



What do we know of the soil-borne plant pathogen *Ralstonia solanacearum* species complex in the Philippines?

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Abstract

Ralstonia solanacearum species complex was reported in the Philippines by Reinking (1918) on tomato, eggplant, pepper, white potato, and tobacco. Currently, the *Ralstonia solanacearum* species complex causes bacterial wilt of 19 plant species in the Philippines. In the potato, Phylotype I (*R. pseudosolanacearum*) is predominant in Mindanao (specifically in Bukidnon), while Phylotype II (*R. solanacearum*) is found mainly in the northern region (Benguet). Bacterial wilt is characterized by sudden wilting of the plant, beginning from the tip or youngest leaves, and discoloration of the stem when cut longitudinally. The bacterium typically forms fluidal, pinkish colonies when grown on a tetrazolium chloride agar medium. Detection is aided by molecular assays using the phylotyping scheme introduced by Fegan and Prior. Since its discovery in the 1920s, significant research has been conducted to manage this destructive soilborne pathogen. This paper discusses what is known about bacterial wilt and the RSSC in the Philippines, as well as the key research conducted over the last few decades.

Keywords – bacterial wilt – genospecies – phylotype – *Ralstonia pseudosolanacearum*– soil-borne disease

Introduction

Considered one of the most significant plant diseases worldwide, bacterial wilt is the most destructive soilborne bacterial disease affecting crops, particularly in the Solanaceous family. The disease is caused by the *Ralstonia solanacearum* (syn. *Pseudomonas solanacearum*) species complex (Buddenhagen & Kelman 1964, Hayward 1991, Prior & Fegan 2005). Most recently, *Ralstonia solanacearum* species complex was detected in ginger in southeastern Minnesota, USA, with plants exhibiting typical wilting symptoms and, in severe cases, plant death (Chiu et al. 2025).

Ralstonia solanacearum species complex was reported in the Philippines by Reinking (1918) on tomato, eggplant, pepper, white potato, and tobacco. In the Philippines, *Ralstonia solanacearum* species complex has been associated with bacterial diseases of 19 plant species (Raymundo 2001, Tangonan 1999). Other plant species reported as hosts in the Philippines are abaca, peanut, ginger, castor bean, cowpea, bush lima bean, winged bean, and marigold (Zehr 1969b, Quimio 1976, Waldez & Almodovar 1980). Bacterial disease in bitter melon was initially associated with *Erwinia*

tracheiphila but was later linked with *R. solanacearum* (Borines & Gerona 2019). In the absence of susceptible crops, alternative weed hosts and non-host plants become important for the survival of the *Ralstonia solanacearum* species complex (Grana & Sequeria 1983). Hence, weed management is important for inoculum management of the *Ralstonia solanacearum* species complex. The bacterium can inhabit the root, rhizosphere soil, and bulk soil of weed species, namely *Ageratum conyzoides*, *Amaranthus espinosus*, *Commelina benghalensis*, *Cyperus brevifolius*, and *Portulaca oleracea* (Desnuria 2003).

According to the Crops Statistics of the Philippines (2018), the production volumes are as follows: tomato, 218.8 metric tons (mt); potato, 537.3 mt; eggplant, 241.9 mt; and banana, 9,166.3 mt, valued at 3.58 billion, 8.54 billion, 5.13 billion, and 147.64 billion pesos, respectively. Bacterial wilt incidence in the Philippines, as reported in individual fields, reached up to 95% (Opina & Miller 2005). Welles & Roldan (1922) considered bacterial wilt a significant impediment to crop production in solanaceous crops in Southern Luzon, estimating annual losses of up to 20%. In 1949, Agati (1949) projected losses of up to 95%, 80%, 40%, and 50% for tomato, eggplant, pepper, and tobacco, respectively, in Central Luzon. Miller et al. (2005) reported that crop losses in the Philippines brought by bacterial wilt-infested fields consistently reach 30 to 80% (Miller et al. 2005) up to 100% (Elphinstone 2005) and averaging 15% in tomato, 10% in eggplant and pepper, and 2-5% in potato (Zehr 1969) depending on the hosts-tomato, potato, eggplant, pepper, and banana (Hayward 1991), cultivar, climate, soil type, and other predominant environmental conditions (Elphinstone 2005, Hayward 1991). Because strains within the *Ralstonia solanacearum* species complex are so diverse, developing universal control methods is difficult (Ivey et al. 2007). Within the Philippines, cultural management practices, such as the use of mulch and reduced soil cultivation, have not significantly reduced bacterial wilt incidence (Miller et al. 2005).

Since its discovery in the Philippines in the 1920s, research has advanced on its etiology, diagnosis, and epidemiology, primarily aimed at managing bacterial wilt. This paper synthesizes information about bacterial wilt and its pathogen, the *Ralstonia solanacearum* species complex, in the Philippines. We hope the information presented will help create an agenda for research on the *Ralstonia solanacearum* species complex in the Philippines and develop sustainable management approaches for bacterial wilt.

Distribution and Phylotypes

The bacterial wilt pathogen was common in regions where its hosts are grown (Dela Cueva et al. 2019). The *Ralstonia solanacearum* species complex is a group of phenotypically and genotypically diverse strains, characterized initially as races and biovars (Buddenhagen 1962, Hayward 1964). A study by Valdez (1986) on the distribution of the *Ralstonia solanacearum* species complex in the Philippines found that most isolates from tomato, white potato, pepper, and eggplant were biovar III, followed by biovar IV, biovar II, and biovar I. Biovars I and II were found in Luzon, based on the distribution of the different biovar isolates across Luzon, the Visayas, and Mindanao. In contrast, biovars III and IV were detected in all three island groups (Valdez 1986). Studies of Opina on the strain infecting eggplant identified Race 1 biovars II and IV (Opina et al. 2001, Opina & Miller 2005). Ivey et al. (2007) reported that eggplant bacterial wilt isolates from Luzon are classified as Phylotype I, Race 1, and Biovar 3 or 4. Biovar 4 strains were predominant in Pangasinan, Batangas, and Quezon, while Biovar 3 strains predominated in Nueva Ecija and Laguna (Opina 2007, Ivey et al. 2007).

Potato bacterial wilt is severe in the highlands of Benguet (north) and Bukidnon (south), making it a significant problem, as both regions are major potato-growing areas (Natural et al. 2005). In 2001, Natural (2001) reported that only a few Benguet isolates were specific to potatoes, and some isolates could also infect tomatoes and peppers. In Bukidnon, some isolates can cause bacterial wilt in ginger, bananas, pepper, and tomato. Therefore, most potato strains belong to Biovar 3, Race 1, which are reported to be more challenging to manage, as they survive longer in the soil and alternate weed hosts, unlike those in other countries, where strains are predominantly Biovar 2, Race 3. Lando (2002) conducted a study to isolate and characterize potato strains of

R. solanacearum from Benguet Province, and most of the isolates collected were of biovar 3 and biovar 2. Justo et al. (2012) studied the molecular characterization of isolates from potato-growing areas of the Northern and Southern Philippines, revealing that the predominant strain was the tropical strain, Phlotype I - Race 1 Biovar 3, and the cooler-climate strain, Phlotype II - Race 3 Biovar 2.

A study by Concepcion et al. (2014) on *R. solanacearum* populations from white potatoes classified them into two phylotypes: phylotype I encompassed lowland or tropical *R. solanacearum* strains, and phylotype II included highland and cold-tolerant potato brown rot strains. Waje et al. (2015) used multiplex PCR with phylotype-specific primers, which revealed that the Mindanao isolates belong to phylotype I, while the Benguet isolates belong to phylotype II. Finally, a study by Dela Cueva et al. (2018) agrees that Phylotype I (*R. pseudosolanacearum*) is predominant in the Southern region (Bukidnon). Phylotype II (*R. solanacearum*) was found mainly in the Northern region (Benguet). Moko disease associated with Phylotype II strains was reported in some parts of Mindanao (Raymundo, 2001).

A recent study by Villa et al. (2021) characterized 89 *R. solanacearum* strains from the islands of Luzon and Mindanao. They observed three Phylotypes: more than half of the strains belonged to Phylotype I, 22 to Phylotype II, and three to Phylotype IV. Eleven strains were pathogenic to tomato, potato, eggplant, sweet pepper, and tobacco test plants (Villa et al. 2021). Their study further indicates the variability of *R. solanacearum* across the country.

Symptomatology of *Ralstonia solanacearum*

The bacterial pathogen *Ralstonia solanacearum* causes bacterial wilt, characterized by sudden foliage wilting. The symptoms manifest as discoloration of the vascular system, ranging from pale yellow to dark (Gota 1992). The pathogen enters roots through wounds caused by transplanting, cultivation, nematodes, insects, and natural wounds (Kelman & Sequeira 1965). Disease incidence may begin with a few scattered plants in the field, progressing to rapid plant death (Kelman & Sequeira 1965). The infected stem of *R. solanacearum*, if cut cross-sectionally and placed in water, exudes a whitish ooze (Champoiseau et al. 2009b). The bacterium typically produces raised, fluidal, pinkish colonies in the TZCA medium (Dela Cueva et al. 2019).

Epidemiology

Ralstonia solanacearum can be spread through irrigation water, via water movement in the soil and on the soil surface, infected plant material, contaminated soil, field supplies, and equipment (Hayward 1991, Louws et al. 2010). The bacterium attacks plants via wound sites and natural openings in roots, then invades cortical tissue, multiplies rapidly within the xylem, and effectively clogs the water-conduction system, causing the characteristic wilting symptom (Meng 2013, Nakaho et al. 2004). High soil moisture, such as during rainy seasons, is associated with increased disease incidence. The bacterium enters the plants through their roots, either naturally or through root injuries. The bacteria colonize the xylem and adhere to its walls. Wilting occurs when vessels are blocked by the bacterial extracellular polysaccharide (EPS). The bacterial pathogen can also be transmitted mechanically during pruning operations. Transmission through water or soil, and the movement of infected vegetative plant parts, are considered more significant. In contrast, some strains of *R. solanacearum* and *R. syzygii* can be transmitted by insects. These strains are known to cause Moko disease and blood disease in the banana plant.

Identification and Detection

The study by Opina (1997) was the first report of a sensitive polymerase chain reaction (PCR)-based technique specific for detecting and diagnosing Philippine banana strains using M114F and M114R primer pairs. Raymundo and Ilagan (1999) identified *Ralstonia solanacearum* species complex strains in banana in the Philippines using repetitive-element cloning. The Audy (1996) and MoBio Kit methods for isolating DNA were used by Lavina (2000). They consistently produced the M114 amplicons. Another study using primers 759/760 and M114 in a PCR assay

yielded the expected 281 bp and 2.28 Kb products, respectively, confirming the primers' specificity for *R. solanacearum* and banana strains (Lavina 2000). Ilagan (2004) revealed that using PrepMan Kit in conjunction with plating of bacterial ooze on KA (Kelman's Agar) for 15h prior to DNA isolation and passing the DNA extracts through the PVPP (polyvinylpyrrolidone) column can detect 17.3 cfu of *Rs* by PCR.

Opina and Miller (2005) and Opina (2007) tested the resistance (*Rs*) of eggplant by culturing and immunoassay (*Rs* BID ELISA and Ps Immuno Strip, Agolia Inc., Elkhart, IN, USA). They stated that it provided consistent results for detecting *R. solanacearum* in eggplant tissue samples. Another study by Ilagan et al. (2010) reported the development of a PCR-based direct detection method for *R. solanacearum* from fruit stalks using specific *Rs* banana strain 24F/24R primers. A recent study by Dela Cueva et al. (2019) recommends using the Multiplex PCR technique with the 759R/760F primer pair (Opina et al. 1997) and the Nmult Primer mix (Prior and Fegan 2005). In a recent report by Chiu et al. (2025), *R. solanacearum* species complex was detected from infected ginger plants using Agdia ImmunoStrips. They then proceeded with the Nmult Primer mix (Prior & Fegan 2005). They conducted a comprehensive genome analysis using a combination of hybrid Illumina and Oxford Nanopore sequencing.

Methods for resistance screening

Developing bacterial wilt-resistant cultivars requires screening a large number of accessions, germplasm, and hybrids. Screening in bacterial-sick soil under field conditions with contaminated inoculum obtained from wilted plants provides inadequate and unreliable results. Thus, various resistance screening methods were conducted through in vitro, greenhouse, and field methods. Winsted and Kelman's (1952) method involved uprooting the plants and dipping the roots for 30 minutes in a bacterial suspension containing 10^{10} CFU/ml. Afterwards, the inoculated plants were transplanted into individual pots and placed in a growth chamber at $28 \pm 1^\circ\text{C}$, $95 \pm 5\%$ relative humidity, and 14 hours of daylight illumination. Xian-Guan et al. (2016) employed the root snip-and-dip method and the leaf snip-and-dip method. They demonstrated efficacy in screening for resistance in greenhouse and growth-chamber settings. On the other hand, the inoculation method used by Caldwell et al. (2017) requires 5-5 minutes of soaking the root-shoot junction of the plant before transferring it back to its original container. Lin et al. (2008) reported using a high-throughput screening procedure and an *Arabidopsis*-based bioassay system.

The soil drenching method of Artal et al. (2012) involved using 5 ml of inoculum suspension and drenching each seedling with the soil using a micropipette. Before inoculation, the roots were slightly severed with a knife 1 cm away from the base of the stem. Drenching the bacterial suspension near the base of the plant has been used by Dela Cueva et al. (2018), with and without wounding the roots. Fonseca et al. (2015) described their injection method as an efficient inoculation method where plants are wounded by making a 3mm deep and 10 mm long downward slanting cut using a scalpel at 5 cm above the soil line and then injected 0.5 mL bacterial cell suspension at the base of the stem and covered with cotton and Parafilm. Aslam et al. (2017a) screened accessions by planting 3-week-old seedlings and inoculating them after a week with a bacterial culture containing 10^7 cfu/ml of *R. solanacearum* via soil drenching. Habe's (2018) method used inoculation of 6-8 leaf-stage plants with *R. solanacearum* bacterial concentration of 10^2 CFU mL⁻¹ and incubated at 28°C .

Nakazawa-Nasa et al. (1999) used a method that employed bioluminescence from *lux*-marked *R. solanacearum*, where 3-week-old tomato seedlings were dipped in a 10^8 CFU/ml *R. solanacearum* solution for 30 minutes. Then, it was washed in flowing water for 1 min. It was then grown in a water culture pot with a fivefold-diluted Hoagland's solution at 25°C in a growth chamber under 20,000 *lux* for 12 hours daily. Cruz et al. (2013) generated *R. solanacearum* that constitutively produces light from a synthetic *luxCDABE* operon stably inserted into its chromosome. Colonization of this reporter strain on different potato accessions was monitored by light microscopy. Singh's (2020) method employed rapid resistance screening, utilizing a 1.5-2 mL centrifuge tube. This approach involved root inoculation under gnotobiotic or controlled conditions

for two weeks during infection. Wang et al. (2019) used the hydroponic infection method and grew potato plants in liquid MS medium for two weeks, injured the roots, and transferred them to the same medium containing 1×10^8 CFU/mL of *R. solanacearum* strain. Hussain et al. (2005) screened one-month-old eggplant accessions in a sick bed pre-inoculated with 2.1×10^8 CFU/ml of *R. solanacearum*.

Disease control methods

There is no single effective management method for bacterial wilt caused by *Ralstonia solanacearum* species complex. Various control strategies were studied and developed to control the inoculum and mitigate disease expression, including cultural, biological, and chemical control. Breeding for resistance is still considered the most effective control method for bacterial wilt caused by *R. solanacearum* (Balatero et al. 2000, Balatero et al. 2001, Raymundo 2001). A study by Farid (1997) on tomatoes found that Florida MH-1 x 508 and its reciprocal cross-produced hybrids resist *R. solanacearum*. These genes can be further combined to develop hybrids with enhanced disease resistance, providing a better genetic source for breeding resistance. The work of Balatero et al. (2000) revealed that all five tomato sources resistant to *R. solanacearum* (Hawaii 7996, L285, R3034, TML 46-N, and Lv1051) showed high levels of resistance across *R. solanacearum* strains.

In contrast, the studies of Orlina et al. (2002) and Villareal et al. (2008) revealed that T523-731, a hypervirulent isolate (Zarate 2006), was able to overcome the resistance of the cultivars H7996, C105, and 508 that were earlier found to be highly resistant to bacterial wilt, which showed that host resistance genes affect the variability of *R. solanacearum* (Orlina et al. 2002). This only proves that the *Rs* tomato strain is a highly diverse pathogen, posing challenges, especially in the production of resistant varieties, leading to the breakdown of resistant lines (Orlina et al. 2002, Raymundo 2007). Thus, pathogen populations are genetically variable and respond to selection pressures (Raymundo 2001). The significant host-strain interaction suggests that virulence genes may interact with various resistance genes, highlighting the need to develop strain-specific resistance to *Rs* (Balatero et al. 1999).

In bananas, Natural (2010) recommends disinfecting tools used for de-suckering, de-budding, or de-leafing, using disease-free planting materials, and removing weeds and volunteer plants to minimize the incidence of Moko disease caused by *R. solanacearum*. If already present on the farm, early detection, swift destruction, and burning of infected plants and mats should be done to prevent a large population of bacteria from spreading into the soil. (Umadhay 1999, Natural 2010).

Grafting technology effectively reduces soil-borne diseases, such as *R. solanacearum*, in sweet pepper (Palada 2008) and eggplant (Opina et al. 2001, Opina 2003, Opina et al. 2007). This technology gave lower bacterial wilt incidence and was comparable with the highly resistant check, Eg 203 (Opina et al. 2001, Opina 2003), and bacterial wilt susceptible eggplant variety grafted with resistant rootstocks, Eg 203 and 89-002 (Opina et al. 2007), which led to increased production and yield. According to Borines and Gerona (2019), grafting sweet peppers to a resistant chili pepper (BPI-HP-001) variety and grafting tomato varieties to a resistant eggplant rootstock (Eg203) resulted in significantly lower BW incidence than non-grafted plants.

Justo et al. (2012) planted corn after potatoes to reduce the potato's bacterial wilt (BW) population. Also, Balendres et al. (2020) reported that roselle plants do not exhibit wilting in glasshouses and field trials and can be used as an alternative to vegetable crops in BW-infested fields. Using this cropping system approach will reduce the soil bacterial wilt population and lessen the incidence of slash-and-burn farming, as farmers do not need to open a forested area to avoid BW (Tatoy et al. 2000).

Soil amendments can be used to control diseases caused by soil-borne plant pathogens (Huang & Huang, 1993). A study by Michel & Mew (1998) reported that the suppressive effects of pH and nitrite on *R. solanacearum* growth were confirmed in in vitro experiments. Ammonium reduced the growth of *R. solanacearum* at pH nine, and nitrite was suppressive only at pH 5.

Borines & Gerona (2019) reported that organic soil amendments (e.g., cabbage residues and forest leaf litter) can reduce bacterial wilt incidence.

Biological control is another agricultural practice (Azcon-Aguilar & Barea 1996) that preserves environmental quality by reducing the dependency on chemical inputs and maintaining sustainable management practices (Barea & Jeffries 1995). Aspiras and dela Cruz (1986) reported that using *Bacillus polymyza* FU6 and *Pseudomonas fluorescens* applied to the roots of tomato arrested the bacterial wilt incidence. Toralba-Ubaub & Ugay (2012) reported that *Lactobacillus bulgaricus* and *L. plantarum* could significantly reduce the bacterial wilt incidence in 'Cavendish' banana seedlings 31 days after incubation at field conditions. Few studies have reported that *Cordyceps* contains antimicrobial components and is more potent against *R. solanacearum* (Yago et al. 2008). Several studies using BCAs were also reported by Borines et al. (2015). Chitosan and chitosan plus acetylsalicylic acid (Aspirin), when applied as a foliar spray, effectively reduced BW incidence in tomatoes grown under a protective structure. *Bacillus subtilis* strain QST713 (Serenade) and Liquid PhosPro significantly lowered BW incidence on pepper. Additionally, wood vinegar (rice hull, madre de cacao, and lomboy) used as a drench was also found to be effective in reducing BW incidence. Various strains of *R. solanacearum*, such as the tomato hypervirulent strain T523-731 (Orlina et al. 2002, Zarate 2006, Villareal et al. 2008), implied the presence of antibiotic resistance that responds differently to biological control agents, and the variability may be partly attributed to the presence of antibiotic genes (Faylon 2005).

Biofumigation is the process by which soil-borne pests and pathogens are suppressed by naturally occurring biocidal compounds (Isothiocyanates-ITCs) released in the soil. Abragan et al. (2008) reported that applying different crucifers reduced the Rs population from the initial count. Brassica wastes used as biofumigants can potentially suppress the *R. solanacearum* population, ranging from 6-15-fold three weeks after incorporation. Broccoli roots, shoots, and radish leaves reduced the *R. solanacearum* population by 72-fold compared to untreated soil (Bayot et al. 2004). Sunflower, as a biofumigant, also reduces bacterial populations in soil compared to non-fumigated soil (Balendres et al. 2012). Decomposed sunflower provides high levels of organic matter, which support the rapid growth of organisms that mask harmful microbes, such as bacterial wilt (Justo et al. 2012). This leads to increased yield due to lower bacterial wilt incidence in both research and field trials (Justo et al. 2013). There was also a significant decrease in the incidence and severity of susceptible tomato cultivars, such as Yellow Plum plants, in fumigated soils (Balendres et al. 2012). Sunflower amendments showed greater suppression than the brassicas, which release ITCs that suppress bacterial wilt disease (Justo et al. 2012). Nevertheless, the effects of these biofumigants on non-target organisms need to be studied, as they may also affect the growth of beneficial soil microbes.

Chemical control is the last resort when all other methods for disease control have been exhausted and found ineffective. However, controlling bacterial wilt with chemicals has been difficult due to the pathogen's biology and its ability to invade the xylem. Exacerbating this is the bacteria's ability to survive at depth in the soil. Besides, it is not economically feasible in the field. In other countries, some scientists have reported that no bactericide controls bacterial wilt (Hartman et al. 1993). Others indicated that controlling bacteria with chemicals is challenging (Grimault et al. 1992). No studies have been reported in the Philippines on bactericides for managing bacterial wilt.

A meta-analysis conducted by Bagri Bouraima et al. (2024) found that agroecological management strategies, specifically the combination of several methods, the use of resistant varieties, the application of biological control agents, and grafting, reduce bacterial wilt incidence and increase the yield of tomatoes and eggplants compared to untreated plots. The results indicate that successful management of bacterial wilt could be achieved by integrating various control measures, with resistance varieties as a key component.

Conclusion

Bacterial wilt, caused by *Ralstonia solanacearum* species complex, remains the most destructive soilborne bacterial disease of vegetables and high-value crops in the Philippines.

Progress in bacterial wilt research over the last two decades has increased our understanding of this pathogen and informed potential management strategies. Molecular-based assays enhanced our understanding of the strains infecting various crops. We now know the distribution of these strains in the three major islands. Various strategies have been tested to address the country's problems associated with bacterial wilt. Consequently, cultural practices, including the use of pathogen-free seeds, sanitation, removal of weeds and alternate hosts, immediate removal of infected plant parts, and continuous disease monitoring, remain essential in mitigating the impact of bacterial wilt.

The search for effective management strategies to control bacterial wilt can be further explored and studied, including screening for safe chemical alternatives and using biological control agents (BCAs). Revalidating and verifying the previously conducted control methods in the Philippines, as well as evaluating those of other countries, can also be carried out to confirm their efficiency and effectiveness against the Philippine strains of the *Ralstonia solanacearum* species complex. Cultivar resistance remains the most preferred and practical approach for controlling bacterial wilt. Thus, exploring novel sources of resistance to bacterial wilt in germplasm collections would be worthwhile. Breeding for resistance using a resistant line as a parent, such as Hawaii 7996, should continue to develop lines adapted to the Philippines and possessing qualities with commercial merit.

In addition, a complete genome sequencing of the Philippine strains of *Ralstonia solanacearum* species complex is warranted to improve our understanding of the pathogenicity and virulence of the three species, gain further insights into genetic diversity and evolution, enhance resistance breeding and host-interaction studies, support biopesticide development, and facilitate data sharing. The approach used by Magar et al. (2025) and Chiu et al. (2025) could be a useful way to address these research gaps.

Conflict of Interest

The authors declare no conflict of interest.

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