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LESSONS LEARNED OVER A CAREER ABOUT VEGETABLE DISEASES, MANAGEMENT AND FUNGICIDE RESISTANCE

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'Change', 'unexpected', 'rewarding', and 'satisfying' are the main words that come to mind when I think about my career as a vegetable pathologist with a research/extension appointment. My entire career has been with Cornell University located on Long Island in one of the most important agricultural counties in New York based on value of production. I started in July 1988 right after obtaining my PhD from Penn State. Over the 34 years there have been a lot of changes in pathogens, diseases, and their management. Observed changes in pathogens have mostly been the result of evolution. There has been much more change than I would have expected over the relatively short time period of a career when I started. Many of the lessons learned pertain to these changes and can be summarized as "expect the unexpected", which is expected to continue! The need for monitoring occurrence of resistance in the cucurbit powdery mildew pathogen and detecting development of resistance to additional fungicide chemistry – needed to be able to develop sound fungicide recommendations – has continued throughout my career. This research was initiated because pumpkin growers on Long Island were experiencing control failure with the targeted fungicide being used when I started. My feeling that my research/extension program has been worthwhile and successful comes from the statements of gratitude I have received from growers, extension specialists and other stakeholders when I've diagnosed a disease, answered a question, given a presentation they appreciated, etc. It has also been rewarding and satisfying to receive acknowledgement of my accomplishments from my scientist colleagues, but not quite as rewarding as when I hear from stakeholders.

Several changes in pathogens during my career lead to change in disease occurrence and a need to promptly change priorities and focus on getting information to growers. Descriptions of the most important are below. For a pathologist, these changes have been scientifically fascinating. Hard not to be amazed by pathogens' ability to evolve while focused on trying to help growers.

Cucurbit downy mildew. In 2004, this disease that had been occurring sporadically and thus was of minor importance, started occurring regularly throughout the eastern U.S. and potentially causing major impact on yield and fruit quality when not managed. Before 2004, this disease was being very effectively managed by genetic resistance that had been bred into cucumber and by two targeted fungicides, Ridomil and Quadris. Re-emergence of downy mildew was due to a change in the pathogen such that it was no longer able to be effectively managed by the resistant varieties or these fungicides. Downy mildew has remained an important disease of cucurbit crops. Today it is effectively managed with new resistant varieties, new targeted fungicides, and a monitoring/forecasting program to guide when fungicide applications are warranted. The pathogen has continued to change, developing resistance to additional fungicides. And it should be expected to continue to change, potentially developing resistance to more fungicides and over-coming genetic resistance. An additional concern is for the two mating types to start to occur together routinely – they now occur dominantly on different cucurbit types – especially in northern states, because this will enable the pathogen to produce oospores which can survive over winter, thereby enabling earlier onset of downy mildew in addition to more opportunity for change in the pathogen because oospores are produced through sexual reproduction.

Phytophthora blight. This was a new disease on Long Island during the start of my career. In 2008 *Phytophthora capsici* was found infecting snap beans in New York, which was five years after blight was first reported on this new host in Michigan. This was an extremely unexpected host range expansion for a pathogen because beans are not related to the pathogen's other hosts (cucurbits, pepper, eggplant, tomato), and this host range is somewhat narrow. Fortunately, Phytophthora blight has rarely re-occurred on beans.

Basil downy mildew. This disease has occurred routinely and remained the most important constraint to basil production in the northeast since 2008 when it was first observed there. It was first detected in the U.S. in fall 2007 in Florida and before that there were several first reports elsewhere in the world during the 2000s. Prior to that the only published report was in Uganda in 1933. It remains unknown what caused the enormous change in occurrence of this disease, but change in the pathogen could have occurred. There were no management practices in the U.S. in 2007. Because basil is the most common herb grown by diversified vegetable growers, some vegetable pathologists with extension appointments, including myself, expanded their programs to address this grower need. Effort included seeking funding through the IR-4 program to conduct evaluations of fungicides (efficacy and crop safety) while their staff did the residue studies and other work to obtain registration. Disease occurrence was studied. And we pathologists worked with herb breeders to develop resistant varieties. The pathogen has demonstrated ability to evolve becoming resistance to fungicides and able to overcome host plant resistance. Changes are expected to continue thus there will continue to be a need for research.

Late blight of tomato and potato. The pandemic of 2009 is a good example of the very unexpected occurring and of extension pathologists throughout a region coming together to share observations and develop a response plan. Widespread occurrences of late blight during June was completely unexpected by growers and pathologists because late blight had been occurring sporadically in the U.S., often only in major potato production areas, and in the northeast it had not been seen so early in the growing season. The fact that the source was infected tomato seedlings sold at garden centers throughout the region was unprecedent and thus unexpected. This was the first time home gardens were an important source of a pathogen for growers. Witnessing how fast spread occurred and the huge impact on production as well as growers themselves, led me to think: this is how agricultural bioterrorism could be conducted. The causal pathogen turned out to be a new genotype (US-22) that was more virulent on tomato then the genotype that had been dominant in the U.S. and mostly affected potato. The late blight pathogen exists in the U.S. as clonal populations with only a few genotypes present each year. Late blight continued to be very important for several years after 2009, especially in the northeast, with three new genotypes arising. Then the disease returned to being generally uncommon. There remains concern about a major change occurring in the pathogen such that its two mating types (pathogen equivalent of gender) start to exist together, because then the pathogen will be able to produce oospores enabling it to survive overwinter in soil in the absence of living host plant tissue (in infected potato tubers is how the pathogen currently survives). This change has already occurred in parts of Europe where consequently late blight now occurs routinely and new genotypes appear more commonly due to sexual reproduction.

Potato blackleg caused *Dickeya*. This destructive, seed-borne pathogen caused extensive losses starting possibly as early as 2013 on Long Island. It is one of several factors that led to substantial decline in potato production in the area. The pathogen is now uncommon.

Some diseases that were observed rarely during my career include Stemphylium leaf spot of spinach, Septoria leaf spot of lettuce, garlic rust, Cercosporoid leaf blight of dill, downy mildew of arugula, and powdery mildews on field grown lettuce, pepper, and carrots (different pathogens). Stewart's wilt of corn, white rust of spinach, and turnip mosaic virus are diseases I detected on Long Island early in my career that have not been seen since. Downy mildew of spinach re-emerged recently primarily as a disease in winter tunnels. It is caused by another pathogen that has proven adept at change, with new races continually appearing that overcome resistance varieties, the main management practice. Stemphylium (gray) leaf spot of tomato is a new disease occurring mainly in high tunnels where temperatures are high enough for it.

Novel management practices. During my career I have evaluated a diversity of practices including soil solarization, reduced tillage, and mustard biofumigation for Phytophthora blight.

Fungicide resistance. Pathogens evolving ability to be unaffected by fungicides is the most common change in pathogens occurring during my career. The main change in the pathogen is to the site where the fungicide binds. There have been several lessons learned while studying fungicide resistance and its management, which are important for improving management strategies. These lessons include now recognizing that predicting potential risk of resistance developing for a new fungicide can be difficult, as can predicting pathogen propensity. When Quadris, the first QoI (FRAC 11) fungicide was registered, the manufacturer thought resistance risk was not high, thus there was not a need to implement a resistance management program right away. Additionally, the cucurbit powdery mildew pathogen was anticipated to be the first to develop resistance to this new chemistry, but the gummy stem blight pathogen was first. An education lesson for growers is that the goal of fungicide resistance management is delaying development of resistance, not managing resistant isolates after they have appeared. Surprisingly, the cucurbit powdery mildew pathogen has not continued to develop resistance to the DMI (FRAC 3) fungicides since 1990 when control failure to the first DMI registered in the U.S. for this use (Bayleton; active ingredient triadimefon) was shown to be associated with occurrence of resistance. Some DMIs, Proline in particular, have continued to exhibit excellent control. Having a good resistance management program cannot prevent resistance development. Resistance to Torino (FRAC U6) was detected just five years after its registration for this use although its use was restricted more than other fungicides with just two applications permitted to a crop, and there were other effective fungicides to apply in alternation to manage resistance (DMIs and Quintec, plus Vivando two years later). Resistance to Pristine was detected six years after its registration and to Quintec eight years afterwards. The resistance management program for these three chemistries may have had an impact considering resistance to Quadris developed in just three years. Another lesson is that resistant isolates typically are not less fit and thus can occur in crops not treated with the fungicide. Frequency of resistance can change substantial in response to fungicide use in a crop during a growing season. When a fungicide applied to a commercial crop is ineffective because of resistance, it may not have an evident impact on control when the other fungicides used in the rotation program are effective, necessitating testing for resistance to detect. Ability of pathogens to develop resistance to chemically different fungicides (up to five FRAC groups for cucurbit powdery mildew) was not expected and makes fungicide resistance management more challenging.

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