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ORIGINAL ARTICLE

Efficacy of *Pantoea agglomerans* strain RK-84 in controlling fire blight caused by *Erwinia amylovora* in pear orchards

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Abstract

Erwinia amylovora is a bacterial pathogen responsible for fire blight, a devastating disease that affects apples, pears, and other plants in the Rosaceae family worldwide. Biological control is considered an environmentally friendly alternative to chemical treatments, with *Pantoea agglomerans* strains playing a key role. This study aims to assess the efficacy of *P. agglomerans* strain RK-84 in controlling fire blight caused by *E. amylovora* in pear orchards in two regions of Türkiye, Amasya and Antalya. In this experiment, a suspension of *P. agglomerans* RK-84 at a density of 10^5 CFU/mL was sprayed on trees at three time points: at the onset of flower blossom, two weeks later, and ten days following the second application. As a positive control, *Bacillus subtilis* QST 713 was applied at a concentration of 10^7 CFU/mL (Serenade® ASO, Bayer CropScience). Results indicated that *P. agglomerans* RK-84, at a concentration of 10^5 CFU/mL, reduced disease incidence with an efficacy of 86.04% in Amasya and 84.28% in Antalya, showing no significant difference from the positive control, which achieved efficacy rates of 86.68% in Amasya and 84.89% in Antalya.

Keywords Biological control · Biopesticide · *Erwinia herbicola* · Pear · PGPB

Introduction

Fire blight, caused by *Erwinia amylovora*, is a severe threat to fruit cultivation globally, including in Türkiye, leading to significant losses in yield and quality (Momol and Zeller 1992; Rosselo et al. 2006; Abdollahi et al. 2015). This pathogenic bacterium primarily infects flowers and can rapidly spread by multiplying on the aerial parts of the tree. Symptoms may appear on various parts of the tree, including flowers, shoots, leaves, branches, trunks, and fruits. If left untreated, *E. amylovora* can cause cankers and severe infections in shoots, branches, and trunks, which may lead to plant death within one growing season (Thomson 2000; Kotan 2002; Kotan et al. 2005; Blachinsky et al. 2006; Yom Din et al. 2007).

The widespread use of chemical pesticides in crop production to prevent yield losses from diseases, pests, and weeds has raised concerns due to their adverse effects on the environment and human health, as well as the development of pathogen resistance and residue issues (Sholberg et al. 2001; McManus et al. 2002). Additionally, the use of antibiotics is restricted in many countries (McGhee and Sundin 2011; Mechan Llontop et al. 2020). As a result, there is a growing interest in alternative methods. Studies have shown that bacteriophages (Buttimer et al. 2017; Park et al. 2022), herbal essential oils (Loukhaoukha et al. 2018; Doukkali et al. 2022), antimicrobial peptides (Mendes et al. 2021) and antibiotics (Wallis et al. 2021; Sundin et al. 2023) can help manage fire blight. Biological control has gained global attention as a promising strategy, including in Türkiye (Vanneste et al. 2004; Kotan 2020).

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Several commercial biological control agents (BCAs) are now available on the market. BCAs like *Pantoea agglomerans* (syn. *Erwinia herbicola*) (Beer and Rundle 1983; Wilson et al. 1992), *Pseudomonas fluorescens* A506 (Lindow et al. 1996), P. *agglomerans* E325 (Mathre et al. 1999; Pusey 1999; Montesinos 2000), *P. agglomerans* P10c (Vanneste et al. 2002), P. *agglomerans* Eh-24 (Özaktan and Bora 2004), *P. vagans* C9-1 (Smits et al. 2010), *B. subtilis*, *Lactobacillus plantarum*, *P. fluorescens*, *P. agglomerans*, *Rahnella aquatilis* (Zeller 2006; Rosello et al. 2013), *B. subtilis*, *P. agglomerans* (Raafat et al. 2015), *P. agglomerans* ACBP2, *B. amyloliquefaciens* LMR2, *Bacillus halotolerans* (SF3 and SF4), and *P. agglomerans* ACBP2 (Bahadou et al. 2018) have proven effective However, their efficacy is often limited and highly influenced by environmental conditions (Ngugi et al. 2011). highlighting the need for new strains with novel biological control mechanisms (Montesinos and Bonaterra 2009; Sundin et al. 2009).

Pantoea agglomerans has emerged as a bacterium with applications beyond plant protection, providing benefits across agriculture, medicine, and environmental science. According to Dutkiewicz et al. (2016), *P. agglomerans* exhibits strong antagonistic activity against pathogens, mediated by bioactive compounds like herbicolin, pantocins, and microcin, which inhibit pathogen growth by disrupting cell membrane integrity and interfering with essential cellular processes, thus reducing reliance on chemical pesticides (Wright et al. 2020). As a symbiotic partner, *P. agglomerans* promotes nutrient uptake and growth in plants by enhancing root structure and increasing resilience against environmental stressors such as drought and soil-borne diseases (Timmusk et al. 2017), reinforcing its role as a sustainable growth promoter.

Environmentally, *P. agglomerans* contributes to bioremediation by degrading pollutants like heavy metals and hydrocarbons and forming biofilms that stabilize contaminated soil, enhancing phytoremediation efforts and soil health (Shanahan et al. 2018). In medical science, the immunomodulatory properties of *P. agglomerans*, particularly via the lipopolysaccharide IP-PA1 have been shown to stimulate macrophage activity, offering potential in managing diseases by boosting immune responses in animals and humans (Endo et al. 2011).

Despite these benefits, certain strains of *P. agglomerans* have been linked to opportunistic infections, especially in immunocompromised individuals, necessitating careful strain selection and rigorous safety protocols for bioformulations (Cruz et al. 2020). Such protocols are essential to balance the bacterium's agricultural and environmental benefits with potential health risks, ensuring safe and effective applications across diverse settings.

The efficacy of bioagent bacteria selected through previous in-vitro and *semi-in-vivo* research (Kotan 2002; Kotan et al. 2005) was tested on 2-3-year-old saplings under field conditions (Karabıçak and Kotan 2014). In this study, *P. agglomerans* RK-84 strain, previously shown to be highly effective against *E. amylovora* in trials, was produced in an emulsion concentrated formulation (EC) under the supervision of the Ministry of Agriculture and Forestry of Türkiye and tested in two locations (Amasya and Antalya) in eight- to ten-year-old pear orchards. Following toxicological and ecotoxicological assessments, this study aims to pursue biopesticide licensing for *P. agglomerans* RK-84.

Materials and methods

Biocontrol bacterial strains

In this study, *Pantoea agglomerans* strain RK-84 was sourced from the culture collection of Kotan et al. (2006) at the Department of Plant Protection, Faculty of Agriculture, Atatürk University, Erzurum, Türkiye. Initial identification of this strain was performed using the BIOLOG and Sherlock Microbial Identification System (MIS) version 4.0 from MIDI, Inc., Newark, DE, USA (Roy 1988). Subsequently, 16–23 S rDNA sequencing confirmed a 97.49% identity with *P. agglomerans* (Accession Numbers: CP046722.1 and CP034148.1).

For routine applications, the bacterial strain was cultivated on Nutrient Agar (NA), and for long-term storage, it was preserved in Luria Bertani (LB) Broth with 30% glycerol at −80 °C. *Bacillus subtilis* QST 713, sourced from the biopesticide Serenade SC, was used as a positive control strain due to its established application in managing fire blight in Türkiye.

Preparation of the bacterial suspensions

To prepare fresh cultures of *P. agglomerans* RK-84, the bacterial strain was streaked onto NA medium and incubated at 27 °C for 24 h. Subsequently, a single bacterial colony was aseptically transferred using a sterile loop into a flask containing 300 mL of Nutrient Broth (NB) and incubated on a rocking shaker at 250 rpm for 24 h at 27 °C. After incubation, the concentration was adjusted spectrophotometrically to 10^7 CFU/mL while Serenade SC was prepared at 10^9 CFU/mL.

The recommended dose for Serenade SC was 10 mL/L (10^7 CFU/mL). Accordingly, the spraying dose of *P. agglomerans* RK-84 was prepared at 10 mL/L (10^5 CFU/mL), with two additional sub-doses prepared at 7.5 mL/L (7.5×10^4 CFU/mL) and 5 mL/L (5×10^4 CFU/mL).

Plant variety and study locations

The experiments were conducted on two farms in Türkiye with a history of recurring fire blight (*E. amylovora*). The first trial was carried out at İbrahim Davulcu's pear farm in Amasya (Taşova-Ziyaret). This farm contained 800 ten-year-old pear trees of the Akça cultivar, planted in rows with 3-meter spacing between trees and 4 m between rows. The trees measured approximately 2.5–3 m in height, with canopy widths ranging from 1 to 1.5 m.

The second trial took place at Mehmet Bayar's pear farm in Antalya (Korkuteli-Kargalik). This farm consisted of 1000 twelve-year-old pear trees of the Santa Maria cultivar with similar spacing and dimensions to those in Amasya. Trees on this farm ranged from 3 to 3.5 m in height, with canopy widths of approximately 1.5–2 m.

Orchard trials

In this experiment, each tree received approximately 1.2 L of bacterial suspensions via spraying. A 25-L motorized backpack sprayer (BOLAT F-768 model) equipped with a 1.2 mm conical nozzle was used for the applications. Three applications were scheduled: the first spray was applied at the 'white tip' stage when flower buds began swelling, the second spray followed two weeks later during the full bloom stage, and the third spray was administered 10 days after the second, at the petal fall stage.

Each experimental plot consisted of three trees, with adequate spacing maintained between adjacent plots. Observations included examining 200 flowers and 100 shoots on each tree. A final assessment was conducted when the average disease rate in untreated control plots exceeded 20%. Infected parts (flower clusters and shoots) were counted for each treatment and control plot, and the disease incidence percentage was calculated.

The disease rate (%) was calculated using the following formula:

$$\text{Disease rate } (\%) = \frac{\text{Total number of infected parts}}{\text{Total number of observed parts}} \times 100$$

Efficacy rate was calculated using the Abbott formula (Abbott 1925).

$$\text{Efficacy rate } (\%) = \text{Mean control disease rate } (\%) - \frac{\text{Disease rate } (\%) \text{ in the tested treatment}}{\text{Mean control disease rate } (\%)} \times 100$$

The experiment was conducted with 4 replications using a randomized complete block design.

Climate data

Meteorological data was collected from the closest meteorological station and included measurements of average temperature, average humidity, and average wind speed prior to each spraying event.

Data analysis

Data were analyzed using one-way ANOVA, and means were compared using the Tukey HSD test at a significance level of $P < 0.05$. All analyses were performed using JMP Pro® 16 (SAS Institute, Cary, NC) software.

Results

The effects of biological control applications in two distinct regions are summarized in Table 1; Fig. 1, highlighting the effectiveness of *P. agglomerans* RK-84 in reducing disease severity compared to both the control and Serenade SC.

The lowest disease severity was observed with *P. agglomerans* RK-84 at 10^5 CFU/mL, achieving 3.67% in Amasya and 4.34% in Antalya. Similarly, Serenade SC at 10^7 CFU/

Table 1 Effects of biological control applications on disease severity and efficacy rate in two regions

Applications	Disease severity (%)*		Efficacy rate (%)*	
	Amasya	Antalya	Amasya	Antalya
RK-84 (5×10^4 CFU/mL)	12.00 ± 1.56^{B}	12.75 ± 1.07^{B}	54.28 ± 5.95^{C}	53.77 ± 3.87^{C}
RK-84 (7.5×10^4 CFU/mL)	7.33 ± 0.98^{C}	8.08 ± 0.57^{C}	72.07 ± 3.75^{B}	70.70 ± 2.07^{B}
RK-84 (10^5 CFU/mL)	3.67 ± 0.61^{D}	4.34 ± 0.61^{D}	86.04 ± 2.32^{A}	84.28 ± 2.20^{A}
Serenade SC (10^7 CFU/mL)	3.50 ± 0.58^{D}	4.17 ± 0.43^{D}	86.68 ± 2.20^{A}	84.89 ± 1.56^{A}
Control	26.25 ± 2.56^{A}	27.58 ± 0.88^{A}	0 ± 0^{D}	0 ± 0^{D}
LSD	2.98	1.79	7.87	5.41
CV	12.53	6.99	5.84	4.09
F ($P < 0.05$)	117.28	340.65	242.42	491.35

LSD least significant difference, *CV* coefficient of variation

*Mean values (±SD) in each column followed by the same letter are not significantly different according to Tukey's HSD test ($p < 0.05$)

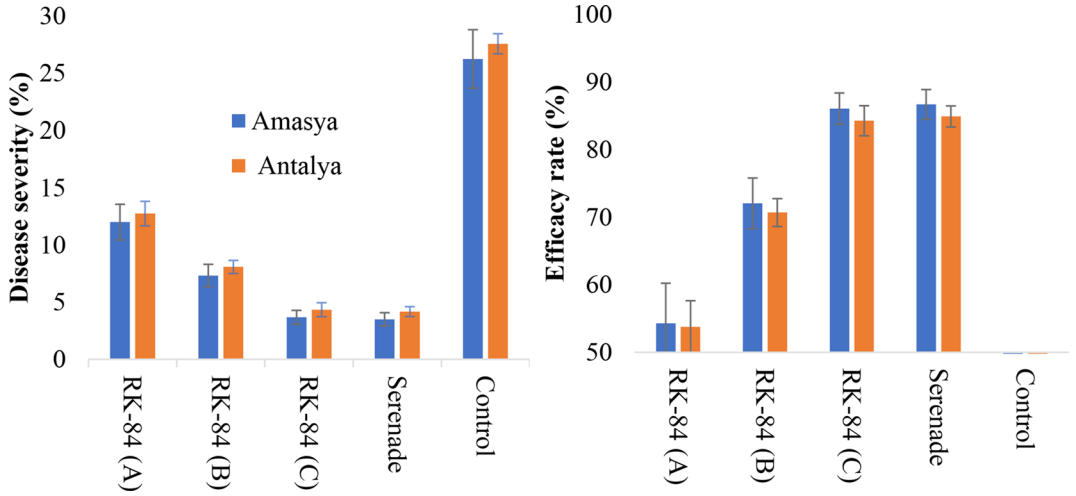

Fig. 1 Effects of biological control applications on disease severity and efficacy rate in two regions. Error bars represent standard deviation. (A): (5×10^4 CFU/mL), (B): (7.5×10^4 CFU/mL), (C): (10^5 CFU/mL), Serenade: Serenade SC (10^7 CFU/mL)

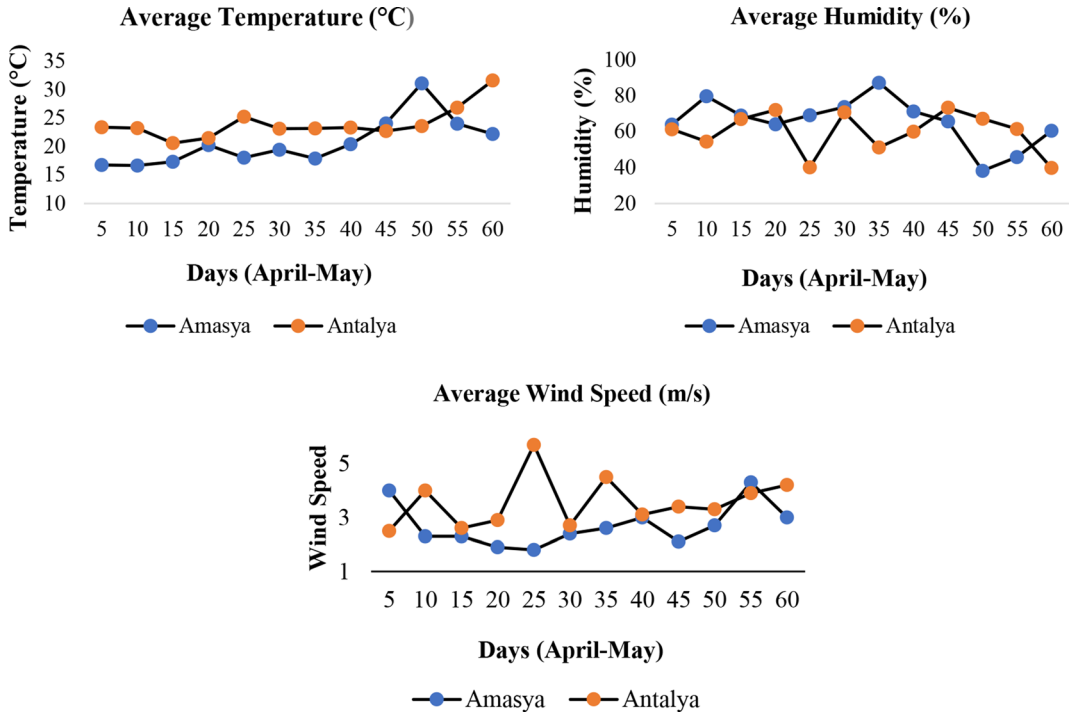

Fig. 2 Average climatic data for Amasya and Antalya in May and July

mL achieved 3.50% and 4.17%, respectively. In contrast, the untreated control group showed significantly higher disease severity rates at 26.25% in Amasya and 27.58% in Antalya.

Notably, *P. agglomerans* RK-84 exhibited the highest efficacy rates of 86.04% in Amasya and 84.28% in Antalya at a concentration of 10^5 CFU/mL. The efficacy rates at a concentration of 7.5×10^4 CFU/mL were 72.07% in Amasya and 70.70% in Antalya. Serenade SC, applied at a concentration of 10^7 CFU/mL demonstrated efficacy rates of 86.68% in Amasya and 84.89% in Antalya. Overall, all treatments, including the lower concentration of 5×10^4 CFU/mL, were effective, as indicated by significant differences compared to the control group.

The five-day average climatic data for the Amasya and Antalya regions in May and July were given in Fig. 2. In Amasya, prior to the first application, the average temperature was 18 °C, with an average humidity of 71.9% and an average wind speed of 2.4 m/s. By the time of the second spraying, the average temperature had risen to 20.1 °C, humidity increased to 74.9%, and wind speed reached 2.8 m/s.

In Antalya, the average temperature before the first application was 22.8 °C, with an average humidity of 60.7% and an average wind speed of 3.4 m/s. For the second spraying, the average temperature was 23.6 °C, with an average humidity of 55.7% and a wind speed of 3.6 m/s.

Discussion

In our previous study (Kotan 2002), 324 bacterial strains were isolated from pome fruit trees, representing 76 different bacterial species across 36 genera. These strains were distributed as follows: 16.9% *E. amylovora*, 16.6% *P. syringae* pv. *syringae*, 11.7% *P. agglomerans*, 10.8% *B. pumilus*, 7.7% *E. intermedius*, 5.8% *A. piechaudii*, 4.0% *Leclercia adecarboxylata*, and 26.5% comprised 69 other species (Kotan et al. 2006). In a subsequent study, 206 bacterial strains were tested for their antagonistic activity against *E. amylovora*, both in vitro and in vivo. Among these strains, 62 strains exhibited potential as biocontrol agents, displaying antagonistic activity against *E. amylovora* in in-vitro conditions. Further evaluations involved testing the antagonistic activities of these selected strains, both individually and in combinations, in vivo on one-year-old Golden Delicious apple twigs. Results indicated that 21 strains and six combinations showed promise as biocontrol agents for fire blight management. Notably, *P. agglomerans* RK-84 emerged as one of the most effective bioagent bacterial strains in both in-vitro and in-vivo studies (Kotan et al. 2004). In subsequent orchard trials, three selected bacterial strains, including *P. agglomerans* RK-84, were tested on apple saplings, with *P. agglomerans* RK-84 reducing disease severity by 48.9% (Karabıçak and Kotan 2014).

In the current study, we evaluated the effectiveness of *P. agglomerans* strain RK-84, previously shown to be effective against *E. amylovora* in liquid suspension trials conducted in pear orchards in Amasya and Antalya. Results demonstrated that *P. agglomerans* RK-84 significantly reduced disease rates compared to the untreated control group, achieving efficacy comparable to the commercial biopesticide Serenade SC (*Bacillus subtilis* QST 713). The study was conducted over a single growing season, with trials across two locations with different climatic conditions, providing valuable insights into the bioagent's adaptability. The significant reduction in disease severity observed at both sites, along with bioagent's consistent performance despite climatic differences, highlights its potential for broader application.

Climatic factors such as temperature, humidity, and rainfall, can significantly impact the effectiveness of biocontrol agents (Loper et al. 2012). In this study, *P. agglomerans* RK-84 showed consistency across both regions, indicating resilience to some environmental fluctuations. Nevertheless, it is crucial to evaluate the interplay of environmental conditions with biocontrol efficacy as previous studies have shown (He et al. 2020). This is particularly important for fire blight, where fluctuating humidity levels can affect the survival and colonization of the biocontrol agent on plant surfaces (Mechan Llontop et al. 2020). Another consideration is the long-term sustainability of *P. agglomerans* RK-84.

While this study demonstrates significant short-term efficacy, the persistence and impact of *P. agglomerans* RK-84 over multiple growing seasons remain uncertain. Long-term studies are needed to determine whether *P. agglomerans* can consistently suppress fire blight across seasons, as shown in some studies where biocontrol efficacy fluctuated over time due to environmental stressors (Endo et al. 2011). Assessing the long-term persistence of *P. agglomerans* on plant surfaces and its interactions with other orchard microbiota could enhance understanding of its role in sustainable disease management (Wright et al. 2020).

Sharifazizi et al. (2017) focused on developing an effective biocontrol method against *E. amylovora*, isolating *P. agglomerans* strains Pa9, Pa10, and Pa21 from pear trees. These strains inhibited *E. amylovora* growth in in vitro assays, with *P. agglomerans* Pa21 showing the greatest potential in reducing disease incidence in immature fruits. Bahadou et al. (2018) evaluated various antagonistic bacteria, including *P. agglomerans*, in both laboratory and field trials. Over two years *P. agglomerans* ACBP2 emerged as one of the most effective strains for controlling fire blight, demonstrating its potential in practical field conditions.

While some *P. agglomerans* strains have shown promise as biocontrol agents, there are reports indicating potential health risks associated with certain strains. Further research is necessary to assess not only long-term sustainability, persistence, and impact on non-target organisms, but also the potential health risks of specific *P. agglomerans* strains. Differentiating between beneficial and harmful strains is essential to ensure the safe application of *P. agglomerans* as a biofertilizer or biocontrol agent (Lorenzi et al. 2022).

In a study conducted by Kim et al. (2022), P. *agglomerans* strain E325, encapsulated in alginate microcapsules (AMCs), demonstrated efficacy in suppressing E. *amylovora* strain Ea153 under varying humidity conditions. The source of BCAs plays a critical role in their ability to withstand environmental stress, affecting survival and functionality in field conditions. Although traditional BCAs from soil and plant surfaces have been extensively studied, atmospheric and precipitation-borne bacteria have emerged as promising candidates due to their inherent resilience to extreme environmental fluctuations (Mechan Llontop et al. 2020; Kim et al. 2022). For example, Mechan Llontop et al. (2020) found that rain-borne *P. agglomerans* isolates

demonstrated substantial inhibitory activity against *E. amylovora* and survived on apple blossoms, even under variable environmental conditions. This suggests that precipitation-borne bacteria could be valuable BCAs in integrated pest management programs, especially in regions with variable climatic conditions. However, further studies are needed to fully understand their efficacy and reliability across diverse climatic settings (Shanahan et al. 2018; Mechan Llontop et al. 2020).

In conclusion, *P. agglomerans* RK-84 demonstrates strong potential as a biocontrol agent comparable to commercial options like Serenade SC, further research should explore its long-term performance, environmental adaptability, and efficacy. Continued study will support the development of sustainable and effective fire blight management strategies, contributing to the protection of pear orchards (Loper et al. 2012; He et al. 2020).

Conclusion

In conclusion, fire blight is a serious threat to pear orchards, causing significant losses in yield and quality. The limitations and potential risks of chemical control methods underscore the need for alternative approaches. This study demonstrates the effectiveness of *P. agglomerans* RK-84 in reducing fire blight in pear orchards with a dosage of 10^5 CFU/mL, achieving over 80% efficacy, indicating its potential as a viable biological control option. However, climate-specific factors and regional variations should be considered during the evaluation. Our findings contribute to the development of environmentally friendly alternatives to chemical pesticides, but further research is needed to optimize application protocols and evaluate commercial feasibility.

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Declarations

Ethics approval and consent to participate Not applicable.

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Competing interests Authors declare that they have no competing interests.

References

Abbott WS (1925) A method of computing the effectiveness of an insecticide. J Econ Entomol 18:265–267

Abdollahi H, Ghahremani Z, Erfaninia K, Mehrabi R (2015) Role of electron transport chain of chloroplasts in oxidative burst of interaction between *Erwinia amylovora* and host cells. Photosynth Res 124(2):231–242

Bahadou SA, Ouijja A, Karfach A, Tahiri A, Lahlali R (2018) New potential bacterial antagonists for the biocontrol of fire blight disease (*Erwinia amylovora*) in Morocco. Microb Pathog 117:7–15

Beer SV, Rundle JR (1983) Suppression of *Erwinia amylovora* by *Erwinia herbicola* in immature pear fruits. Phytopathology 73:1346

Blachinsky D, Shtienberg D, Zamski E, Weinthal D, Manulis S (2006) Effects of pear tree physiology on fire blight progression in perennial branches and on expression of pathogenicity genes in *Erwinia amylovora*. Eur J Plant Pathol 116:315–324

Buttimer C, McAuliffe O, Ross RP, Hill C, O'Mahony J, Coffey A (2017) Bacteriophages and bacterial plant diseases. Front Microbiol 8:212667

Cruz C, Sanchez E, Gonzalez R, Ramirez A, Perez LM (2020) Safety concerns and clinical risk associated with *Pantoea agglomerans*. Clin Infect Dis 72(5):893–899

Doukkali E, Radouane N, Tahiri A, Tazi B, Guenoun F, Lahlali R (2022) Chemical composition and antibacterial activity of essential oils of Cinnamomum cassia and Syzygium aromaticum plants and their nanoparticles against *Erwinia amylovora*. Archives Phytopathol Plant Prot 55(2):217–234

Dutkiewicz J, Mackiewicz B, Lemieszek MK, Golec M, Milanowski J (2016) *Pantoea agglomerans*: a mysterious bacterium of evil and good. Part IV. Beneficial effects. Ann Agric Environ Med 23(2):206–222

Endo Y, Shirakawa T, Wakame K, Watanabe H (2011) Immune-boosting effects of IP-PA1 from *Pantoea agglomerans*. Immunol Lett 138(1):12–20

He Z, Dong C, Liu H (2020) The impact of climatic variables on the effectiveness of biological control agents in agricultural settings. Agric for Meteorol 291:108089

Karabıçak Y, Kotan R (2014) The investigation of biological control facilities against fire blight on pear trees caused by *Erwinia amylovora* by using bacteria. Plant Prot Bull 54(4):355–370

Kim IY, Lew B, Zhao Y, Korban SS, Choi H, Kim K (2022) Biocontrol of fire blight via microcapsule-mediated delivery of the bacterial antagonist *Pantoea agglomerans* E325 to apple blossoms. Biocontrol 67(4):433–442

Kotan R (2002) Isolation and identification of pathogenic and saprophytic bacterial organisms from pome fruits grown in Eastern Anatolia Region of Turkey by commercial and molecular techniques, and research on the biological control strategies. PhD Thesis, Atatürk University, Institute of Science and Technology, Department of Plant Protection. p 217

Kotan R (2020) Biological solutions in agriculture. Harman Publishing, İstanbul, ISBN: 978-605-68060-4-9. p 158

Kotan R, Sahin F, Görmez A (2004) Nutritional similarity in carbon source utilization of *Erwinia amylovora* and its potential biocontrol agents. J Turkish Phytopathol 33(1–3):25–38

Kotan R, Sahin F, Ala A (2005) Identification and pathogenicity of bacteria isolated from pome fruits trees in eastern Anatolia region of Turkey. J Plant Dis Protect 113:8–13

Kotan R, Sahin F, Ala A (2006) Identification and pathogenicity of bacteria isolated from pome fruits trees in eastern Anatolia region of Turkey. J Plant Dis Prot 113(1):8–13

Lindow SE, McGourty G, Elkins R (1996) Interactions of antibiotics with *Pseudomonas fluorescens* strain A506 in the control of fire blight and frost injury to pear. Phytopathology 86:841–848
Loper JE, Buyer JS, Rangarajan S (2012) Environmental influences on the efficacy of biological control agents. Annu Rev Phytopathol 50:377–403
Lorenzi AS, Bonatelli ML, Chia MA, Peressim L, Quecine MC (2022) Opposite sides of *Pantoea agglomerans* and its associated commercial outlook. Microorganisms 10(10):2072
Loukhaoukha R, Saidi F, Jullien F, Benabdelkader T (2018) Chemical composition and antibacterial activity of Lavandula stoechas essential oil and its main components against Erwinia amylovora and Pectobacterium carotovorum subsp. Carotovorum. Phytothérapie 16(3):149
Mathre DE, Cook RJ, Callan NW (1999) From discovery to use: traversing the world of commercializing biocontrol agents for plant disease control. Plant Dis 83:972–983
McGhee G, Sundin GW (2011) Evaluation of kasugamycin for fire blight management, effect on nontarget bacteria and assessment of kasugamycin resistance potential in *Erwinia amylovora*. Phytopathology 101:192–204
McManus PS, Stockwell VO, Sundin GW, Jones AL (2002) Antibiotic use in plant agriculture. Annual Rev Phytopathol 40:443–465
Mechan Llontop ME, Hurley K, Tian L, Bernal Galeano VA, Wildschutte HK, Marine SC, Yoder KS, Vinatzer BA (2020) Exploring rain as source of biological control agents for fire blight on apple. Front Microbiol 11:199
Mendes RJ, Sario S, Luz JP, Tassi N, Teixeira C, Gomes P, Fernando T, Santos C (2021) Evaluation of three antimicrobial peptides mixtures to control the phytopathogen responsible for fire blight disease. Plants 10(12):2637
Momol MT, Zeller W (1992) Infections in Turkey thought to be part of an expanding epidemic originating in Egypt. Plant Dis 76:1114–1116
Montesinos E (2000) Pathogenic plant-microbe interactions. What we know and how we benefit. Int Microbiol 3:69–70
Montesinos E, Bonaterra A (2009) Microbial Pesticides. In: Schaechter M (ed) Encyclopedia of Microbiology, 3rd edn. Elsevier, Amsterdam, pp 110–120
Ngugi H, Lehman BL, Madden LV (2011) Multiple treatment meta-analysis of products evaluated for control of fire blight in the Eastern United States. Phytopathology 101:512–522
Özaktan H, Bora T (2004) Biological control of fire blight in pear orchards with a formulation of *Pantoea agglomerans* strain eh 24. Brazilian J Microbiol 35:224–229
Park J, Byeori K, Sujin S, Whan Lee Y, Roh E (2022) Isolation of nine bacteriophages shown effective against *Erwinia amylovora* in Korea Jungkum Park. Plant Pathol J 38(3):248–253
Pusey PL (1999) Laboratory and field trials with selected microorganisms as biocontrol agents for fire blight. Acta Horticulturae Acta Hortic (489):655–662
Raafat KH, Hanan SA, Rabab AM (2015) Antibacterial activity of antagonistic bacteria and plant extract on *Erwinia amylovora* the pathogen of fire blight disease in Egypt. Int J Phytopathol 4:73–79
Rosello G, Bonaterra A, Frances J, Montesions L, Badosa E, Montesions E (2013) Biological control of fire blight of apple and pear with antagonistic *Lactobacillus plantarum*. Eur J Plant Pathol 137:621–633
Rosselo M, Pefialver J, Llop P, Gorris MT, Chartier R, Garcia F, Monton C, Cambra M, Lopez MM (2006) Identification of an *Erwinia* sp. from different *Erwinia amylovora* and responsible for necrosis on pear blossoms. Can J Plant Pathol 28:30–41
Roy MA (1988) Use of fatty acids for the identification of phy- to pathogenic bacteria. Plant Dis 72:460
Shanahan P, O'Sullivan DJ, Simpson P, Glennon JD, Grant J (2018) Bioremediation of contaminated soils using beneficial bacteria. J Environ Manage 216:55–64
Sharifazizi M, Harighi B, Sadeghi A (2017) Evaluation of biological control of *Erwinia amylovora*, causal agent of fire blight disease of pear by antagonistic bacteria. Biol Control 104:28–34
Sholberg PL, Bedford KE, Haag P, Randall P (2001) Survey of *Erwinia amylovora* isolates from British Columbia for resistance to bactericides and virulence on apple. Can J Plant Pathol 23:60–67
Smits THM, Rezzonico F, Kamber T, Goesmann A, Ishimaru CA, Stockwell VO (2010) Complete genome sequence of Pantoea vagans plant-beneficial strain C9-1. J Bacteriol 192:6486–6487
Sundin GW, Werner NA, Yoder KS, Aldwinckle HS (2009) Field evaluation of biological control of fire blight in the Eastern United States. Plant Dis 93:386–394
Sundin GW, Peng J, Brown LE, Zeng Q, Förster H, Adaskaveg JE (2023) A novel IncX plasmid mediates high-level oxytetracycline and streptomycin resistance in *Erwinia amylovora* from commercial pear orchards in California. Phytopathology 113(12):2165–2173
Thomson S (2000) Epidemiology of fire blight. In: Vanneste JL (ed) Fire blight: the disease and its causative agent: *Erwinia amylovora*. CAB International, Wallingford, pp 370–382
Timmusk S, Behers L, Muthoni J, Muraya A, Aronsson AC (2017) Bacterial endophytes as growth promoters in agriculture. Environ Microbiol Rep 9(1):57–64
Vanneste JL, Cornish DA, Yu J, Voyle MD (2002) P10c: a new biological control agent for control of fire blight which can be sprayed or distributed using honeybees. Acta Hortic 590:231–235
Vanneste JL, Conish DA, Spinelli F, Yu J (2004) Colonization of apple and pear leaves by different strains of biological control agent of fire blight. N Z Plant Prot 57:49–53
Wallis A, Gu G, Ramachandran P, Reed E, Ottesen A, Nou X, Cox KD (2021) Endophytic bacterial communities in apple leaves are minimally impacted by streptomycin use for fire blight nanagement. Phytobiomes J 5(3):350–361
Wilson M, Epton HAS, Sigee DC (1992) Interactions between *Erwinia herbicola* and *E. Amylovora* on the stigma of hawthorn blossoms. Phytopathology 82:914–918
Wright GD, Patel JC, Thomson RA, Jenkins MD, Anderson PL (2020) Antagonistic mechanisms of *Pantoea agglomerans* against phytopathogens. Agricultural Sci J 58(2):121–136
Yom Din G, Zugman Z, Sheglov N, Manulis S, Reuveni M (2007) Description of the elongation of fire blight canker, caused by *Erwinia amylovora*, in trunks of pear trees. Crop Prot 26:612–624
Zeller W (2006) Status of biocontrol methods against fire blight. Phytopathol Pol 39:71–78

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