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Potato blackleg and soft rot diseases caused by *Pectobacterium* spp and *Dickeya dianthicola*: A review

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Abstract
Solanum tuberosum is the fourth main food crop in the world after rice (*Oryza sativa*), maize (*Zea mays*) and wheat (*Triticum aestivum*). The bacteria causing blackleg, which affect the growing plant and results in tuber soft rot of potato, are part of a disease complex that includes *Pectobacterium* spp. and *Dickeya* spp. Blackleg is characterized by stunted, yellowish foliage that has a stiff, upright habit. Management (Seed Quality and Certification, Biological Control, Resistant Cultivars and Chemical Control with Pesticides and cultural (Sanitation, Crop Rotation, Seed Treatment, Irrigation, Fertilization, Harvest, Sprout Inhibitors and Storage) methods apply for disease management.

Keywords: *Solanum tuberosum*, *Pectobacterium*, *Dickeya*, lesion, blackleg and soft rot

Introduction
Potato, (*Solanum tuberosum*) is an annual plant of family (*Solanaceae*), grown for its starchy edible tubers which is the fourth main food crop in the world after rice (*Oryza sativa*), maize (*Zea mays*) and wheat (*Triticum aestivum*), in terms of both area cultivated and total production (Douches *et al.*, 1996) [11]. Potato produces more carbohydrate per acre per year than any other crop except sugarcane. It has a higher quality protein than any other vegetable, and only soybean yields more protein per acre (Rhoades, 1982; Ortiz, 1998) [39, 29]. The potato has historically contributed to food and nutrition security in the world (Yuan, 2003; FAOSTAT, 2015; FAO, 2015) [50, 17, 17]. Western South America is the primary center of the origin of the potato and its wild relatives (Haan, 2016) [20]. The potato was introduced in India from Europe in early 17th century, only 40 years after introduction in Europe by Portuguese (Reddy, 2018) [38]. The major potato producing states are Uttar Pradesh, West Bengal, Bihar, Gujarat, Madhya Pradesh, Punjab, Haryana, Assam, Jharkhand and Chhattisgarh. The estimated production of potato during the year 2018-19 was 52.588mt and productivity was 23.07 Tones/ha. Area covered by potato was 20.85 lakh ha (Horticulture Division, Ministry of Agriculture). The relationship between plant diversity, ecological stability and ecosystem productivity is of great importance to natural systems. Plant pathogens alter such relationships by affecting plant fitness, reducing the growth and competitive ability of diseased plants which can impact heavily upon plant population and community structure (Burdon, Thrall & Ericson 2006; Bradley, Gilbert & Martiny 2008; Maron *et al*. 2011; Latz *et al*. 2012) [5, 4, 27, 24].

General information
Blackleg and Soft Rot are caused by bacteria belonging to the *Pectobacterium* and *Dickeya* genera (Pérombelon & Kelman, 1980; Pérombelon, 2002) [36, 35]. *Pectobacterium* and *Dickeya* genera belong to the genus *Erwinia* (*E. carotovora* subsp. *carotovora*, *E. carotovora* subsp. *atroseptica* and *E. chrysanthemi*) (Dye, 1969) [13]. Their production of pectolytic enzymes cause a wet, mushy rot of tissues they infect. Pectolytic enzymes dissolve the middle lamella, composed of pectin, which holds plant cells together. They characteristically produce a variety of cell-wall-degrading enzymes that allow infiltration and maceration of plant tissues on which they feed (Barras *et al.*, 1994) [3]. Different aspects of blackleg and tuber soft rot and their pathogens have been reviewed during last 40 years. Some scientists has focused on taxonomy (Graham, 1964; Dye, 1969; Hauben *et al.*, 1998; Samson *et al.*, 2005) [19, 13, 22, 41] while some has focused on ecological and epidemiological characteristics

(Starr & Chatterjee, 1972; Pérombelon & Kelman, 1980; Pérombelon & Salmond, 1995; Pérombelon, 2002; Toth *et al.*, 2011) [43, 36, 31, 35, 46]. Pérombelon, 1982, 2002 [35]; Stanghellini, 1982 [42]; Barras *et al.*, 1994 [3]; Hugouvieux-Cotte-Pattat *et al.*, 1996 [23]; De Boer, 2003 [9] has worked on pathogenesis and regulation of extracellular enzyme synthesis. Robert-Baudouy, 1991 [40] focused on genetics and molecular biology while Toth *et al.*, 2003, 2006 [44, 45] has worked on comparative genomics of pectinolytic bacteria. Lyon, 1989 [26] has worked on the biochemical basis of resistance of potato to blackleg and soft rot.

Symptoms and spread

Blackleg of potato plants and soft rot of tubers are widely distributed diseases that are especially harmful in humid climates which affects the growing plant and the tuber soft rot of potato (van der Wolf & De Boer, 2007) [49]. Blackleg of potato plants and soft rot of tubers are widely distributed diseases in wet soil and relatively low, (18-19°C) temperatures and higher temperatures 25-30°C, respectively (Oliveira *et al*., 2003) [28]. Temperature plays a critical role in mother-tuber rotting; it has been demonstrated that *Pectobacterium* spp. grow better and are more pathogenic at lower temperatures (<25°C) compared to *Dickeya* spp. (>25°C) (Pérombelon, 1980; du Raan, 2016; Elphinstone, 1987; Pérombelon, 1987) [36, 12, 15, 34]. Blackleg disease sometimes develops early in the growing season soon after the plants emerge. Blackleg is characterized by stunted, yellowish foliage that has a stiff, upright habit. The lower part of the belowground stem of such plants is dark brown to black in color and extensively decayed. In wet conditions, the most characteristic symptom of potato blackleg is a slimy, wet, black rot lesion spreading from the rotting mother tuber up the stems while in dry conditions, symptoms show to be stunting, yellowing, wilting and desiccation of stems and leaves (Pérombelon & Kelman, 1980) [36]. Under wet conditions, Tuber soft rot is initiated at lenticels, the stolon end and/or in wounds. The lesion can spread to the whole tuber and thence to neighbouring tubers in storage. Tuber tissue is macerated to a creamy consistence which turns black in the presence of air, developing an evil smell when invaded by secondary organisms. When seed tubers start rotting in the field before emergence, blanking occurs. Depending on environmental conditions such as soil temperature, moisture and pH, survival of soft rot bacteria in soil is restricted to 1 week to 6 months. The bacteria cannot survive in the soil in a crop rotation system of 3–8 years (Anilkumar & Chakravarti, 1970; Rangarajan & Chakravarti, 1970; Lim, 1975; Pérombelon & Hyman, 1988) [2, 25, 30]. Blackleg disease spread from latently infected seed tubers, when seed tubers rots, the bacteria are released into the soil and are transmitted by soil water to contaminate neighbouring progeny tubers (Pérombelon, 1974) [32]. The bacteria in soil can also colonize potato roots and subsequently move via the vascular system into progeny tubers. Once in the stems, the bacteria do not necessarily cause stem rot (blackleg) and can survive in latent form. (Czajkowski *et al.* (2010) [8]. Graham, 1976 [18]; Pérombelon *et al.*, 1979 [33]; Harrison *et al.*, 1987 [21]; showed that Crop contamination can also occur from airborne sources.

Disease management

Disease control measures are based on avoiding tuber contamination by cultural means (early harvesting), reducing tuber contamination level (dry storage and hot water treatment) and planting 'clean' seed identified by quantifying tuber contamination rather than by visual crop inspection. Finally, recently identified highly resistant, even under anaerobic conditions, wild *Solanum spp.* could be used to breed for resistant cultivars by conventional methods or by genetic engineering. El-Naggar, *et al*, (2016) [14] were study to evaluate the role of four bio agents *(P. fluorescens, B. subtilis, T. harzianum and T. viride)* in the management potato soft rot disease either in field production or during storage. In the in vivo tests, using the method of "slices of potato" bacterial and fungal bio-control agents protected potato slices from the development of soft rot and reduced the amount of tissue maceration. In field experiment, tuber pieces coating before sowing with compost amended with *B. subtilis* followed by foliage spraying with *B. subtilis* suspension at 46, 60 and 80 days after planting, protected the potato tuber against soft rot disease, where the percentage of soft rot incidence were 4.5 and 4.0%, comparing with the incidence of 23.5 and 25.2% in untreated plants, during the first and the second seasons, respectively. Revealed that three different antagonistic bacterial isolates, *Pseudomonas fluoresces* (Pf2), *Bacillus subtilis(Bs3)* and *Rahnella acquatilis* (Ra39) restricted the growth of *Pectobacterium atrosepticum,* the causal agent of black leg disease of potato, in vitro. Under greenhouse and field conditions, potato plants pre-treated with the three antagonistic bacterial isolates, individually or in combination, showed reduced disease severity relative to non-treated control plants. All isolates produced siderophores in different degrees but did not produce indole acetic acid (IAA) or hydrogen cyanide (HCN).The obtained results indicated that combination of *Pseudomonas fluoresces* (Pf2), *Bacillus subtilis* (Bs3) and *Rahnella acquatilis* (Ra39) is beneficial in controlling black leg disease of potato caused by *Pectobacterium atrosepticum.* Alptekin (2011) [1] concluded from his study that disease management includes regular inspection for healthy seed or nursery, crop production, correct identification of the problem, cultural practices (crop rotation, sanitation etc.), biological control, soil fumigation, seed or nursery stock treatment and disinfestations of cutting tools. Crépin *et al*, (2011) [7] concluded from the bio-control method (*Rhodococcus* bacteria) has been applied for the first time for the control of *Pectobacterium atrosepticum. Rhodococcus* bacteria have the ability to disrupt the quorum sensing-based communication of *P. atrosepticum* by degrading N-acylhomoserine lactone signaling molecules and prevent disease.

Management Methods

Seed quality and certification: Stem cutting and micro-propagation techniques have been developed to obtain pest-free potato plants for propagation and production of certified seed tubers.

Biological control: Bacteria antagonistic to Erwinia caratovora are being developed as seed piece treatments for reducing seed piece decay and blackleg. Among rhizobacteria Agrobacterium radiobacter, Bacillus subtilus and Pseudomonas spp. are antagonistic to potato cyst nematodes

Resistant cultivars: Plant breeding is one of the most powerful tools avail- able for both the management of pests and the production of the best crop. Resistance to insect pests is being investigated.

Chemical control with pesticides: Properly used, pesticides can provide economical protection from pests that otherwise would cause significant losses.

Cultural practices

Sanitation: Sanitation is essential to the prevention of seed piece infection during cutting and handling, and prevention of spread of the pathogens in contaminated soil, water, and field equipment.

Crop Rotation: Proper crop rotations enhance soil fertility, maintain soil structure, reduce certain pest problems, increase soil organic matter, and conserve soil moisture.

Seed Treatment: Seed piece decay frequently involves a Fusarium fungus acting synergistically with bacteria. Therefore, chemical seed treatments, which primarily act as fungicides, are useful when conditions favour development of Fusarium on seed pieces.

Irrigation: Availability of soil water is a major factor that determines yield and quality of the potato crop. Too little water will reduce yields, induce tuber malformations, or increase severity of scab or Verticillium with symptoms.

Fertilization: Adequate nutrient availability throughout the growing season is necessary for the best yield and quality. Excess fertilizer delays the onset of tuber growth in indeterminate cultivars and may reduce their yields; tuber decay after harvest may also be increased and processing qualities such as specific gravity may be lowered.

Harvest: Before harvest, the infected vines must be killed with chemicals to destroy late blight inoculum that could be in contact with the tubers when they are dug up.

Sprout Inhibitors: Sprout inhibitors should be applied to fresh market or processing potato tubers that are to be stored for more than 2 to 3 months. Low storage temperature cannot be used to prevent sprouting without undesirable accumulation of sugars.

Storage: A large part of the crop in most growing areas is stored for fresh market or processing during the winter and spring.

Conclusion

Solanum tuberosum is the main crop food after cereal crops. The bacteria causing blackleg, which affect the growing plant and results in tuber soft rot of potato, are part of a disease complex that includes *Pectobacterium* spp. and *Dickeya* spp. Integrated pest management of potatoes includes regular inspection for healthy seed or nursery, crop production, correct identification of the problem, cultural practices (Crop rotation, sanitation etc.), biological control, soil fumigation, seed or nursery stock treatment and disinfestations of cutting tools.

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