

EPPO Datasheet: *Ralstonia solanacearum* species complex

Last updated: 2021-11-29

IDENTITY

Preferred name: *Ralstonia solanacearum* species complex

Authority: (Smith) Yabuuchi, Kosako, Yano, Hotta & Nishiuchi

Taxonomic position: Bacteria: Proteobacteria: Betaproteobacteria: Burkholderiales: Burkholderiaceae

Other scientific names: *Bacterium solanacearum* Smith, *Burkholderia solanacearum* (Smith) Yabuuchi, Kosako, Oyaizu, Yano, Hotta, Hashimoto, Ezaki & Arakawa, *Pseudomonas solanacearum* (Smith) Smith, *Ralstonia solanacearum sensu lato* (Smith) Yabuuchi, Kosako, Yano, Hotta & Nishiuchi, *Xanthomonas solanacearum* (Smith) Dowson

Common names: bacterial wilt

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EPPO Categorization: A2 list

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EPPO Code: RALSSO



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Notes on taxonomy and nomenclature

Ralstonia solanacearum (Smith) Yabuuchi *et al.* (1995) is a species complex (RSSC) that comprises four phylotypes (Fegan & Prior, 2005). Each phylotype includes multiple phylogenetic and pathogenic variants differing in barcoding markers (including the 16S-23S rRNA gene intergenic spacer region and the, *hrpB*, *mutS* and *egl* genes), known as sequevars. Safni *et al.* (2014) reclassified the four phylotypes of the RSSC into three distinct species: *R. solanacearum* (Smith, 1896) Yabuuchi *et al.*, 1996 emend. Safni *et al.*, 2014 (Phylotype II), *Ralstonia pseudosolanacearum* Safni *et al.*, 2014 (Phylotypes I and III) and *Ralstonia syzygii* (Roberts *et al.*, 1990) Vaneechoutte *et al.*, 2004 emend Safni *et al.*, 2014 (Phylotype IV). *R. syzygii* comprises three subspecies: subsp. *syzygii*, subsp. *celebesensis* and subsp. *indonesiensis*. Taxonomy and nomenclature have been reviewed in detail by Paudel *et al.* (2020).

HOSTS

Some genotypes with apparent host specificity were historically designated race status, i.e. *R. solanacearum* (Phylotype II) on banana/plantain (race 2) and potato (race 3) as well as *R. pseudosolanacearum* (Phylotype III) on ginger (race 4) and mulberry (race 5). It is now recognized that there are genetically variable strains within each phylotype and species, which collectively affect a very wide range of hosts (over 250 species), including many tropical and subtropical crops, in 54 botanical families. In Indonesia, two host-specific subspecies of *R. syzygii* (subsp. *syzygii* and subsp. *celebesensis*) respectively cause the spittlebug-transmitted Sumatra disease of cloves and the pollinator-transmitted banana blood disease. The third subspecies of *R. syzygii* (subsp. *indonesiensis*) has a wider host range. Many perennial non-crop species, including nightshades of the Solanaceae family, are also hosts of the pathogen and increase the potential of *R. solanacearum* to persist in the environment. The list below includes natural hosts worldwide, focusing mainly on cultivated plants where isolates of the bacterium have been characterized to phylotype and sequevar of the RSSC. The RSSC has a wide and growing host range that is not yet fully known, especially regarding the full range of wild hosts around the world. For historical host lists, see Kelman (1953), Bradbury (1986), Persley (1986) and Hayward (1994a). Several other lists of wild herbaceous and tree hosts have been reported, with a wider range than currently shown here, but for which the pathogen has yet to be fully characterized (e.g. Abdulha, 1993; Supriadi *et al.*, 2001; Janse *et al.*, 2004; Lopes & Rossato, 2008; Obregón *et al.*, 2008; Paret *et al.*, 2008; Mondal *et al.*, 2011; Prieto *et al.*, 2012).

A single sequevar of Phylotype II (PIIB-1) of *R. solanacearum* (formerly referred to as race 3 biovar 2) has spread worldwide through trade in infected potatoes and has been introduced in to the EPPO region. This strain has

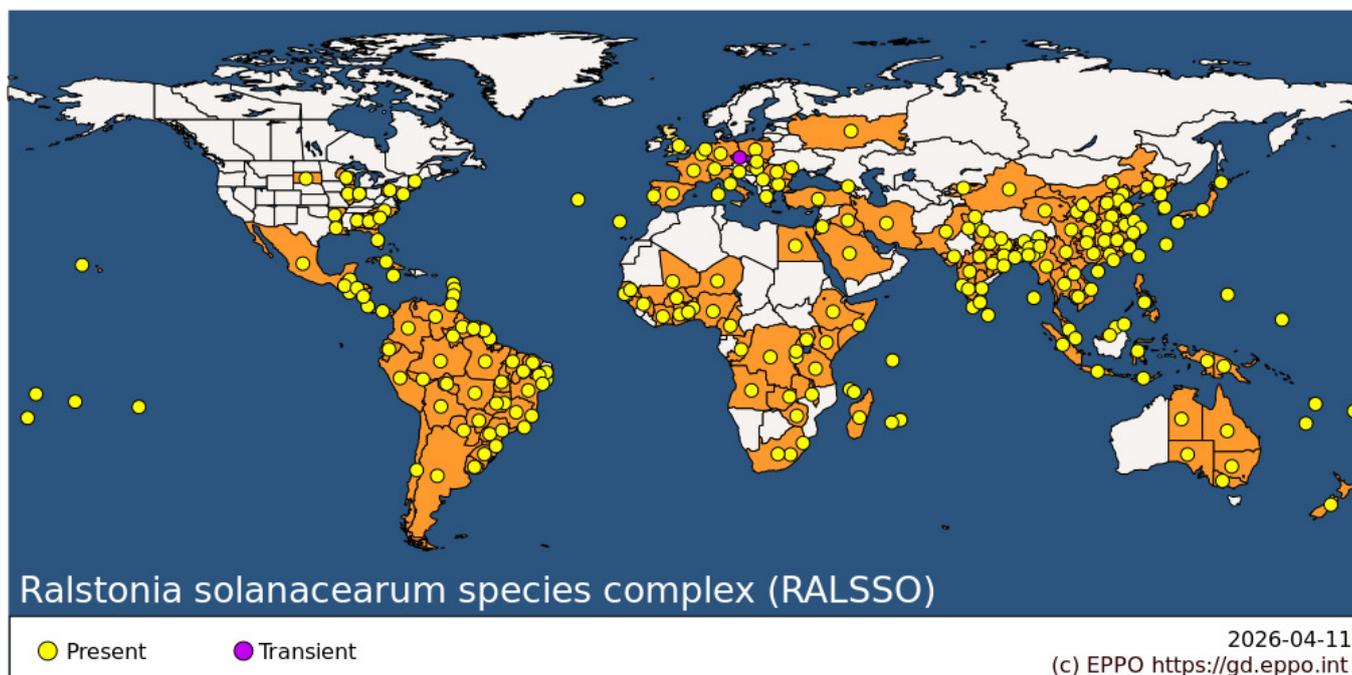
established within some river catchments in wild riparian plants (mainly *Solanum dulcamara*) and further spread occasionally to potato (*Solanum tuberosum*) crops and to a limited extent to tomato (*Solanum lycopersicum*) has been observed. A second sequevar of phylotype II (PIIA-50), which is widespread on potato in Brazil, has also been found on potato in one area of Portugal (Cruz *et al.*, 2012). Some strains of *R. pseudosolanacearum* have also occasionally been introduced into the EPPO region with ornamental/herbal plants or plant parts of tropical origin and have caused bacterial wilt disease under heated greenhouse conditions in temperate climates. These include *Curcuma longa* (turmeric), *Anthurium* spp., *Epipremnum pinnatum* and, more recently, *Rosa* spp. (Tjou-Tam-Sin *et al.*, 2016).

Host list: *Ageratum conyzoides*, *Amaranthus* sp., *Amomum compactum*, *Angelica keiskei*, *Annona squamosa*, *Anthurium andraeanum*, *Anthurium* sp., *Anthurium*, *Arachis hypogaea*, *Aralia cordata*, *Artemisia* sp., *Asclepias curassavica*, *Begonia hybrids*, *Begonia* sp., *Beta vulgaris* subsp. *vulgaris* var. *cicla*, *Bidens mitis*, *Bidens pilosa*, *Boehmeria nivea*, *Bougainvillea* sp., *Brassica oleracea*, *Campanula* sp., *Canna indica*, *Capsicum annuum*, *Capsicum frutescens*, *Capsicum pubescens*, *Casuarina equisetifolia*, *Cereus repandus*, *Cestrum nocturnum*, *Chaenostoma cordatum*, *Chenopodium album*, *Chrysanthemum* sp., *Cicer arietinum*, *Cichorium intybus*, *Citrullus lanatus*, *Cleome viscosa*, *Coleus amboinicus*, *Coleus barbatus*, *Coleus* sp., *Corchorus olitorius*, *Cosmos caudatus*, *Croton hirtus*, *Cucumis melo*, *Cucumis sativus*, *Cucurbita maxima*, *Cucurbita pepo*, *Curcuma alismatifolia*, *Curcuma aromatica*, *Curcuma longa*, *Curcuma zedoaria*, *Cyamopsis tetragonoloba*, *Cyphostemma mappia*, *Dahlia* sp., *Datura stramonium*, *Delphinium* sp., *Dimorphotheca ecklonis*, *Eleusine indica*, *Emilia sonchifolia*, *Ensete ventricosum*, *Epipremnum pinnatum*, *Eruca vesicaria* subsp. *sativa*, *Eucalyptus urophylla*, *Eucalyptus*, *Eupatorium cannabinum*, *Eustoma russellianum*, *Fagopyrum esculentum*, *Ficus carica*, *Fragaria x ananassa*, *Fuchsia* sp., *Galinsoga parviflora*, *Galinsoga quadriradiata*, *Gliricidia sepium*, *Grevillea striata*, *Hedychium coronarium*, *Helianthus* sp., *Heliconia*, *Hibiscus sabdariffa*, *Hibiscus* sp., *Hydrangea macrophylla*, *Hydrangea paniculata*, *Hydrangea* sp., *Hydrocotyle ranunculoides*, *Impatiens* sp., *Impatiens*, *Ipomoea aquatica*, *Ipomoea batatas*, *Justicia adhatoda*, *Kaempferia galanga*, *Kalanchoe* sp., *Lagenaria siceraria*, *Limonium* sp., *Ludwigia octovalvis*, *Luffa aegyptiaca*, *Mandevilla* sp., *Manihot esculenta*, *Maranta arundinacea*, *Marsypianthes chamaedrys*, *Momordica charantia*, *Morus alba*, *Musa* sp., *Musa x paradisiaca*, *Musa*, *Nicotiana tabacum*, *Olea europaea*, *Oxalis* sp., *Pandanus* sp., *Pelargonium x hortorum*, *Pelargonium*, *Peperomia pellucida*, *Perilla frutescens*, *Persicaria capitata*, *Persicaria pensylvanica*, *Petroselinum crispum*, *Phaseolus vulgaris*, *Physalis angulata*, *Piper dilatatum*, *Piper hispidum*, *Platostoma palustre*, *Plukenetia volubilis*, *Pogostemon cablin*, *Polygonum arenastrum*, *Portulaca oleracea*, *Psidium guajava*, *Raphanus sativus*, *Rosa*, *Salix gracilistyla*, *Salpiglossis sinuata*, *Senecio vulgaris*, *Sesamum indicum*, *Sesbania herbacea*, *Sesbania*, *Smallanthus sonchifolius*, *Solanum aethiopicum*, *Solanum americanum*, *Solanum betaceum*, *Solanum campylacanthum*, *Solanum capsicoides*, *Solanum carolinense*, *Solanum cinereum*, *Solanum dulcamara*, *Solanum incanum*, *Solanum lycopersicum*, *Solanum macrocarpon*, *Solanum melongena*, *Solanum muricatum*, *Solanum myriacanthum*, *Solanum nigrum*, *Solanum pseudocapsicum*, *Solanum sarrachoides*, *Solanum scabrum*, *Solanum sisymbriifolium*, *Solanum tuberosum*, *Solanum villosum* subsp. *miniatum*, *Solanum villosum*, *Soliva anthemifolia*, *Spigelia anthelmia*, *Strelitzia reginae*, *Symphytum officinale*, *Syzygium aromaticum*, *Syzygium samarangense*, *Tagetes* sp., *Tagetes*, *Talinum fruticosum*, *Urtica urens*, *Vaccinium corymbosum*, *Vaccinium membranaceum*, *Vicia faba*, *Vinca major*, *Xanthosoma* sp., *Zingiber mioga*, *Zingiber montanum*, *Zingiber officinale*, *Zingiber* sp., *Zinnia* sp.

GEOGRAPHICAL DISTRIBUTION

Within the *R. solanacearum* species complex, each phylotype is thought to have a different geographical origin. Phylotype I is regarded to be of Asian origin, Phylotype II of Central and South American Origin, Phylotype III of African origin and Phylotype IV of Indonesian origin. Whereas Phylotypes III and IV appear to have largely remained in their centres of origin, Phylotypes I and II have been dispersed worldwide. International transmission of distinct genotypes is likely to have occurred through trade in infected, often asymptomatic, vegetatively propagated crops (e.g. banana/plantain, potato and ginger) and ornamental host plants and plant parts). Specific maps for the different species of the RSSC complex is available in EPPO Global Database and a meta-analysis of the known global distribution and host range of the RSSC compiled at the University of California Davis (Lowe-Power *et al.*, 2021) has resulted in a database of phylotype and sequevar distribution, available at https://github.com/lowepowerlab/Ralstonia_Global_Diversity.

The worldwide reported distribution of the *R. solanacearum* species complex, is as follows:



EPPO Region: Belgium, Bulgaria, Czechia, France (mainland), Georgia, Germany, Greece (mainland), Hungary, Italy (mainland, Sardegna), Jordan, Kyrgyzstan, Moldova, Republic of, Netherlands, Poland, Portugal (mainland, Azores, Madeira), Romania, Russian Federation (Central Russia), Serbia, Slovakia, Slovenia, Spain (mainland), Switzerland, Türkiye, United Kingdom

Africa: Angola, Benin, Burkina Faso, Burundi, Cameroon, Comoros, Congo, Congo, The Democratic Republic of the, Cote d'Ivoire, Egypt, Eswatini, Ethiopia, Gambia, Ghana, Guinea, Kenya, Lesotho, Madagascar, Malawi, Mali, Mauritius, Mayotte, Niger, Nigeria, Reunion, Rwanda, Senegal, Seychelles, Somalia, South Africa, Tanzania, United Republic of, Togo, Uganda, Zambia, Zimbabwe

Asia: Bangladesh, Bhutan, Brunei Darussalam, Cambodia, China (Anhui, Beijing, Chongqing, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hainan, Hebei, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Jilin, Liaoning, Neimenggu, Ningxia, Qinghai, Shaanxi, Shandong, Shanghai, Shanxi, Sichuan, Xianggang (Hong Kong), Xinjiang, Yunnan, Zhejiang), India (Andaman and Nicobar Islands, Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Chhattisgarh, Goa, Gujarat, Himachal Pradesh, Jammu & Kashmir, Jharkand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Mizoram, Nagaland, Odisha, Punjab, Tamil Nadu, Tripura, Uttarakhand, Uttar Pradesh, West Bengal), Indonesia (Irian Jaya, Java, Nusa Tenggara, Sulawesi, Sumatra), Iran, Islamic Republic of, Iraq, Japan (Hokkaido, Honshu, Kyushu, Ryukyu Archipelago), Jordan, Korea, Democratic People's Republic of, Korea, Republic of, Kyrgyzstan, Lao People's Democratic Republic, Malaysia (Sabah, Sarawak, West), Myanmar, Nepal, Pakistan, Philippines, Saudi Arabia, Singapore, Sri Lanka, Taiwan, Thailand, Vietnam

North America: Mexico, United States of America (Alabama, Arkansas, Florida, Georgia, Hawaii, Illinois, Indiana, Louisiana, New Hampshire, New Jersey, North Carolina, Pennsylvania, South Carolina, South Dakota, Wisconsin)

Central America and Caribbean: Belize, Costa Rica, Cuba, El Salvador, Grenada, Guadeloupe, Guatemala, Honduras, Jamaica, Martinique, Nicaragua, Panama, Saint Vincent and the Grenadines, Trinidad and Tobago

South America: Argentina, Bolivia, Brazil (Acre, Alagoas, Amapa, Amazonas, Bahia, Ceara, Distrito Federal, Espirito Santo, Goias, Maranhao, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Para, Paraiba, Parana, Pernambuco, Piaui, Rio de Janeiro, Rio Grande do Sul, Rondonia, Roraima, Santa Catarina, Sao Paulo, Sergipe, Tocantins), Chile, Colombia, Ecuador, French Guiana, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela

Oceania: Australia (New South Wales, Northern Territory, Queensland, South Australia, Victoria), Cook Islands, Fiji, French Polynesia, Guam, Micronesia, Federated States of, New Caledonia, New Zealand, Papua New Guinea, Samoa, Tonga, Vanuatu

BIOLOGY

Although often described as soilborne, survival is usually short lived at low temperature in bare soil but is significant in alternative wild host plants (especially perennial nightshade species growing in waterlogged conditions or overwintering volunteers from susceptible crops) (Charkowski *et al.*, 2020). In Europe for example, infected riparian plants of *Solanum dulcamara* harbour *R. solanacearum* (strain PIIB-1) that can then spread to susceptible

potato and tomato crops when irrigated with contaminated surface water in the summer. *R. solanacearum* has been shown to survive in a viable but non-culturable (VBNC) form at low temperature, but the epidemiological relevance of this is unclear. Disease is usually most severe at temperatures of 24-35°C, although one strain (PIIB-1), which has spread with the movement of potato across the world, has a lower optimum growth temperature than other strains and is therefore more suited to temperate potato-growing climates. High soil moisture or periods of wet weather or rainy seasons are associated with high disease incidence. Entry into plants is usually through root injuries from where the bacteria move by colonization of the xylem. Blocking of the vessels by bacterial biofilm is considered to be the major cause of wilting. Disease severity generally increases if the bacteria are found in association with root nematodes. In tobacco and other crop hosts, nematode infestation changes the physiology of the plants, causing susceptibility to bacterial wilt (Chen, 1984). Several researchers have shown that the combined pathogenic effects of *Ralstonia* spp. and *Meloidogyne* spp. are greater than their independent effects (e.g. Sitaramaiah & Sinha, 1984; Kidane, 2019).

DETECTION AND IDENTIFICATION

Symptoms

In most hosts wilting is a common symptom of infection. The youngest leaves usually wilt first, with this symptom appearing at the warmest time of day. Wilting may be visible in only one stem, on one side of a plant or even sectoral in part of a leaf, depending where vascular infections occur (e.g. if they are restricted to sectors of stems and/or leaf petioles). Leaves may become bronzed or chlorotic and epinasty may occur. Wilting of the whole plant may follow rapidly if environmental conditions are favourable for pathogen growth. As the disease develops, a brown discoloration of the xylem vessels in the stem may be observed above the soil line and adventitious roots may develop. A creamy, slimy mass of bacteria exudes from vascular bundles when the stem is cut. Wilting and collapse of whole plants can lead to rapid death.

On potato

Foliar symptoms include rapid wilting of leaves and stems, usually first visible in single stems at the warmest time of day. Eventually, plants fail to recover and become yellow and then necrotic. As the disease develops, a streaky brown discoloration of the stem may be observed on stems above the soil line, and the leaves may have a bronze tint. Epinasty of the petioles may occur. A white, slimy mass of bacteria often exudes from vascular bundles which are cut or broken. If cut stem or tuber vascular tissue is placed in water, threads of bacterial ooze exude, distinguishing this from diseases caused by other wilting pathogens e.g. *Fusarium*, *Verticillium*, *Dickeya* and *Clavibacter*. This test is of presumptive diagnostic value in the field. Plants with foliar symptoms may bear healthy and diseased tubers, while plants that show no signs of the disease may sometimes produce infected tubers. On potato tubers, external symptoms may or may not be visible, depending on the state of development of the disease in relation to the prevailing temperature. Infection eventually results in bacterial ooze emerging from the eyes and stolon end of infected tubers. Soil may adhere to the tubers at the eyes. Cutting the diseased tuber reveals a browning and eventual necrosis of the vascular ring and immediately surrounding tissues up to 0.5 cm each side of the ring, starting from the stolon end. A creamy fluid exudate usually appears spontaneously on the vascular ring of the cut surface a few minutes after cutting. In the case of ring rot the tuber has to be squeezed in order to express a mass of yellowish dissolved vascular tissue and bacterial slime. Atypical symptoms on potato (necrotic spots on the epidermis), possibly caused after lenticel infection, have been described by Rodrigues-Neto *et al.* (1984).

On tomato, aubergine and *Capsicum* spp.

The youngest leaves are the first to be affected and have a flaccid appearance, usually this first occurs at the warmest time of day. Wilting of the whole plant may follow rapidly if environmental conditions are favourable for the pathogen. Under less favourable conditions, the disease develops less rapidly, stunting may occur, and large numbers of adventitious roots are produced on the stem. The vascular tissues of the stem show a brown discoloration and, if the stem is cut crosswise, drops of white or cream bacterial ooze may be visible.

On tobacco

One of the main symptoms is unilateral wilting and premature yellowing. Leaves on one side of the plant or even a

half leaf may show wilting symptoms. In severe cases, leaves wilt without changing colour and stay attached to the stem. As in tomato, the vascular tissues show a brown discoloration when cut open. The primary and secondary roots may become brown to black (Echandi, 1991).

On cucurbits

Symptoms on cucurbits, due to infection with the *R. solanacearum* PIIB-4NPB strain, develop rapidly from older to younger leaves that may wilt or not. Leaves turn yellow with necrotic lesions between or along major veins. Plants become flaccid and eventually collapse and die; there are no apparent symptoms on mature fruits (Wicker *et al.*, 2007).

On banana and plantain

Moko disease on AAA Cavendish banana or Bugtok disease on AAB type cooking banana, caused by some strains of *R. solanacearum* Phylotype II, first appears on young and fast-growing plants, the youngest leaves turn pale-green or yellow, and wilt. Within a week all leaves may collapse. Young suckers may be blackened, stunted or twisted. The pseudostems show brown vascular discoloration (Hayward, 1983). Moko disease is easily confused with Panama disease caused by *Fusarium oxysporum* f. sp. *cubense* Tropical race 4. A clear distinction is possible when fruits are affected: brown dry rot is seen only in the case of Moko disease

In Indonesia, mature leaves of banana plants with blood disease, caused by *R. syzygii* subsp. *celebesensis*, show a conspicuous transient yellowing, followed by loss of turgor, desiccation and necrosis. In mature plants, the base of the petiole collapses, causing wilted leaves to hang down around the pseudostem. The youngest leaves cease to emerge and develop whitish and later necrotic panels in the lamina. Daughter suckers may show general wilting, but infection is not always systemic and healthy suckers are sometimes produced. Internally, vascular bundles exhibit a reddish-brown discoloration which, depending on the mode of infection, may extend throughout the plant or may be confined to the central fruit stem. If kept moist, cut vascular tissues exude droplets of bacterial ooze which can vary in colour from white to reddish-brown or black. Blackening and shrivelling of male flowers is frequently found in mature plants, indicating that infection occurs via inflorescences and is transmitted by insects in a similar way to Moko disease. Where this occurs, dieback may extend into the lower fruit bunches, but remaining fruits, and often the whole raceme, may appear outwardly healthy. Internally, fruits in all bunches are usually uniformly discoloured reddish-brown and rotten.

On ornamental hosts

Most ornamentals exhibit typical wilting symptoms as described above. Symptoms observed on ornamentals under glasshouse conditions in the EPPO region are described here.

The first symptoms caused by *R. solanacearum* PIIB-1 on *Pelargonium* (geranium) are wilting and subsequent chlorosis (often sectorial yellowing) of leaves. Stems may blacken and eventually become necrotic. Internally, vascular browning is often visible. Leaves later become brown and necrotic as the whole plant desiccates, collapses and dies.

Symptoms due to *R. pseudosolanacearum* infections include the following:

On *Curcuma longa*, the first symptoms are wilting and subsequent chlorosis of leaves. Stems, including the flower stems (stalks), may acquire a brownish to black discoloration and become necrotic. Similar symptoms may be seen in the roots, including the rhizomes, of the plant. Internal vascular browning is often visible. Under favourable environmental conditions, wilting of the whole plant may follow rapidly.

On *Anthurium*, greasy, water-soaked lesions (on the lower leaf surface) turn necrotic with greasy margins (on the upper leaf surface). When the disease becomes systemic, these lesions (generally originating from the insertion point of the leaf with the petiole) develop following the main and secondary veins in a full or partial glove-shape. External infections (disseminated by water) may develop from any natural opening such as hydathodes. Leaves may turn yellow depending on the severity of the systemic invasion, and the stem may rot with abundant bacterial ooze. The plant eventually collapses and dies.

On *Rosa* spp., initial wilting of young shoots and flower stalks is followed by yellowing and early abscission of leaves, stunting, dieback with black necrosis of pruned branches, and in some cases purulent discharge of creamy white slime on cut wounds in the stem. Typical symptoms following heavy infections include necrosis of the stems and intense brown discoloration at the stem base (Tjou-Tam-Sinet *et al.*, 2016).

Morphology

Gram-negative rods with a polar tuft of flagella, non-fluorescent, but diffusible brown pigment often produced. Virulent isolates develop pearly (opalescent) cream-white, flat, irregular and fluidal colonies often with characteristic whorls in the centre, which characteristically stain blood red on media containing tetrazolium. A small, fluidal and round (SFR) colony-forming type is described amongst insect-transmitted Moko disease strains. Avirulent isolates form small round non-fluidal, butyrous colonies. See also Lelliott & Stead (1987) and Saddler (1994).

Detection and inspection methods

EPPO Standard PM 7/21 describes sampling methods, screening and identification tests for inspection and detection of the *R. solanacearum* species complex relevant for symptomatic and asymptomatic plant samples, and water samples. For field diagnosis from symptomatic tissues, bacterial slime oozing into clean water (as described above) is a simple test and lateral flow serological tests are commercially available. Suspected infections should be confirmed by laboratory testing. For testing asymptomatic plant material, it is advised to bulk sample and prepare extracts of vascular tissues from up to 200 stem base pieces, or in the case of potato tubers, up to 200 tissue cores from the heel ends at the point of stolon attachment. A range of screening tests are available that include isolation on semi selective and selective media, immunofluorescence microscopy (EPPO Standard PM 7/97) and a range of DNA-based tests that include conventional PCR, real-time PCR and LAMP tests. It is recommended to use more than one screening test to safeguard against false positive and false negative results. These tests can also be used to confirm the identity of bacterial colonies isolated on agar media. It may also be useful to conduct a pathogenicity test on a susceptible host, especially if the pathogen is found in a location for the first time. For accurate pathogen identification, phylotypes and sequevars are differentiated by DNA sequencing of 16S rRNA, *egl*, *mutS* and *hrpB* barcodes. Conventional PCR (Opina *et al.*, 1997) or TaqMan qPCR (Weller *et al.*, 2000) tests universally identify strains in all phylotypes whereas multiplex PCR tests identify each individual phylotype (Fegan and Prior, 2005) or host-specific strains within phylotypes (e.g. Cellier *et al.*, 2015). See EPPO Standard PM 7/21 for detailed information on the available tests.

PATHWAYS FOR MOVEMENT

The main pathway for international spread is via infected vegetative propagating material (e.g. seed potatoes, rhizomes of ginger and turmeric, banana suckers) as well as ornamental plants for planting. Asymptomatic (latent) infections, which escape visual inspections, are common at low temperatures when the rates of infection and colonization are slower, allowing host resistance mechanisms to be more effective. Latent infections also tend to occur in tolerant varieties.

Once infections are established, local spread can occur when the bacteria are transmitted mechanically during pruning operations or when cuttings are taken for propagation. Spread to neighbouring plants can also occur through soil drainage water and by root contact. The bacteria also spread through surface water. For example, many outbreaks of potato brown rot in Europe have been associated with spread from infected riparian *Solanum dulcamara* growing with roots in surface water which has then been used to irrigate potato or tomato crops. It is thought that initial infections of the *S. dulcamara* occurred when waste from imported ware potatoes with latent infections survived or bypassed sewage treatment, leading to contamination of watercourses inhabited by the wild host.

Within the RSSC complex natural infection of true seed has only been established for *R. pseudosolanacearum* in peanut (*Arachis hypogaea*) in Indonesia and China (Zhang *et al.*, 1993). There have been findings of contaminated seed of other hosts (including tomato, Capsicum, aubergine and soybean) although seed infection and transmission has not been substantiated. At present, transmission through water, soil or movement of infected vegetative plant parts is considered to be more important for most host plants than transmission via true seed.

Some strains of *R. solanacearum* which cause Moko disease and strains of *R. syzygii*, which cause blood disease of banana and Sumatra disease of clove are transmitted by insects (including pollinating flies, bees, wasps and thrips on banana and xylem-feeding spittlebugs of *Hindola* spp. on clove) with potential for rapid spread over several kilometres.

PEST SIGNIFICANCE

Economic impact

R. solanacearum constitutes a serious obstacle to the culture and export of many crops in both tropical and temperate regions. Recently ranked by international phytobacteriologists as the second most important of all plant pathogenic bacteria after *Pseudomonas syringae* (Mansfield *et al.*, 2012), the *Ralstonia* spp. have an extremely wide geographic distribution and host range. On potato alone, it is thought to be responsible for approximately 1 billion USD in losses each year, affecting some 3 million farmers and their families over 1.5 million ha in around 80 countries (Elphinstone, 2005). Moko disease has affected banana and plantain over thousands of km² in Central and South America, particularly affecting small scale subsistence farmers. Also, in Indonesia and the Philippines, *Ralstonia* spp. have caused considerable hardship to both subsistence and cash economies, where banana is a major, low input, staple source of carbohydrate, vitamins and minerals for countless communities. In many countries in which the pathogen has quarantine status, important losses result from regulatory eradication measures and restrictions introduced on further production on infested land.

Control

Disease management remains limited and is hampered by the faculty of the pathogen to survive for years in wet environments on plant debris or in asymptomatic weed hosts, which act as inoculum reservoirs. In the absence of any curative chemical control methods, prevention of bacterial wilt largely relies on the availability of pathogen-free planting material and effective surveillance and monitoring to protect areas which are free from the bacteria. For potato, effective disease management mainly relies on the use of limited generation seed multiplication from pathogen-free nuclear stocks with zero tolerance for the disease in official seed certification. Regular post-harvest testing of seed potato tubers is usually also necessary to avoid distribution of latent infections. Similarly, for other vegetatively propagated crops, there is a need to ensure planting material has been tested and found to be free of infection and that there are restrictions on the movement of planting material from affected to disease-free areas.

The effectiveness of strict regulatory control within Europe has been reviewed (EFSA, 2019). In relation to potato brown rot outbreaks, use of healthy (tested) seed potatoes, early and accurate detection and reporting of the pathogen, quarantine measures on infected fields and farms, rotation with non-host crops for at least two years, control of weed hosts and volunteer plants (and in some cases of nematodes), prohibition of the use of contaminated surface water for irrigation, and education are key factors in control of *R. solanacearum* (EPPO Standard PM 9/3). For hydroponic glasshouse production systems, disinfection of recirculating water (e.g. using chlorine dioxide) can prevent spread of any introduced bacteria. These approaches have effectively halted international spread of *R. solanacearum* in geranium cuttings produced in Central America and East Africa for export to USA and Europe (Janse *et al.*, 2004; USDA-APHIS, 2004).

For countries where the pathogen is widespread, various approaches to reduce disease impact through integrated cultural and biological control strategies have been reviewed (Yuliar *et al.* 2015). Disinfection of pruning and harvesting tools, e.g. using 20% solution of household bleach (3.5 % sodium hypochlorite) or less corrosive ammonia-based disinfectants, is important in preventing spread of disease e.g. in banana and plantain production. Insect transmission of Moko and banana blood diseases in commercial banana production has been successfully reduced by the now widespread practices of early male bud removal and/or bagging of the emerging florescence (Blomme *et al.*, 2017). Hot-air treatment of ginger roots for 30 min at 50°C is reported to successfully remove viable infections (Tsang and Shintaku, 1998). Drying of peanut seeds to <10% water content has significantly reduced seedborne infection (Zhang *et al.*, 1993). Although resistant varieties have been reported for some hosts (e.g. peanut, tobacco, tomato, aubergine) their widespread use is hampered by the broad diversity of the pathogenic strains and the difficulty of introducing resistance from related wild species without losing commercial yield and quality

requirements. It is hoped that modern breeding methods will help to increase future availability of acceptable resistant varieties for the wide range of host crops (Huet, 2014).

Phytosanitary risk

R. syzygii, *R. solanacearum* and *R. pseudosolanacearum* are quarantine organisms in many countries. The occurrence around the world of different strains of the pathogen presents an ongoing risk of the introduction of new variants capable of affecting potato and tomato production in the EPPO region. Absence of the bacteria is an important consideration for countries and pest free areas exporting seed potatoes.

The PIIB-1 strain of *R. solanacearum* (formerly known as race 3 biovar 2) causing potato brown rot has a lower growth temperature optimum than other strains and appears to present the most important risk for the wider EPPO region. There is a definite risk that it could spread through imports of (latently) infected seed potatoes from countries where the disease now occurs. Furthermore, introduction of *R. solanacearum* by use of (latently) infected potatoes for table consumption, use as cattle fodder or for industrial processing is a potential risk if the potatoes, or wastes derived from them, are reintroduced into the agricultural system. Natural spread may take place if the bacteria are introduced via discharge of poorly or non-treated wastes into surface water, which is then used to irrigate susceptible crops. The PIIB-1 strain of *R. solanacearum* has been previously introduced into the EPPO region in infected geranium plants for planting originating in Eastern Africa and Central America. Increased stringency of phytosanitary measures during production of the young geranium plants appears to have eliminated this risk.

Hosts other than potato are most likely to be affected in the warmer parts of the EPPO region, or under heated glasshouse conditions. There are already several examples of *R. pseudosolanacearum* being introduced into the EPPO region in traded ornamentals. These strains are unlikely to establish outside of protected glasshouse environments in temperate areas but may pose a higher risk in the warmer southern regions. Banana-infecting strains of the species complex are not found in the banana-producing areas of the southern Mediterranean zone. A particular variant of the banana infecting strain PIIB-4 of *R. solanacearum* (named PIIB-4NPB), is not pathogenic on banana but has been shown to infect cucurbits and Anthurium in Martinique and is also pathogenic on tomato, pepper, aubergine, *Impatiens hawkeri*, *Heliconia caribaea* and some weeds. This strain is also present in Brazil, Costa Rica, French Guiana and Trinidad and presents a potential risk if spread to the EPPO region in imported ornamentals (Wicker *et al.*, 2007). Similarly, *R. syzygii* subsp. *indonesiensis* has a wide host range including solanaceous crops and could present a risk if accidentally imported into the EPPO region (Safni *et al.*, 2014).

PHYTOSANITARY MEASURES

EPPO Standard PM 9/3 (under revision) describes a national regulatory control system for *Ralstonia solanacearum* species complex that provides guidance on surveillance for the pathogen and its containment and eradication if found with a focus on potato. Seed potato tubers, and other plants for planting of known hosts, should have been grown in areas found free from strains of the *R. solanacearum* species complex during the growing season and during the previous two growing seasons. Since *R. solanacearum* can also contaminate water courses, the irrigation of host plants with water from contaminated waterways should be prohibited.

Visual inspections should be performed routinely upon export and import of known host plants for planting. Laboratory checks are necessary to detect asymptomatic (latent) infections. EPPO Standard PM 8/1 recommends the phytosanitary measures which EPPO countries should use or require for seed and ware potatoes moving in international trade to prevent the introduction and spread of *Ralstonia* and other quarantine pests. PM 3/21 *Post entry quarantine for potato* describes inspection and tests for the detection of pests (including *R. solanacearum*) infecting *Solanum* species or hybrids imported for germplasm conservation, breeding or research purposes, in post-entry quarantine. Plants for planting of *Musa* spp. and other host plants may be placed in post-entry quarantine to observe any symptoms and if relevant to test them to ensure their freedom from the *R. solanacearum* species complex.

Measures for seed are usually not needed except for peanut.

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ACKNOWLEDGEMENTS

This datasheet was prepared in 2021 by John Elphinstone, Fera Science Limited, UK. His valuable contribution is gratefully acknowledged.

How to cite this datasheet?

EPPO (2026) *Ralstonia solanacearum* species complex. EPPO datasheets on pests recommended for regulation.

Available online. <https://gd.eppo.int>

Datasheet history

This datasheet was first published in the EPPO Bulletin in 1978 and revised in the two editions of 'Quarantine Pests for Europe' in 1992 and 1997, as well as in 2021. It is now maintained in an electronic format in the EPPO Global Database. The sections on Identity; Hosts and Geographical distribution are automatically updated from the database. For other sections, the date of last revision is indicated on the right.

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Co-funded by the
European Union