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Late blight situation in USA and trends of pathogen's population and control

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The most notable situation concerning late blight recently in the USA was the tomato late blight pandemic in the summer of 2009. It made late blight into a household term in much of eastern USA. Many home gardeners, and many organic producers lost most if not all of their tomato crop. Some CSAs (Community Supported Agriculture) could not provide tomatoes to their members. In response, many questions emerged: How did it happen? What was unusual about this event compared to previous late blight epidemics? What is the current situation in 2012 and what can be done?

This pandemic was unusual. It started synchronously in mid-late June over much of the Northeastern USA. The pathway was via infected tomato transplants shipped to garden centers in large retail stores throughout the Northeast. The fact that infected transplants were being sold in such stores from Pennsylvania to Maine became abundantly clear by late June, 2009. Most employees in the garden centers did not recognize the symptoms of late blight and most home gardeners also were unaware of the disease. did not recognize the disease, so planted infected transplants into their gardens. The first warning to the plant pathology community in the Northeast was on 18 June, when late blight was reported on tomato transplants for sale in a garden center in New Jersey. This report was shared widely with plant pathologists in the Northeast via a "Late blight" email list serve. This report was followed shortly by a report from Long Island of late blight on commercial potatoes on Long Island (23 June). However, the seriousness of the situation was not fully appreciated until 24-26 June, when plant pathologists in New York and Maine found

infected tomato transplants in many big box stores. This was reported widely when Tom Zitter described the situation in Ithaca, NY. Transplants in big retail ("box") stores supplied by the same single national supplier were infected, but transplants in local garden centers which had obtained tomato transplants from local sources were free of late blight. From 24 to 30 June, we know of 49 reports to the list-serve and the Northeast Plant Disease Network -- 37 described infected transplants being sold in big box stores. Extension staff everywhere were alerted, and in New York almost all counties had reported late blight by mid-August. In many cases, extension personnel informed store managers that the infected transplants were dangerous to home gardens, organic farms and conventional crops. In some cases, store managers were helpfully responsive. However, because the transplants were on consignment (the store did not own them), some managers felt that they could not summarily destroy the plants and had to depend on the supplier to remove the transplants. From 23 June to 29 July, we know of 155 reports of late blight from throughout the Northeast. Reports of late blight on infected transplants in stores ceased after mid-July.

Weather in the Northeast was relatively favorable to late blight development during June and July 2009. For example in central NY there was a rapid accumulation of "severity values" on the Blitecast forecast system from late June to early-mid July. (Severity values are a measure of how favorable the weather has been for late blight development. For example, if fewer than four Blitecast "severity values" occurred in the past week, there is a "no fungicide spray" recommendation, but if more than seven severity values were recorded, a fungicide schedule of every five days is recommended.) This weather enabled *P. infestans* in infected transplants planted into home gardens to sporulate, disperse to, and infect neighboring potatoes and tomatoes. A pandemic was initiated, and it caught the attention of the general population in the Northeast. Most early reports of late blight in the field were from home gardens and organic farms. Commercial potatoes were largely unaffected in early 2009 – probably because commercial potato growers typically apply fungicides.

Reactions and impacts. Prior to 2009 (and in most subsequent outbreaks) late blight occurred in production fields where fungicide applications were applied unevenly, and rows or edges were missed. Extension personnel were surprised in 2009 because this outbreak was entirely different. Suddenly the disease was widespread on tomatoes in home gardens and in retail outlets throughout the Northeast. Communicating with the

home gardener audience was a challenge because this audience is diverse and widespread, and often served by personnel who do not also serve commercial growers. Extension personnel quickly strengthened linkages with extension home and garden agents to educate the public about the need to take prompt action to protect crops.

The pathogen in 2009. Because infected transplants in June 2009 were associated with a single supplier throughout the Northeast, it seemed important to determine if the isolates causing late blight in these box stores were similar to each other or different from each other. Many samples of infected tissues were shipped to Cornell during the summer. These were assayed for allozymes at the *glucose-6-phosphate isomerase* (*Gpi)* locus using sporangia from sporulating lesions. Using sporangia from a sporulating lesion, this assay can be completed in just a few hours. All samples from big box stores, from organic farms, and from home gardens had the same (*Gpi*) genotype (100/122). A more informative technique was DNA fingerprinting using fingerprint probe RG57. However, this technique requires a significant amount of pathogen tissue (for DNA extraction), so we isolated the pathogen into pure culture from many samples. We then also assayed these cultures for mating type and mefenoxam sensitivity. As the results gradually came in over the summer, we learned that all of the isolates from box stores, home gardens and organic farms were indistinguishable from each other: they were all A2 mating type, had the same DNA fingerprint, had the same *Gpi* genotype, and were sensitive to mefenoxam. Unfortunately, these additional data did not become available until the epidemic was well established. The pandemic strain was termed US22.

Rapid genotypic assay. When we learned in late July 2009 that the strain causing the pandemic was sensitive to mefenoxam, it became clear that a technique to rapidly identify this particular strain was highly desired. The allozyme assay was insufficient, because although it could be applied to sporangia from a sporulating lesion on the day of receipt in a lab, and results could be obtained in a few hours, the assay was insufficiently discriminatory. Other diverse strains could have the same allozyme genotype by chance. We therefore initiated an analysis of microsatellite markers to assess diversity among the strains, employing a procedure that interrogates genotypes at more than 10 loci. Microsatellite markers are PCR-based and therefore can be employed on small samples (sporangia from lesions) and therefore if one starts with sporangia from a lesion, the results can often be obtained in 24 h. Using microsatellite markers we were able to obtain a multilocus genotype that separated the 2009 pandemic strain from other recent strains.

Thus, microsatellites became a very useful tool to rapidly identify specific clonal lineages. If the phenotypic characteristics of a strain were already known, one could use microsatellites to rapidly predict the traits of the pathogen in a sample.

Other strains. While US22 dominated the population in the Northeast in 2009, a few other clonal lineages were also detected. US8 was detected in a few samples from commercial potatoes. After the summer of 2009 and upon assessment of additional samples, it became clear that another lineage (US23) was present in the east (PA) and south. However, US23 did not appear to have been distributed on tomato transplants, and was not detected in northeastern USA during the summer 2009. Finally, another new strain (US24) was reported on potatoes from the upper Midwest. US8, US22, US23 and US24 can be distinguished from each other by their allozyme genotype, RG57 fingerprint, and microsatellite genotype. The phenotypes of these lineages are also distinct from each other (see below).

Phenotypes of common lineages. Isolates of four lineages (US22, US23, US24 and US8) collected in 2010 were investigated for phenotypic characteristics such as pathogenicity on potato and tomato sensitivity to mefenoxam, and speed of germination. These isolates (total n = 59) came from many different locations in 12 states and one Canadian province). The number of isolates of each lineage ranged from 8 to 35. These laboratory assessments confirmed preliminary field observations. First, both US22 and US23 are pathogenic to both potato and tomato. However, it seems that US23 might be even more aggressive than US22 on both potatoes and tomatoes. This discovery supports the conclusion that a major reason for the pandemic of 2009 was that US22 was so widely and efficiently dispersed on tomato transplants – not that US22 is more aggressive than other strains. US22 and US23 are also fairly sensitive to mefenoxam. US24 is pathogenic mainly on potatoes, and not at all aggressive to tomato. These pathogenicity characteristics are similar to those of US8. Most individuals of US24 are sensitive to mefenoxam, but there may be some diversity in this lineage for mefenoxam sensitivity. US8 has been previously characterized and the 2010 isolates were shown to have characteristics similar to isolates collected in the 1990s. The phenotypic characterization has only just begun, and there may be other important differences among the lineages.

The epidemic of 2009 reawakened interest in late blight. In 2010, this interest coincided with an opportunity from USDA National Institute of Food and Agriculture to submit a research-extension proposal focused on oomycetes. Such a proposal (with >25 co-PIs, including participants from 13 states in the USA and two other countries, and acknowledged at the end of this abstract) was constructed and submitted to the USDA. Fortunately, the proposal was funded and the project started in March 2011. This grant supports many efforts in extension and research (ranging from very basic to very applied). Because US22 appears to be thwarted by tomato resistance genes *Ph2* and *Ph3*, tomato cultivars with these resistances have been targeted for rapid development. Other approaches to developing host resistance are also being investigated. Some of the other very basic research has the practical goal of developing rapid diagnostic tools – such as a rapid diagnostic test for mefenoxam resistance. Participating extension plant pathologists are not only heavily involved in education but also in rapid diagnosis and reporting. These plant pathologists have agreed to report occurrences of late blight to the USAblight website (http://usablight.org/) and to send samples for genotypic analyses. Because of the explosive potential of late blight, early warning is crucial to effective suppression.

Decision Support System (DSS) for late blight management. Many of the participants in the AFRI grant have participated in the evaluation and improvement of a DSS that provides near “real-time” information for late blight management. This DSS is available via USABlight or directly at (http://blight.eas.cornell.edu/blight/). After the initial set-up, the DSS provides weather data from the nearest weather station (including on-farm weather stations), and also highly localized (4 km grid) weather forecasts. The weather data are updated several times per day. Both observed and forecast weather data are used in two late blight forecasts (Blitecast and Simcast) hosted on the DSS. The forecast weather can be used to provide information concerning the potential future need (up to 7 days into the future) for fungicide application. The weather data can also be used to drive a simulator of late blight that is available on the DSS. Simcast enables a ready integration of weather, host resistance, and fungicide into a simple late blight forecast. Future improvements are to include lineage-specific traits into Simcast. Several alerts are available in the DSS. One is an alert from Blitecast to indicate when in the season the accumulated weather has been sufficiently favorable to trigger an initial fungicide application. Additionally, there is an alert (“inoculation alert”) currently under development to identify to the user if late blight has been reported within a radius of 30 miles, and if the

weather patterns have been such that the user's crop might be subject to inoculation and disease development.

Late blight in 2011 In 2011, the participants of the NIFA grant cooperated to keep each other and their stakeholder communities informed of events during the season. More than 150 samples in the eastern USA were submitted via overnight courier to our labs. These samples were assayed using microsatellite markers and allozyme analysis. Because fresh samples sent overnight often have sporulating lesions, it was possible to analyze many samples immediately upon receipt. For at least 80% of the samples submitted during the growing season, the clonal lineage in the sample was determined and the information returned to the submitter within 24-48 hr of receipt of the sample. Because the phenotypic characteristics of the common lineages were already known, lineage identification could inform management decisions.

This review began by asking several questions. I return here to address those questions.
1) *"How did the 2009 pandemic happen?"* The pandemic was initiated by a synchronous region-wide release of one strain of the pathogen into the environment on infected tomato transplants bought by home gardeners who did not know about late blight. The subsequent weather was favorable to the pathogen and susceptible hosts were readily available – so that all requirements necessary for a pandemic were met.
2) "What was unusual about this epidemic?" In my experience, the scale of pathogen release was completely unexpected and unprecedented. The pathogen was released via infected tomato transplants throughout the entire Northeast at the same time.
3) "What is the current situation and what can be done?" New understanding, education and communication have contributed greatly to the effective management of this disease in 2010 and 2011 compared to 2009. My personal belief is that very personal (local) and timely information are necessary to achieve satisfactory management.

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