IRIS AperTO

UNIVERSITÀ DEGLI STUDI DI TORINO

AperTO - Archivio Istituzionale Open Access dell'Università di Torino

Efficacy of different chemical and biological products in the control of Pseudomonas syringae pv. actinidiae on kiwifruit.

This is the author's manuscript

Original Citation:

Availability:

This version is available http://hdl.handle.net/2318/157911 since 2016-07-04T22:28:07Z

Published version:

DOI:10.1007/s13313-014-0328-1

Terms of use:

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)

30 September 2022

Short title: Control of *Pseudomonas syringae* pv. *actinidiae* on kiwifruit

Title:

Efficacy of different chemical and biological products in the control of *Pseudomonas syringae* pv. *actinidiae* on kiwifruit

Matteo Monchiero[1], Maria Lodovica Gullino[1,2], Massimo Pugliese[1,2], Davide Spadaro[1,2*], Angelo Garibaldi[1]

[1] Centre of Competence for the Innovation in the Agro-environmental Sector (AGROINNOVA), University of Turin, Grugliasco (TO), Italy.

[2] DISAFA, Dept. Agricultural, Forestry and Food Sciences, University of Turin, Grugliasco (TO), Italy.

Correspondence*:

Davide Spadaro, University of Turin, Via L. da Vinci 44, I-10095 Grugliasco (TO), Italy.

Telephone: +39-011-6708942

Fax: +39-011-6709307

E-mail: davide.spadaro@unito.it

Keywords

Actinidia deliciosa, bacterial canker, chemical control, control strategies, Italy.

Abstract

The recent outbreak of bacterial canker on kiwifruit, caused by *Pseudomonas syringae* pv. *actinidiae*, has caused considerable damage to the international kiwifruit industry.Commercial products, and products under development, were evaluated over two years to assess their ability to control bacterial canker on kiwifruit under controlled conditions. The results were compared with two trials carried out in a kiwifruit orchard located in northern Italy during 2011 and 2012, to test the preventative efficacy of different copper formulations against *P. syringae* pv. *actinidiae*. In the greenhouse and orchard trials, copper hydroxide and the mixtures of copper hydroxide and copper oxychloride, significantly reduced the foliar symptoms by 70-80% compared with the control, and showed low phytotoxicity. Similar efficacy was provided by acibenzolar-S-methyl, whose use has been temporarily extended to kiwifruit in Italy, with a maximum of four treatments per year. However, the product showed phytotoxicity on one-year old plants. The efficacy of fosetyl-Al was lower, particularly in the first orchard trials of 2012 and 2013. The efficacy of the other products tested never exceeded 30-40%, and some products were not significantly different from the control. Kiwifruit plants grown in a steamed peat substrate mixed with compost obtained from digested organic matrices of municipal solid waste showed significantly fewer leaf spots compared with untreated controls. Copper compounds alternated with resistance inducers could be used in combination with compost, in order to develop new integrated control strategies to reduce the disease development and spread.

Introduction

Kiwifruit originated in China, but it was New Zealand that introduced its cultivation, which has been gradually adopted by other countries, becoming of primary importance in global fruit production. Kiwifruit is characterized by a high adaptability of the two species *Actinidia deliciosa* and *A. chinensis* (Ferguson and Huang, 2007). The global production was over 1.4 million tons in 2012, and Italy produced around 384,000 tons (FAOSTAT, 2014). Italy produces more kiwifruit than any other country apart, possibly, from China (Testolin and Ferguson, 2009). Piedmont (northwest Italy), where

6,050 hectares of kiwifruit are cultivated (Piedmont Region - AGRISTAT, 2011), is the largest Italian region responsible for kiwifruit storage and export, and the second largest producer of the fruit (ISTAT, 2011).

Pseudomonas syringae pv. *actinidiae* (Psa) was first isolated and described in Japan in 1984 (Takikawa et al., 1989), then in Italy and South Korea (Koh et al., 1994; Scortichini, 1994) on cv. Hayward (*A. deliciosa*). For more than 15 years this bacterial disease was considered to be of low importance on kiwifruit produced in Italy. However, since 2008, the first outbreaks of bacterial canker on kiwifruit cultivated in Central Italy, led to the removal of most orchards of *A. chinensis* in the region (Balestra et al., 2009; Ferrante and Scortichini, 2009, 2010). During 2009-2011, *P. syringae* pv. *actinidiae* started to severely infect *A. deliciosa* cv. Hayward in the main fruit producing regions of Italy. During spring 2010, the first outbreaks were identified in Piedmont (northern Italy), where the pathogen was most probably introduced by infected propagation material (Armentano, 2010; Spadaro et al., 2010). Despite the strict application of preventative measures to avoid the spread of the disease, in 2011 the pathogen was present throughout the kiwifruit production area in northern Italy, with considerable yield losses and the removal of hundreds of hectares (Spadaro et al., 2011).

In 2010, the pathogen was also officially reported in New Zealand, where severe damage was caused to *A. chinensis* and *A. deliciosa* crops (Everett et al., 2011). The disease has reached pandemic proportions by spreading to France, Spain, Portugal, Switzerland, Chile, Turkey, South Korea and Japan (Vanneste et al., 2011; Renzi et al., 2012; EPPO, 2012).

The sudden disease outbreaks were caused by strains of *P. syringae* pv. *actinidiae* not derived from the pre-existing strains, but evolved separately from Chinese strains (Mazzaglia et al., 2012; Butler et al., 2013; McCann et al., 2013; Vanneste, 2013). The more recent strains rapidly adapted to new hosts and environments through the gain or loss of mobile genetic elements and virulence factors (Scortichini et al., 2012).

Damages caused by *P. syringae* pv. *actinidiae* are worsening the possibility of cultivating kiwifruit, particularly in areas such as northern Italy, which are closer to the thermal limits for *Actinidia* spp.

77 cultivation (EPPO, 2012). The climate pattern of northern Italy, characterized by cold winters with
78 minimum temperatures lower than -15°C, and fresh and humid spring and autumn seasons, creates
79 favourable conditions for the pathogen spread.
80 Due to the virulence of the bacterial pathogen, preventative crop protection strategies play a major
81 role and are mainly based on symptomatic plant removal and destruction, due to the high survival
82 capacity of the pathogen in fallen leaves and pruning debris (Tyson et al., 2012), and on asymptomatic
83 leaves as an epiphyte (Vanneste et al., 2011b). The pathogen can be found on the external surfaces of
84 footwear, vehicles, and tools, which could be efficient vectors of the disease (Everett et al., 2012).
85 When purchasing plants for new orchards, it is important to check the production area of the scions
86 and of the mother plants, to ensure plants are sourced from healthy nurseries. Among the agronomic
87 practices, excessive nitrogen fertilization stimulates the pathogen development, while extensive
88 pruning favours bacterial spread (Spadaro et al., 2011).
89 Preventative practices are fundamental, due to the prohibition of using antibiotic products and the
90 reduced availability of active ingredients registered for use on kiwifruit. Currently, chemical control
91 of *P. syringae* pv. *actinidiae* is mainly based on copper products, most of them authorized for winter
92 treatment and effective against other bacterial pathogens on kiwifruit, such as *P. syringae* pv. *syringae*
93 and *P. viridiflava* (Fratarcangeli et al., 2010). The first opportunity to use such products are as
94 preventative applications during plant dormancy, such as after harvest and at leaf fall in autumn, and
95 after pruning and at budding in winter, and also after every frost period. Moreover, during the growing
96 season, other copper treatments could be used every time wounds are caused by hail or green pruning,
97 by choosing formulates with a low copper content. However, the above mentioned strategies seem to
98 be insufficient in controlling bacterial canker on kiwifruit, so new products have been evaluated and
99 introduced into the market, such as formulations of copper with humic acids, amino acids or nitrates
100 (Quattrucci et al., 2010), where the metal ions can be partially absorbed by the plant, reducing the
101 runoff of the active ingredient.

Moreover, other interesting products are resistance inducers, such as fosetyl-Al, potassium phosphites, and acibenzolar-S-methyl, registered and used on other crops, and antagonistic microorganisms, such as *Bacillus subtilis* and *B. amyloliquefaciens*. Natural products, such as essential oils, could be used to control different diseases on fruit crops in the orchard (Lopez-Reyes et al. 2010; 2013). Together with commercial products, many other formulations can be found on the market, generally described as leaf fertilizers or plant strengtheners, to avoid the strict European regulations for registering and commercialising new agrochemicals. Another preventative strategy, which has previously been shown to have disease suppression characteristics, is to use soil amended with compost obtained from digested organic matrices of municipal solid waste (Pugliese et al., 2008; 2011).

The aim of the present work was to evaluate the efficacy of commercial products, and products under development, in controlling bacterial canker on kiwifruit under controlled conditions. The results were also compared with two trials carried out at a kiwifruit orchard located in Piedmont (northern Italy) during 2011 and 2012 to test the preventative efficacy of different copper formulations, used alone or in mixture with resistance inducers or mancozeb, against *P. syringae* pv. *actinidiae*.

Materials and methods

Plants and microorganisms

For the controlled conditions experiments, female plants of *Actinidia deliciosa* cv. Hayward were used. The plants were grown in black plastic pots containing 5 l of a sterilized peat mixture substrate (Irish peat : Swedish peat, 1:1 vol/vol) and were determined to be free of Psa symptoms following visual inspection. One leaf was sampled from every plant, DNA extracted and polymerase chain reaction (PCR) tests conducted according to the method described by Rees-George et al. (2010). All samples were negative for Psa.

Plants were spray-inoculated with strains of *Pseudomonas syringae* pv. *actinidiae* by directly spraying cell suspensions (10^8 cells ml^{-1}) on to the leaves of the kiwifruit plant. The strains used were isolated from kiwifruit leaves infected with *P. syringae* pv. *actinidiae*, harvested from orchards located in Piedmont. Inoculations were performed just after sunset, to exploit the overnight temperature reduction. After inoculation, plants were covered for 72 h with a transparent plastic film to maintain a humidity saturated environment.

Greenhouse trials in 2012

To test the efficacy of different products, trials were performed in two subsequent years, 2012 and 2013. In each trial, 25 treatments were compared, with each treatment being tested on 10 plants (Table 1 and 2).

A set of 500 potted plants of *Actinidia deliciosa* cv. Hayward 30-40 cm high were divided into two 250 plant groups. In January 2012, the first group of plants was moved to the greenhouse where the temperature was kept at 20°C.

The trial included two treatments with resistance inducers and one treatment of all other products, such as protectants, disinfectants or bactericides prior to spray-inoculation with Psa. Plants were treated with resistance inducers on March 13, 2012, and then with all the products seven days later. The products were applied by spraying a 25 ml suspension per plant. On the following day, all plants were spray-inoculated with a suspension of bacterial cells (10^8 cells ml^{-1}); each plant was sprayed with a 30 ml suspension. Seven days after inoculation, when the first symptoms occurred, plants were treated again. After the second application of all treatments, pots were moved outside under a shadow net and treatments were performed by following the calendar indicated in Table 1. In the case of compost treatments, kiwifruit plants were planted in a mixture of steamed peat mixture substrate (Irish peat:Swedish peat, 1:1 vol/vol) (80%) and compost (20%), but no other treatments were performed, in order to evaluate the potential induction of resistance by compost.

At the end of June, when the plants had reached 2 m in height and started to show symptoms of water and nutritional stress due to the high ambient temperatures of this time of the season in Italy, not favourable to the growth of the bacterium, the trial was interrupted. In July, plants were pruned, transferred into larger pots (7 l), fertilized and left to rest in order to repeat the trial in the following year.

The second group of plants were kept in a growth chamber at 12°C to slow down development and transferred to a greenhouse on March 29, 2012. The first treatment with resistance inducers was applied on April 4, 2012, while the second treatments with all the products were applied seven days later.

The first inoculation with Psa was conducted on April 12, 2012, as described previously, but due to the absence of symptoms, a second inoculation was conducted on April 24, just after the treatment on April 23. The other treatments were applied according to the schedule in Table 1. In May, the pots were moved outside, under a shade cloth (50% shade). At the end of June, the trial was suspended as for the first group of plants. In July, the plants were pruned, repotted in larger pots (7 l), fertilized and left to rest in order to repeat the trial in the following year.

Greenhouse trials in 2013

At the end of January 2013, the first group of pots was placed in the greenhouse at approximately 20°C. The treatments conducted were similar to the trial in 2012, with the introduction of new products and with new dosage levels for already used products (Table 2). Plants were treated by spraying a 25 ml suspension of product per plant; first with the resistance inducers on March 5, 2013, and then with all the products seven days later. On the following day, plants were spray-inoculated, as described previously. The plants were inoculated with Psa a second time on March 19, 2013, due to the lack of symptoms. When the first leaf spots occurred, the treatments were applied according to the schedule in Table 2.

177 On April 20, 2013, plants were moved outside, but the low temperatures registered during the month
178 of May induced symptoms of phytotoxicity, particularly on plants treated with copper products. Such
179 damages and a severe hail on May 17, progressively worsened the plant health, therefore the trial was
180 concluded on June 18.
181 The second group of plants was placed in a greenhouse in February and the first treatments were
182 performed on April 16, 2013. The second and third treatments were performed on May 3 and 13,
183 while Psa was inoculated on May 4 and 14. After the first occurrence of leaf spots, treatments
184 continued according to the schedule in Table 2. At the end of May, pots were moved outside under a
185 shade cloth (50% shade). On July 15, 2013, when the plants started to show symptoms of water and
186 nutritional stress, as temperatures increased, the trial was concluded.
187
188 **Orchard trials**
189 To test the efficacy of different products, a two-year trial was established in a young orchard of *A.*
190 *deliciosa* cv. Hayward, planted during spring 2011 in Costigliole Saluzzo (Piedmont, Northern Italy).
191 The treatments included the use of single products, alternating two products, and mixtures of products
192 (Table 3). A randomized block design with four replicates, each one of five plants, was used for the
193 trials. Treatments were applied by using a motor knapsack sprayer. Chemicals were applied with 500
194 to 800 l/ha, depending on the growth phase of the plants.
195 In 2011, treatments started after spring budding and continued every 14 days up to complete leaf fall
196 (Table 3). The winter of 2012, particularly the month of February, was characterized by a prolonged
197 cold period, with temperatures below -20°C for long periods. For this reason, plants were severely
198 damaged and it was necessary to cut them back to the crown to allow growth from a basal bud. This
199 caused a budding delay in 2012, so that treatments started at the end of May, and were performed
200 every 14 days up to complete leaf fall (Table 3). In 2012, the copper product IRF 096 was substituted
201 by the newer formulation IRF 155, including the same active ingredients but in a different
202 formulation: emulsifiable, instead of wettable powder.

Assessments

In the greenhouse conditions tested, only leaf spots with a chlorotic halo were observed, while large necrotic areas never occurred. Also in orchard experiments, leaf spots with a chlorotic halo were observed during the vegetative season. Exudates were not observed during winter of 2011-12 and 2012-13. The first exudates were observed in February 2014, at the end of the experiments. In all the trials, surveys were carried out every 14 days to evaluate the percentage of symptomatic plants, the percentage of infected leaves, the percentage of infected leaf surface, and any symptoms of phytotoxicity. The percentage of infected leaf surface was assessed by adopting a standardized leaf infection index. The same specialized technician did all the assessments. Data were analysed by performing an analysis of variance and Tukey's test. Phytotoxicity was evaluated using the scale reported in Table 4.

Results

Greenhouse trials

In the greenhouse trials, no one product tested was able to totally control the development of the bacterial disease, with all plants showing leaf symptoms one week after spray-inoculation. There was, however, significant control of disease symptoms by some treatments.

In the two trials carried out in 2012, the best results were obtained by using formulations of copper and acibenzolar-S-methyl. Particularly, in the first trial, the copper formulate IRF 155, composed of copper oxychloride and copper hydroxide, and acibenzolar-S-methyl at 20 g/hl a.i., significantly controlled the disease compared with all the other treatments tested. Copper hydroxide, the mixtures of copper hydroxide and oxychloride, fosetyl-Al and the two fertilizers, one composed of copper oxychloride, manganese oxide and zinc oxide (Kendal TE, Valagro S.p.A.), and the other one of glucohumates (Inductor kiwi, Fertirev s.r.l.), all significantly reduced disease symptoms compared with the control, but to a lesser extent. The results obtained with copper oxychloride, sodium silicate,

229 zinc sulphate, *Bacillus subtilis*, *Bacillus amyloliquefaciens* and zeolites were not significantly
230 different from the inoculated control (Table 5).
231 In the second trial of 2012, a temperature increase slowed down the pathogen spread. All the products
232 were significantly different from the inoculated control. The best results were obtained by using the
233 copper formulate IRF 155, acibenzolar-S-methyl, copper hydroxide, the mixtures of copper
234 hydroxide and copper oxychloride, fosetyl-Al and the two fertilizers, one composed of copper
235 oxychloride, manganese oxide and zinc oxide (Kendal TE, Valagro S.p.A.), and the other one of
236 glucohumates (Inductor kiwi, Fertirev s.r.l.), copper chelate and propolis (Table 5). Some formulates,
237 such as some copper formulates, acibenzolar-S-methyl, the fertilizer composed of copper
238 oxychloride, manganese oxide and zinc oxide, and copper chelate, showed phytotoxicity by causing
239 foliar lesions and reduction of plant growth (Table 5). In particular, acibenzolar-S-methyl strongly
240 reduced plant growth and development.
241 Also in the two trials performed in 2013, the best results were obtained by using the copper formulate
242 IRF 155 and acibenzolar-S-methyl, together with potassium phosphite, introduced in the second year
243 of experimentation. In particular, in the first trial, only these three commercial formulations
244 significantly reduced the percentage of infected leaf surface (0.9%, 1.2%, and 0.8% respectively) and
245 the foliar disease incidence (26.5%, 29.4%, and 26.8% respectively) more than the other products.
246 Most of the other products, though different from the inoculated control, only partially controlled
247 disease development. The results obtained by using copper oxychloride, potassium silicate and thyme
248 essential oil were not significantly different from the control (Table 6).
249 In the second trial, all the products significantly reduced the disease severity compared to the
250 inoculated control. The best results were obtained by using the copper formulate IRF 155,
251 acibenzolar-S-methyl and potassium phosphite. Copper hydroxide, the mixture copper hydroxide +
252 copper oxychloride, and fosetyl-Al reduced the percentage of infected leaves by 60%, while the other
253 treatments only partially reduced disease symptoms on the leaves (Table 6).

Due to the temperatures in May 2013 being below the average for that time of year, when plants were moved outside, symptoms of phytotoxicity became evident in the plants treated with copper products, as in 2012, and with acibenzolar-S-methyl.

In the four trials carried out in 2012 and 2013 (Table 5 and 6), a partial but significant symptom reduction occurred when the plants were grown in a mixture of a steamed peat mixture substrate (80%) and compost obtained from digested organic matrices of municipal solid waste (20%).

Orchard trials

In the 2011 trial, though the experimental site was a new kiwifruit orchard, the first foliar symptoms occurred during that summer, and by October 19, 2011, all the plants of the untreated control were characterized by leaf spots typical of Psa. The reason for this high infection level could be explained by the close proximity (50 m distance) of infected orchards. The symptoms appeared in plants tested with all the treatments except for acibenzolar-S-methyl (0% infected plants) and the mixture copper hydroxide + copper oxychloride (IRF 096), where the symptoms occurred in just two plants of one replicate. The other products and strategies partially controlled disease development, however when mancozeb was used, the percentage of infected plants was not statistically different from the untreated control (Table 7).

In 2012 the best results were provided by the new copper formulate IRF 155 and by acibenzolar-S-methyl, which partially controlled disease progression (Table 7). It should be considered that from July, one month after the start of the treatments, all the plants showed foliar symptoms, though the percentage of infected leaves was low. During the summer, the pathogen spread was slowed down, but not stopped, so that on October 4, 2012, over 40% leaves were infected in the untreated control, and just the treatments with acibenzolar-S-methyl, the mixture copper hydroxide + copper oxychloride (IRF 155) and fosetyl-Al were significantly different from the control (Table 7). The treatment with mancozeb alone was not significantly different from the control, while mancozeb with

279 the mixture copper hydroxide + copper oxychloride was statistically similar to the treatment with the
280 copper product alone.
281 Both in 2011 and 2012, weak phytotoxicity symptoms were visible in the plants treated with copper
282 products. In spring 2013, the bacterial ooze was evaluated on the surface of vines and trunks. Exudates
283 were only visible on the main vines of two plants of the untreated control.
284
285 **Discussion**
286 In this study, four trials in greenhouse conditions and two trials in an orchard were conducted to
287 assess the level of control of Psa on kiwifruit cv. Hayward, by using chemical and biological products.
288 Chemical control of bacterial diseases, and particularly of Psa, is highly dependent on spraying
289 antibiotics, such as streptomycin, or copper formulations (Cameron and Sarojini, 2014). In Europe
290 the use of streptomycin for control of plant pathogens is not legal, so copper formulations remain the
291 main management strategy for crop protection against bacterial diseases (Gullino and Brunelli, 2012).
292 Copper fungicides should be used carefully, particularly on young plants and during spring, because
293 low temperatures can induce phytotoxicity. In addition, copper bactericides have other possible
294 disadvantages after long-term use, including resistance to copper in bacterial populations (Rinaldi
295 and Leite, 2000) and the accumulation of copper metal in soils with potential environmental effects
296 (Alva et al., 1995). Repeated spraying with copper bactericides resulted in Japanese Psa strains
297 developing maximal copper resistance (Marcelletti et al., 2011). However, the strains of Psa from
298 the recent Italian outbreak were sensitive to copper compounds (Ferrante and Scortichini, 2010).
299 Traditional copper formulations, including Cu-hydroxide, Cu-oxychloride or their mixture, were
300 tested during the experiments, together with new experimental formulations of copper products,
301 which should have high biological efficacy achieved with much lower hectare rates. In the new
302 experimental formulations tested (IRF 120 and IRF 155) copper is complexed with organic
303 molecules, but the exact formulation is covered by trade secret. However, traditional copper
304 fungicides are preventive, acting by contact compounds, while copper complexes show also partially

305 systemic and curative properties. In the greenhouse and orchard experiments, copper hydroxide and
306 the mixtures of copper hydroxide and copper oxychloride, significantly reduced foliar symptoms of
307 the disease, and showed low phytotoxicity levels. In all the trials, the new formulate IRF 155 (copper
308 oxychloride + copper hydroxide) was one of the most promising products for bacterial disease control,
309 able to reduce the leaf disease symptoms by 70-80%, compared with the control.
310 Acibenzolar-S-methyl, a functional analogue of salicylic acid, has demonstrated good efficacy against
311 bacterial diseases, including bacterial spot and bacterial speck on tomato (Louws et al., 2011) and fire
312 blight in apples (Bastas and Maden, 2007). Similar efficacy was provided by acibenzolar-S-methyl
313 against Psa on kiwifruit. The product showed a high level of phytotoxicity in 2012, on one-year old
314 plants in pots, but it was much less phytotoxic on the same plants the following year suggesting that
315 younger plants are more susceptible. The use of acibenzolar-S-methyl has been temporarily extended
316 to kiwifruit in Italy, with a maximum of four treatments per year.
317 The efficacy of fosetyl-Al was lower in the first trials of 2012 and 2013, when the disease severity
318 was higher. Vice versa, the product was more effective in the second trials of 2012 and 2013,
319 performed later in the growing season, with higher average temperatures and lower disease severity.
320 Fosetyl-Al shows better efficacy in presence of lower disease pressure, as already demonstrated for
321 other pathogens (Brown et al, 2004).
322 The efficacy of the other products tested in greenhouse conditions never exceeded 30-40%, and some
323 products were not significantly different from the control. Similarly, in the orchard trials, the other
324 products tested were less effective, in particular, mancozeb did not show significant preventative
325 action against Psa either alone, or when used together with copper products. Previously mancozeb
326 showed a synergistic effect with copper compounds against bacterial diseases on other crops (Gent
327 and Schwartz, 2005).
328 The antagonistic microorganisms tested, *Bacillus subtilis* and *B. amyloliquefaciens*, commercialized
329 mainly to control soilborne pathogens (Spadaro and Gullino, 2005) or for flowering treatments
330 (Oancea et al., 2009), showed a low efficacy in the protection of leaves and buds. *B.*

amyloliquefaciens, in particular, was effective against *Psa in vitro*, and was able to survive on kiwifruit female flowers, reducing the *Psa* population on flowers (Biondi et al., 2012), by producing iturins which disrupt pathogen cell wall production (Highland et al., 2012).

Even in absence of other treatments, a reduction of the disease was reported when using the mixture of a steamed peat mixture substrate with compost obtained from digested organic matrices of municipal solid waste. Composts could become an effective low cost tool to be included in the crop protection strategy. Compost-amended soils offer the potential to manage soilborne diseases, but also to reduce foliar diseases, by improving plant health and inducing systemic resistance (Hahn et al., 2000). Infected radish and tomato grown in compost-amended substrates harbored significantly lower populations of the bacterial pathogens *Xanthomonas campestris* pv. *armoraciae* and *Xanthomonas campestris* pv. *vesicatoria*, respectively (Aldahmani et al., 2005).

In conclusion, no one product tested here could be considered as a suitable solution for the control of Psa on kiwifruit, but in the framework of integrated control strategies, copper compounds alternated with resistance inducers could be used in combination with compost, to develop new strategies to reduce the disease development and spread. New strategies should be tested under natural conditions, by considering the different climate conditions of the kiwifruit production areas, as it is not possible to design one unique strategy to control Psa on kiwifruit for every region.

Acknowledgements

The authors wish to thank the Piedmont Region and the European Union in the framework of the projects SAFEFOODCONTROL (European Fund for Development POR FESR 2007/2013, Axis I – I.1.1 Innovative Platforms and PSR FEASR 2007/2013, European Fund for Rural Development, Measure 124, Action 1), "Agrobiocat" and "ECOMOL", Sustainable Chemistry Pole (European Fund for Development POR FESR 2007/2013, Axis I – I.1.3 Innovation and SMEs) for the financial support. A particular thank to Dr. Graziano Vittone (CReSO S.C. a R.L.) for his technical support and to Dr. Kathryn Webb for her accurate English revision.

357

358 **References**

359

360 Alva AK, Graham JH, Anderson CA (1995). Soil pH and copper effects on young 'Hamlin'orange
361 trees. *Soil Science Society of America Journal* **59**, 481–487.

362 Armentano G (2010) La mappa del cancro batterico in Italia. *L'Informatore Agrario* **66 (25)**, 54.

363 Balestra GM, Mazzaglia A, Quattrucci A, Renzi M, Rossetti A (2009) Occurrence of *Pseudomonas*
364 *syringae* pv. *actinidiae* in Jin Tao kiwi plants in Italy. *Phytopathologia Mediterranea* **48**, 299-301.

365 Bastas KK, Maden S (2007). Evaluation of host resistance inducers and conventional prod ucts for
366 fire blight management in loquat and quince. *Phytoprotection* **88**, 93–101.

367 Biondi E, Kuzmanovic N, Galeone A, Ladurner E, Benuzzi M, Minardi P, Bertaccini A (2012).
368 Potential of *Bacillus amyloliquefaciens* strain D747 as control agent against *Pseudomonas syrinage*
369 pv. *actinidiae*. Journal of Plant Pathology 94 (Supplement 4): S4.58.

370 Brown S**,** Koike ST**,** Ochoa OE, Laemmlen F**,** Michelmore RW (2004). Insensitivity to the
371 Fungicide Fosetyl-Aluminum in California Isolates of the Lettuce Downy Mildew Pathogen, *Bremia*
372 *lactucae.* Plant Disease 88, 502-508.

373 Butler MI, Stockwell PA, Black MA, Day RC, Lamont IL (2013) *Pseudomonas syringae* pv.
374 *actinidiae* from recent outbreaks of Kiwifruit Bacterial Canker belong to different clones that
375 originated in China. *PLoS ONE* **8 (2)**, e57464.

376 Cameron A, Sarojini V (2014). *Pseudomonas syringae* pv. *actinidiae*: chemical control, resistance
377 mechanisms and possible alternatives. *Plant Pathology* **63**, 1-11.

378 EPPO (2012) Pest Risk Analysis for *Pseudomonas syringae* pv. *syringae*. September 2012.
379 Available at: http://www.eppo.org . Accessed on September 20, 2013.

380 Everett KR, Pushparajah IPS, Vergara MJ (2012) *Pseudomonas syringae* pv. *actinidiae* on surfaces
381 in the orchard. *New Zealand Plant Protection* **65**, 19-24.

382 Everett KR, Taylor RK, Romberg MK, Rees-George J, Fullerton RA, Vanneste JL, Manning MA

383 (2011) First report of *Pseudomonas syringae* pv. *actinidiae* causing kiwifruit bacterial canker in New
384 Zealand. *Australasian Plant Disease Notes* **1**, 67–71.
385 FAOSTAT (2014) Available at: http://faostat3.fao.org/faostat-gateway/go/to/browse/Q/QC/E
386 Accessed on September 26, 2014.
387 Ferguson AR, Huang H (2007) Genetic resources of kiwifruit: domestication and breeding. In:
388 Janick J (ed) Horticultural reviews, vol 33. Wiley, Hoboken. doi:10.1002/9780470168011.ch1
389 Ferrante P, Scortichini M (2009) Identification of *Pseudomonas syringae* pv. *actinidiae* as causal
390 agent of bacterial canker of yellow kiwifruit (*Actinidia chinensis* Planchon) in central Italy. *Journal*
391 *of Phytopathology* **157**, 768–70.
392 Ferrante P, Scortichini M (2010) Molecular and phenotipic features of *Pseudomonas syringae* pv.
393 *actinidiae* isolated during recent epidemics of bacterial canker on yellow kiwifruit (*Actinidia*
394 *chinensis*) in central Italy. *Plant Pathology* **59**, 954-96.
395 Fratarcangeli L, Rossetti A, Mazzaglia A, Balestra GM (2010) Il ruolo del rame nella lotta al cancro
396 batterico del kiwi. *L'Informatore Agrario* **66 (8)**, 52-55.
397 Gent DK, Schwartz HF (2005) Management of *Xanthomonas* Leaf Blight of Onion with a Plant
398 Activator, Biological Control Agents, and Copper Bactericides. *Plant Disease* **89**, 631-639.
399 Gullino ML, Brunelli A, (2012) Prevenzione e difesa del kiwi dalla batteriosi da PSA. *Rivista di*
400 *Frutticoltura* **74 (S9)**, 20-24.
401 Hadar Y (2011) Suppressive compost: when plant pathology met microbial ecology.
402 *Phytoparasitica* **39**, 311-314.
403 Han DY, Coplin DL, Bauer WD, Hoitink HAJ (2000). A rapid bioassay for screening rhizosphere
404 microorganisms for their ability to induce systemic resistance. *Phytopathology* **90**, 327–332.
405 Highland H, Ockey S, Dimock M (2012). A new generation of bacterial biofungicides based on the
406 bacterium *Bacillus amyloliquefaciens* (strain D747) from Certis USA for use in vegetable and fruit
407 disease control. *Phytopathology* **102** (8), 53.
408 ISTAT (2011) Available at: http://www.istat.it Accessed on September 20, 2013.

409 Koh JK, Cha BJ, Chung HJ, Lee DH (1994) Outbreak and spread of bacterial canker in kiwifruit.
410 *Korean Journal of Plant Pathology* **10**, 68–72.
411 Lopez-Reyes JG, Spadaro D, Garibaldi A, Gullino ML (2010) Efficacy of plant essential oils on
412 postharvest control of rot caused by fungi on four cultivars of apples *in vivo. Flavour and Fragrance*
413 *Journal* **25**, 171-177.
414 Lopez-Reyes JG, Spadaro D, Prelle A, Garibaldi A, Gullino ML (2013) Efficacy of plant essential
415 oils on post-harvest control of rots caused by fungi on different stone fruits in vivo. *Journal of Food*
416 *Protection* **76**, 631-639.
417 Louws FJ, Wilson M, Campbell HL, Cuppels DA, Jones JB, Shoemaker PB, Sahin F, Miller SA
418 (2001). Field control of bacterial spot and bacterial speck of tomato using a plant activator. *Plant*
419 *Disease* **85**, 481–488.
420 Marcelletti S, Ferrante P, Petriccione M, Firrao G, Scortichini M, 2011. *Pseudomonas syringae* pv.
421 *actinidiae* draft genomes comparison reveal strain-specific features involved in adaptation and
422 virulence to *Actinidia* species. PLoS ONE 6, e27297.
423 Mazzaglia A, Studholme DJ, Taratufolo MC, Cai R, Almeida NF, Goodman T, Guttman DS,
424 Vinatzer BA, Balestra GM (2012) *Pseudomonas syringae* pv. *actinidiae* (PSA) isolates from recent
425 bacterial canker of kiwifruit outbreaks belong to the same genetic lineage. *PLoS ONE* **7 (5)**, e36518.
426 McCann HC, Rikkerink EHA, Bertels F, Fiers M, Lu A, Rees-George J, Andersen MT, Gleave AP,
427 Haubold B, Wohlers MW, Guttman DS, Wang PW, Straub C, Vanneste J, Rainey PB, Templeton
428 MD (2013) Genomic analysis of the kiwifruit pathogen *Pseudomonas syringae* pv. *actinidiae*
429 provides insight into the origins of an emergent plant disease. *PLoS Pathogens* **9 (7)**, e1003503.
430 Noble R, Coventry E (2005) Suppression of soil-borne plant diseases with composts: a review.
431 *Biocontrol Science and Technology* **15**, 3-20.
432 Oancea F, Cornea P, Popa G, Sicuia O, Draganoiu M, Dinu S, Elad Y, Maurhofer M, Keel C, Gessler
433 C, Duffy B (2009). *Bacillus amyloliquefaciens* strain antagonistic to Erwinia amylovora and elicitor of
434 tomato defense response. *IOBC/WPRS Bulletin* **43**, 172.

435 Piedmont Region – AGRISTAT (2011) Available at:
436 http://www.sistemapiemonte.it/anau/elenco.jsp Accessed on September 20, 2013.
437 Pugliese M, Liu BP, Gullino ML, Garibaldi A (2011) Microbial enrichment of compost with
438 biological control agents to enhance suppressiveness to four soil-borne diseases in greenhouse.
439 *Journal of Plant Disease and Protection* **118**, 45-50.
440 Pugliese M, Liu BP, Gullino ML, Garibaldi A (2008) Selection of antagonists from compost to
441 control soil-borne pathogens. *Journal of Plant Disease and Protection* **115**, 220-228.
442 Quattrucci A, Renzi M, Rossetti A, Ricci L, Taratufolo C, Mazzaglia A, Balestra GM (2010) Cancro
443 batterico del kiwi verde: nuove strategie di controllo. *L'Informatore Agrario* **66 (16)**, 53-57.
444 Rees-George J, Vanneste, JL, Cornish DAS, Pushparajah IPS, Yu J, Templeton MD, Everett KR
445 (2010) Detection of *Pseudomonas syringae* pv. *actinidiae* using polymerase chain reaction (PCR)
446 primers based on the 16S–23S rDNA intertranscribed spacer region and comparison with PCR
447 primers based on other gene regions. *Plant Pathology* **59**, 453-464.
448 Renzi M, Mazzaglia A, Balestra GM (2012) Widespread distribution of kiwifruit bacterial canker
449 caused by the European *Pseudomonas syringae* pv. *actinidiae* genotype in the main production areas
450 of Portugal. *Phytopathologia Mediterranea* **51**, 402−409.
451 Rinaldi DAMF, Leite RP Jr (2000). Adaptation of *Xanthomonas axonopodis* pv. *citri* population
452 to the presence of copper compounds in nature. *Proceedings of the International Society of*
453 *Citriculture* **2**, 1064.
454 Scortichini M (1994) Occurrence of *Pseudomonas syringae* pv. *actinidiae* on kiwifruit in Italy.
455 *Plant Pathology* **43**, 1035-1038.
456 Scortichini M, Marcelletti S, Ferrante P, Petriccione M, Firrao G (2012) *Pseudomonas syringae* pv.
457 *actinidiae*: a re-emerging, multi-faceted, pandemic pathogen. *Molecular Plant Pathology* **13**, 631-
458 640.
459 Spadaro D, Amatulli MT, Garibaldi A, Gullino ML, Vittone G, Nari L, Pellegrino S, Morone C,
460 Mason G, Ortalda E, Grosso S (2010). È arrivato in Piemonte il cancro batterico del kiwi.

461 *L'Informatore agrario* **66 (27)**, 58-59.

462 Spadaro D, Gullino ML (2005). Improving the efficacy of biocontrol agents against soilborne
463 pathogens. *Crop Protection* **24**, 601-613.

464 Spadaro D, Nari L, Vittone G, Morone C (2011) La batteriosi del kiwi in Piemonte: diagnosi e
465 prevenzione. *Protezione delle colture* **4 (2)**, 58-61.

466 Takikawa Y, Serizawa S, Ichikawa T, Tsuyumu S, Goto M (1989) *Pseudomonas syringae* pv.
467 *actinidiae* pv. nov.: the causal bacterium of canker of kiwifruit in Japan. *Annals of Phytopathological*
468 *Society of Japan* **55**, 437-444.

469 Testolin R, Ferguson AR (2009). Kiwifruit (*Actinidia* spp.) production and marketing in Italy. *New*
470 *Zealand Journal of Crop and Horticultural Science* **37**, 1-32.

471 Tyson JL, Rees-George J, Curtis CL, Manning MA, Fullerton RA (2012) Survival of *Pseudomonas*
472 *syringae* pv. *actinidiae* on the orchard floor over winter. *New Zealand Plant Protection* **65**, 25-28.

473 Vanneste JL (2013) Recent progress on detecting, understanding and controlling *Pseudomonas*
474 *syringae* pv. *actinidiae*: a short review. *New Zealand Plant Protection* **66**, 170-177.

475 Vanneste JL, Poliakoff F, Audusseau C, Cornish DA, Paillard S, Rivoal C, Yu J (2011a) First report
476 of *Pseudomonas syringae* pv. *actinidiae*, the causal agent of bacterial canker of kiwifruit in France.
477 *Plant Disease* **95**, 1311.

478 Vanneste JL, Yu J, Cornish DA, Maxi S, Clarck G (2011b) Presence of *Pseudomonas syringae* pv.
479 *actinidiae*, the causal agent of bacterial canker of kiwifruit, on symptomatic and asymptomatic tissues
480 of kiwifruit. *New Zealand Plant Protection* **64**, 241-245

481 Vittone G, Nari L, Morone C (2011) Come affrontare in campo la batteriosi del kiwi. *L'Informatore*
482 *Agrario* **67 (18)**, 46-47.