Eco Friendly Approaches for Bacterial Disease Management in Agriculture

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Introduction

Agriculture is the backbone of developing and developed economies of nations. In due course, the advancements in agriculture mainly focussed on increasing production quantity have led to the use of monoculture, narrowed genetic diversity and heritable vulnerability associated with domestication which make the crops susceptible to biotic and abiotic stresses. Amongst the stresses- 10 to 13% of losses in food production is due to plant diseases. It is estimated that up to 40% of agricultural yields can be lost due to plant illnesses brought on by bacteria (Venbrux, M. et al., 2023). Some major bacterial plant diseases include fire blight (apple, pear), rice leaf blight, tomato and potato wilt, banana wilt, kiwifruit canker, and cassava blight caused by various pathogens like *Erwinia, Xanthomonas, Ralstonia, and Pseudomonas* species

Antibiotics were immediately seen as the panacea for all infectious disorders after penicillin, streptomycin, and the sulfonamides were discovered and used in clinical medicine. Antibiotic therapy is still vital in plant agriculture today, and it has undoubtedly helped to plant illnesses. However, the widespread development of antibiotic resistance which is now particularly important in clinical bacterial pathogens has undermined the enthusiasm around the use of antibiotics (Moh et al., 2020).

With this emerging issue, various contemporary solutions to bacterial diseases began to find its way to the limelight. Even though, traditional approaches like cultural control, physical and biological control were used from time immemorial, their efficiency was always put to question especially after the introduction of antibiotics. However, procedures like phage therapy, microbiome engineering, use of plant extracts etc. are all new methods to combat bacterial diseases and are proving to be a useful tool. This review article focuses mostly on the modern techniques harnessed to manage bacterial plant diseases.

Traditional Eco-friendly approaches: The traditional methods used in bacterial plant disease management are- cultural and physical techniques

1. Cultural control

i. Crop Rotation

Ralstonia solanacearum, a soilborne bacterial pathogen that causes bacterial wilt in solanaceous crops (such as tomatoes and potatoes), can be lessened by rotating non-host crops. Crop rotation with non-hosts like maize or cereals has been shown to lower the incidence of bacterial wilt in tomatoes (Wicker et al., 2007).

ii. Sanitation and Tool Disinfection

Cleaning tools and removing infected plant debris helps prevent the spread of bacterial canker in kiwifruit (*Pseudomonas syringae pv. actinidiae*) and fire blight in apples and pears (*Erwinia amylovora*). Disinfection of pruning tools significantly reduces transmission of P. syringae in kiwifruit (Vanneste, 2017).

iii. Removal of Infected Plant Residues

Prompt removal and destruction of infected plants or debris can prevent the build-up and spread of bacterial pathogens. Residue removal reduced Xanthomonas wilt incidence in banana plantations (Ocimati et al., 2013).

iv. Optimized Irrigation Practices

Adjusting irrigation methods to minimize leaf wetness and soil moisture can reduce bacterial disease incidence. Modifying irrigation practices to limit excessive moisture helps control bacterial growth and disease spread (Ul Haq et al., 2021)

2. Physical control

i. Hot Water Treatment

Seed-borne bacterial infections can be successfully eradicated by soaking seeds in hot water. For example, *Xanthomonas campestris pv. campestris* (Xcc), the bacteria that causes black rot in brassicas, is greatly reduced when cauliflower seeds are submerged in water at 50–52°C.

ii. Radiation from Ultraviolet (UV)

Bacterial infections can be suppressed by UV-C light exposure. It has been demonstrated that low UV-C doses (3.6 kJ/m2) lessen the severity of black rot and Xcc populations in cabbage leaves (Liu Z et al., 2022).

iii. Soil solarization

In order to trap solar energy and raise soil temperatures to levels that are fatal to soil-borne diseases, this technique entails covering moist soil with sheets of transparent polyethylene. *Clavibacter michiganensis subsp. michiganensis* is the cause of bacterial canker in tomatoes, which soil solarization has been shown to effectively prevent (Singh et al., 2012).

iv. Use of Nanoparticles in Photocatalysis

When exposed to light, nanoparticles such as titanium dioxide (TiO_2) can cause photocatalysis, producing reactive oxygen species that are harmful to bacteria. This antibacterial action is enhanced by doping TiO_2 with metals like zinc (Zn) and silver (Ag), which effectively reduces pathogens like Xanthomonas perforans in tomatoes (Sundin et al., 2016).

The recent trends

A. Biological control- The use of Microbial Biological Control Agents (MBCA)

Microbial Biological Control Agents (MBCAs) have garnered significant attention in recent years for their potential to manage bacterial plant diseases sustainably.

Bacillus species: Some *Bacillus* strains have shown antagonistic effects on plant diseases. *Bacillus velezensis* BTR11, for example, proved successful in preventing bacterial leaf blight in rice and encouraging plant development (Do et al., 2023).

The broad-spectrum antibacterial action of *Pseudomonas species* is well-known. According to one study, *Pseudomonas alcaligenes* considerably decreased the postharvest tomato fruit rots brought on by *Alternaria alternata* and *Geotrichum candidum* .

The potential of *Streptomyces species* as biocontrol agents against a range of plant infections has been investigated and are known to produce a variety of antibacterial chemicals (Khan et al., 2023).

Paecilomyces lilacinus A65's ability to protect tea plants from gray blight disease was assessed in a 2023 study. This agent's foliar treatments dramatically decreased the incidence of disease, indicating that it may have microbial pesticide potential (Xu et al., 2023).

A natural alternative for managing diseases is provided by some strains of *Lactobacillus plantarum* that have demonstrated broad-spectrum action against bacterial plant infections.

The effectiveness of disease control can be increased by combining chemical and biological treatments. For instance, *Fusarium* crown and root rot in tomatoes was considerably better controlled when *Bacillus velezensis* SDTB038 and the fungicide phenamacril were used in tandem.

B. Biological control- The phage therapy

In contrast to broad-spectrum antibiotics and chemical bactericides, bacteriophages specifically infect and lyse their bacterial hosts without harming beneficial microorganisms, making them ideal candidates for integrated disease management strategies. Recent studies have shown the effectiveness of phage applications against several important plant pathogens. Bacteriophage (phage) therapy has emerged as a promising, targeted, and environmentally sustainable approach for managing bacterial plant diseases.

In 2023, for instance, a study found that a phage cocktail comprising strains J2, J3, and E significantly decreased the severity of the disease caused by *Xanthomonas oryzae pv. oryzae*, the causative agent of bacterial leaf blight in rice; the treatment not only suppressed pathogen populations but also promoted microbial diversity on the rice phyllosphere (Wu et al., 2023). In another study, phages targeting *Pseudomonas syringae pv. actinidiae*, the causative agent of bacterial canker in kiwifruit, effectively reduced disease symptoms and pathogen loads under controlled conditions. The results collectively highlight the potential of phage therapy as a viable biological alternative to traditional chemical controls in plant disease management.

C. Biological control- Induced Systemic Resistance

One important defence mechanism in plants is Induced Systemic Resistance (ISR), which is triggered by some beneficial microbes to protect against a variety of pathogens, including bacteria. ISR is usually mediated by signalling molecules like ethylene (ET), salicylic acid (SA), and jasmonic acid (JA), which prime plant immune responses. Recent research has shown that ISR is an effective way to manage bacterial diseases.

By promoting the formation of reactive oxygen species (ROS) and strengthening the SA and ET signaling pathways, *Bacillus velezensis* CLA178, for example, dramatically reduced crown gall disease in *Rosa multiflora*. This, in turn, resulted in the activation of genes linked to defense Another example shows how *Bacillus proteolyticus* OSUB18 caused ISR in *Arabidopsis thaliana*, which improved resistance to *Pseudomonas syringae* and *Botrytis cinerea* by increasing callose deposition and ROS generation (Park et al., 2023).

Biological Control- Use of Plant Extracts

Plant extracts have gained significant attention in recent years as eco-friendly alternatives for managing bacterial plant diseases due to their rich composition of bioactive compounds. For instance, *Punica granatum* (pomegranate) peel extracts have demonstrated potent antibacterial activity against *Ralstonia solanacearum, Pectobacterium carotovorum*, and *P. atrosepticum*. In vitro assays showed strong inhibition of bacterial growth, while in vivo experiments on potatoes reported up to 91% reduction in disease severity following soil drench applications (Abdelkhalek et al., 2024). Despite promising results, further standardization of extraction protocols, dosages, and delivery methods is essential to transition these botanicals into reliable biopesticides for integrated disease management strategies.

Technological Advancements in Bacterial Disease Management in Crops

a. CRISPR- Based Gene Editing

This technology enables precise genetic modifications to enhance disease resistance in crops as against bacterial blight (Xanthomonas oryzae) in rice. This enables the creation of resistant crop varieties by modifying their susceptible genes

b. Nanotechnology

Nanoparticles (Silver, copper, chitosan) exhibit antibacterial properties and act as delivery system for biopesticides. This gives a more targeted action, reduced chemical usage and increased effectiveness. It was developed by Ranade et al. in 2020 that suppressed *Erwinia amylovora* (fire blight in apples).

c. Smart Sensors and IoT (Internet of Things)

Sensors detect early bacterial infections in crops based on volatile compounds, moisture levels, and plant stress makers. This was currently used in *Pectobacterium carotovorum* (soft rot in potatoes).

d. Artificial intelligence

AI- powered tools analyze the plant disease images and predict the bacterial infections. One case study was done in *Xanthomonas campestris* by apps like AgroAI and Plantix.

e. RNA interference

This technology uses double stranded RNA to supress bacterial virulence gene. This technology was used against *Xylella fastidiosa* (Pierce's grape disease). This is a highly targeted, eco-friendly approach for bacterial plant disease management.

Conclusion

Eco-friendly management of bacterial crop diseases combines traditional practices like crop rotation and resistant varieties with modern tools such as biocontrol agents, plant extracts, and precision technologies. This integrated approach reduces pesticide use, supports soil and plant health, and enhances sustainability in the face of climate and resistance challenges.

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