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Review article – Thematic Issue

Aspects still to solve for the management of kiwifruit bacterial canker caused by *Pseudomonas syringae* pv. *actinidiae* biovar 3

M. Scortichini

Council for Agricultural Research and Analysis of Agricultural Economics (CREA) – Research Centre for Olive, Fruit Trees and Citrus, Roma, Italy

Summary

The pandemic wave of kiwifruit bacterial canker, caused by *Pseudomonas syringae* pv. *actinidiae* biovar 3, has caused, in recent years, severe economic losses in all major areas of kiwifruit production. After the initial discouragement, each country affected by the disease promptly reacted trying to establish and promote phytosanitary and agronomic measures aiming at reducing the incidence and severity of the disease and the risk for further spreading. Within this context, public and private research groups, strongly supported by ad hoc projects funded by international, national and local political and commercial Institutions, have made considerable efforts. After about 10 years since the initial outbreak of May 2008 in central Italy (i.e., Latina province), the management of the disease has reached in many areas of cultivation worldwide a rather satisfactory level, despite the endemic presence of the pathogen in the orchards. However, if the coexistence has been successfully obtained in some circumstances, some aspects of disease control still require particular attention. Among the others, there are: a) the rapid occurrence of copper-resistant *P. s.* pv. *actinidiae* and *P. s.* pv. *syringae* strains in New Zealand and Italy, respectively; b) the winter and spring frost promoting an increase in the aggressiveness of the pathogen; c) the susceptibility of the new gold and red cultivars; d) the control measures to perform during the plant dormancy season; e) the upgrade of some agronomical techniques to prevent the multiplication and spread of the pathogen within and between the orchards.

Keywords

Actinidia, copper-resistance, frost, germplasm susceptibility, dormant season, pandemia

Significance of this study

What is already known on this subject?

- Bacterial canker of kiwifruit, caused by *Pseudomonas syringae* pv. *actinidiae* biovar 3 (Psa), is one of the most studied topics of plant pathology during last decade. Many aspects related to the pathogen origin, population structure, genetic traits, detection, cycle of disease, epidemiology and control have been faced and elucidated.

What are the new findings?

- The widespread utilization of copper compounds has most probably incited in New Zealand and Italy the occurrence of copper-resistant Psa and *P. s.* pv. *syringae* strains, respectively. New cultivars are released and for some of them a cover to avoid Psa colonization is required. Agronomical techniques should to be adjusted for a better management of bacterial canker.

What is the expected impact on horticulture?

- The overall impact of this review is to highlight some of the main aspects of bacterial canker management that require special attention for a better coexistence with the pathogen.

Introduction

The recent history of *Pseudomonas syringae* pv. *actinidiae* (Psa) tells us about a remarkable example of how fast a rather neglected phytopathogen can emerge and, in very few years, reach all major areas of kiwifruit cultivation worldwide causing very severe economic losses everywhere. Before 2008, Psa caused damages solely in Japan and South Korea, whereas in Italy, after the initial record (Scortichini, 1994) it remained unnoticed for more than 15 years. Interestingly, upon the new wave of spreading, in any country, despite the cultural and social differences, it incited an equal reaction that can be defined as astonishment and/or panic. In New Zealand, Psa caused economic losses due to immediate negative impacts of the disease on kiwifruit yield and export and delays in the expected rate of industry expansion (Tanner, 2015). In this country, the estimated economic losses due to Psa ranged between 330 and 400 million of Euros from 2012 to 2021 (Greer and Sanders, 2012).

From a strict phytopathological point of view, the pandemic outbreaks of "kiwifruit bacterial canker" caused by Psa, represent a practical lesson of how, in the presence of a very susceptible plant germplasm to a new population of a known bacterial pathogen, the incidence and severity of the disease is everywhere very high. In addition, when the crop is cultivated as a monoculture, a situation occurring in several areas of kiwifruit cultivation worldwide, the pathogen dispersal and plant colonization proceeded in a very rapid way. As a direct consequence of this scenario, the highly prized but susceptible *A. chinensis* cv. Hort16A was promptly replaced by other more tolerant yellow-fleshed cultivars worldwide.

Within this context, in central Italy, a combination of factors seems to have played a role of great relevance in initiating the epidemics of bacterial canker, firstly on *A. chinensis* during 2008–2010 and, subsequently, on *A. deliciosa*:

(i) presence of a very susceptible *A. chinensis* cultivar such as 'Hort16A' which is extensively grown, in some cases, on a large acreage; (ii) presence of a very aggressive population of the specific pathogen; (iii) occurrence of predisposing stress factors like winter frosts and heavy rainfall, that enable the massive colonization, multiplication and dispersal of bacterial inoculum in the area; (iv) underestimation of the risk potential during the early phases of the epidemics; (v) delayed implementation of measures aiming at lowering the inoculum level in the whole area; (vi) unavailability of registered chemicals for controlling the disease (Ferrante et al., 2012).

It should be said that, if Psa was very rapid in colonizing kiwifruit orchards worldwide, a corresponding, fast and strong reaction by the scientific and technical community linked to the kiwifruit industry was observed everywhere. In a few years, the knowledge about many features and facets of the cycle of disease of this phytopathogen have been investigated and released and, for any country, the bases for a rather satisfactory field control have been promptly given (Vanneste, 2013; Scortichini et al., 2014). In parallel, a large body of fundamental studies has had Psa as the main subject, so that this bacterium rapidly became a new model of study in plant pathology (Baltrus et al., 2017). Remarkably, it has been verified that a single, almost clonal, population of the pathogen, namely Psa biovar 3, has been responsible for this pandemic disease (Marcelletti et al., 2011; Abelleira et al., 2011; Koh et al., 2012; Mazzaglia et al., 2012; Butler et al., 2013; McCann et al., 2013; Zhao et al., 2013; Ciarroni et al., 2015; Cunty et al., 2015; Sawada et al., 2015; Parada et al., 2017).

Nowadays, after almost 10 years of experience with Psa biovar 3, kiwifruit orchardists are well acquainted with the problem and, in many situations, a sort of coexistence with the disease is evident (Scortichini et al., 2014; Froud et al., 2015). However, despite such consistent progress, there are well-known and new findings linked to "bacterial canker" that still pose relevant risks to the cultivation of old and new kiwifruit cultivars. Some aspects of these risk factors are discussed herein.

The rapid occurrence of copper-resistant *P. s.* pv. *actinidiae* and *P. s.* pv. *syringae* strains in New Zealand and Italy, respectively, and upgrading of control measures

In any country, since the very first outbreaks of "bacterial canker" of kiwifruit, copper-based compounds have been suggested as the main, in some case unique, possibility to mitigate the damage caused by Psa biovar 3. Actually, such compounds are traditionally used to control most of the plant pathogenic bacteria worldwide (Marco and Stall, 1983; Norelli et al., 2003). However, one of the main and known pitfalls in the long-term utilization of copper for controlling bacterial phytopathogens, is the very frequent occurrence, after some years of continuous utilization, of copper-resistant populations of the pathogen. Concerning fruit tree species, failure in effectively controlling plant pathogenic bacteria solely with copper-based compounds are often recorded mainly among *Xanthomonas*, *Erwinia amylovora* and *Pseudomonas syringae* strains (Loper et al., 1991; Gardan et al., 1993; Sundin and Bender, 1993; Cazorla et al., 2002; Vanneste and Voyle, 2003; Stockwell et al., 2015), and resistance to copper was also found in another Psa population isolated, in the past, in Japan (Goto et al., 1994).

Recently, frequent occurrences (i.e., 25% of the total Psa strains) of copper-resistant Psa biovar 3 strains have been reported in New Zealand (Colombi et al., 2017). The occurrence of this population has been linked to the use of copper-based sprays used extensively since 2011, after the first record of Psa in the country. In fact, the Psa population originally introduced into New Zealand were revealed to be sensitive to copper and lacked the genes encoding copper resistance, so that the acquisition from other bacteria of this genetic trait has been verified (McCann et al., 2013).

The quite rapid acquisition of the genetic trait conferring resistance to copper was acquired through lateral gene transfer of integrative conjugative elements and plasmids obtained from other microorganisms (Colombi et al., 2017). This finding, potentially, raises up concern about the possibility to effectively control Psa biovar 3 in the future mainly by using copper. In fact, such a copper-resistant trait would seem quite stable in the bacterial genome and the pathogen could even acquire, in future, additional copper-resistance-encoding genes thus increasing the resistance (Colombi et al., 2017).

In parallel, in northern, central and southern Italy there have been recently isolated, from both *A. deliciosa* and *A. chinensis*, copper-resistant strains belonging to *P. s.* pv. *syringae* (Petriccione et al., 2017). However, so far, copper-resistant Psa strains have not been obtained. Interestingly, the study ascertained that, in some cases, the copper-resistant *P. s.* pv. *syringae* strains replaced Psa in causing leaf spotting during spring. By contrast, Psa was found present in the woody part of the plant (i.e., twigs, branches), so that it was postulated that Psa escaped from the copper treatment of the leaves by migrating inside the plant and surviving during winter as an endophyte. The study also revealed the frequent occurrence of *P. s.* pv. *syringae* strains showing resistance to copper in rain splash collected in kiwifruit orchards infected by Psa biovar 3 (Figure 1). Resistance to copper appears as a rather frequent feature characterizing *P. s.* pv. *syringae* in Italy since this genetic trait was also found in mango orchards grown in Sicily infected by this polyphagous pathogen (Aiello et al., 2015).

Collectively, these studies indicated that for the management of kiwifruit vines there has to be taken into consideration that a possible reduced effectiveness of the copper-based compounds to control Psa biovar 3 might occur in the future. Other compounds showing bactericidal activity have to be introduced into the control, especially because the use of copper is usually scheduled from the bud break until and during the dormant phase of the plant. Chitosan-based compounds (Scortichini, 2014) and biocontrol agents (Tontou et al., 2016; Wicaksono et al., 2017) could replace, in future, copper sprays in some periods. Furthermore, the assessment of other potential categories of controlling agents not readily inducing resistance to pathogens, such as host resistance elicitors (Hill et al., 2015), essential oils (Ferrante and Scortichini, 2010; Song et al., 2016; Vavala et al., 2016) and oxidative agents (Ghods et al., 2015) should be investigated in future research projects for their effectiveness in field control of Psa biovar 3. The use of copper compounds would remain important for some key-points such as wound protection after the harvest, hail and frost as well as during pruning. It is fundamental to protect the fruit peduncle and leaf scars with copper compounds. The sprays should be carried out immediately after the harvest and during the leaf fall, especially at the beginning when the leaf petiole is not naturally protected by suberin. During winter, the trunk and leaders should be protected, once a month, by using



Figure 1. Plastic screen with stucked Petri dishes to intercept rain-splash placed between *Actinidia deliciosa* plants in Campania region (southern Italy). The dishes allowed to isolate both *Pseudomonas syringae* pv. *actinidiae* biovar 3 and copper-resistant *P. s*. pv. *syringae* isolates.

filming compounds such as chitosan (Scortichini, 2014) or zinc-copper-citric acid biocomplex capable of reducing the bacterial exudates (Scortichini, 2016). In addition, in case of pruning, all the cuts should be protected with copper as soon as possible and the scissors should be disinfected when passing from one plant to another (Donati et al., 2014).

Winter and spring frost promoting an increase in the aggressiveness of the pathogen

The genus *Actinidia* originated in eastern China, in the hilly and mountainous areas of the Yangtze River valleys, characterized by a humid and/or dry-winter subtropical climate. Generally, the green-fleshed cultivars tolerate frost better than the yellow-fleshed cultivars. However, for *A. deliciosa* a temperature of -2°C occurring during spring causes severe damage to young buds and leaves, whereas temperature of -8°C in winter damaged the woody part of the plant (Morley-Bunker and Lyford, 2011). The occurrence of autumn and winter frosts has been linked to the initial outbreak of kiwifruit "bacterial canker" caused by Psa biovar 3 in the province of Latina (Latium region, central Italy) (Ferrante et al., 2012). Two distinct frost events occurred during autumn-winter 2007–2008 in that area: an autumn frost, recorded on November 4 (i.e., a 6-h duration with a minimum temperature of -8°C) and November 5 (i.e., a 2-h duration with a minimum temperature of -2°C), and a winter frost, recorded on February 17 (i.e., a 5-h duration with a minimum temperature of -8°C). The initial epidemic was observed during the following spring 2008 on *A. chinensis* cv. Hort16A, also favored by an unusual very rainy period occurred both in spring and autumn (i.e., 35% more than the average rainfall) (Ferrante et al., 2012). Some years later, the two frost events were experimentally reproduced in a climatic chamber by using pot-cultivated *A. deliciosa* and *A. chinensis* plants, inoculated one month before with a Psa biovar 3 strain isolated during the initial outbreak (Ferrante and Scortichini, 2014). Remarkably, the day after the frost events, extensive exudates oozing out from the inoculation points were observed on all *Actinidia* plants. Psa biovar 3 was always isolated from the exudates, and multiplication trend experiments revealed its very rapid multiplication upon the frost (Ferrante and Scortichini, 2014).

During subsequent years, it was observed in all areas of kiwifruit cultivation of Italy that a strong correlation occurred between winter frost events and the appearance of symptoms of "bacterial canker" during the following spring. The recent case observed in spring 2017 was quite remarkable since during winter 2015–2016 frost events were absent in almost most all areas of kiwifruit cultivation of Italy, and no symptoms were recorded during the following seasons. In contrast, during January 2017 repeated frosts were recorded in all areas of cultivation and, during spring, very severe damages caused by Psa biovar 3 had been recorded from northern to southern Italy. The situation resulted in even more damage upon the unexpected frost of April 20. A strict linkage between frost events and the occurrence of kiwifruit "bacterial canker" was also pointed out for Chile where a model has been developed that correlated areas characterized by winter and spring frosts with a relevant higher risk of disease occurrence (Santibanez, 2014). Similarly, in New Zealand, the incidence of "bacterial canker" after its first appearance and during the following six months resulted in much higher damage in the Whakatane region than in the Te Puke due to the higher occurrence of frost in that region (Froud et al., 2015). Finally, surveys carried out in China observed a higher presence of



Figure 2. Over-head irrigation to protect kiwifruit orchards during frost events. This technique did not incite significant multiplication of *Pseudomonas syringae* pv. *actinidiae* biovar 3. However, it should be said that the relevant amount of water occurring after the thawing represents a risk for the possible subsequent spread of the pathogen within the orchard.

"bacterial canker" in kiwifruit plants cultivated above 750 m elevation (Li et al., 2001).

Controlling frost events is not an easy task. Apart from very deep frost (i.e., more than -15°C), during winter that both *A. deliciosa* and *A. chinensis* can resist to frost damage outside of their origin (Testolin and Messina, 1987). However, also with milder temperatures, the risk is due to the endophytic presence of Psa within the plant tissue. Even though it is still not known whether the pathogen is incited to rapid multiplication by the frozen tissues of the plant or by a direct action of the low temperatures rapidly triggering the virulence factors of the bacterium, it is evident that Psa biovar 3 is greatly favored by temperatures below 0°C (Ferrante and Scortichini, 2014). Consequently, in areas where winter and, especially, spring frosts occur frequently, preventive measures to reduce the risk of frost, mainly for the yellow and red-fleshed cultivars, should be applied. Among them, overhead sprinklers, fans, plastic covers, sprinklers over covers, and straw cover for young plantations can be utilized (Figure 2). Moreover, the forecasting models can also play an important role in monitoring the weather and informing the farmer about the possible frost occurrence. In addition, to mitigate the bacterial oozing during end-winter time, a biocomplex compound containing zinc, copper and citric acid, sprayed once a month to the main trunk and leaders, has shown a good potential to reduce the amount of trunk exudation during spring, both in green and yellow-fleshed kiwifruit orchards infected by Psa biovar 3 (Scortichini, 2016).

The susceptibility of the new gold and red-fleshed cultivars and pollinators

Recently, many new *A. deliciosa* and *A. chinensis* cultivars have been released from both private and governmental institutions. A major example is the yellow-fleshed 'Gold 3' or 'G3' or 'SunGold'®, a Zespri-Plant and Food Research cultivar, currently replacing the highly susceptible 'Hort16A' worldwide. 'G3' has been claimed to be more tolerant than 'Hort16A' to Psa biovar 3, and, so far, such a trait would seem confirmed. Apart from these cases, all the other new cultivars, mainly the yellow and red-fleshed ones, have been released to try to exploit the good commercial conjuncture currently characterizing the kiwifruit industry worldwide (Testolin, 2014). The relative and field susceptibility of the new cultivars to Psa biovar 3 is still largely unknown and trials for comparing their behavior towards the pathogen, possibly in different environments, are lacking even though considered important (Nardozza et al., 2015). However, a general survey performed in South Korea indicated that the yellow (i.e., 'Zecygold', 'Haegeum', 'Yellow King') and red-fleshed (i.e., 'Hongyang', 'Enza Red') cultivars are quite sensitive to Psa biovar 3 (Kim et al., 2016). Considering the relevant economic budget to invest for the cultivation of the new kiwifruit germplasm, it would be advisable to preliminary perform cultivar susceptibility tests regarding the tolerance to Psa biovar 3. In addition, a thorough screening of pollinators more tolerant to Psa biovar 3 is under way both in New Zealand and Italy.

The upgrade of some agronomical techniques to prevent the multiplication and spread of the pathogen within and between the orchards

Agronomical techniques play a relevant role in promoting or reducing the pathogenic activity of Psa biovar 3 and, during last years, research has provided useful data that linked common practices performed in kiwifruit orchard to the pathogen aggressiveness. Concerning fertilization, an excess of nitrogen supply incited a risk for Psa biovar 3 higher multiplication. A balanced fertilization providing nitrogen, phosphorus and potassium seems to reduce the risk for a higher disease severity. Moreover, the depletion of calcium and manganese also increased the symptom severity (Mauri et al., 2016). Also irrigation can affect the outcome of symptoms. In fact, a water deficit directly promoted symptom development, whereas kiwifruit orchards irrigated according to the maintenance of soil field capacity resulted in being less prone to Psa biovar 3 infection (Mauri et al., 2016).

Rain and wind are indicated as major factors for Psa biovar 3 spread within and between orchards. For reducing the effect of pathogen dispersal, various screens protecting the canopy of the plants have been recently proposed and verified in field trials (Black et al., 2015). Plastic covering and hail netting were among the proposed solutions for reducing the rain and wind impact on the plant canopy (Black et al.,



Figure 3. The modification of the orchard training system to reduce the woody volume of the plant and enhancing air circulation can also reduce the risk for *Pseudomonas syringae* pv. *actinidiae* biovar 3 damage.

2015). The covering of the orchard with plastic or glass structures required additional modification of the orchard itself. Ventilation system and drip irrigation were necessary for properly buffering the internal environment, whereas screens have to be installed in order to better control the light and heat. Venting enabled air exchange and lowering of both temperature and humidity. However, particular care should be taken for avoiding physical damage to the foliage during ventilation. In the case of the traditional over-head irrigation system, particular care has to be put in watering the plant during morning, thus allowing the foliage to dry (Kiwifruit Vine Health, 2016). The modification of the training system to reduce the woody volume of the plant and enhancing the air circulation within the canopy could also yield a better management of kiwifruit "bacterial canker" (Figure 3).

References

Abelleira, A., Lopez, M.M., Penalver, R., Aguin, O., Mansilla, J.P., Picoaga, A., and Garcia, M.J. (2011). First report of bacterial canker of kiwifruit caused by *Pseudomonas syringae* pv. *actinidiae* in Spain. Plant Dis. *95*, 1583. https://doi.org/10.1094/PDIS-06-11-0537.

Aiello, D., Ferrante, P., Vitale, A., Polizzi, G., Scortichini, M., and Cirvilleri, G. (2015). Characterization of *Pseudomonas syringae* pv. *syringae* isolated from mango in Sicily and occurrence of copper-resistant strains. J. of Plant Pathol. *97*, 273–282. http://dx.doi.org/10.4454/JPP.V9712.015.

Baltrus, D.A., McCann, H.C., and Guttman, D.S. (2017). Evolution, genomics and epidemiology of *Pseudomonas syringae*: challenges in molecular plant pathology. Mol. Plant Pathol. *18*, 152–168. https://doi.org/10.1111/mpp.12506. PubMed.

Black, M.Z., Casonato, S., and Bent, S. (2015). Opportunities for environmental modification to control *Pseudomonas syringae* pv. *actinidiae* in kiwifruit. Acta Hortic. *1105*, 253–259. http://dx.doi.org/1017660/ActaHortic.2015/1105.36.

Butler, M.I., Stockwell, P.A., Black, M.A., Day, R.C., Lamont, I.L., and Poulter, R.T.M. (2013). *Pseudomonas syringae* pv. *actinidiae* from the recent outbreaks of bacterial canker belongs to different clones that originated in China. PLoS ONE *8*, e57464. https://doi.org/10.1371/journal.pone.0057464.

Cazorla, F.M., Arrebola, E., Sesma, A., Pérez-Garcia, A., Codina, J.C., Murillo, J., and De Vicente, A. (2002). Copper resistance in *Pseudomonas syringae* strains isolated from mango is encoded mainly by plasmids. Phytopathol. *92*, 909–916. https://doi.org/10.1094/PHYTO.2002.92.8.909.

Ciarroni, S., Gallipoli, L., Taratufolo, M.G., Butler, M.I., Poulter, R.T.M., Pourcel, C., Vergnaud, G., Balestra, G.M., and Mazzaglia, A. (2015). Development of a multiple loci variable number of tandem repeats analysis (MLVA) to unravel the intra-pathovar structure of *Pseudomonas syringae* pv. *actinidiae* populations worldwide. PLoS ONE *10*, e0135310. https://doi.org/10.1371/journal.pone.0135310.

Colombi, E., Straub, C., Künzel, S., Templeton, M.D., McCann, H.C., and Rainey, P.B. (2017). Evolution of copper resistance in the kiwifruit pathogen *Pseudomonas syringae* pv. *actinidiae* through acquisition of integrative conjugative elements and plasmids. Environ. Microbiol. *19,* 819–832. https://doi.org/10.1111/1462-2920.13662.

Cunty, A., Cesbron, S., Poliakoff, F., Jacques, M.-A., and Manceau, C. (2015). Origin of the outbreak in France of *Pseudomonas syringae* pv. *actinidiae* biovar 3, the causal agent of bacterial canker of kiwifruit, revealed by a multilocus variable-number tandem-repeats analysis. Appl. Environ. Microbiol. *81*, 6773–6789. https://doi.org/10.1128/AEM.01688-15.

Donati, I., Buriani, G., Cellini, A., Mauri, S., Costa, G., and Spinelli, F. (2014). New insights on the bacterial canker of kiwifruit (*Pseudomonas syringae* pv. *actinidiae*). J. of Berry Res. *4*, 53–67. https://doi.org/10.3233/JBR-140073.

Ferrante, P., and Scortichini, M. (2010). Molecular and phenotypic features of *Pseudomonas syringae* pv. *actinidiae* isolated during recent epidemics of bacterial canker on yellow kiwifruit (*Actinidia chinensis* Planchon) in central Italy. Plant Pathol. *59*, 954–962. https://doi.org/10.1111/j.1365-3059.2010.02304.x.

Ferrante, P., Fiorillo, E., Marcelletti, S., Marocchi, F., Mastroleo, M., Simeoni, S., and Scortichini, M. (2012). The importance of the main colonization and penetration sites of *Pseudomonas syringae* pv. *actinidiae* and prevailing weather conditions in the development of epidemics in yellow kiwifruit, recently observed in central Italy. J. of Plant Pathol. *94*, 455–461. http://dx.doi.org/10.4454/JPP.FA.2012.033.

Ferrante, P., and Scortichini, M. (2014). Frost promotes the pathogenicity of *Pseudomonas syringae* pv. *actinidiae* in *Actinidia chinensis* and *A. deliciosa* plants. Plant Pathol. *63*, 12–19. https://doi.org/10.1111/ppa.12070.

Froud, K.J., Everett, K.R., Tyson, J.L., Beresford, R.M., and Cogger, N. (2015). Review of the risk factors associated with kiwifruit bacterial canker caused by *Pseudomonas syringae* pv. *actinidiae*. N. Z. Plant Prot. *68*, 313–327.

Gardan, L., Brault, T., and Germain, E. (1993). Copper resistance of *Xanthomonas campestris* pv. *juglandis* in French walnut orchards and its association with conjugative plasmids. Acta Hortic. *311*, 259–265. https://doi.org/10.17660/ActaHortic.1993.311.33.

Ghods, S., Sims, I.M., Moradali, M.F., and Rehm, B.H.A. (2015). Bactericidal compounds controlling the growth of the plant pathogen *Pseudomonas syringae* pv. actinidiae, which forms biofilms composed of a novel exopolysaccharide. Appl. Environ. Microbiol. *81*, 4026–4036. https://doi.org/10.1128/AEM.00194-15.

Greer, G., and Saunders, C. (2012). The cost of Psa-V to the New Zealand kiwifruit industry and the wider community. (Canterbury, New Zealand: Lincoln University Research Center; Agribusiness and Economy Research Unit), Research Report No. 237.

Goto, M., Hikota, T., Nakajima, M., Takikawa, Y., and Tsuyumu, S. (1994). Occurrence and properties of copper-resistance in plant pathogenic bacteria. Ann. Phytopathol. Soc. of Japan *60*, 147–153. https://doi.org/10.3186/jjphytopath.60.147.

Hill, R., Stark, C., Cummings, N., Elmer, P., and Hoyte, S. (2015). Use of beneficial microorganisms and elicitors for control *Pseudomonas syringae* pv. *actinidiae* in kiwifruit (*Actinidia* spp.). Acta Hortic. *1095*, 137–146. https://doi.org/10.17660/ActaHortic.2015.1095.17.

Kim, G.H., Kim, K.-H., Son, K.I., Choi, E.D., Lee, Y.S., Jung, J.S., and Koh, Y.J. (2016). Outbreak and spread of bacterial canker of kiwifruit caused by *Pseudomonas syringae* pv. *actinidiae* biovar 3 in Korea. Plant Pathol. J. *32*, 545–551. https://doi.org/10.5423/PPJ.OA.05.2016.0122.

Kiwifruit Vine Health (2016). KPCS Best Practice Fact Sheet. www.org.nz./vdb/document/100457.

Koh, Y.J., Kim, G.H., Koh, H.S., Lee, Y.S., Kim, S.C., and Jung, J.S. (2012). Occurrence of a new type of *Pseudomonas syringae* pv. *actinidiae* strain of bacterial canker of kiwifruit in Korea. Plant Pathol. J. *28*, 423–427. https://doi.org/10.5423/PPJ.NT.05.2012.0061.

Li, Y., Cheng, H.Y., Fang, S.M., and Qian, Z. (2001). Ecological factors affecting prevalence of kiwifruit bacterial canker and bacteriostatic action of bactericides on *Pseudomonas syringae* pv. *actinidiae.* Chin. J. of Appl. Ecol. *12*, 359–362.

Loper, J.E., Henkels, M.D., Roberts, R.J., Grove, J.J., Willet, M.J., and Smith, T.J. (1993). Evaluation of streptomycin, oxytetracycline, and copper resistance of *Erwinia amylovora* isolated from pear orchards in Washington State. Plant Dis. *75*, 287–290. https://doi.org/10.1094/PD-75-0287.

Marcelletti, S., Ferrante P., Petriccione, M., Firrao, G., and Scortichini, M. (2011). *Pseudomonas syringae* pv. *actinidiae* draft genome comparison reveal strain-specific features involved in adaptation and virulence to *Actinidia* species. PLoS ONE *6*, e27297. http://dx.doi.org/10.1373/journal.pone.0027297.

Marco, G.M., and Stall, R.E. (1983). Control of bacterial spot of pepper initiated by strains of *Xanthomonas campestris* pv. *vesicatoria* that differ in sensitivity to copper. Plant Dis. *67*, 779–781. https://doi.org/10.1094/PD-67-779.

Mauri, S., Cellini, A., Buriani, G., Donati, I, Costa, G., and Spinelli, F. (2016). Optimization of cultural practices to reduce the development of *Pseudomonas syringae* pv. *actinidiae*, causal agent of the bacterial canker of kiwifruit. J. of Berry Res. *6*, 355–371. https://doi.org/10.3233/JBR-160115.

Mazzaglia, A., Studholme, D.J., Taratufolo, M.C., Cai, R., Almeida, N.F., Goodman, T., Guttman, D.S., Vinatzer, B., and Balestra, G.M. (2012). *Pseudomonas syringae* pv. *actinidiae* (PSA) isolates from recent bacterial canker of kiwifruit outbreaks belong to the same genetic lineage. PLoS ONE *7*, e36518. https://doi.org/10.1371/journal.pone.0036518.

McCann, H.C., Rikkerink, E.H.A., Bertels, F., Fiers, M., Lu, H., Rees-George, J., Andersen, M.T., Gleave, A.P., Haubold, B., Wohlers, M.W., et al. (2013). Genomic analysis of the kiwifruit pathogen *Pseudomonas syringae* pv. *actinidiae* provides insight into the origin of an emergent plant disease. PLoS Pathog. *9*, e1003503. https://doi.org/10.1371/journal.ppat.1003503.

Morley-Bunker, M., and Lyford, P. (2011). Kiwifruit. In Temperate and Subtropical Fruit Production, 3rd edn., D.I. Jackson, N.E. Looney, M.J. Morley-Bunker and G.F. Thiele, eds. (Wallingford, Oxfordshire, UK: CABI Publishing), pp. 239–245.

Nardozza, S., Martinez-Sanchez, M., Curtis, C., Datson, P.M., and Montefiori, M. (2015). Screening *Actinidia* germplasm for different levels of tolerance, or resistance, to Psa (*Pseudomonas syringae* pv. *actinidiae*). Acta Hortic. *1096*, 351–335. https://doi.org/10.17660/ActaHortic.2015.1096.40.

Norelli, J.L., Jones, A.L., and Aldwinckle, H.S. (2003). Fire blight management in the twenty-first century using new technologies that enhance host resistance in apple. Plant Dis. *87*, 756–765. https://doi.org/10.1094/PDIS.2003.87.7.756.

Parada, J.P., Orellana, M., Amaza, L., Pérez-Martinez, I., Holuigue, L., and Salinas, P. (2017). Characterization of Chilean *Pseudomonas syringae* pv. *actinidiae* strains isolated from infected orchards. PeerJ Preprints. http://dx.doi.org/10.7287/peerj.preprints.2787.v1.

Petriccione, M., Zampella, L., Mastrobuoni, F., and Scortichini, M. (2017). Occurrence of copper-resistant *Pseudomonas syringae* pv. *syringae* strains isolated from rain and kiwifruit orchards also infected by *P. s.* pv. *actinidiae.* Eur. J. of Plant Pathol. *149*(4), 953–968. https://doi.org/10.1007/s10658-017-1246-1.

Santibanez, F. (2014). Modelo de determinacion de riesgo de infeccion de la bacteriosis del kiwi causada por *Pseudomonas syringae* pv. *actinidiae*. http://pdtpsa.comitedelkiwi.cl/modelo-de-riesgo-psa/descripcion-del-modelo.html.

Sawada, H., Shimizu, S., Miyoshi, T., Shinozaki, T., Kusumoto, S., Noguchi, M., Naridomi, T., Kikuhara, K., Kansako, M., Fujikawa, T., et al. (2015). Characterization of biovar 3 strains of *Pseudomonas syringae* pv. *actinidiae* isolated in Japan. Jap. J. of Phytopathol. *81*, 111–126. https://doi.org/10.3186/jjphytopath.81.111.

Scortichini, M. (1994). Occurrence of *Pseudomonas syringae* pv. *actinidiae* on kiwifruit in Italy. Plant Pathol. *43*, 1035–1038. http://dx.doi.org/10.1111/j.1365-3039.1994.tb01654.x.

Scortichini. M. (2014). Field efficacy of chitosan to control *Pseudomonas syringae* pv. *actinidiae*, the causal agent of kiwifruit bacterial canker. Eur. J. of Plant Pathol. *140*, 887–892. http://dx.doi.org/10.1007/s10658/-014-0515-5.

Scortichini, M. (2016). Field efficacy of a zinc-copper-hydracid of

citric acid biocomplex compound to reduce oozing from winter cankers caused by *Pseudomonas syringae* pv. *actinidiae* to *Actinidia* spp. J. of Plant Pathol. *98*, 651–655. http://dx.doi.org/10.4454/JPP.V98I3.044.

Scortichini, M., Ferrante, P., Marcelletti, S., and Petriccione, M. (2014). Omics, epidemiology and integrated approach for the coexistence with bacterial canker of kiwifruit, caused by *Pseudomonas syringae* pv. *actinidiae*. Ital. J. of Agron. *9*, 606. https://doi.org/10.4081/ija.2014.606.

Song, Y.R., Choi, M.S., Choi, G.W., Park, I.K., and Oh, C.S. (2016). Antibacterial activity of cinnamaldehyde and estragole extracted from plant essential oils against *Pseudomonas syringae* pv. *actinidiae* causing bacterial canker disease in kiwifruit. Plant Pathol. J. *32*, 363–370. https://doi.org/10.5423/PPJ.NT.01.2016.0006.

Stockwell, V., Shaffer, B., Bennett, R., Lee, J., and Loper, J.E. (2015). Characterization of *Pseudomonas syringae* from blueberry fields in Oregon and Washington. Phytopathol. *105*, 54.

Sundin, G.W., and Bender, C.L. (1993). Ecological and genetic analysis of copper and streptomycin resistance in *Pseudomonas syringae* pv. *syringae*. Appl. Environ. Microbiol. *59*, 1018–1024.

Tanner, D.J. (2015). A biosecurity incursion: the impact of *Pseudomonas syringae* pv. *actinidiae* (Psa) on the New Zealand kiwifruit industry. Acta Hortic. *1105*, 379–384. https://doi.org/10.17660/ActaHortic.2015.1105.54.

Testolin, R. (2014). Voglia di cambiare: il kiwi verso un nuovo panorama varietale. Frutticoltura *1/2*, 8–15.

Testolin, R., and Messina, R. (1987). Winter cold tolerance of kiwifruit. A survey after winter frost injury in Northern Italy. N. Z. J. Exper. Agric. *15*, 501–504. https://doi.org/10.1080/03015521.1987.10425604.

Tontou, R., Giovanardi, D., Ferrari, M., and Stefani, E. (2016). Isolation of bacterial endophytes from *Actinidia chinensis* and preliminary studies on their possible use as antagonist against *Pseudomonas syringae* pv. *actinidiae.* J. of Berry Res. *6*, 395–406. https://doi.org/10.3233/JBR-160118.

Vanneste, J.L. (2013). Recent progress on detecting, understanding and controlling *Pseudomonas syringae* pv. *actinidiae*: a short review. New Zeal. Plant Protect. *66*, 170–177.

Vanneste, J.L., and Voyle, M.D. (2003). Genetic basis of copper resistance in New Zealand strains of *Pseudomonas syringae*. New Zeal. Plant Protect. *56*, 109–112.

Vavala, E., Passariello, C., Pepi, F., Colone, M., Garzoli, S., Ragno, R., Pirolli, A., Stringaro, A., and Angiolella, L. (2016). Antibacterial activity of essential oils mixture against PSA. Nat. Prod. Res. *30,* 412–418. https://doi.org/10.1080/14786419.2015.1022543.

Wicaksono, W., Jones, E.E., Casonato, S., Monk, J., and Ridgway, H.J. (2017). Biological control of *Pseudomonas syringae* pv. *actinidiae* (Psa), the causal agent of bacterial canker of kiwifruit, using endophytic bacteria recovered from a medicinal plant. Biological Control. https://doi.org/10.1016/j.biocontrol.2017.03.003.

Zhao, Z.B., Gao, X.N., Huang, Q.L., Huang, L.L., Qin, H.Q., and Kang, Z.S. (2013). Identification and characterization of the causal agent of bacterial canker of kiwifruit in the Shaanxi province of China. J. of Plant Pathol. *95*, 155–162. http://dx.doi.org/10.4454/JPP.V95I1.005.

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Address of author:
Marco Scortichini
Council for Agricultural Research and Analysis of Agricultural Economics (CREA) – Research Centre for Olive, Fruit Trees and Citrus, Roma, Italy
E-mail: marco.scortichini@crea.gov.it
Tel.: +39 0679348102; Fax: +39 0679340158