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REVIEW ARTICLE

Current Status of Bacterial Diseases of Vegetable Crops

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Abstract

Emerging bacterial plant diseases became a major threat for the vegetable production system. In the recent past, with changes in farming practices, abrupt weather climate, and the introduction of new varieties and hybrids are considered major factors for the emergence and outbreak of new bacterial pathogens (diseases). The bacterial wilt is an emerging threat for the cultivation of almost all the solanaceous vegetables caused by *Ralstonia pseudosolanacearum* in India. Incidence of more emerging bacterial diseases in vegetable crops viz tomato leaf blight (*Xanthomonas axenopodis* pv *vesictoria*) up to 20% and fruit canker- (*Corneybacterium michiganens*) up to 5%, bacterial speck (*Pseudomonas syringae*); brinjal little leaf of brinjal (phytoplasma) up to 40%, cabbage and cauliflower black rot (*X. compestris* pv *compestris*) up to 10% and summer squash soft rot and wilting (*Erwinia* spp.) up to 20% on summer sqash and 19.5% on cauliflower has been recorded. It clearly revealed the cross-infectivity of the bacterial pathogen, indicating the emergence of these pathogens as a broad spectrum covering a wide host range. Future research in this field will include a better understanding of the molecular basis of variability in the pathogen, pathogenesis, accurate and reliable diagnostic of the disease and to engineer novel and durable protection strategies against devastating post-harvest diseases of vegetable crops.

Keywords: Bacterial disease, bio-control, biovars, race, pathogen, variability.

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Introduction

Different bacterial species from genera of *Pseudomonas*; *Ralstonia*; *Agrobacterium*; *Xanthomonas*; *Xanthomonas*; *Xanthomonas*; *Erwinia*; *Xylella*; *Dickeya (dadantii* and *solani)*; *Pectobacterium* are devastating bacterial plant pathogens of vegetable crops (Strange and Scott, 2005; Mansfield *et al*., 2012). Bacterial pathogens, namely *Erwinia* spp. *Pseudomonas* spp. *Ralstonia solanacearum*, *Xanthomonas euvesictoria* on vegetable crops increased tremendously (Thind 2011; Tripathi *et al*., 2013; 2021; Tripathi, 2018; 2021; 2023; Singh *et al*., 2016). Bacterial wilt caused by *R. solanacearum* is a major disease of solanaceous vegetable crops in Asia. The pathogen is widely distributed in warm humid and temperate regions and gradually spreads from hills to plains in India. Consequently, potato, tomato, chili, brinjal and capsicum production are severely threatened (Sood & Tripathi, 2005). A wide array of hybrid varieties of tomato, chili and brinjal of the multinational companies (MNCs) were found under cultivation in the Mirzapur, Sonebhadra and Varanasi districts of Eastern Uttar Pradesh. Its incidence was recorded up to 40% on chili at district Sonabhadra, 75% in tomato and 35% on brinjal at Mirzapur district under field conditions (Tripathi *et al*., 2019; 2020). Several post-harvest bacterial pathogens, namely *X. euvesictoria* canker on tomatoes, *Xanthomonas* black rot and Erwinia soft rot were recorded as emerging post-harvest pathogens on cole crops (Tripathi *et al*., 2022). Every year, diseases cause regional and seasonal losses in vegetable crops up to 40 to 60% under field (15–20%), packaging and storage (15–20%) and transport (30–40%). If we could alleviate the losses due to plant diseases, we could produce roughly 20% more food to feed the predicted world population of 9.1 billion by 2050 (Maxmen, 2013). Therefore, there is an urgent need for profiling, diagnosis and quantification of emerging plant diseases for a better understanding of variability in pathogens, genetics of disease resistance and formulation of their viable management strategies in vegetable crops under changing climatic scenarios. Integrated disease management (IDM) strategies advocate managing bacterial diseases of vegetable crops with minimal use of synthetic pesticides.

Post-harvest Bacterial Diseases

Phytopathogenic bacteria cause post-harvest diseases of economically important vegetables. Different species of bacteria belonging to top ten genera viz. *Pseudomonas*; *Ralstonia*; *Agrobacterium*; *Xanthomonas*; *Xanthomonas*; *Xanthomonas*; *Erwinia*; *Xylella*; *Dickeya*; *Pectobacterium* are devastating plant pathogens (Strange & Scott, 2005; Mansfield *et al*., 2012). The major causal agents of bacterial soft rots are various species of *Erwinia*, *Pseudomonas*, *Bacillus*, *Lactobacillus* and *Xanthomonas*. *Psuedomonas syringae* pv. *syringae*, *P. syringae* pv. *pisi* and *P. syringae* pv. *phaseolicola* cause diseases in vegetables (Ashan, 2006; Chikkasubbanna, 2006; Tripathi, 2018; 2019; 2021; 2022; Tripathi *et al*., 2021; 2022).

Diagnostics and Detection of Bacterial Pathogens/ Disease

Pathogens were isolated on nutrient agar medium and identified on the basis of macroscopic and microscopic analysis of colony and cell morphology by Microscopy, Sero-diagnostics (ELISA, Dot-blot assays) and nucleic acid (PCR) based methods. Biological (Culture media, Diagnostic hosts, Bacteriophages (phage typing); Biochemical (based on properties of the bacteria in culture (gram stain, bacterial cell size, flagella), metabolic fingerprinting (API/BIOLOG system), thin layer chromatography, gel electrophoresis, conductance assays, isozyme analysis); immunoassays (Agglutination, Gel diffusion, ELISA, dot blot assays, immunofluorescence, flow cytometry); nucleic acid (Hybridization, RFLPs, PCR, ICAN, DNA arrays, Multilocus sequence typing) were used for reliable and accurate detection of bacterial plant pathogens for their effective management (Vavterin *et al*., 2000; Young *et al*., 2008). We detect emerging bacterial pathogens (diseases) in vegetable crops for determine the regional and seasonal presence and quantity of the bacterial pathogen (s) in seed and other planting material for quarantine legislation, issuing of sanitary and phytosanitary (SPS), yield losses and formulation of tactics for sustainable bacterial disease management of vegetable crops (Table 1). The important bacterial pathosystem and disease diagnostics of economically important vegetable diseases are given as below:

Table 1: Incidence of emerging bacterial diseases

Crop	*Disease*	*Average incidence (%)*
Brinjal	Bacterial Wilt	40
Tomato	*Xanthomonas* leaf spot	35
	Pseudomonas speck	10
	Bacterial wilt	30
	Xanthomonas fruit spot	1
	Pectinovora fruit rot	5
Chili/ Capsicum	*Xanthomonas* leaf spot	22
	Pectinovora soft rot	2
	Bacterial wilt	40
Cucurbits	*Erwinia* wilt	5
Cole crops	Black rot	10
	Soft rot	19
Beans	Soft rot	5
Summer squash	Soft rot	5-10
Root crops	Soft rot	5
Leafy vegetable	Soft rot	2

Bacterial Wilt: R. Solanacearum

*R. solanacearum (*synonyms *Pseudomonas solanacearum)* Yabuuchi *et al*. (1995) is ranked second among top ten most destructive, economically important, enigmatic soil-borne, vascular bacterial phytopathogen of solanaceous vegetable crops grown in the tropical, subtropical as well as warm humid region of the world. Its causes bacterial wilt in more than 450 plant species in over 54 botanical families (Kelman, 1953; Hayward, 1994; Tripathi & sood, 2005; Sood & Tripathi, 2005; Tripathi *et al*., 2015; 2017; 2018; 2019; 2020; 2022). The pathogen species has a very broad host range and is the causal agent of bacterial wilt of potato, tomato, tobacco, brinjal, capsicum and ginger, geranium, and banana. Its species comprises many races and biovars varying in their geographical origin, host range, and pathogenic behavior (Mishra *et al*., 2021; Sood & Tripathi, 2005). It comprises five races and six biovars with different hosts and geographic distributions. Race 1 (solanaceous race) has a very wide host range, including potatoes and is distributed in Asia and the southern United States. Race 2 (banana and heliconia race), is present in the Caribbean, Brazil, and the Philippines. Race 3 (potato race) is distributed worldwide with the exception of the United States and Canada. Race 4 (ginger race) is prevalent in Asia. Race 5 infecting mulberries in China. The organism is categorized into races on the basis of disease

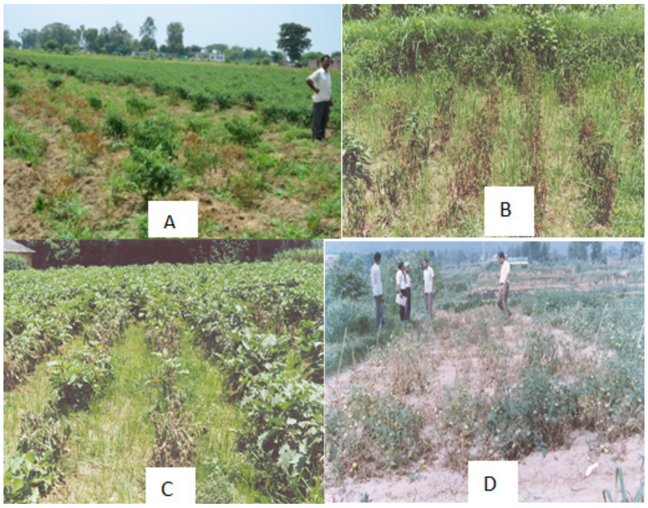


Figure 1: *R. solanacearum* disease wilting symptoms on (a) Chilli (b) Capsicum (c) Brinjal (d) Tomato (E) Potato

symptoms produced on host; however, it is differentiated into biovars on the basis of biochemical tests, e.g., race 3 biovar 2, which is present in Europe, Asia, South and Central America, and Australia (22); http://www.aphis.usda.gov/ppq/ep/ralstonia/background.html. Pathogen 'species complex' has been divided into four main phylotypes (phylogenetic grouping of strains). As a soil-borne, root and vascular pathogen, *R. solanacearum* is a model system for the study of bacterial pathogenicity. The bacterium was one of the first plant pathogen genomes to be entirely sequenced and the development of pathosystems with model plants. Pathogen has quarantine status; it is also responsible for important losses because of regulatory eradication measures and trade restrictions. Because of its intractable nature, USA has already declared this pathogen as a biosecurity policy to check the interstate spread of this damaging pathogen. The bacterial wilt is an emerging threat for the cultivation of almost all the solanaceous vegetables caused by *Ralstonia pseudosolanacearum* (Fig. 1). A wide array of hybrid varieties of tomato, chili, and brinjal from multinational companies (MNCs) were cultivated in different Eastern Uttar Pradesh districts. Its incidence was recorded up to 40% on chili (cv VNR 305) at district Sonabhadra, 75% in tomato (cv Namdhari 585) and brinjal at Mirzapur district under field condition (Tripathi, 2018; 2021).

Geographical distribution

In India, bacterial wilt is endemic in Assam, Arunachal Pradesh, Andaman & Nicobar Island, Gujrat, Karnataka, Kerala, Madhya Pradesh, Maharastra, Meghalaya, Mizoram, Nagaland, Orissa, Tripura, Uttar Pradesh and West Bengal (Chakrabarty, 2011; Tripathi *et al*., 2017).

Symptoms

The disease is caused by a bacterial pathogen *R. solanacearum*. The disease is prevalent in warmer climates with high humidity under tropical and sub-tropical conditions. Relatively high soil moisture, soil temperature and acidic soil pH favor the disease.

It appears on chili, tomato, brinjal (eggplant) and capsicum (bell pepper). Itis a soil-borne, xylem-colonizing vascular pathogen which leads to wilting symptoms and plant death. The lower leaves droop before wilting occurs. The vascular systems become light brown. The chlorosis of the leaves seldom accompanies Wilt and sudden death. In the cross-section of the infected portion, creamy and slimy bacterial matrix exudates from the vascular bundle. The pathogen is soil inhabitant, persisting for many years in the soil. Bacteria enter in the plant through intercultural wounds and other injuries, usually on the ground surface. Disease management remains difficult due to the non-feasibility of chemical control and the exceptional survival ability of pathogens for years in soil and weed hosts, which act as inoculum reservoirs. Breeding for race-specific resistance, although effective but difficult due to the broad genetic and phenotypic diversity of the pathogenic races/strains.

Biology and etiology

Bacterial wilt pathogen *R. solanacearum* is a gram-negative; rod-shaped, mesophilic, non-fluorescent pigment-producing plant pathogenic bacteria. It reflects high level of phenotypic and genotypic plasticity. Yabuuchi *et al*. (1995) proposed new genus from *Pseudomonas* to *Burkholderia* to accommodate RNA homology group II, including *P. solanacearum* with *P. cepacia* as type species. On the basis of 16S rRNA genes and polyphasic taxonomy, genus Burkholderia showed dichotomy, and the new genus *Ralstonia* was proposed with *R. picketti* as the type species (Yabuuchi *et al*., 1995). Using nucleic acid probes, Cook *et al*. (1989) placed *R. solanacearum* strains in two broad divisions: division 1, race 1/ biovars 3,4,5 and division II, race 1/ biovar 1, and race 2 and 3. Sequence analysis of *R. solanacearum* showed that it is a species complex that can be subdivided into four phylotypes. This phylotype I includes all strains belonging to biovars 3, 4, and 5 and Phylotype II includes race 3 potato pathogen and race 2 banana pathogen. The phytotype represents a number of sequevar groups that are identified by the characterization of the endoglucanase gene. Phylotype I consisting Asian strains; phylotype II consisting American strains; Phylotype III comprising African strains while phylotype IV consisting strains isolated from Indonesia. An intriguing aspect of *R. solanacearum* is that in advanced stage of wilting, the wild types spontaneously generate avirulent variants. This type of variant conversion is common in many strains under cultural conditions (Kelman, 1954). The rapid shift occurs while bacteria are in active multiplication in plant and *in-vitro* cultures. Kelman and Hruschka (1973) demonstrated that the shift to avirulence in still broth was due to the preferential multiplication of motile avirulent cells due to aerotaxis. However, the bacterium also segregates into virulent and avirulent populations even on solid media, showing that other factors are also involved in shifting to avirulence. High (35°C) and low (5°C) temperatures, low pH (4.5) and anaerobiosis induced higher shift towards avirulence. Virulent isolates of *R. solanacearum* forms white and irregular fluidal/mucoid colonies with pinkish centre and produce abundant extracellular polysaccharide (EPS) on Kelmans triphenyl tetrazolium chloride (TZC) medium. Avirulent types produce round, non-flidal/non-mucoid dark red colonies and are deficient in extracellular polysaccharide (EPS) production. The other associated changes are that the bacterial cells become flagellated and highly motile, one or more components of extracellular polysaccharides is altered and amount of extracellular endoglucanase production is reduced (Schell *et al*., 1988). The colony morphology changes and its associated collective alterations are called "phenotype conversions (PC)". The range of generic variation in *R. solanacearum* and the basis of this variation is poorly understood. Modern genetic studies on the organism are required to better understand the genetic basis of pathogenicity.

Diversity spectrum of existing race and biovar

There are considerable differences in host range of individual strains of *R. solanacearum*. *R. solanacearum* isolates are classified into 5 races on the basis of host range, geographic distribution and ability to survive under different environmental conditions (Buddanhagen & Kelman, 1964; Buddenhagen *et al*. 1962; Quinon *et al*., 1964) and into six biovars on the basis of utilization/oxidization of disaccharides and sugar alcohols (Hayward, 1994; 1991). Solanaceous strain (Race I): wide host range, distributed throughout the low- lands of the tropics and subtropics; Musaceous strain (Race 2): restricted to Musa, Plantain and a few perennial hosts, initially limited to American tropics, now spreading to Asia; Potato strain (Race 3): restricted to potato and a few alternative hosts in the tropics and subtropics; Ginger strain (Race 4) from the Philippines; and Mulberry strain (Race 5) from China. *R. solanacearum* isolates from Asia, including Indian plains and plateau, belong to race 1 and biovar III (Shekhawat *et al*., 1978). However, in recent years, race 3, and biovar 2 have been reported from Madhya Pradesh and other areas in the plains (Sagar *et al*., 2010).

In general, the solanaceous race (race 1) has a wide host range and is prevalent in tropical and sub-tropical climates; however race 3 is restricted to potato and a few other alternative hosts. Race 1 can survive for 2 to 10 years in soil more than race 3 (Shekhawat *et al.,* 1979). The longer soil survival of race 1 may be due to its better competitive ability, wide host range and higher aggressiveness. A recent study demonstrated a very high level of genetic variability within field collected and clonal isolates of *R. solanacearum* from a single field (Grover *et al*., 2006). This might be a reason for the wide host range of this bacterium and for the quick breakdown of wilt resistance in host plants. The results also suggested that it would be difficult to design specific diagnostic protocol for *R. solanacearum* even for a localized population and to breed cultivars with broad-spectrum resistance.

Epidemiology

R. solanacearum is primarily a root-inhabitant soil-borne bacterial pathogen. Inoculum survival of *R. solanacearum*in soil depending on soil type and physico-chemical properties, soil pH reaction (pH 4.3–6.8), cropping sequences practised and the native weed flora presen. Nursery of Tomato, brinjal and chili raised in infested areas are also act as important inoculum sources for the disease. However, *R. solanacearum* fails to survive in true potato, tomato, brinjal and chili seeds. From infected plants, secondary spread over short, medium and long distances takes place by root contacts, flood/irrigation water, farm implements, storage and packaging material. Areas where cut tubers are used for planting, cutting knife may also spread the pathogen to healthy tubers. A relatively high-temperature regime (20–30°C) is favorable for wilt development by race 1 of *R. solanacearum* (Hingorani *et al*., 1956; Devi *et al*., 1982). At lower temperatures, infection can occur but symptoms do not develop. The pathogen can also survive symptomlessly in weed-hosts' or presumed non-host plants' roots. *R. solanacearum* is a harmful organism whose introduction and spread are prohibited in the European Union (Directive 2000/29/EC; Annex I, Sect. II, comma b, 2). All EU member states must adopt measures to prevent the introduction and spread of *R. solanacearum.* Several environmental factors affecting the survival of the pathogen are:

High soil moisture content, favoring survival and increase in pathogen production; high soil organic matter content leading to a decline in pathogen population; High temperatures decreasing pathogen population; Presence of alternate hosts favoring survival, as the pathogen is able to survive in association with non-host plants.

The disease is caused by a bacterial pathogen *R. solanacearum*. The disease is prevalent in warmer climates with high humidity under tropical and sub-tropical conditions. Disease appeared in the form of leaf drooping and browning of vascular bundle with bacterial ooze and wilting of the plant (Tripathi *et al*., 2005; 2020) (Fig. 2).

Integrated disease management

Wide host range, exceptional survival ability, high level of genetic diversity, cultural reversion and genome/plasmid plasticity, complex etiology and epidemiology of bacterial vegetable infecting pathogen make it a very difficult to manage. Information on the ecology of the disease and variation in the pathogen is important in establishing national disease management strategies, including the

Incidence of Bacterial Wilt on tomato | 100% incidence of Bacterial Wilt on brinjal | 100% incidence of Bacterial Wilt on chili | Growth of *R. solanacearum* isolates on TZC medium

Figure 2: Typical symptoms of bacterial wilt on Solanaceous vegetables and culture plate

development of resistant varieties, shifting of cropping patterns and appropriate cultural management.

- When the pathogen is established in soil, satisfactory control is very difficult.
- Always prefer to grow resistant varieties because chemical control is neither feasible nor economical.
- Use of antagonistic bacteria, neem cake, and organic matter as soil application.
- Maintain soil pH to neutral by liming.
- Avoid water stagnation and anerobic conditions in the field.
- Light texture of soil and well-drained field reduces the disease incidence.
- Follow long crop rotation for 3 years with cereals and non-solanaceous host.
- Green manuring, biofumigation and soil solarisation of crop field.

Xanthomonas – Spot/Blight

The genus *Xanthomonas* comprises 20 different species (Vauterin *et al*., 2000) with many pathovars causing economically important diseases on different vegetable crops (Young *et al*., 2008). *Xanthomonas* is a rod-shaped, gram-negative bacterium. It produces a yellow soluble pigment called xanthomonadin and extracellular polysaccharide (EPS). EPS is an important pathogenicity factor of bacteria which protect from desiccation and for the attenuation of wind- and rain-borne dispersal.

Symptoms

X. campestris pv. *vesicatoria*, now reclassified as *X. euvesicatoria*, the causal agent of bacterial spot of tomato. The disease severely affects the Kharif/rainy season from July to October crop of tomatoes. *X. campestris* pv. *vesicatoria,* now reclassified as *X. euvesicatoria*, the causal agent of bacterial spot of tomato. The disease is prevalent in warm, humid and temperate region of the world. *Xanthomonas* is a rod-shaped, gram-negative bacterium. It produces a yellow soluble pigment, called xanthomonadin and extracellular polysaccharide (EPS). EPS is an important pathogenicity factor of bacteria that protects from desiccation and for the attenuation of wind- and rain-borne dispersal. Disease appeared as small, dark spots on the leaflets and stems of seedlings and transplanted crop. A prominent yellow halo is observed around the spot (Fig. 3). Numerous bacterial spots coalesced and later caused severe burning of the leaves. Disease appeared from the seedling phase of the crop and continued up to fruit initiation stage. Fruits are slightly raised and corky in appearance, neither fit for human consumption nor for market.

Integrated disease management

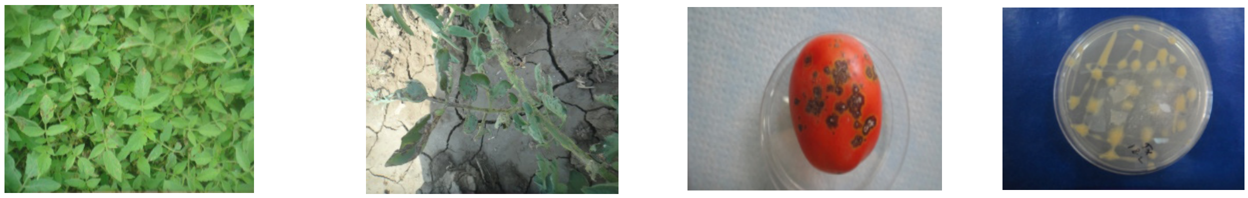
- Use disease-free certified seed for raising nursery, which should be collected from disease-free plants.
- Deep ploughing in the summer season to desiccate the bacteria and host.
- Soil solarization in nursery bed to avoid seedling infection.
- Rotation of nursery seedbed and main field.
- Hot water treatment of seed at 50°C for 30 minute.
- Seed treatment with dipping in streptocycline solution @100 ppm.
- Adopt intercropping of urd (*Vigna mungo*) and mung (*Vigna radiate*) as mulches to prevent rain splash.
- Foliar spraying of streptocycline @ 150 to 200 ppm.
- Spray of copper oxychloride @ 0.2% after 15 days interval in the afternoon.

Bacterial Speck

P. syringae is a seed-borne disease. *P. syringae* pv. *tomato* is increasing, its economic impact with a resurgence/re-emergence of bacterial speck on tomato, worldwide. The disease is caused by *Pseudomonas syringae* pv. *tomato*. Generally, bacterial speck disease is more prevalent in the winter from November to January when fruit ripens. It is characterized by the absence of chlorotic halo around the spot, and crusty and comparatively larger spots. Small black necrotic, circular to roughly circular spots appear on leaf, petiole, pedicel, and peduncle, while irregular, elongated lesions on the stem.

Integrated disease management

- Summer plowing of the field to desiccate the bacteria and host.
- Soil solarization in a nursery bed to avoid seedling infection.



Xanthomonas Tomato leaf spot | Xanthomonas Tomato leaf blight | Tomato speck | Xanthomonas NA culture plate

Figure 3: Typical symptoms of *Xanthomonas euvesicatoria* on tomato and NA culture plate

- Rotation of nursery seedbed and main field.
- Use disease free certified seed and seed should be collected from disease-free plants.
- Seed treatment done with dipping in streptocycline solution @100 ppm or seed treatment with hot water at 50°C for 30 minute.
- Foliar spraying of streptocycline @150 to 200 ppm followed by one spray of kasugamycin @0.2% in afternoon.
- One spray of copper oxychloride @0.3%, after 10 days of antibiotic application.

Pseudomonas - Blight

The emergence of *P. syringae* is increasing, its economic impact on the bean with a resurgence of bean halo blight caused by pv. *Phaseolicola* (Murillo *et al*., 2010), worldwide whichever pv. *pisi* on pea blight in temperate regions. *Pseudomonas* - blight (*Xanthomonas campestris pv. Phaseoli (common blight); X. phaseolivar. fuscans (Fuscous blight), Pseudomonas syringae pv. Phaseolicola (Halo blight), P. syringae pv. syringae (Brown spot blight)* Halo blight has most of the symptoms of common blight along with a chlorotic halo and vascular discoloration. Bigger blotch symptoms appear on the leaves in severe cases of common blight. *Pseudomonas syringae* pv. *pisi*. has also been infecting vegetable pea in temperate regions. The disease affects leaves, stems and pods. Brown discolored streaks are observed on the stem and petiole. Spots on leaflets are round, oval or irregular, 2 to 5 mm in diameter, reddish brown with a translucent centre and a darker brown margin. Later the whole stem and pods discolored and dried. Pods become glossy and seeds become discolored and shriveled. Spots enlarged and may coalesce to produce a blighted appearance. Typical symptoms of common blight are first seen as small translucent, water-soaked spots on the leaves of leguminous vegetable crops. Tender pods are chocolate brown, thin, twisted and shriveled. Lesions are large on older pods and they become thin, twisted and dry. Seeds become discolored and shriveled. Dried bacterial ooze makes pod surface glossy.

Integrated disease management

- For the control of these diseases, always include the reduction of seed infection through "dry bean clean seed" programme.
- Crop rotation followed for 2 to 3 years to dispose of over-wintering bacteria.
- Field sanitation reduces inoculums in the field.
- Use disease-free, certified seed of resistant varieties. Proper drainage should be maintained in the field.
- Sowing time should be adjusted so that the fruiting stage should not coincide with heavy rainy periods.
- Seed treatment is done by soaking in a streptocycline solution @100 ppm for 30 minutes.

Xanthomonas: Black Rot

Xanthomonas campestris pv. *campestris* is the causal agent of black rot of cole vegetable crops, viz. cabbage, cauliflower, and kale. The foliage infection and transmission is through water pores, insect injury, infested soil, storm, cultural practices and seedlings. The bacteria usually enter the cotyledons through stomata and pass to the young leaves and progress systematically throughout the plant system. Disease appears along the margins of leaves as chlorotic lesions and chlorosis progresses in the direction of the midrib usually forming "V" shaped area. Yellowing of leaves was observed from lower portion of mid vein in severe infection on cole vegetable crops (Fig. 4).

Integrated disease management

- Seed obtained from disease-free plants for next year use.
- Seed treatment done with hot water at 50°C for 30 minutes or seed treatment with dipping in @100 ppm antibiotic solution for 30 minutes.
- Crop rotation followed with non-cruciferous crops.
- Use intercrop of creeping type urd and mung as mulches to reduce rain splash.
- Detach the lower infected leaves in the afternoon when dew and bacterial ooze dried up from them and then burn them.
- Nursery bed should be changed frequently to avoid seedling infection.
- Spraying of antibiotics like streptocycline @ 150 to 200 ppm or kasugamycin @ 0.2% at 15-day interval.
- Mixture of tetracycline @100 ppm and copper oxychloride @0.3% should be used for foliar spray.

Bacterial Wilt – Erwinia tracheiphila

Bacterial wilt caused by *Erwinia tracheiphila* is a common and often destructive disease of cucurbitaceous vegetable viz

Xanthomonas Blight on Kale — *Xanthomonas* blight on cauliflower — *Xanthomonas* blight on lai-patta

Figure 4: Typical symptoms of *Xanthomonas campestris* on cole crops

cucumber, muskmelon, squash and pumpkin. The bacteria over winters in the bodies of adult cucumber beetles (insect vector) particularly red striped and spotted beetle. Disease symptoms appeared in the form of drooping of leaves, which become flaccid in sunny weather and later eventually an entire plant is wilted. The wilting then becomes permanent, and the leaves and vine die. When wilted stems are cross-sectioned, viscid and sticky bacterial ooze/exudates comes from the vascular bundles. The bacteria present in the vessels of infected plants die within 1 or 2 months after the dead plants dry up.

Integrated disease management

- Control insect vector cucumber beetles from the soil with neem cake or systemic granular insecticides at the initial stage.
- Summer polughing of field to expose all the stages of beetles.
- Resistant varieties with restricted use of exotic cucumber lines should be grown.

Bacterial Soft Rot of Fleshy Root and Leafy Vegetable

Pectobacterium carotovorum and *P. atrosepticum* (formerly *E. carotovora* subspecies *carotovora* and subspecies *atroseptica)* cause huge losses of economically important fleshy vegetables worldwide. *P. atrosepticum* was the first genomically sequenced plant bacterial pathogen which is taxonomically related to animal pathogens. Genomic information is now available for *P. carotovorum* strains and other 'former Erwinia' species, which have now been reclassified in the genus *Dickeya*. Geographically, *P. carotovorum* is widely distributed and causes soft rot diseases of several vegetable crops (Fig. 5). However, *P. atrosepticum* is an economically important pathogen of potato blackleg disease and is restricted into the world's temperate region (Toth *et al.,* 2003).

Phytoplasma Incited Little Leaf of Vegetables

Disease symptoms appear in the form of stunting the plants and rosetting the leaves. Infected plants giving a bushy appearance without flowers and fruits. Phyllody symptom of vegetables includes stem flattening with abnormal green structure virescens and yellowing, internode shortening, and intense proliferation of leaves and flower buds reported in many crops (Arocha *et al.*, 2009). Little leaf of brinjal is caused by vector-borne phytoplasma (a mollicute bacterium). Pathogen is transmitted by an insect vector (leaf hopper – *Hishimonas phycitis).* Big bud disease-infected tomato plants showed reproductive malformation in which stamen and overy transformed into unopened bud or capsule structure and commonly exhibit symptoms such as virescence (green pigmentation in plant tissues that are not normally green), phyllody, yellowing, witches'- broom (wild, erratic, broom-like growth at the ends of shoots, stems or branches), leaf roll and generalized decline. These mollicutes are obligate parasites and are naturally transmitted by a number of phloem-feeding insect species of the order Hemiptera in a persistent propagative method. However, they are not known to be transmitted by sap or seed. Dienes' staining of the microtom section of the symptomatic plants stem under light microscopy showed regularly distributed dark blue areas in the phloem region, whereas no such areas were found in the microtome section of apparently healthy stem tissues. Other than the phloem, no staining and color differentiation was observed.

Integrated disease management

Currently, there are no simple measures to control phytoplasma diseases. However, some phytoplasma diseases could be managed by spraying systemic insecticides to control the leafhopper vectors.

- Grow okra as a trap crop for control of insect vector.
- Insect vector control by spraying of neem seed kernal extract (NSKE) 5% or quinalphos 25% EC 2 mL/litre or thiamethoxam 25% WP @ 0.3 g/litre or cypermethrin 25% EC @ 0.4 mL/litre or deltamethrin 1% + triazophos 35% EC @ 2 mL/litre.

Pectobacterium- Soft Rot

Pectobacterium carotovorum and *P. atrosepticum* (formerly *E. carotovora* sub species *carotovora* and subspecies *atroseptica)* causes huge losses of economically important fleshy vegetables worldwide. Geographically, *P. carotovorum* is widely distributed and causes soft rot diseases of several vegetable crops. However, *P. atrosepticum* is an economically important pathogen of potato blackleg disease and

Erwinia soft rot on summar squash | *NA* plate of *Erwinia spp* | *Pectobacterium* NA culture plate | *Pectobacterium* soft rot on cauliflower

Figure 5: Typical symptoms of *Erwinia* on summer squash and cauliflower and culture plate

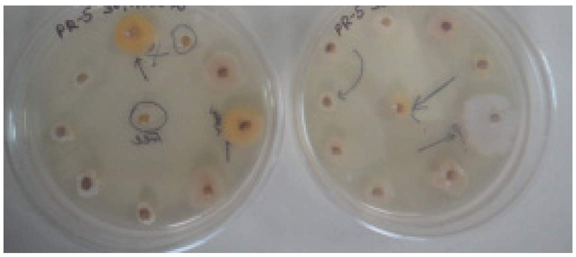


Figure 6: *Xanthomonas axenopodis* pv *vesictoria* on brinjal seeds plated on nutrient Agar

restricted into the world's temperate region (Toth *et al.*, 2003; 2011).

Vegetable Seed Borne/seed Transmitted Bacterial Pathogens

Seed samples of different vegetable crops viz. brinjal, chili, tomato, cabbage, cauliflower, bottle gourd, cowpea, cluster bean, French bean (rajma), Indian bean, pea, winged bean were subjected agar plate method for seed health evaluation to determine germination percentage and detection of seed-borne/seed-transmitted bacterial pathogens. Vegetable crop seeds are sterilized with sodium hypochlorite (1.0%) for one minute and rinse with sterilized water. Surface sterilized seeds were plated @ 10 seeds per nutrient agar petri plates and incubated at 24 ± 2°C for 7 days. Seed borne bacterial pathogens viz *Xanthomonas axenopodis* pv *vesictoria* on brinjal (11%) and tomato (10%); *Xanthomonas compestris* pv *compestris* on cabbage (10%) and *Pseudomonas* spp. on winged bean (33%) were recorded. *P. syringae* is seed-borne and its occurrence are more sporadic, and outbreaks are often associated with sowing of contaminated seed (Singh *et al*., 2019, Trpathi *et al*., 2023; Tripathi, 2023, Morris *et al*., 2007). Black rot of cole crops is an economically important seed-borne disease of cabbage that is more prevalent in regions with warm and humid climates, including temperate regions.

Management of Bacterial Diseases of Vegetable Crops

Use of disease free certified seed, seed treatment with chemicals or bioagents, foliar spraying of bactericides/chemicals, crop rotation with non-host crop and growing of disease-resistant varieties are core components for integrated bacterial disease management of vegetable crops (Ampatizidis, 2017; Pandey *et al*., 2016; Lognathan *et al*., 2016; Tripathi *et al*., 2014). A better understanding of ecology, biology and epidemiology of bacterial wilt pathogens plays an important role in more rigorous studies on the disease and formulation of location-specific integrated disease management strategies. The various core components of IDM approach are described as below.

Cultural Management

Avoidance of the disease is possible through the use of disease-free certified planting materials, rotation with non-host plants and growing after flooded crops in some instances. Manipulation of soil pH through soil amendment.

Chemical Management: Chemical Control

Many workers have attempted use of Chemicals to manage bacterial wilt, but it was found ineffective and non-feasible (De *et al*., 1993; Tripathi and Singh, 2021; Tripathi, 2019). The antibiotic streptocyclin was found to reduce wilt incidence in eggplant when roots of seedlings were dipped in a suspension 25 ppm (25 mg/litre) for 30 minutes before transplanting. Streptomycin sulphate 90% + tetracycline hydrochloride 10% @ 100 ppm; copper oxychloride 50% WP @ 0.20%, copper hydroxide 77% WP @ 0.20%, copper oxychloride 45% + kasugamycin 5% @ 0.20% use as need based foliar spray or drenching and applied bleaching powder @ 12 to 15 kg/h in soil for effective management of soil-borne bacterial diseases of vegetable crops.

Biological Control

Certain bacteria like *Pseudomonas fluorescens, Bacillus polymyxa*, *Bacillus* spp. and actinomycetes delayed wilt development and reduced the incidence of bacterial wilt (Alabouvetti *et al.*, 2006; Cheng *et al.*, 2010; Tripathi, 2017; Singh *et al*. 2021. The *P. fluorescens* @ 10 g/kg of seed should be used for seed treatments. Root dipping of vegetable seedlings by *P.* formulation @ 1% for 10 to 25 minutes is very effective in *kharif* season. The *B. subtilis* (strain-B5) formulation has been adopted by many farmers in the Rajasthan, Punjab, Gujarat and Madhya Pradesh states. Application of talc-based formulations of *Bacillus subtilis* (BS2-IIVR strain) having minimum cfu of $2.5X10^8$ as seed treatment @ 4 g/kg seed, soil application as 10 g/m^2 soil drenching @ 5%, has recorded reduced bacterial diseases in the vegetable. Application of actinomycetes and *Trichoderma asperullum* improved germination percentage, vigor index of seedlings and controlled soil-borne bacterial diseases in vegetable crops (Chaurasia *et al*., 2018; 2019; Tripathi *et al*., 2018; 2019; 2020; 2021).

Host Resistance

In Asia and the Pacific bacterial wilt in crops is considered to be a major limiting factor. Breeding for disease resistance is the most appropriate solution. There should be much more emphasis on local breeding programs to identify material suited for particular ecosystems. Bacterial wilt is still a serious disease on crops such as chili, capsicum, eggplant, potato, tomato, tobacco, zinger and jute where narrow resistance germplasm/gene pool are available for disease resistance breeding. Though effective source of resistance to bacterial wilt has been identified in tomato, brinjal, chili etc, available sources of resistance in potato against *R. solanacearum* has two major problems viz. (i) the resistance is strain specific and is broken down under warm climates, and (ii) the resistant clones are susceptible to latent infection which builds up with successive vegetative propagation and knocks down the resistance. The narrowness of race 3 should make it an easier breeding target than race I. Solanaceous race I, more prevalent in India, appears to be the most virulent. Potatoes in India are grown in comparatively warmer climates and wilt is caused mainly by race 1, which has wide genetic variability. Bacterial wilt has been regarded as a problem primarily of solanaceous crops in hill and coastal area. Wide host range of the pathogen has increased its exceptional survival ability, better competitive ability and high aggressiveness. The extent of crop losses depends on the soil ecosystem, age and variety of the crop. Bacterial wilt is still a serious disease on crops such as chili, capsicum, eggplant, potato, tomato, tobacco, zinger and jute where narrow resistance germplasm/gene pool is available for disease-resistance breeding (Tripathi *et al*., 2017). An effective source of resistance to bacterial wilt has been identified in tomatoes, brinjal, chili, etc. Information on the ecology of the disease and variation in the pathogen is important in establishing national disease management strategies, including the development of resistant varieties, shifting of cropping pattern and appropriate cultural management. Successful breeding programs require knowledge of the pathogen's biology, which is inadequate. The race/biovar distribution picture is unknown in many countries. The importance of true seed in pathogen dispersal is needed to be examined. Better understanding of molecular genetics elucidate the genetic basis of pathogenicity in *R. solanacearum*. Such studies may play a much more important role in developing host resistant mediated management and guiding plant breeders in their search for resistance to particular strains of *R solanacearum*.

Post-harvest Handling Operations of Vegetable Crops

Maintenance of hygiene in all stages of post-harvest handling is critical to minimize the source of primary inoculum for post-harvest diseases. Produce should be harvested during the day instead of early morning (Choudhury, 2006; Droby *et al*., 2000, 2001; 2003; Tripathi, 2021; Tripathi *et al*., 2014; 2021). Field containers should be smoothed. Containers should be cleaned. Sterilized packing and grading equipment, particularly brushes and rollers, are used. Chlorinated water @ 100 ppm is commonly used for washing of vegetables. This can be done with chlorine gas or with either liquid hypochlorite (pH 6.0–7.0). Containers should not be overfilled, which causes severe damage during stacking. Management of temperature is the most important factor to extend shelf life of fresh vegetables after harvest. It begins with rapid removal of the field heat by using any of the following cooling methods: Hydro-cooling, in-package ice, top icing, evaporative cooling, room cooling, forced air cooling, serpentine forced air cooling, vacuum cooling and hydro-vacuum cooling. The relative humidity during storage should be maintained about 85 to 95% for most fruits and 95 to 98% for vegetables. Transport vehicles should always be cleaned and sanitized before loading.

Conclusion

Integrated disease management is an economical, sustainable and viable approach to manage plant diseases. Emphasis on bio-control and regulation for judicious use of chemicals has been increasing for managing of bacterial diseases of vegetable crops. Therefore, location-specific surveys and surveillance are urgently needed for scouting and monitoring of pathogens/diseases of vegetable crops for their cost-effective management. For post-harvest disease management, various strategies such as post-harvest handling systems, sanitation and integration of botanicals/plant essential oil, microbial bioagents and safe chemicals need to be integrated and integrated post-harvest disease management techniques under World Trade Organization (WTO) regime. Future research in this field will include a better understanding of the molecular basis of variability in the pathogen, pathogenesis, accurate and reliable diagnostic of the disease and to engineer novel and durable protection strategies against devastating remerging and re-emerging bacterial diseases of vegetable crops under changing climatic scenario.

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सारांश

कृषि पद्धतियों में बदलावए मौसम बदलाव की स्थिति और नई किस्मों और संकरों का सब्जी उत्पादन में प्रयोग जीवाणु रोगजनकों के उद्भव और प्रकोप के लिए प्रमुख कारक है। जीवाणु जनित पादप रोग सब्जी उत्पादन के लिए सबसे अधिक क्षति पहुँचाने वाले रोग बन गए हैं। सब्जियों में जीवाणु जनित म्लानि रोग रालस्टोनिया सोलेनासिएरम का प्रकोप पहाड़ी क्षेत्रों से मैदानी क्षेत्रों की ओर बढ़ता जा रहा है। यह मृदा जनित रोग लगभग सभी सोलानेसियस सब्जियों में जीवाणु जनित रोगों के अन्तर्गत दूसरा महत्वपूर्ण रोगजनक है। सब्जियों की फसलों में जीवाणु रोगों जैसे टमाटर की पत्ती का झुलसना; ज़ैंथोमोनस एक्सिनोपोडिस पीवी वेसिक्टोरिया द्ध 20ः तक और फलों का कैंकर ;कॉर्नीबैक्टीरियम मिशिगनेंस द्ध 5ः तकए बैक्टीरियल स्पेक; स्यूडोमोनस सिरिंज द्धय बैंगन में बैंगन की छोटी पत्ती; फाइटोप्लाज्माद्ध 40ः तकए पत्तागोभी और फूलगोभी में काला सड़न; ज़ैंथोमोनस कॉम्पेस्ट्रिस पीवी कॉम्पेस्ट्रिस द्ध 10ः तक और ग्रीष्मकालीन स्क्वैश में सड़न और विल्टिंग ;इरविनिया एसपीपी द्ध 20ः तक क्षति होती है। इससे स्पष्ट रूप से इन रोगजनकों की क्रॉस संक्रामकता का पता चला जो रोगजनकों के उद्भव का संकेत देता है। रोगजनकों के उŸारजीविता की समयावधि अधिक होने एवं वृहद् पोषक परास होने के कारण इन रोगों का सब्जियों में प्रबंधन बहुत कठिन होता है। भविष्य में सब्जी फसलों में रोगज़नक़ए रोगजनन में परिवर्तनशीलता के आणविक आधार की समझए रोग के सटीक और विश्वसनीय निदान के अनुसंधान को शामिल करना होगा।