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Editorial

Genomic Discoveries Advance the Battle against Black Rot in Crucifers

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EDITORIAL

Xanthomonas campestris pv. *campestris*, the explanation for disease of crucifers, was one of the first bacterial plant pathogens ever identified. Over 130 years later, disease remains a threat to cabbage, cauliflower, and other Brassica crops around the world. Recent genomic and genetic data are informing our understanding of *X. campestris* taxonomy, dissemination, inoculum sources, and virulence factors. This new knowledge promises to positively impact resistance breeding of Brassica varieties and management of inoculum sources.

X. campestris, a historical foe

Bacteria of the *Xanthomonas* cause an array of diseases on over 300 plant species. *Xanthomonas campestris* pv. campestris (Xcc), the cause of plant disease of Brassicaceae, was one among the primary identified plant pathogenic bacteria, described by Harrison Garman in 1889 in Kentucky, USA. Garman determined that a disease of cabbages causing "brown watery lesions" appearing in times of high rainfall and humidity was caused by a bacterium. Erwin Smith further described the disease and studied control methods within the years following its discovery. Smith used Xcc as a central example during heated debates with Alfred Fischer between 1897 and 1901 on whether bacteria could cause disease.

Through quite a century of research, taxonomy, modes of pathogen transmission and virulence are described supported observations of pathogenicity on crops and survival in weeds, soil, and seeds. Despite the rich history of Xcc research, effective control of plant disease remains elusive. Recent advances in genetic characterization and next generation whole genome sequencing have enabled more conclusive determination of the connection of Xcc to other Xc pathovars, better understanding of the distribution and sources of Xcc inoculum, and characterization of Xcc virulence factors. Beginning with an summary of the disease and a snapshot of the currently available genome sequences for Xc, this review summarizes these recent advances, and highlights prospects for improved control of plant disease.

Symptoms, diagnosis, and control of plant disease

Black rot symptoms include V-shaped lesions originating from bacterial points of entry at hydathodes or wounds. Xcc travels through the plant vasculature leaving a trail of blackened veins that the disease gets its name. In severe cases, Xcc can travel systemically through the plant to succeed in plant tissue within the head, leading to discolored, unmarketable cabbage susceptible to secondary infection during storage. Xcc typically enters through hydathodes as overnight guttation fluid is drawn back to the plant within the morning hours. It's going to also enter through wounds, from the leaf surface or in rain splash. Unlike many other bacterial pathogens, Xcc cannot infect through stomates. There's evidence that Xcc can cause a hypersensitive response (HR) at stomates which may limit further ingress of the pathogen. it's alternatively possible that the power of stomates to shut in response to a pathogen limits entry of Xcc; hydathodes haven't been found to undergo this pre-invasive immune reaction . Other barriers, including incompatibility with the mesophyll environment, may additionally play a task (Laurent Noël, personal communication).

Xcc is primarily seed-dispersed; one infected seed in 10,000 can cause a plague within the field. Cabbage seeds are typically started in high-density transplant facilities with overhead watering, which may end in extensive bacterial spread. Germinating seed contaminated with Xcc will often remain asymptomatic under greenhouse conditions. Yet, when these infected seedlings are moved to the sector, they become sources of secondary inoculum later within the season.

Black rot is often diagnosed visually supported lesions and blackened veins. The presence of the pathogen are often confirmed by using PCR or by plating tissue or seed extracts on MCS20ABN, FS, or YDC media. Control measures for plant disease are limited, but include copper application, crop rotation, removal of crop debris and cruciferous weeds, seed treatment, and using pathogen-free seed. Planting tolerant varieties is suggested, but not always practiced thanks to varietal preference among growers and a scarcity of obtainable tolerance in certain brassicas. There are not any identified major genes for plant disease resistance in commercial cole crops. Progress

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and challenges in Brassicaceae resistance breeding are reviewed. As black rot-resistant cabbage remains elusive in traditional breeding, it's important to realize a greater understanding of the worldwide spread, sources of inoculum, and virulence mechanisms of Xcc to assist growers make educated choices to limit disease impact within the field and to enable breeders to follow targeted strategies to supply more resistant Brassica varieties. As temperatures rise and weather patterns change, it's been hypothesized that bacterial diseases, including those caused by Xanthomonads, will emerge or re-emerge more intensely even in previously disease-free areas, increasing the necessity for sustainable control strategies.