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Bacterial wilt of solanaceous crops

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Abstract
Solanaceous crops play an important role in human diet and the economy of nations. They are also called as "Nightshades". This family is distributed throughout the world in all continents except Antarctica. Solanaceae family consists of 98 genera and 2700 species, with greater habitat, morphological and ecological diversity. The family Solanaceae includes number of commonly cultivated species. Most important genus of the family Solanaceae is "Solanum", which includes Potato, Tomato, Brinjal, Chilli and Capsicum, that are used as food. They can grow in several conditions ranging from tropics to sub-tropics. In this diverse climatic conditions they are infested by several diseases, one among them is bacterial wilt caused by bacterium *Ralstonia solanacearum* (most damaging plant pathogen). *Ralstonia solanacearum* has been reported to conquer 450+ plant species belonging to 54 different botanical families, the most susceptible hosts being solanaceous crops. Potato, tomato, brinjal and chilli are mostly affected by this bacterial wilt. Poor seed systems were a major contributor to the extensive spread, high incidence and high prevalence of this devastating disease. This review article focuses on etiology, epidemiology, diagnosis and management practices (physical, cultural, biological & chemical control measures) that are used in management of this disease.

Keywords: Bacterial wilt, solanaceous crops, etiology, epidemiology, *Ralstonia solanacearum*, integrated disease management

Introduction
Bacterial wilt is one of the main diseases of nightshades so called solanaceous crops such as potato, tomato and chilli [1, 2]. This disease occurs in wet tropics, sub-tropics and also in some temperate regions in different parts of the world [3]. Bacterial wilt in solanaceous crops is caused by the bacterium *Ralstonia solanacearum* which was previously called as *Pseudomonas solanacearum* [4]. Bacterial wilt is known as "green wilt" disease as the leaves of the infested plant remain green when the plant begins to show wilting symptoms [5]. *Ralstonia solanacearum*, the causative agent of bacterial wilt, is one of the most devastating phytopathogenic bacteria [6]. *Ralstonia solanacearum* has been reported to conquer 450+ plant species belonging to 54 different botanical families, the most susceptible hosts being solanaceous crops [7, 8]. Bacterial wilt ends up with substantial losses in crops like tomato, eggplant, potato, tobacco and banana [9]. *Ralstonia solanacearum* is a soil borne bacterium which penetrates the roots of the plant and invades the xylem vessels, then spreads rapidly to the aerial parts of the plant through the vascular system where its faster multiplication leads to wilting and ultimately to the death of the plant [10]. In addition to *Ralstonia solanacearum* lethal ability, its ability to remain in the soil for several years and form latent infection within native weeds contributes to the difficulty of eradicating this destructive bacteria [11, 12]. The spread of this bacterium is considered a threat to crops and this pathogen is considered a quarantine bacterium [13].
Ralstonia solanacearum is an extraordinarily diverse and complex species. The pathogen is divided into five races (due to its ability to infect different plant species) and six biovars (due to its ability to oxidize hexoses, alcohols and sorbitol as well as disaccharides) [14, 15]. These bacterial strains present a wide genetic diversity and are divided into four phylotypes that correspond roughly to the geographical origin of the strain: Asia (Phylotype I), America (Phylotype II), Africa (Phylotype III) and Indonesia (Phylotype IV). Phylotype II has two subgroups namely IIA and IIB [16]. & only strains belonging to phylotype IIB are responsible for bacterial wilting of potatoes in cold and temperate regions [17].

Phylotypes are not related to host preference because strains of all phylotypes are capable of causing disease in potatoes, tomatoes, peppers and eggplants [7 & 18]. *Ralstonia solanacearum* has been listed as a selection plant pathogen under the Agricultural Bioterrorism Act 2002.

Table 1: Difference between pathological wilt and physiological wilt

Pathological wilt	Physiological wilt
Loss of turgidity and dropping of plant parts due to infection by microbes resulting in blockage of water transport or toxicity is known as pathological wilt.	Loss of turgidity and dropping of plant parts due to insufficient water in plant body is known as physiological wilt.
It is a type of soil borne pathogenic disease.	It is a physiological imbalance.
Pathogens like fungi, bacteria, etc. can be isolated from diseased samples.	No pathogens are found in disease samples.
Original healthy stages do not come again generally.	Original healthy stages may come again if proper measures taken.
In case of bacterial wilt, ooze test can be performed.	No oozing can be seen.

Table 2: Difference between bacterial wilt and fungal wilt

Bacterial wilt	Fungal wilt
Disease symptoms progress from younger to older leaves.	Disease symptoms progress from older to younger leaves.
Young emerging buds can be distorted, necrotic and eventually die.	No symptom in young growing leaves and suckers (in case of banana).
Bacterial ooze can be observed on exposed cut plant parts like roots, stem, pseudo stem (banana), rachis, flowers, fruits, rhizome etc.	No exudation in exposed plant parts
Internally fruit rot and necrosis developed.	Generally no development of symptoms in fruits.
For Example:- *Clavibacter/Cornybacterium* - bacterial wilt in potatoes and tomatoes. *Curobacterium* - bacterial wilt of beans. *Erwinia* - bacterial wilt of cucurbits, fire blight of pome fruits (apple and pear) and soft rot of potatoes. *Pontoea stewartii* - stewart's wilt of corn. *Ralstonia solanacearum* – other bacterial wilt of solanacea. *Xanthomonas* - black rot/black vein of crucifers.	For Example:- *Ceratocystis* – wilt of oak tree. *Ophiostoma* - wilt of elm tree (Dutchelm disease). *Fusarium* - causes vascular wilt of vegetables, flowers, pulses, cereals, herbaceous, perennial, ornamental and cash crops etc. *Verticillium* - causes vascular wilt in vegetables, field crops

Note: *Ralstonia* is named after the American bacteriologist Ericka Ralston. *Ralstonia* was recently classified as *Pseudomonas* with similarity in most aspects, except that it does not produce fluorescent pigment. *Ralstonia* colonizes the xylem, causing bacterial wilt in a very wide range of potential host plants mainly belongs to the Family Solanaceae (*Ralstonia solanacearum*).

Economical importance of bacterial wilt

The extensive economic losses brought about by the pathogen can be attributed to its wide host range and its expansive geological dispersal in some warm temperate regions of the world [9]. *Ralstonia solanacearum* causes significant yield losses subject to the pathogen strain, atmosphere, soil type, cropping practices and cultivar [9].

The world's human population is extended to arrive at 10.5 billion by 2050. This will make an interpretation of more mouths to take care of, with the most appeal in the helpless networks of the world. It has been determined that food supplies would need increment by 60% to satisfy the normal food need [19, 20]. Consequently, expanding agricultural productivity while limiting food losses is basic in guaranteeing worldwide food security. About 1.3 billion tons of food around the world squandered or lost every year. Decrease in these misfortunes would expand the measure of food accessible for human utilization, improving worldwide food security. Microbial (microorganisms) waste is the primary driver of postharvest losses of numerous yields including pepper, representing a 14% decline in crop production around the world. Hence, a decrease of plant ailments will add to increased yield. Among the plant diseases, soil-borne infections are assessed to represent 10–20% of yield misfortunes or losses yearly [21, 22].

Ralstonia solanacearum is positioned as the second ruinous among the 10 most fatal bacterial species influencing monetarily significant yields [6]. The pathogen has been accounted for to cause serious yield losses in numerous solanaceous crops, with 88% loss of tomatoes detailed in Uganda, and 70% loss of potato in India and different nations in changing degrees [23]. Bacterial wilt was accounted for to influence 50–100% of potatoes crop yield loss in Kenya [24]. In Ethiopia, bacterial wilt frequency is practically 100% on pepper, 63% on potato and 55% on tomato [25]. On account of potato, since most wilted potato plants don't produce attractive or marketable tuber, crop yield losses from the bacterial wilt disease could be extremely high [8].

In spite of the fact that there is no complete data on economic impact of the pathogen on solanaceous yields around the world, considerable losses of roughly 75% in potato and obliteration of tomato harvest because of its susceptibility to bacterial wilt have been accounted for [9, 26]. Damages are increasing in light of the fact that agriculture is presently reaching out to nations where susceptible crops have not been cultivated previously. The presence of *Ralstonia solanacearum* in fields debilitates the planting of numerous vegetables on home and family gardens, prompting a noteworthy decrease in food sources [27]. In numerous parts of the world, particularly Africa, small farmers don't cultivate GM (Genetically Modified) crops; thus, the crops they cultivate are more vulnerable to bacterial wilt. The pathogen has been known to have high endurance and harming danger to other vegetation around the world. Cost-effective postharvest treatment comprises of controlled atmospheric storages, pesticides and waxes which were utilized to control the infection [28 & 29]. Notwithstanding, the greater part of these post-harvest treatments are moderately costly and additionally represent a few dangers for people as well as nature [30]. Subsequently, there is a critical requirement for appropriate and more compelling management against this pathogen around the world.

Dispersal of Plant pathogen

Dispersal of *Ralstonia solanacearum* happens through various methods; Nevertheless environmental factors are the fundamental drivers of development, spread and dissemination of bacterial wilt. Climate conditions, for example, moistness and temperature substantially affect disease advancement and have been seriously studied as indicators of disease development brought about by fungi and bacteria [31]. Ralstonia solanacearum can spread over significant distances through vegetative propagating materials, making due for around 2–3 years of survival within vegetative organs without a doubt being an essential source of inoculum [32]. Weeds and Infested wet soil, contaminated water and farm equipment, crop processing industry waste as well as latently infected crops for example, potato tubers and tomato seeds all have a high risk to house Ralstonia solanacearum [33]. Crop residues in fields that were tainted by Ralstonia solanacearum serve as source of inoculum in the encompassing region [34]. Besides, Insects have been even considered as vectors that normally spread R. solanacearum race 3 [35, 36]. Thus, broad appropriation and long saprophytic endurance in nature makes the control of the bacterial wilt brought about by Ralstonia solanacearum more troublesome.

Symptoms and Signs

Plants infected with *Ralstonia solanacearum* can show symptoms a few days after infection and are characterized by sudden wilting and yellowing of the leaves, followed by undersized growth and eventually death of the plants. In early stages of the disease the first symptoms are usually seen on the foliage of plants. These symptoms occur through in the hottest part of the day which shows wilting of the youngest leaves [9]. In this stage only a few leaflets may wilt, and at night when the temperature cools down, the plants will again recover very soon. Under the unfavorable conditions the entire plant may wilt and dry quickly, although dried leaves remain green, leading to general wilting and yellowing of foliage and plant dies eventually [37].

Another common symptom of bacterial wilt in the field is stunting of plants. These symptoms may appear at any stage of plant growth even though in the field it is common for healthy appearing plants that wilting occurs suddenly when fruits are expanded rapidly [38]. In young stems of solanaceous crops, vascular bundles are affected showing visible appearance like long, narrow, dark brown streaks. Collapse of the stem may be seen in young succulent plants which belong to the varieties that are of highly susceptible [39].

The favorable temperature for symptom expression are high temperatures (85-95F) which progresses immediately after infection [40]. However, under favorable conditions. The plants which does not show symptoms may remain hidden infected for longer period of time. After infection the pathogen may survive in infected plant and can be spread from the infected plant [41]. The most common sign of bacterial wilt are observed on the surface of freshly-cut sections from severely infected stems showing sticky, milky-white exudates. This shows the presence of dense masses of bacterial cells in infected vascular bundles, mainly in the xylem vessels [32]. The disease can also be observed when the cut stem sections are placed in clear water. A viscous white spontaneous slime streaming out from the cut end of the stem which is a also another common sign of this disease [42]. The bacterial ooze which exudes from the cut ends of colonized vascular bundles are represented by this streaming. This type of test is more convenient for the experimenter and is very helpful to detect this type of disease [3]. The wilted leaves keep up their green shading and they don't fall as the ailment spreads. Under hot, sticky circumstances, complete shrinking happens and the plant die [43]. A plant infected with Ralstonia solanacearum may go through latency, which may lead the plant into expressing all the above mentioned symptoms or none of them, even under conditions that are favorable for Ralstonia solanacearum [35]. Further the symptoms of bacterial wilt are described by discoloration of the vascular system framework from streaky light yellow to dark brown [44].

Causal organism

Ralstonia solanacearum (formerly called *Pseudomonas solanacearum*), is a soil borne bacterial pathogen that is a major limiting factor in the crop production system. it is the causal agent of brown rot of potato, bacterial wilt or southern wilt of tomato, tobacco, brinjal and some ornamentals, and Moko disease of banana.

Ralstonia solanacearum is a gram-negative, rod-shaped, strictly aerobic bacterium which is 0.5-0.7 x 1.5-2.0 micro meter in size. This pathogen is very sensitive in desiccation and is inhibited in culture by low concentrations (2%) of sodium chloride (NaCl) [16]. Majority of the strains have optimal growth temperature $82^0 – 90^0$ F; however some of the strains have low optimal temperature 80.5^0F. The commonly used growth media for culture of the bacterium are liquid and solid (agar) [37]. When in solid agar medium, the individual bacterial colonies are commonly observable after 36 to 48 hours of growth at 82.4^0F, and the two main types of colonies which differs in morphology can be distinguished: colonies of the normal or virulent type are white or cream-colored, irregularly-round, fluidal, and opaque; and colonies of the mutant or nonvirulent type are uniformly round, smaller, and butyrous (dry) [38]. This shift from virulent to non-virulent bacterial cells occurs when in storage or under oxygen stress in liquid media. In order to differentiate between the two colony types, Tetrazolium chloride (TZC) medium was developed in such a way that virulent colonies appear white with pink centers and nonvirulent colonies appear dark red [41]. For detection of *R. solanacearum* in water and soil samples and in plant extracts, a semi-selective medium known as modified SMSA was developed. A typical bacterial colonies appear fluidal, irregular in shape, and white with pink centers in this medium just after 2 to 5 days incubation at 82.4ºF [40]. *R. solanacearum* is prevalent in the tropics and subtropics around the world and many strains of the pathogen have been identified and characterized so far, which reveals a significant variability within the species.

Therefore *R. solanacearum is* considered as a "species complex". *R. solanacearum* strains were initially subdivided into races and biovars based on variability in host range and ability for utilizing various substrates of carbohydrates [45]. Five races and five biovars have been identified within the species so far, but this old classification system is undesirable since it is not predictive and some groups (e.g. race 1) contain very large variation.

A new classification scheme has been described recently for strains of *R. solanacearum*, which is based on variation of DNA sequences [4]. Four phylotypes has been identified within the species which broadly reflects the ancestral relationships and geographical origin of the strains. These type of phylotypes can further be subdivided into sequevars. The bacterial wilt of tomato are cause by both race 1 and race 3 with similar disease symptoms. Race 1 corresponds to biovars 1, 3, and 4. It has a wide host range and contains strains which infects ornamentals and many other major economic crops worldwide, namely banana, eggplant,

geranium, peanut, pepper, potato, tobacco and tomato [42]. This particular race is finite only to tropical, subtropical and warm-temperate locations and most of the time it cannot survive under cold climatic conditions. Race 3, which rigidly consistent to biovar 2 (or 2-A), has a finite host range. At first it is described as pathogens on particular plants such as potato and tomato, it was shown that it infects and generates symptoms on eggplant, geranium, and pepper [46]. Other solanaceous and non-solanaceous weeds, such as the bittersweet or woody nightshade (*Solanum dulcamara*), are considered to be an alternate hosts. Majority of the alternate hosts causes infections to the plant which will not show much disease symptoms and infected latently, but they can be epidemiologically important as inoculum sources and refuges [37]. Bacterial wilt of tomato is caused in both the races, 1 and 3 with appearance of similar symptom. Race 1 shows very close similarity to biovars 1, 3 and 4. However the race has a wide range of host and has possess potential strains for infecting many other major economic and ornamental crops throughout the world which include banana, pepper, peanut, eggplant, potato, tomato, geranium and tobacco. The race particularly is favored to tropical, subtropical and warm-temperate conditions and usually doesn't survive under cool temperature weather/condition [42]. Unlike Race 1, Race 3 corresponds to only biovar 2 and also has a limited host range. This race is found to show pathogenic on potato and tomato initially, also it was shown to have infect and induce symptoms on other crops like eggplant, pepper and geranium [46]. It also survive on other solanaceous and non-solanaceous weeds, like bittersweet or woody nightshade as alternate host. Of all alternate host, most of them remain latently infected and may sometimes not show any typical symptoms of the diseases, but still serve as epidemiologically important inoculum sources and an important refuges. Sometimes to have referred as a cold tolerant race, *R. solanacearum* (race 3) corresponding to biovar 2 was originated from the Andes and was spread on potato crops worldwide.

Now the disease occur in the highlands of tropics, subtropics and temperate areas worldwide, except in North America. The disease is found to have reported in causing several outbreaks of Brown Rot of Potato. The Race cause serious losses but occasionally on tomato plants at higher tropical altitudes [40].

Disease cycle and Epidemiology

Ralstonia solanacearum being a soil-borne as well as waterborne pathogen, it can survive and spread for long period of time in infected/contaminated soil or water. In tomato, the bacterium infects through roots where certain other soil borne pathogen, such as root knot nematodes help with its entry by causing injury to the roots of the plants [32]. Also pathogen can enter through the infection in plants stem caused by certain cultural practices and damaged caused by insects. The pathogen is considered to not have spread through air as dissemination and contamination to healthy plant is not known to have spread through foliage till date [3].

The growth and development of disease is most favored with high temperature of 85-95^{0}F. Also several other factors like soil type, soil structure, soil moisture content, pH and salt content etc. affect the survival and development of diseases [38]. The bacterium can also sometimes survive on outside of the plant which is term as epiphyte or exterior phase. This phase act as a minor importance for the epidemiology of the pathogen, the bacterium does not stay long outside when it is exposed to hot condition or with RH lower than 95%. The tomato plant which is infected with *R. solanacearum* may sometimes not show any kind of symptoms related to the disease even at favorable condition [3]. This termed to be latently infected and act as important source for further spread of the bacterium.

The southern states in the US act as major source of tomato transplant for the north eastern states and southern part of Canada which is the reason why this disease is found rarely in the North via infected seedlings. However the bacterium does not overwinter in the North. Transplants comes from either the field grown or in greenhouses. And the cultural practices carried out during the field or greenhouse production cause plant infection and help in spread of the bacterium from the infected transplants or infected sites to that of healthy sites [37].

The survival of *R. solanacearum* range from days to years in soils, disease contaminated irrigation water and infected weeds. These sources act as inoculum and got disseminated from the infested to healthy fields by transfer of soils through machinery and when irrigated water gets surface runoff [32]. The bacterium also can propagate at infected water sources like ponds or rivers and further spread to non-infested sites after rainfall or using the infested water bodies as irrigation water. Infected semi aquatic weeds can also be considered a major factor for the spread of the pathogen where the bacteria got released from roots into the irrigation waters [42].

The population density of the bacteria falls rapidly when they meet low temperature but they can survive in their physiological latent state. For instants, *R. solanacearum* race 3 biovar 2 can survive during winter in certain semi aquatic weeds, plant debris, rhizosphere of alternate and non-host plants acting as reserves for the bacterial inoculum.

Diagnosis and Identification

The first step for early diagnosis of the bacterial wilt of tomato is the identification with disease symptoms. Correct identification of the disease either from symptomatic or asymptomatic plants, water or soil samples require many microbiological and molecular techniques [39]. Certain tests which differs in terms of sensitivity and specificity are needed for the diagnosis and analysis for unambiguous identification of bacteria on the basis of species and biovar in field and laboratory. Early detection and identification of bacteria in infected plants, contaminated soil and water samples by *R. solanacearum* can be made easier with screening test [3].

Screening test include plating, semi selective medium, stem streaming, immunodiagnostic assays using *R. solanacearum* specific, antibiotics nucleic acid based identification using specific primers and pathogenicity assessment using specific tomato seedlings(susceptible host). However they are not useful for identifying the race or biovar of that organism [4]. Specific test like immune strips also known as Agdia can be used for rapid field detection of the disease, and they are available commercially. For identification of different biovars of *R. solanacearum,* a biochemical growth test is used. The test is performed on the differential ability of strains of the pathogen where acid are differentially produced from several carbohydrate sources such as disaccharides and sugar alcohols [16]. Several nucleic-acid based techniques including DNA probe hybridization and polymerase chain reaction (PCR) amplification with specific probes and primers are used for proper assessment of identification of strains of *R. solanacearum* at the sub-species level. *R. solanacearum* strains have wide range of host thus they do not have race cultivar specificity on the hosts. So determination of the Races are not possible. And this is the reason why the

scientist lose acceptance or approval with the race sub-classification system even though the quarantine rules written for Race 3 biovar 2 has its regulatory meaning [38].

Management practices for bacterial wilt of solanaceous crops

As indicated by Kurabachew and Ayana, 2017 [8], bacterial wilt is a troublesome disease to control, particularly once it is built up in the soil. This is a direct result because of its wide host range, capacity to make due for extensive periods in soil; this is because of the expansive host range & pathogen's genetic diversity, its delayed endurance in the soil and endurance on vegetation as a latent infection [42 & 47]. Bacterial wilt control has been conceivable through different strategies as appeared in Table 3, which incorporate cultural, physical, biological and chemical control measures [8 & 48].

No single technique has shown cent percent efficacy in controlling this disease yet. Some bactericides (copper) as well as antibiotics like streptomycin, tetracycline and penicillin have been proven efficient in very low scale in suppressing *R. solanacearum* but with some hefty price to pay for their expensiveness and environmental hazards [46]. So, the best approach is to use a combination of different control methods, cultural methods, chemical, biological methods and host resistance as a part of integrated disease management [3].

Table 3: Management of Bacterial Wilt of Solanaceous Crops

Method of control	Mechanism involved	Examples
Cultural [9 & 49-55]	Restricted movement of *R. solanacearum* from the primary xylem to other xylem tissues, Nutrient uptake and distribution is induced, Induced resistance of plants, Reduction in disease inoculum	Crop rotation, Growing resistant varieties, Usage of grafting, Soil amendments
Physical [3 & 56-57]	Killing of the pathogen using the low or higher temperature	Biological soil disinfection, Soil solarization, Hot water treatment
Biological [58-64]	Antibiosis, Parasitism siderophore production, Competition for survival (space and nutrients), Extracellular degrading enzyme production & decrease colonization of roots,	*Bacillus amyloliquefaciens, Bacillus cereus, Burkholderia nodosa Burkholderia pyrrocinia, Burkholderia sacchari, Burkholderia tericola, Chryseobacterium daecheongense,*
Chemical [65-69]	Antibacterial/bacteriostatic, Increase in soil microbiota, Induction of systemic resistance, Increase in tolerance of plants to *Ralstonia solanacearum.*	Algicide (3-3-Indolyl botanic acid), Fumigants, Acibenzolar-S-methyl, Chitosan and Sodium chloride bactericides, Cholopicrin,

Physical control measures

Various techniques for physical control have been created and demonstrated valuable for controlling *R. solanacearum*. These techniques incorporate soil solarization, hot water and bio-fumigation, known as biological soil disinfection [22].

1. Soil Solarization

Soil solarization is finished by spreading a transparent plastic mulch sheet over the soil during extensive stretches of high surrounding temperature. This assists with catching the brilliant energy of the sun, accordingly warming the soil layer, which thus kills insects, pathogens, weed seeds & weed seedlings and nematodes [70]. Vinh, 2005 [71] found that solarization of the soil utilizing plastic mulches for 60 days before planting tomatoes decreased the occurrence of bacterial wilt. Solarization of the soil improves soil structure and increases the accessibility of nitrogen and other basic plant supplements [70]. The principle downside of solarization is its negative potential effect on beneficial soil organisms since they will experience similar destiny as their hurtful partners [72].

2. Hot water disinfection of soil

This is generally done as a pre-planting treatment, and post-planting technique. Heated water between a temperature of 70 and 90°C can be poured on the soil before planting to build soil temperature to levels deadly for weed seeds, insect-pests and phytopathogens. It is an earth inviting system, as it doesn't upset soil microflora totally, for instance, heat-resistant, spore framing microorganisms can endure and recover the soil subsequent to cooling, consequently fortifying protections against plant ailment [73].

3. Biological soil disinfection

Biological soil disinfestation is the cycle of homestead attempting to kill soil-borne plant pathogens before planting crops. The cycle requires neither higher temperature nor long temperature incubation to stimulate activities of indigenous microorganisms in the soil through addition of organic materials [74]. The treatment involves four stages including: (I) flooding soil by water system, (ii) covering the soil with plastic film to instigate decreased soil conditions, (iii) presentation of effectively decomposable organic materials (for example rice straw, wheat bran and rice bran) to soil and (iv) utilizing volatile chemicals released from residues of plant. Bio fumigation utilizing wheat bran or molasses end up being compelling against an expansive scope of soil-borne plant microorganisms including *R. solanacearum*, *Phomopsis sclerotioides*, *F. redolens* and *Verticillium dahliae* just as the nematodes, for example, *Meloidogyne incognita* [75].

Cultural control measures

Cultural control envelops cultivating methods that will assist with raising the quality and amount of the crop yield and decreases the impact of diseases [76].

1. Crop rotation

This is a reasonable strategy to effectively manage plant diseases and it includes developing various crops on a similar ranch, in substitute seasons [76]. Nonstop cultivation of same crops may prompt the foundation of specific populaces of plant microorganisms; for instance, tomatoes planted in a similar farm quite a long time after year will urge disease-causing life forms to multiply in the soil. Crop rotation breaks this impending impact and results in the

decrease of disease prompted by soil-borne microbes [50 & 77]. For instance, potato cultivation in rotation with carrots, millet, yams or sorghum has been appeared to reduce the occurrence of bacterial with increased potato crop yield contrasted with that of mono-cultured tubers [23]. For crop rotation to adequately manage soil-borne plant pathogens, they must be entirely killed from the farmland by supplanting the defiled soil with garden-fresh soil from another part of the farm [77].

2. Cultivar resistance

Developing cultivars that are profoundly impervious to bacterial wilt is the best, practical and ecologically cordial way to deal with infection control [22]. Breeding of cultivars that are impervious to bacterial ailments has been practiced mostly for crops, such as potato, eggplant, tomato, nut and pepper. For instance, potato genotype BP9, acquainted with *Solanum tuberosum* and *Solanum phureja* have decreased frequency of bacterial wilt by around 90–100% [56].

Arabidopsis NPR1 gene introduced into a tomato cultivar effectively reduced bacterial wilt by 70% twenty-eight days after inoculation [78]. NPR1 gene assumes a basic part in the plant's reaction to pathogen challenge by setting up induced systemic and systemic acquired resistance [78]. It likewise works as the ace key corresponding to plant defence-signalling network, encouraging a cross-talk between the salicylic acid (SA) and jasmonic acid/ethylene (JA/ET) reactions. In Arabidopsis thaliana, articulation of NPR1 ensures a quick reaction to salicylic acid (SA) [80]. Resistance plants attacked by *R. solanacearum* showed resistance of the vascular tissues to bacterial wilt disease [8]. As much as the cultivar resistance has demonstrated extraordinary credits in decreasing the bacterial wilt of solanaceous crops, public acknowledgment is required before the business utilization of such GM - Genetically Modified crops. Moreover, decrease of bacterial wilt in numerous plants has by and large been contrarily corresponding to the yield and crop quality [22]. In addition, the unpredictability of Ralstonia strains has prompted the improvement of resistant defences, which are successful in some developing regions and are ineffectual in different locales [81].

3. Soil amendment

The utilization of organic matter as a choice to reduce bacterial wilt has valuably impacted harvest efficiency by means of improving the biological, chemical and physical properties of soil, which impacts plant health emphatically [82]. Degradation of organic matter may influence the endurance of pathogens legitimately by releasing inhibitory substances in the soil, thereby restricting the nutrient availability. It might likewise increase microbial exercises; along these lines upgrading the chance of rivalry impacts [82, 83]. These exercises can prompt incitement of micro-organisms with opposing exercises against pathogens [84]. Likewise, soil amendments regularly contain bioactive molecules, for example, growth regulators, toxins & vitamins, which can legitimately or by implication influence micro-organisms. Lemaga, 2001 [85] revealed that organic amendment of soil with *Leucaena diversifolia* and *Sesbania sesbana*, combined with inorganic fertilizer, reduced the rate of bacterial wilt while increasing the potato tuber yield.

The utilization of silicon fertilizers and sugarcane bagasse (an elective silicon source) has likewise been accounted for to decrease bacterial wilt incidence and population, while increasing tomatoes yield [86]. Soil amendments with FYM or coco peat have been found to improve tomato yield contrasted with un-amended soil, while fundamentally reducing bacterial wilt frequency by 81% in tomato [87]. This might be because of improvement in soil's physical & chemical properties and soil microorganisms activity, to the benefit of crop growth. In this way, soil amendment could be valuable in managing *Ralstonia solanacearum* in the primary Solanaceous crop cultivating areas of the world. Yamazaki, 2000 [88] announced that increased calcium fixation in tomato plants decreased *R. solanacearum* population in the stems of the tomato.

Biological control

Biological control includes the killing of one living being by another [89]. It has developed as a promising alternative to the usage of chemicals, especially as an Integrated Pest Management (IPM), to decrease the utilization of fungicides. For instance, adversarial rhizosphere inhabiting microbes have been utilized to improve plant growth, and also to control plant ailments [89 – 90].

Bio-control agents show various attributes that have increased their utilization on comparison to usage of chemicals. Such highlights include decreased contribution of nonrenewable resources, their capability to be self-sustaining and spread after establishment and the capacity to give long-term ailment concealment [91 – 92].

Different examinations revealed that biocontrol of bacterial wilt might be mastered by utilizing antagonistic rhizobacteria and epiphytic bacteria, for example, *Serratia marcescens*, *Bacillus subtilis*, *Bacillus cereus*, *Paenibacillus macerans*, *Bacillus pumilus*, *Pseudomonas fluorescens*, and *Pseudomonas putida* [93 – 94].

As of late, Biratu, 2013 [95] have likewise revealed the possible utilization of actinobacteria, as a part of the integrated management of bacterial wilt infection, through the *in vitro* assessment of actinobacteria isolates. The conceivable biocontrol measures of these species includes multifaceted interactions between the host, pathogen and antagonists, containing cycles, for example, Competition for Survival (space and nutrients), mycoparasitism, plant-mediated systemic resistance, production of siderophore and extracellular degrading enzymes production [89, 96].

The majority of the confirmations of bacteria utilized as biocontrol agents of bacterial wilt includes rhizobacterial, endophytic and epiphytic bacterial species. Among the epiphytes, some are helpful as biocontrol agents, for instance, *Paenibacillus macerans*, *Bacillus pumilus* and *Bacillus subtilis* has been accounted for to be compelling which instigate protection from *Xanthomonas vesicatoria* and *Ralstonia solanacearum* in tomato plants [97 – 98]. Hence, understanding the assorted diversity and ecology of epiphytic bacteria in Solanaceous crops might be basic in prospecting for genera that can be utilized as biocontrol agents against bacterial wilt of solanaceous crops.

Chemical control

Different kinds of chemicals have been used to manage bacterial wilt from several years. Unfortunately due to the complex nature of *Ralstonia solanacearum* no method was proven to be successful when applied alone [22]. In chemical control measures we use agricultural chemicals to manage soil-borne plant pathogens, insect-pests and weeds. Benomyl, carbendazim, flubendazole and propiconazole are some of the chemicals used. Fumigants such as (meta sodium, 1,3-dichloropropene and chloropicrin), algicide (3-[3-indolyl] butanoic acid) and plant activators such as (Val doxylamine

and validamycin A) have been applied to manage bacterial wilt incidence.

Utilization of methyl bromide combined with 1,3-dichloropropene has decreased the incidence of bacterial wilt by 72% – 100% while significantly increasing tomato yield by 1·7- to 2·5-fold.

Pesticides have been accounted for to bring to the table a more huge net advantage than different methodologies of fighting bacterial wilt; but not generally [99]. Obliviousness and ill-advised use of pesticides in the environment may bring about a portion of the pesticides staying in nature for quite a long while, turning into a soil and groundwater contaminant, and making poisonousness the farmers and buyers [100 – 101]. Accordingly, the utilization of synthetic substances like antibiotics to control plant pathogens has been seriously questioned on account of the effect on human wellbeing & nature, and moreover pathogens are becoming resistant [102].

Conclusion

Clear understanding of pathological & physiological wilt and in pathological wilt – Fungal and Bacterial wilt helps farming community to follow timely & appropriate control measures. Bacterial wilt has been a major problem in solanaceous crops like potato, tomato, brinjal, pepper (sweet & hot). Due to its (*Ralstonia solanacearum*) complex nature, wider host range and faster adaptability to changing environments counteracting this devastating plant pathogen has become one of the major challenge. There is no one successful mode of managing this pathogen, however the integrative utilization of cultural, physical, biological and chemical control's gives the best possible results. Conceiving technically adapted, socially acceptable, farmer friendly, economically viable, health & environment benign solutions is a great challenge to global scientific community.

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