006. Evaluation of formulations of *Bacillus licheniformis* for the biological control of tomato gray mold caused by *Botrytis cinerea*. Biological Control 37, 329-337.

Li, X., Han, J.-S., Jin, X., Yin, D., Choi, J.-E., 2008. Control of *Alternaria* leaf blight of ginseng by microbial agent and fungicides. Research in Plant Disease 14, 102-106.

Mahony, J., Mauliffe, O., Ross, R.P., van Sinderen, D., 2011. Bacteriophages as biocontrol agents of food pathogens. Current Opinion in Biotechnology 22, 157-163.

Mao, W., Lewis, J.A., Lumsden, R.D., Hebbar, K.P., 1998. Biocontrol of selected soilborne diseases of tomato and pepper plants. Crop Protection 17, 535-542.

Olanya, O.M., Larkin, R.P., 2006. Efficacy of essential oils and biopesticides on *Phytophthora infestans* suppression in laboratory and growth chamber studies. Biocontrol Science and Technology 16, 901-917.

Oregon State University, 2007. Materials for Late Blight Management - OSPUD: Organic Late Blight Management Report 2007. http://ospud.org/materials_for_late_blight_management (Last updated 09/08/2007; last accessed 29/08/2011).

Pusey, L., Stockwell, V., Reardon, C., Smits, T., Duffy, B., 2011. Antibiosis activity of *Pantoea agglomerans* biocontrol strain E325 against *Erwinia amylovora* on apple flower stigmas. Phytopathology 101, 1234-1241.

Pusey, P.L., Stockwell, V.O., Rudell, D.R., 2008. Antibiosis and acidification by *Pantoea agglomerans* strain E325 may contribute to suppression of *Erwinia amylovora*. Phytopathology 98, 1136-1143.

Raudales, R., Cao, C., Vallad, G., McGrath, M., Gardener, B.M., 2010. Efficacy of microbial biopesticides that may be used in organic farming. http://www.extension.org/pages/29382/efficacy-of-microbial-biopesticides-that-may-be-used-in-organic-farming (Last updated 25/08/2010; last accessed 22/8/2011).

Reglinski, T., Elmer, P.A.G., Taylor, J.T., Parry, F.J., Marsden, R., Wood, P.N., 2005. Suppression of Botrytis bunch rot in Chardonnay grapevines by induction of host resistance and fungal antagonism. Australasian Plant Pathology 34, 481-488.

Robinson-Boyer, L., Jeger, M.J., Xu, X.-M., Jeffries, P., 2009. Management of strawberry grey mould using mixtures of biocontrol agents with different mechanisms of action. Biocontrol Science and Technology 19, 1051-1065.

Seibold, A., Fried, A., Kunz, S., Moltmann, E., Lange, E., Jelkmann, W., 2004. Yeasts as antagonists against fireblight. EPPO Bulletin 34, 389-390.

Sigler, W.V., Nakatsu, C.H., Reicher, Z.J., Turco, R.F., 2001. Fate of the biological control agent *Pseudomonas aureofaciens* TX-1 after application to turfgrass. Applied and Environmental Microbiology 67, 3542-3548.

Stockwell, V.O., Johnson, K.B., Sugar, D., Loper, J.E., 2010. Control of fire blight by *Pseudomonas fluorescens* A506 and *Pantoea vagans* C9-1 applied as single strains and mixed inocula. Phytopathology 100, 1330-1339.

Sundin, G.W., Werner, N.A., Yoder, K.S., Aldwinckle, H.S., 2009. Field evaluation of biological control of fire blight in the Eastern United States. Plant Disease 93, 386-394.

Syrovy, L., Sakalauskas, K., Dessureault, M., 2009. Late blight control alternatives for organic potato growers. Fraserland Organics, Certified Organic Association of British Columbia, Surrey, Canada.

pp. 26. http://www.certifiedorganic.bc.ca/programs/osdp/I-105%20Late%20blight%20organic%20efficacy_Final%20200911.pdf (last accessed: 29/08/2011).

US EPA, 2011. *Bacillus subtilis* Strain QST 713 (006479) Fact Sheet. Environmental Protection Agency Office of Pesticide Programs. http://www.epa.gov/oppbppd1/biopesticides/ingredients/factsheets/factsheet_006479.htm (Last updated 17/02/2011; last accessed: 25/08/2011).

Vanneste, J.L., Cornish, D.A., Yu, J., Voyle, M.D., 2002. P10c: A new biological control agent for control of fire blight which can be sprayed or distributed using honey bees. Acta Horticulturae 590, 231-235.

Vanneste, J.L., Cornish, D.A., Spinelli, F., Yu, J., 2004. Colonisation of apple and pear leaves by different strains of biological control agents of fire blight. New Zealand Plant Protection 57, 49-53.

Wang, X., Li, G., Jiang, D., Huang, H.-C., 2009. Screening of plant epiphytic yeasts for biocontrol of bacterial fruit blotch (*Acidovorax avenae* subsp. *citrulli*) of hami melon. Biological Control 50, 164-171.

Whipps, J.M., 2001. Microbial interactions and biocontrol in the rhizosphere. Journal of Experimental Botany 52, 487-511.

Yu, G.Y., Sinclair, J.B., Hartman, G.L., Bertagnolli, B.L., 2002. Production of iturin A by *Bacillus amyloliquefaciens* suppressing *Rhizoctonia solani*. Soil Biology and Biochemistry 34, 955-963.

Appendix

Attached: Complete list and ranking of microbial and botanical candidates for control and/or suppression of Psa assessed as part of the desktop evaluation

Complete list of microbial and botanical candidates for the control and/or suppression of Psa assessed as part of the desktop evaluation.

Total Score	Product Name	Biocontrol agent/ organism	Target pathogen/ disease	Mode of action	Target crop
20	**Serenade Max/ Serenade ASO**	*Bacillus subtilis* QST 713	Powdery mildew (*Podosphaera leucotricha, Uncinula necator, Sphaerotheca macularis, Oidiopis taurica, Leveillula taurica*); Gray mould (*Botrytis cinerea*); Downy mildew (*Plasmopara viticola, Bremia lactucae, Peronospora* spp.); Early Blight (*Alternaria solani*); Late Blight (*Phytophera infestans*); Bacterial spot (*Xanthomanas* spp.); Walnut blight (*Xanthomanas campestris*); *Monilinia* spp., *Venturia* spp., Fire Blight; *Pseudomonas syringae*	Antagonism through nutrient competition, site exclusion, colonization and attachment of the bacteria to the fungal pathogen; production of a class of lipopeptide antibiotics (incl. iturins) that help out-compete other microorganisms by either killing them, disrupting development or reducing their growth rate. May induce plants' natural systemic resistance or systemic acquired resistance (SAR) against bacterial pathogens.	acc to EPA: wide variety of food crops, including cherries, cucurbits, grapes, leafy vegetables, peppers, potatoes, tomatoes, and walnuts. Serenade Max: vegetables, fruit (Peach, apricot, plum, cherry, nectarine), nut and vine crops (grape vine, table grapes), tomato; kiwifruit, berries,
19	**BacStar ™**	*Bacillus subtilis var. amyloliquefaciens* D747	Powdery mildew, Botrytis and sour rot, fireblight	Competition for space and nutrients; antibiosis through production of antibiotic compounds; possibly plant growth regulator (as for *Bacillus subtilis var. amyloliquefaciens* strain FZB24)	grapes, kiwifruit, pipfruit, berryfruit, persimmon, onions, avocado, citrus, lettuce, turf
18	**BlightBan® A506**	*Pseudomonas fluorescens* A506	Frost damage. *Erwinia amylovora* . and russet-inducing bacteria	reduces/ suppresses growth of frost forming and fireblight inducing bacteria; competition, colonizes blossoms of apples and pears before pathogenic bacteria can get a foothold	almond, apple, apricot, blueberry, cherry, peach, pear, potato, strawberry, tomato
18	**Blossom Bless™**	*Pantoea agglomerans* P10c	fire blight	Nutrient competition (nectar, stigma), Exclusion by preemptive occupation of flower infection sites. Antibiosis	Pip fruit flowers
17.5	**Companion Gold**	*Bacillus subtilis* GB03	powdery mildew, sour rot and botrytis	Competition for space and nutrients; anitbiosis (antibiotic Iturin disrupt the cell wall formation of pathogens); Induced Systemic Resistance (ISR)	grapes and ornamentals
17.5	**Regalia®**	*Reynoutria* spp extract	Powdery Mildew, Downy Mildew, Botrytis Gray Mold, Early Blight, Late Blight, Citrus Canker, Brown Rot, Greasy Spot, Bacterial Leaf Spot, Target Spot, Gummy Stem Blight, Walnut Blight	improves plant defense system and induces resistance; stimulates plants to produce and accumulate proteins and other compounds (incl. phytoalexins, cell strengtheners, antioxidants, phenolics) that inhibit fungal and bacterial plant pathogen.	almonds, blueberries, citrus, grapes, cucurbits, leafy greens, tomato and peppers, walnuts
17	**Sonata®**	*Bacillus pumilus* QST 2808	*Alternaria* spp., *Botrytis*, *Bremia lactucae, Cercospora* spp., *Cercosporidium personatum, Erysiphe* spp., *Erwinia amylovora, Oidiopsis taurica, Peronospora* spp., *Phoma cucurbitacearum, Phytophthora* spp., *Plasmopara viticola, Podosphaera leuchotricha, Pseudoperonospora cubensis, Puccinia* spp., *Sclerotinia* spp., *Sphaerotheca* spp., *Uncinula necator, Uromyces* spp., *Venturia* spp., *Xanthomonas* spp.	Antibiosis: antifungal amino sugar compound that disrupts cell metabolism and destroys cell walls; competition for space and nutrients: physical barrier between the leaf and the pest spores, may induce systemic acquired resistance in plants.	cucurbits, grapes, hops, vegetables, peanuts, pome fruits, stone fruits, and others; black sigatoka in bananas; Many food and non-food crops, including trees susceptible to sudden oak death syndrome. For use outdoors, including nurseries, landscapes, and rights-of-way, and for use in greenhouses.
16	**Bloomtime ®**	*Pantoea agglomerans strain E325*	fire blight in apples and pears *Erwinia amylovora*	Nutrient competition (nectar, stigma), Exclusion by preemptive occupation of flower infection sites. Antibiosis	apples and pears
16	**Cease®/ Rhapsody®**	*Bacillus subtilis* strain QST 713	foliar diseases: Powdery Mildew, Leaf Spot and Speck, Anthracnose and Rust (*Pseudomonas, Erwinia, Xanthomonas*), fungal soil diseases	contact bactericide/ fungicide; competition for space and nutrients; antibiosis (lipopeptides produced by the bacterium disrupt cell membranes)	agricultural greenhouse crops (incl. leafy vegetables, roots and tubers, herbs/ spices, fruiting vegetables; Cucurbits; bulb vegetables; brassica, strawberries) Rhapsody: turf, landscape areas, ornamental and greenhouse plants
16	**Clarity/ Subtilex ® NG**	*Bacillus subtilis* MBI600	Soil borne pathogens *Fusarium* spp., *Rhizoctonia* spp. *and Pythium* spp. that cause seed and root rots; Botrytis, Powdery Mildew, Sour rot	colonizes and protects plant roots while producing a metabolite that destroys the pathogen's cell wall; suppressing disease organisms by competition	ornamentals, vegetable field and greenhouse crops Clarity: kiwifruit, grapes, citrus, onions,
15.5	**Blossom Protect™**	*Aureobasidium pullulans* DSM 14941, *Aureobasidium pullulans* DSM 14940	*Erwinia amylovora*	block fire blight pathogen, *Erwinia amylovora*, from colonizing the apple blossom, natural competition for space and nutrients	Citrus, pome fruit, sugarcane, Florida greenway and trail lands
15	**Ballad® Plus**	*Bacillus pumilus* QST2808	fungicide: rust, powdery mildew, *Cercospora*, and brown spot, Asian Soybean Rust *Phakopsora pachyrhizi* , Bacterial Blight and Streak *Xanthomonas* spp., Bacterial Speck *Pseudomonas syringae* pv. *glycinea*	antifungal amino sugar compound. Creates a zone of inhibition on plant surfaces, preventing pathogens from establishing on the plant.	Barley, Corn, Millets, Oat, Rice, Rye, Sorghum, Triticale, Wheat and other cereal grain crops; grass seed, Canola, Castor, Cotton, Flax, Oil Palm, Olive, Peanut, Rapeseed, Safflower, Sesame, Sunflower, Soybeans and other oilseed crops, Sugar Beets, sweet corn
15	**Companion®**	*Bacillus subtilis* GB03, other *B. subtilis, B. licheniformis, B. megaterium*	*Rhizoctonia, Pythium, Fusarium, Phytophthora;* Bacterial leaf spot *Xanthomonas campestris*	Competition for space and nutrients; anitbiosis (antibiotic Iturin disrupt the cell wall formation of pathogens); Induced Systemic Resistance (ISR)	turf, greenhouse, nursery, ornamental crops, field grown trees (preventative)
15	**GC-3™**	Cottonseed Oil, Corn Oil, Garlic Extract	powdery mildew	physical barrier	many crops, incl. kiwifruit
15	**Tri-D25™**	*Trichodema koningii, Trichodema hazianum*	*Phythophthora* spp., *Rhizoctonia* spp., *Botrytis* spp.	Hyperparasitism: Mycoparasitism, improved plant health; increase beneficial microbial populations	Avocados, Macadamias, Chestnut, Pistachio, Almonds & Kiwifruit; Brassicas; Carrot, Onion & Potato; Lettuce; Tomato, Capsicum, Eggplant & Strawberries; Fruit Trees; Tropical Fruits; Table & Wine Grape
14.5	**Botry-Zen®**	*Ulocladium oudemansii*	*Botrytis cinerea /Sclerotinia sclerotiorum*	competition for nutrients / space; out-competes the disease for the same ecological niche.	Registered for: Grapes, Kiwifruit, Blackcurrants, Ornamentals
14.5	**Vinevax™**	*Trichoderma harzianum*	wood-infecting fungal pathogens: *Eutypa lata, Botryosphaeria* spp., *Phaeomoniella chlamydospora, Cylindrocarpon destructans, Phomopsis viticola,* and *Botrytis cinerea.*	Niche exclusion and competition for nutrients; Myco-parasitism - degradation of other fungi; antibiosis: Production of metabolites with antifungal activity; Stimulation of the plant's defence mechanism (SAR)	Pruning wound dressing in vine
14.5	**TripleX**	*Bacillus amyloliquefaciens* BS 1b	*Botrytis cinerea*	Competition; Antibiosis	grapes, top fruit, vegetables
14.5	**Bio Sol B Sub Plus**	*Bacillus subtilis* strain ATCC6051 + seaweed extract	Powdery Mildew, *Botrytis*, Sour rot	Competition for nutrients and space; antibiosis through production of antifungal products; improved plant nutrient status and resistance.	grapes, fruits, vegetables, potatoes, ornamentals
14	**AgriPhage™**	bacteriophages	*Bacterial diseases: Xanthomonas campestris* pv. *vesicatoria*, or *Pseudomonas syringae* pv. *tomato*.	Predation: Bacteriophage destroy bacteria through lysis. Lysing begins the moment a phage comes in contact with a bacterium and results in a release of additional phages within 30 minutes. Over four billion phages are included in every ml of AgriPhage. Each phage is capable of destroying bacteria, and can replicate as many as 100 additional phage.	tomato, pepper
14	**Sentinel®**	*Trichoderma* LC52	*Botrytis cinerea*	colonises the foliage, flowers and fruit. repels invasion by B*otrytis* from affecting the plant	Grapes and tomatoes
14	**Superzyme®**	*Bacillus subtilis, Pseudomonas putida, Trichoderma koningii & Trichoderma harzianum*	plant growth promotor/ soil or foliar application	stimulate plant growth, reduce risk of disease; provide beneficial microbes to the root zone	all crops
14	**Fulzyme Plus™**	*Bacillus subtilis* + amino acids	plant growth promotor	solubilises nutrients, aids in decomposing organic matter, produces natural and beneficial substances essential for plant productivity	all crops
13.5	**Actinovate® / Microplus**	*Streptomyces lydicus* WYEC 108	soil borne diseases: *Pythium, Phytophtora, Rhizoctonia, Fusarium*, *Phytomatotricum, Aphanomyces, Monosprascus, Armillaria, Sclerotinia, Postia, Verticillium, Geotrichum;* foliar diseases: powdery mildew, downy mildew, *Botrytis*, walnut blight, *Monilinia*, Greasy Spot and *Alternaria*	Competition for space and nutrients (colonizes root tips and leaves of plants); mycoparasitism of fungal root pathogens (preys on fungi). Other possible mechanisms: production and excretion of antifungal metabolites (e.g. antibiotics, siderophores or lytic enzymes like chitinase).	Soil mixes (for potted plants and agricultural uses), turf grass, and plant foliage in greenhouses. Microplus: avocado, vegetables
12.5	**Prestop® Biofungicide WP**	*Gliocladium catenulatum strain* J1446	soil and foliar pathogens: *Pythium* spp. and *Rhizoctonia* spp., *Botrytis* grey mould and stem cancer, *Didymella* gummy stem blight	Hyperparasitism: Mycoparasitism, chitinase activity, competition for space and food (colonization of roots)	wide variety of vegetables, herbs and spices. It can also be used on turf, ornamentals, and on tree and shrub seedlings.
12.5	**Trichopel®, Trichodry®, Trichoflow ®**	*T. harzianum + T. viride*	plant growth promotor	Bio-inoculant, nutrient start-up, ensuring establishment in the root zone. Bio-active inoculation conditions the roots and boosts the plant health and vigour.	Field crops e.g. beetroot and sweet corn, indoor crops and nurseries, orchards and vineyards, flower crops (trichopel); turf (trichoflow); nursery crops (Trichodry)
12	**Botector ™**	*Aureobasidium pullulans* DSM 14941, *Aureobasidium pullulans* DSM 14940	*Botrytis cinerea*	block the grey mould pathogen, Botrytis cinerea, from colonizing infection sites on the berry surface, natural competition for space and nutrients	grapes
11.5	**Binab® Pellets**	*Trichoderma* IMI 206039 and IMI 206040	*Chondrostereum purpureum*	*Trichoderma* are saprophytes and/or mycoparasites living of other fungi	fruit trees
11.5	**Binab® Vector**	*Trichoderma polysporum, Trichoderma harzianum*	As for Binab TF WP	*Trichoderma* are saprophytes and/or mycoparasites living of other fungi	flowers in all flowering crops, in greenhouses and in the open ground.
11.5	**RootShield, PlantShield**	*Trichoderma harzianum* Rifai strain KRL-AG2 (T-22)	*Phytium* spp., *Rhizoctonia* spp., *Fusarium* spp., *Cylindrocladium* spp., *Thielaviopsis* spp., *Myrothecium* spp., *Armillaria mellea*	mycoparasitism; competition with pathogens for nutrients and space; antibiosis: release of enzymes that dissolve the cell wall of the fungal pathogens; increased tolerance to biotic and abiotic stress factors due to enhancement of root and plant growth; resistance induction against pathogens	Trees (citrus fruit, stone fruits, grapevine, table grapes, small fruits, flowers and ornamentals), shrubs, transplants, all ornamentals, cabbage, lettuce, tomato, cucumber, herbs, turf
11.5	**Trilogy®**	Clarified Hydrophobic Extract of Neem Oil	*Alternaria*, Anthracnose, Early blight, Leaf blight, *Botrytis*, Greasy spot, Leaf spot, Post bloom fruit drop, Powdery mildew, Moulds, Scabs, Rusts, Shothole	prevents fungal attack of plant tissue and contact activity to lower pressure on the plant	Citrus, Tree fruits, Cucurbits, Bulb, Cole and leafy vegetables, Legume and fruiting vegetables, Root and tuber vegetables, Small fruits and berries, Herbs and spices, Cereal and grains, Nuts, Corn, Alfalfa, Cotton
11	**AQ10 ® WG**	*Ampelomyces quisqualis* isolate M-10	powdery mildew; *In vitro: Botrytis cinerea*, *Alternaria solani*, *Colletotrichum coccodes* and *Cladosporium cucumerinum*	hyperparasitism	apples, cucurbits, table grapes, grapevine, ornamentals (rose), strawberries, and solanaceous crops
11	**Binab ® TF WP**	*Trichoderma harzianum* ATCC 20476, *Trichoderma polysporum* ATCC 20475	*Botrytis, Verticillium, Pythium, Fusarium, Phytophthora, Rhizoctonia,* fairy rings and other soil-borne fungal pathogens, and *Didymella, Chondrostereum* and *Heterobasidion*	*Trichoderma* are saprophytes and/or mycoparasites living of other fungi.	in crops, in greenhouses and in the open ground for cut flowers, pot plants, vegetables and mushrooms, flower bulbs and nurseries, berries and fruit as well as ornamental trees and grass fields.
11	**Bio-save® 10LP, 110**	*Pseudomonas syringae* Strain ESC-10	*Botrytis cinerea, Penicillium* spp., *Mucor pyroformis, Geotrichum candidum;* blue mould and gray mould. Dry rot (*Fusarium sambucinum*) and silver scurf (*Helminthosporium solani*)	enters the wounded crop where the mould spores are located and will last, under competitive inhibition, in the wounds throughout the storage period	pome fruit, citrus, cherries, seed and storage white potatoes, sweet potatoes, apples, pears.
10.5	**Green Releaf = Ecoguard**	*Bacillus licheniformis* Strain SB3086	many fungal species especially those causing leafspot and blight diseases	Soil conditioner	ornamental turf, lawns, golf courses, ornamental plants, conifers and tree seedlings in outdoor, greenhouse, and nursery sites
9.5	***Bacillus subtilis* CX-9060 - not yet available**	*Bacillus subtilis* CX-9060	Fungicide, Bactericide	production of antibiotics or other inhibitory substances; inhibition of spore germination; nutrient competition	Food crops, turf and ornamental
9.5	**AF36**	*Aspergillus flavus* AF36	*Aspergillus flavus* strains that produce aflatoxin	Outcompetes toxigenic strain of *A. flavus*	cotton
9.5	**Mycostop ®**	*Streptomyces griseoviridis* K61	*Fusarium* spp., *Alternaria brassicola, Phomopsis* spp., *Botrytis spp., Rhizoctonia* spp., *Pythium* spp. *and Phytophthora* spp. that cause seed, root, and stem rot, and wilt disease	deprives pathogenic fungi of space and nourishment by colonising plant roots; acts as a hyperparasite, disrupting cell walls of pathogens; produces metabolites that inhibit plant pathogens	field, ornamental, and vegetable crops
9	**FZB24® Bacillus subtilis**	*Bacillus subtilis var. amyloliquefaciens* strain FZB24	'plant strengthening agent'	Competition; Induced resistance; Promotion of plant and root growth.	approved for use only in greenhouses and other indoor sites. It can be used at these sites on shade and forest tree seedlings, ornamentals, and shrubs. Its use is not permitted on food crops. http://www.epa.gov/oppbppd1/biopesticides/ingredients/factsheets/factsheet_006480.htm
9	**Bacteriophage of *Clavibacter michiganensis* - not yet available**	Bacteriophage of *Clavibacter michiganensis*	bacteriosis on tomato	Predation	tomato
9	***Burkholderia cepacia* (currently no product available)**	*Burkholderia cepacia*	*Rhizoctonia, Pythium, Fusarium*, *Alternaria*, *Aphanomyces euteiches*, *Cylindrocarpum*, and *Botrytis*	antibiosis, inhibiting spore germination; growth promotion (PGPR)	Seedlings, alfalfa, barley, beans, clover, cotton, peas, grain sorghum, rape and canole, ginseng, vegetable crops, and wheat, conifers
9	**Yeast strain 0732-1 (no product available)**	yeast strain 0732-1 *Pichia anomala* Kurtzman	Bacterial fruit blotch caused by *Acidovorax avenae* ssp. *citrulli*	Antibiosis/ Acidic compounds	cucurbitaceous crops / hami melon

*, Target pathogen/ disease: 5 – Pseudomonas; 4 – Other bacterial diseases on fruit; 3 – All other bacteria; 2 – Foliar diseases caused by fungi; 1 – Soil-borne diseases

**, Mode of action: 5 – Several modes of action against bacterial pathogens; 4 – One mode of action against bacterial pathogens; 3 – Several modes of action against fungal pathogens; 2 – One mode of action against fungal pathogens; 1 – Plant growth promotion, if only mode of action

***, Target crop: 5 – Perennial vine crops (including grape and kiwifruit); 4 – Fruit trees; 3 – Other perennial tree crops; 2 – Perennial vegetables / arable crops (incl. tomato); 1 – Annual vegetables / arable crops.

****, Availability / ease of import: 5 – Available in NZ; 3 – Most other products and organisms where species might be present in NZ and organism is not on MAF unwanted organism list; 1 – No product available, i.e. organism would need to be isolated or imported from culture collection; 0 – Organism on MAF list of unwanted organisms / regulated pest.

Manufacturer/distributor	NZ Kiwifruit Industry Psa Screening Status	Ref	Ranking*	Ranking**	Ranking***	Ranking****	Total Score
Serenade: AgraQuest, Inc., USA, http://www.agraquest.com; BASF New Zealand Ltd; ACVM Registered, New Zealand	GH testing complete/ field trials pending	Li et al. (2008), Olanya & Larkin (2006) http://www.epa.gov/opppbpd1/biopesticides/ingredients/factsheets/factsheet_006479.htm http://www.epa.gov/opppbpd1/biopesticides/ingredients/tech_docs/tech_006479.htm http://www.agro.basf.com/agr/AP-Internet/en/content/solutions/solution_highlights/serenade/bacillus-subtilis	5	5	5	5	20
ETEC Crop Solutions Limited; http://www.elliottchemicals.co.nz/	GH testing complete	http://tinyurl.com/6zhjpf3	4	5	5	5	19
NuFarm Inc.. USA http://www.nufarm.com	GH testing complete/ field trial pending	http://www.nufarm.com/USAg/BlightBanrA506 Sundin et al. (2009)	4	5	4	5	18
AgriNova NZ Ltd, New Zealand http://www.grochem.co.nz	GH testing complete/ field trial results pending	http://www.grochem.co.nz/Default.aspx?TabID=35618&productid=25&a=2 http://www.grochem.co.nz/Portals%5C537%5Csds/BlossBless%20SDS.pdf http://www.grochem.co.nz/Portals%5C537%5Clabels/BlossomBless_300g.pdf	4	5	4	5	18
Zelam Ltd, NZ; www.nuchem.co.nz	*in vitro* testing complete	http://www.nuchem.co.nz/Zelam%20MSDS/Companion%20Gold%20MSDS.pdf	3.5	4	5	5	17.5
Marrone Bio Innovations, USA, http://marronebioinnovations.com	testing pending	http://marronebioinnovations.com/pdf/regalia_msds.pdf http://marronebioinnovations.com/pdf/regalia-caution-specimenlabelJan2011.pdf	4	4	4.5	5	17.5
AgraQuest, Inc., USA, http://www.agraquest.com		http://www.agraquest.com/agrochemical/products/fungicides-sonata.php http://www.agraquest.com/docs/labels-msds/Sonata-Label.pdf http://www.epa.gov/pesticides/biopesticides/ingredients/factsheets/factsheet_006485.htm	4	5	5	3	17
Northwest Agricultural Products, USA http://www.nap-chem.com/		Pusey et al. (2008), http://www.nap-chem.com/Product_Pages/yeoman_products.htm	4	5	4	3	16
BioWorks, USA. http://www.bioworksinc.com		Gilardi et al. (2009)	5	5	3	3	16
Becker Underwood, Australia, http://www.beckerunderwood.com in NZ Registered as Clarity; Gro-Chem, T/A Agrinova NZ Ltd	GH testing complete	http://www.beckerunderwood.com/en/products/subtilexng:usa http://web.pppmb.cals.cornell.edu/resourceguide/mfs/01bacillus_subtilis.php http://www.grochem.co.nz/Default.aspx?TabID=35618&productid=37&a=2	3	3	5	5	16
BIO-FERM GMBH, Austria, http://www.bio-ferm.com/en office@bio-ferm.com		http://www.bio-ferm.com/en/index.php?id=211 http://www.bio-ferm.com/media/file/Blossom_Protect_Comp_A_GB_2011.pdf http://www.bio-ferm.com/media/file/Blossom_Protect_Comp_B_GB_2011.pdf	4	5	3.5	3	15.5
AgraQuest, Inc., USA. http://www.agraquest.com		http://www.agraquest.com/docs/labels-msds/Ballad-Plus-Label.pdf	4.5	4	3.5	3	15
Growth Products, Ltd., USA. www.growthproducts.com		Lee et al. (2006), http://www.growthproducts.com/pages/horticulture.asp?tables=featured&product=10	4	5	3	3	15
JH Biotech, Inc.; USA, Roots Shoots and Fruits Ltd, New Zealand, www.rd2.co.nz		http://www.rd2.co.nz/uploads/MSDS%20GC-3%20NZ.doc http://www.rd2.co.nz/images/labels/qc_3.gif	3	2	5	5	15
Roots Shoots and Fruits Ltd, New Zealand, www.rd2.co.nz	included but no testing	http://www.rd2.co.nz/index.php?page=biologicals http://www.rd2.co.nz/uploads/TriD25%20NZ(1).pdf http://www.rd2.co.nz/uploads/TriD25%20105x100%20180907(1).pdf	2	3	5	5	15
Botryzen New Zealand http://www.botryzen.co.nz		http://www.botryzen.co.nz/pdf/Botry-Zen_MSDS_v5.pdf	2	3	4.5	5	14.5
Agrimm Technologies Ltd, New Zealand, http://www.vinevax.com		http://www.vinevax.com/vinevax.html http://www.vinevax.com/pdfs/BrochureVinevaxPWD.pdf	2	3	4.5	5	14.5
BioStart Limited, NZ; http://www.biostart.co.nz	GH testing complete	http://tinyurl.com/5rtlt9f	2	3	4.5	5	14.5
Biological Solutions Ltd., New Zealand; http://www.biosolutions.co.nz/	*in vitro* testing complete	http://www.biosolutions.co.nz/b-sub-plus http://www.biosolutions.co.nz/assets/pdfs/bol-sol-b-sub.pdf	2	3	4.5	5	14.5
Omnilytics, USA Http://www.omnilytics.com		http://www.omnilytics.com/documents/infosheet.pdf http://www.omnilytics.com/documents/AgriPhage,%20T&P%20Xanth%20MSDS.pdf	4.5	4	2.5	3	14
Agrimm Technologies Ltd, New Zealand, http://www.vinevax.com		http://www.vinevax.com/sentinel.html http://www.vinevax.com/pdfs/BrochureSentinel.pdf http://www.vinevax.com/pdfs/MSDSSentinel.pdf	2	2	5	5	14
Roots Shoots and Fruits Ltd, New Zealand, www.rd2.co.nz	*in vitro* testing complete	http://www.rd2.co.nz/uploads/MSDS%20Superzyme%20NZ.pdf http://www.rd2.co.nz/uploads/Superzyme%20105x100%20180907(1).pdf	1	3	5	5	14
Roots Shoots and Fruits Ltd, New Zealand, www.rd2.co.nz	*in vitro* testing complete	http://www.rd2.co.nz/uploads/Fulzyme%20Plus%20100x100%20180907(1).pdf http://www.rd2.co.nz/uploads/MATERIAL%20SAFETY%20DATA%20SHEET-%20FULZYME-PLUS.doc	1	3	5	5	14
Natural Industries, Inc. USA. http://www.naturalindustries.com/index.html Microplus: Sustainable Ventures Pty Limited trading as Organic Farming Systems Australia/ Mantissa Corporation Ltd, New Zealand http://www.organicfarming.com.au/		http://www.epa.gov/pesticides/biopesticides/ingredients/factsheets/factsheet_006327.htm http://www.naturalindustries.com/2005-sp.factsheet-MSDS.pdf	3	3	2.5	5	13.5
Verdera Oy, Finland, http://www.verdera.fi/homeeng.html; NZ distributor in NZ: Lallemand Plant Care, Nelson, infos@ithec.fr		http://orgprints.org/10640/1/Lepaa2.pdf	2	2.5	3	5	12.5
Agrimm Technologies, New Zealand, www.tricho.com		http://www.tricho.com/pdfs/MSDSTrichopel.pdf http://www.tricho.com/pdfs/MSDSTDryNursery.pdf	1	3	3.5	5	12.5
BIO-FERM GMBH, Austria, http://www.bio-ferm.com/en office@bio-ferm.com		http://www.bio-ferm.com/en/index.php?id=217	2	2	5	3	12
BINAB Bio-Innovation EFTR AB, Sweden; info@binab.com;		http://www.algonet.se/~binab/english/tp.htm	2	2.5	4	3	11.5
BINAB Bio-Innovation EFTR AB, Sweden. info@binab.com; http://www.algonet.se/~binab/index2.html		http://www.algonet.se/~binab/english/vect.htm	2	2.5	4	3	11.5
Bioworks, Inc., USA, http://www.bioworksbiocontrol.com		http://www.bioworksbiocontrol.com/products/shared/rootshield.pdf http://www.bioworksbiocontrol.com/products/plantshield-hc/plantshield-hc.pdf	1	2.5	5	3	11.5
Certis U.S.A. L.L.C. USA http://www.certisusa.com		http://www.certisusa.com/pdf-labels/Trilogy-label-08072009.pdf http://www.certisusa.com/pdf-msds/trilogy-70EC-msds.pdf	2.5	2	4	3	11.5
Intrachem Bio Italia SpA, Italy http://www.intrachem.com		http://www.epa.gov/opp00001/biopesticides/ingredients/factsheets/factsheet_021007.htm	2	2	4	3	11
BINAB Bio-Innovation EFTR AB, Sweden. info@binab.com;		http://www.algonet.se/~binab/english/tf.htm	2	2.5	3.5	3	11
JET Harvest Solutions, USA. http://www.jetharvest.com		http://www.jetharvest.com/biosave.html http://www.epa.gov/pesticides/biopesticides/ingredients/factsheets/factsheet_006441.htm Bull et al. (1997, 1998)	2	2	4	3	11
Novozymes A/S, Denmark; or Novozymes Biologicals, Inc., USA; http://www.novozymes.com		Lee et al. (2006)	2	2.5	3	3	10.5
www.certisUSA.com		http://www.epa.gov/opp00001/biopesticides/reqtools/biopesticides_2011_workplan.html	3.5	2.5	2.5	1	9.5
Arizona Cotton Research and Protection Council USA. http://azcotton.org/		http://azcotton.org/AF36/AF36%20COVER%20PAGE.htm	2	2	2.5	3	9.5
Verdera Oy, Finland; http://www.verdera.fi/homeeng.html		http://verdera.com/documents/MycostopMixqb-eng.pdf	2	2.5	2	3	9.5
Bayer CropScience AG, Germany; http://www.bayercropscience.com		http://www.bayercropscience.com/bcsweb/cropprotection.nsf/id/2ndArticle012000_EN http://www.epa.gov/opppbpd1/biopesticides/ingredients/factsheets/factsheet_006480.htm	1	5	0	3	9
Omnilytics USA Http://www.omnilytics.com		http://www.epa.gov/opp00001/biopesticides/reqtools/biopesticides_2011_workplan.html	4	2	2	1	9
n/a		http://www.epa.gov/opppbpd1/biopesticides/ingredients/factsheets/factsheet_006465.htm	2	3	3	1	9
n/a		Wang et al. (2009)	3	4	1	1	9

Complete list of microbial and botanical candidates for the control and/or suppression of Psa assessed as part of the desktop evaluation.

Total Score	Product Name	Biocontrol agent/ organism	Target pathogen/ disease	Mode of action	Target crop
9	**Cedomon**	*Pseudomonas chlororaphis* MA 342	seed-borne diseases on barley and oats.	Antibiosis: production of 2,3-deepoxy-2,3-didehydrorhizoxin (DDR) during exponential growth phase	Blackcurrants
9	**EcoGuard**	*Bacillus licheniformis* SB3086	Dollar spot (*Sclerotinia homoeocarpa*) and anthracnose (*Colletotrichum graminicola*); GN: *Rhizoctonia solani* and *Phytophthora drechsleri*.	inhibits fungal growth.	turf; GN: greenhouses, nurseries, and ornamental gardens
9	**PIX PLUS**	*Bacillus cereus* BP01/ Mepiquat Chloride	plant regulator	When applied with mepiquat chloride, plant regulator promotes uniform plant height in cotton, decrease vegetative growth and promote boll growth, leading to yield increases.	cotton plants
8.5	**AtEze**	*Pseudomonas chlororaphis* 63-28	controls several kinds of harmful fungi (*Pythium* spp., *Rhizoctonia solani, Fusarium oxysporum*) that grow on or near crop roots and cause stem and root rot	Competition for space and nutrients (the bacterium seems to contain a special protein that binds iron that the fungi might need for growth and reproduction); antibiotic production, growth factor production (cytokinin), which could help the plant to limit fungal damage	ornamentals and vegetables grown in greenhouses, nursery crops, vegetable transplants
8	**Supresivit**	*Trichoderma harzianum* Rifai aggr PV5736-89	Damping off of ornamentals, fungal diseases of peas	mycoparasitism; competition for nutrients and space; antibiosis; resistance induction	Ornamentals; peas
8	**Afla-Guard GR**	*Aspergillus flavus* NRRL 21882	aflatoxin-producing fungi in peanuts and corn	Outcompetes toxigenic strain of *A. flavus*	Corn, field; Corn, popcorn; Corn, sweet; Peanuts
8	**Contans WG**	*Coniothyrium minitans* strain CON/M/91-08	*Sclerotinia sclerotiorum and S. minor: white mold, pink rot, and water soft rot.*	Predation: attacks sclerotia in soil	agricultural soil: vegetables and fruit, ornamentals, herbs and spices, agricultural crops susceptible to Sclerotinia
8	**Kodiak**	*Bacillus subtilis* GB03	*Rhizoctonia solani, Fusarium* spp., *Alternaria* spp., *Aspergillus* spp. that attack roots, *Bradyrhizobium*	Competition for space and nutrients; antibiosis (iturin inhibits the pathogen's growth)	Barley, Field Bean, Green Bean, Kidney Bean, Lima Bean, Navy Bean, Pinto Bean, Snap Bean, Wax Bean, Field Corn, Sweet Corn, Cotton, Garden Pea, Peanut, Soybean, Wheat
8	**MeloCon WG**	*Paecilomyces lilacinus* strain 251	Plant parasitic nematodes		Vegetables, Strawberries, Citrus, Nuts, Peaches, Grapevines. Ornamental plants
8	**HiStick ® N/T or Peat**	*Bacillus subtilis* MBI600 (+ *Rhizobium leguminosarum* bv. *phaseoli* as rhizobial inoculant)	*Fusarium* spp., *Rhizoctonia* spp., *Aspergillus* spp.	*Bacillus subtilis* MBI 600 extend along the developing root systems, promoting more effective nodulation by its nitrogen fixing partners, resulting in a more uniform stand with great yield potential.	soybean, alfalfa, dry/snap beans, peanuts
7	**Trichodex**	*Trichoderma harzianum* Rifai Strain T-39	*Botrytis cinerea*	Competition: displaces the disease-causing gray mould from plants if it is applied early in the growing season.	For ground application only to all food commodities, except apple fruit, sugar cane, rice, corn, bok choy, tomato, mushrooms, lemon, kiwi, cotton, tobacco, wheat, barley, oats, and soybean.
7	***Pseudomonas aureofaciens* Tx-1 (no product available)**	*Pseudomonas aureofaciens* Tx-1	*Sclerotinia homeocarpa* (dollar spot), *Colletotrichum graminicola* (anthracnose), *Pythium aphanadermatum* , *Michrodochium nivale* (pink snow mold).	Antimicrobial compound phenazine-1-carboxylic acid; inhibition of development; competition	Foliar diseases on Turfgrass
7	**Cerall**	*Pseudomonas chlororaphis*	most commonly occurring seed-borne diseases	Antibiosis: production of 2,3-deepoxy-2,3-didehydrorhizoxin (DDR) during exponential growth phase	Ornamentals
6.5	**Twist Fungus**	*Dilophospora alopecuri*	*Rathayibacter toxicus* and *Anguina funesta*	restricts the growth and reproduction of nematodes and bacterium in ryegrass; may be several years before it reaches a level of prevalence that may restrict the causative organisms of ryegrass toxicity	annual ryegrass toxicity
5	**SoilGard ® 12 G**	*Gliocladium virens* GL-21/ *Trichoderma virens*	Target Crop/Pathogen: damping-off and root rot pathogens especially *Rhizoctonia solani* and *Pythium* spp., *Sclerotinia minor/S. sclerotiorum*	Antibiosis; Mycoparasitism; Competition; Exclusion	Greenhouse/Ornamentals Greenhouse/Transplants Field Crops (Agricultural crops, including melons—watermelons, cantaloupes, honeydew-- spinach, lettuces, etc.)
5	***Talaromyces flavus* (product no longer available)**	*Talaromyces flavus*	*Verticillium albo-atrum*	fungal antagonist; stimulates plant growth, strengthens plant against the pathogens	cucumber
5	**GB34 Biological Fungicide (no longer available)**	*Bacillus pumilus* strain GB34	fungal pests *Rhizoctonia and Fusarium*	prevents germination of the spores of the target fungi *Rhizoctonia* and *Fusarium*, and the bacterium may subsequently grow on the fungal spores.	soybean seeds

*, Target pathogen/ disease: 5 – Pseudomonas; 4 – Other bacterial diseases on fruit; 3 – All other bacteria; 2 – Foliar diseases caused by fungi; 1 – Soil-borne diseases

**, Mode of action: 5 – Several modes of action against bacterial pathogens; 4 – One mode of action against bacterial pathogens; 3 – Several modes of action against fungal pathogens; 2 – One mode of action against fungal pathogens; 1 – Plant growth promotion, if only mode of action

***, Target crop: 5 – Perennial vine crops (including grape and kiwifruit); 4 – Fruit trees; 3 – Other perennial tree crops; 2 – Perennial vegetables / arable crops (incl. tomato); 1 – Annual vegetables / arable crops.

****, Availability / ease of import: 5 – Available in NZ; 3 – Most other products and organisms where species might be present in NZ and organism is not on MAF unwanted organism list; 1 – No product available, i.e. organism would need to be isolated or imported from culture collection; 0 – Organism on MAF list of unwanted organisms / regulated pest.

Manufacturer/distributor	NZ Kiwifruit Industry Psa Screening Status	Ref	Ranking*	Ranking**	Ranking***	Ranking****	Total Score
BioAgri/Ing Rudolf Woisetchlager www.bioagri.se		M. Hökeberg (2006): http://www.rebeca-net.de/downloads/P%20%20chlororaphis%20MA%20342%20.pdf	1	2	3	3	9
LebanonTurf, USA http://www.lebanonturf.com		http://cropsoil.psu.edu/turf/research/annual-reports/2010/PSU10_R09_EcoGuard.pdf/view http://www.lebanonturf.com/products/items/1557107/index.aspx http://www.lebanonturf.com/products/items/1556786/index.aspx	2	2	2	3	9
Arysta Life Sciences , Japan http://www.arystalifescience.us/		http://www.cdms.net/LDat/ld83C000.pdf http://www.cdms.net/LDat/mp83C002.pdf	1	2	3	3	9
EcoSoilsystems Inc., USA http://www.splashcreations.com/portfolio/ecosoil/ateze.html, epedersen@ecosoil.com		http://www.epa.gov/opbppd1/biopesticides/ingredients/factsheets/factsheet_006478.htm	1	3	1.5	3	8.5
Borregaard BioPlant ApS, Denmark or Fytovita, Czech Republic http://uk.bioplant.dk/		Hýsek et al. (2002), Koch (1999) http://bioplant.dk/produkter/mikrobiologi/supresivit.aspx	1	3	1	3	8
Syngenta Crop Protection USA. http://www.syngentacropprotection-us.com/		http://tinyurl.com/65r3dvz http://tinyurl.com/6gxqrj9 http://www.sciencedaily.com/releases/2010/09/100903121416.htm	2	2	1	3	8
Prophyta Biologischer Pflanzenschutz GmbH, Germany; http://www.prophyta.de/en		http://www.epa.gov/opbppd1/biopesticides/ingredients/factsheets/factsheet_028836.htm http://www.prophyta.de/en/technology/sclerotinia-diseases/ http://neu.prophyta.de/wp-content/uploads/2010/07/Folder-Contans-english.pdf	1	2	2	3	8
Bayer CropScience, USA http://www.bayercropscience.us		Brannen & Kenney (1997), Backman et al. (1998) http://www.bayercropscience.us/products/seed-treatments/kodiak/	1	3	1	3	8
Certis USA LLC, http://www.certisusa.com		http://www.cdms.net/LabelsMsds/LMDefault.aspx?pd=9428&t=1,2,3,4 http://www.certisusa.com/pdf-labels/MeloCon_Label.pdf	0	0	5	3	8
Becker Underwood, 801 USA, http://www.beckerunderwood.com		http://www.beckerunderwood.com/library/HS%20Dry%20Bean%20NT.pdf http://www.beckerunderwood.com/library/HS%20Hairy%20Vetch.pdf http://www.beckerunderwood.com/library/HS%20Alfalfa.pdf http://www.beckerunderwood.com/library/HS%20Soybean%20NT.pdf http://www.beckerunderwood.com/librarv/HS%20Peanut%20NT.pdf	1	2	1	4	8
Makhteshim-Agan of North America, USA. No website		http://www.epa.gov/opbppd1/biopesticides/ingredients/factsheets/factsheet_119200.htm	2	2	2	1	7
n/a		http://www.epa.gov/opbppd1/biopesticides/ingredients/factsheets/factsheet_006473.htm Sigler et al. (2001)	2	3	1	1	7
BioAgri/Ing Rudolf Woisetchlager www.bioagri.se		M. Hökeberg (2006): http://www.rebeca-net.de/downloads/P%20%20chlororaphis%20MA%20342%20.pdf	1	2	1	3	7
Becker Underwood Australia & Asia http://www.beckerunderwood.com		http://www.beckerunderwood.com/en/products/twist%20fungus	0.5	1	1	4	6.5
Certis USA LLC, http://www.certisusa.com		*G. virens* MAF status: Regulated pest/ on Unwanted Organism Register; however indigenous in NZ according to EPA list	1	3	1	0	5
n/a		Regulated Pest; on Unwanted Organism Register / however present in NZ according to EPA list	1	3	1	0	5
n/a		http://www.epa.gov/opbppd1/biopesticides/ingredients/factsheets/factsheet_006493.htm	1	2	1	1	5