Emerging diseases of cultivated potato and their impact on Latin America.

Enfermedades emergentes de la papa cultivada
Y su impacto en America Latina.

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INTRODUCTION

Potatoes are one of the staple foods of the world. It is ranked fourth as a major food crop after rice, maize and wheat, and provides subsistence to people in all parts of the world. Historically is has fed people from the high Andes to the plains of east Africa, and because it can be stored to provide food during difficult times, potatoes are part of both commercial and subsistence agriculture. Potatoes have been used as emergency food rations in Ireland when the crops were burned, and hoarded in Russia where is called “second bread”. Potatoes are relatively easy to grow, provide complex carbohydrates for nutrition, can be stored, and are genetically complex that allows a diversity of genotypes for any climate, culture and conditions.

One of the reasons that potatoes are popular throughout the world is that they can be vegetatively propagated. This allows growers, large or small, to save some of the crop to replant as seed potatoes to both increase the food supply, and maintain a desired variety, whether indigenous or commercially bred. In most areas of the world, seed potatoes for replanting are usually small potatoes that are not cut, but in some areas of the world, particularly in the United States where there is a large commercial industry, seed potatoes are usually cut into seed pieces prior to planting. Either way, cultivated potatoes are grown by the process of vegetative propagation. While this method is easy, useful and effective for propagation, it is also the greatest weakness of the cultivated potato, because pathogens that cause disease are also spread with the seed tubers. This allows pathogens that cause disease of potatoes a perfect mechanism to persist with their host, the potato, as long as the potato is propagated vegetatively. Successive multiplication of seed for several generations (years) in this manner can disease causing pathogens throughout the seed, and result in a crop highly contaminated with disease, even up to 100% in some instances, such potato virus X.

Hence, one of the limiting factors of potato production is disease. Potatoes are probably affected by more diseases than any other cultivated crop, and most can be spread during propagation from one season to the next. The second edition of the Compendium of Potato Disease, published by the American Phytopathological Society Press in 2001 lists 60 major diseases; seven caused by bacteria including, 35 caused by fungi, six caused by nematodes, and 12 caused by viruses. If the minor diseases and diseases with unknown etiology are counted, potatoes are affected by over 100 diseases. Many of the diseases of importance are newly discovered, and the international importance of many diseases has changed substantially in the recent years as new varieties are introduced, new technologies are introduced and new areas of cultivation are opened for production. The scientific and technical community continues to discover new diseases and to understand newly emerging diseases throughout the world in order to develop management strategies and tactics to limit the impact of disease on food production.

There are three areas of emerging potato diseases that are a concern to potato producing areas worldwide – including Latin America from my point of view – emerging diseases, changing pathogens and surviving diseases. They are important because they all have on common feature: they are difficult to control, and in most cases, do not have effective control except avoidance.

Examples of emerging pathogens and the diseases they cause include *Spongospora subterranea* the cause of powdery scab, the tuber necrotic virus complex composed of Tobacco Rattle Virus, Potato Virus Y NTN strains and Potato Mop Top Virus, *Synchitrium endobioticum*, the cause of wart, Phytoplasma, the cause purple top and other related diseases and *Angiosorus solani*, the cause of smut.

Examples of changing pathogens include *Ralstonia solanacearum*, the cause of brown rot*, Fusarium sambucinum,* the cause of dry rot, *Helminthosporium solani,* the cause of silver scurf, *Phytophthora erythroseptica*, the cause of pink rot, and *Alternaria solani*, the cause of early blight. These pathogens have changed in their biology or their sensitivity to fungicides and are causing new problems.

The quintessential example of a surviving pathogen is *Phytophthora infestans*, the cause of late blight. Despite intensive study and eradication efforts, it still remains the most important disease worldwide 150 years after it was identified as a major disease of potatoes. Because of its genetic versatility, it adapts to persist, and is able defeat modern technology by overcoming resistance genes, developing resistance to fungicides, changing aggressiveness, and moving around the world.

Because most of these diseases do not have effective controls once they become established, we must depend on preventing movement and spread of these new and altered pathogens It is important to establish international rules and regulations for movement of potatoes, especially seed potatoes, to prevent the introduction and establishment of pathogen into new environments.

EMERGING DISEASES

POWDERY SCAB.

This disease, caused by *Spongospora subterranean*, is emerging as an important disease probably because of wide distribution of infected seed. It will probably become more important because it is seed and soil borne, persists in the soil longer than ten years, effective control measures do not exist, there are few if any resistant varieties, and it is the vector of potato mop top virus.

The pathogen is a primitive fungus common in many soils and has become well adapted to the potato world. The incidence of this disease has increased dramatically in recent years. It is more like a protozoan, and is an obligate parasite, and cannot be cultured which makes it difficult to work with. On the tubers it causes erumpent lesions that can resemble common scab and can be easily confused with common scab and go unrecognized. Symptoms are not always clear. It can cause root galls which vary in size depending on variety from barely visible to easily visible. It survives as sporeballs (cystosori) 20-100 um in diameter which are composed of hundreds of spores (cysts) clumped together. The spores are thick-walled, hardy and long-lived, and are diagnostic for the disease as they can easily be seen with a microscope. The source and spread of powdery scab is by infected or contaminated seed tubers, contaminated soil, contaminated manure from feeding on diseased tubers, on equipment moved from field to field or dispersal by wind-borne particles. The fungus has a limited host range. It will only complete its life cycle on potato, tomato and solanaceous weeds such as black nightshade. It will infect the roots only of many monocotyledons including wheat, barley and oats, and many dicotyledons such as rape, turnips, clover and several weeds. Infection occurs through

proliferating lenticels and tubers are most susceptible at tuber initiation, but infection can also occur at the apical end of the tuber anytime during the growing season.
Many factors affect powdery scab, but the most important is soil water. The disease is favored by cool, wet conditions, and free water is necessary for the zoospores to release and swim through the soil matrix to the roots and tubers. Optimum soil temperatures are 11-18C, and alternating wet and dry periods favor disease. Sporeballs can persist for longer than 10 years in the soil, individual spores have different dormancy periods and potato volunteers maintain sporeball numbers.

Control of this disease is difficult if not impossible. In the US, it was a zero tolerance disease in certified seed potatoes, but the regulations were recently changed to allow limited coverage, similar to regulations in Europe and elsewhere. No seed treatment or in furrow chemicals have been shown to be effective in controlling powdery scab. The best in trials is fluazinum (Shirlan, Omega), which only provides partial reduction of disease. Work in Israel has shown that soil fumigation by methyl bromide and metham sodium can provide some control of powdery scab. A few varieties are tolerant of powdery scab, but there are almost no resistant varieties. The most effective control is to plant clean seed into clean ground.

WART.

This has been a major quarantine disease throughout the world for many years. The disease is caused by another primitive, obligate parasite that produces zoospores, *Synchitrium endobioticum*, that needs cool, wet conditions for disease to manifest itself. Inoculum is spread by seed and soil. Potato is the only important host on which galls form, but other members of the Solanaceae family can be infected experimentally, but galls do not form. The pathogen can persist in the soil for 40 or more years. Control of this disease depends on pathogen exclusion and quarantines insuring clean seed. Breeding programs have developed resistant varieties which are widely grown, and are often mandatory, in areas of Europe and Russia.

This disease is not important commercially because of concerted quarantine and eradication efforts and resistant varieties. However, the disease has not been eradicated, and continues to persist most often in kitchen gardens. Recent finding of this disease in the eastern Canadian province of Prince Edward Island has brought new attention to this disease and shown how a disease thought to be eradicated can reoccur. This is an example of a disease that has the potential to emerge in new areas and need for continuing vigilance is necessary to prevent its introduction and spread.

TUBER NECROTIC VIRUSES.

There are three virus diseases that produce similar necrotic symptoms in potato tubers, tobacco rattle virus (TRV), certain strains of potato virus Y (PVY) and potato mop top virus (PMTV). They are collectively called the tuber necrotic viruses. All produce similar necrotic arcs and rings of potato tubers both externally and internally, (spraing), and are difficult to differentiate based on tuber symptoms, requiring sophisticated laboratory testing such as ELISA and PCR for positive identification. In most cases, diagnosis of the necrotic viruses in dormant tubers is difficult and a plant needs to be grown from a suspect tuber in order to make a reliable diagnosis. All three viruses are transmitted by three different vectors – nematodes, aphids and fungus - which complicates management tactics and makes them difficult to control. TRV is transmitted by the stubby root nematodes *Trichodorus spp.* and *Paratrichodorus spp.* PVY is transmitted by many species of aphids, including *Myzus persicae*, the green peach aphid. PMTV is vectored by the powdery scab fungus *Spongospora subterrranea*.

TRV has a wide host range including many weed species which allows the virus to persist from year to year. The nematode vector is difficult to control even with soil fumigation because it can migrate deep into the soil below the zone of fumigation. There are resistant varieties, but market requirements limit their production.

PVY has been the leading cause of rejection of seed potatoes for certification in the US in recent years. The virus may be latent in certain varieties, such as Russet Norkotah and Shepody, and rejection based on ELISA testing has exceeded 50% of seed lots grown. PVY cannot be controlled by insecticides because it is transmitted in a stylet borne, non-persistent manner, and aphids can transmit the virus before the insecticides can act. In addition, aphids may be resistant to certain insecticides, and application serves to flare the aphids thereby increasing the spread. There are a number of reasons for the increase including more inoculum, high aphid numbers, lack of effective insecticides, the increase in other crops such as canola, and the weather. The most important is the inoculum. PVY has different biological forms called strains: PVY^O is the Ordinary common strain; PVY^N is the Necrotic strain, which is mild on potato but causes veinal necrosis on tobacco, and PVY^{NTN}, a variant of PVY^N that causes Tuber Necrosis. The NTN strain was first found in Hungary in the 1970's and spread throughout Europe. It was also found in Canada in1996, and the US in 2001. Sophisticated molecular testing has shown that the European NTN strain is distinct from the North American NTN strain, and the US strain is thought to have arisen independently of the European NTN as a new recombinant between PVY^N which came from Canada, and the common PVY^O. There is evidence that new recombinants between N and O continue to develop in the US, and many of these new PVY strains are designated $PVY^{N:O}$. Management practices for the strains are the same, but because of potential quarantine and movement issues, definitive diagnosis is critical. Conclusive diagnosis requires a combination of bioassay, serology and PCR techniques, and definitive diagnosis has only been recently developed. It appears that there ay be geographical differences that make detection and diagnosis difficult among strains. The most important control remains virus-free seed.

PMTV has been known in Europe since 1957, and is known to occur in the Andes, China, Israel and Japan, but is new to the US, having been found for the first time in Maine in 2001. This has been a quarantine disease because it was not previously known to be present in North America. The virus is considered to be soil borne, because it is only transmitted by the powdery scab fungus, *Spongospora subterranea*, and not by any other vector. Spread in the field is slow and seed transmission is 20-50%, but the disease is mobile by both seed and soil. It has a narrow host range limited to the solanaceous plants potato, nightshade and tomato, and a few members of the Chenopodiaceae family.

The tuber necrotic symptoms of PMTV are favored by cool wet weather, increase in severity during storage, are more evident at 9C compared to 4C, and may be asymptomatic (unapparent) in warm climates. There are no foliar symptoms with primary infection, and planting infected seed results in foliar symptoms consisting of yellow blotches or chevrons on lower leaves and shortened internodes giving rise to the name "mop top". Diagnosis must be confirmed by ELISA and PCR tests, but these are not 100% reliable because of uneven virus distribution in the plant. Control depends on controlling the powdery scab vector by selecting clean seed and avoiding infested fields. The virus may be self eliminating from seed lots planted three years in *S. subterranea* soils. European countries with mop top have implemented tolerances ranging from 0.1% in seed lots to 4% in tablestock potatoes, and the disease is generally treated as just another virus.

SMUT.

This disease caused by *Angiosorus solani* is endemic to many countries in South America, and there is concern for its continued movement and spread within and outside of South America. Consequently, this disease has serious quarantine issues, particularly for seed exporting countries and regions of South America. Like many diseases of concern, the pathogen is both seed and soil borne, and can persist in the soil for up to seven years. There is a general awareness to manage this disease in South America by embargoes and quarantines for seed movement from infested areas, but the disease may be spreading to new areas by planting infected tubers that are mistakenly thought to be free of the disease because they are symptomless. This is a serious issue, and continued vigilance and new solutions will be necessary to prevent this disease from spreading into clean seed production areas. New and creative solutions will be necessary to eradicate the disease from infested fields and areas, and will be a challenge to the potato industry of South America.

PHYTOPLASMAS.

Phytoplasmas are phloem limited bacteria that cannot be cultured as other bacteria can, and are therefore difficult to work with. They are vectored by transient leafhoppers and require long feeding times to acquire and transmit, but once acquired, persist for the life of the insect because they multiply in the leafhopper. Phytoplasmas have been associated with disease in hundreds of plants, including many important food crops, ornamentals and trees. Phytoplasmas are poorly understood and difficult to work with and most of these diseases have only been recognized as caused by Phytoplasmas in recent years. Molecular techniques are required to identify and characterize Phytoplasmas. Phytoplasma are causing devastating losses of crops throughout the world. One aster yellows strain is causing huge losses of grapes and other fruits and vegetables of Europe. The purple top Phytoplasma has also caused serious outbreaks of diseases in potatoes in Russia, Mexico and the US, and have the potential to be a serious, emerging disease of potatoes. In 2002, a serious outbreak of the clover proliferation Phytoplasma, transmitted by the beet leafhopper, caused major losses of commercial processing potatoes in the Columbia Basin of Washington in the Pacific Northwest in the US. A Phytoplasma-like disease, called zebra chip because of the dark and light striping pattern seen in the chips fried from affected plants, caused serious quality losses of potatoes grown for chipping in the southwestern US in 2000 and 2001. The exact cause of this disease is unknown, but appears to be caused by a previously undescribed Phytoplasma or bacteria-like organism. This same disease is present in Guatemala, where the incidence is as high as 80% in some fields. The occurrence of these two diseases, and other similar diseases seen in commercial fields that appear to have a Phytoplasma etiology based on field symptoms, indicate that this group of pathogens may be an emerging problem for Latin America.

CHANGING PATHOGENS

There are two areas of changing pathogens that could have an impact on Latin America. One is the ability of pathogens to adapt to a new environment, and the second is the ability of pathogens to develop resistance to fungicide used to control them. Of the two, to me the most important is the latter – fungicide resistance.

NEW ENVIRONMENTS.

There is one good examples of a pathogen that has adapted to a new environment that is not considered typical; brown rot caused by *Ralstonia solanacearum,* Brown rot is normally considered a tropical, hot climate disease, and consequently, rarely, if ever, occurs in temperate climates where the majority of potatoes are grown. Recently, a new biovar of *R. solanacearum* race 3 the “potato” race of brown rot, has been found in several European countries. The new biovar (biovar 2) is tolerant to low temperatures, and has established itself in potato fields and adjacent waterways, where it infects *Solanum dulcamara*. Obviously, the brown rot pathogen has adapted itself to this new environment. Because this low-temperature biovar occurs in many important seed exporting countries, particularly in The Netherlands which exports Dutch seed worldwide, including to Latin America, seed should be carefully monitored to prevent introduction of low temperature isolates of this pathogen which could establish itself in temperate seed producing areas.

Low temperature isolates of *R. solanacearum* have recently been found in geranium cuttings imported into the United States from Kenya and Guatemala to be used for greenhouse geranium production. The cuttings were exported to states in the US which also have an important seed potato industry, and the geranium cuttings could serve as a source of inoculum that could easily spread to potatoes since both are susceptible to race 3 of *R. solanacearum*. Fortunately, the geranium cuttings were confiscated before planting, demonstrating that existing quarantine programs do work. This incident clearly points out the need continuing for quarantine and inspection services in all countries to prevent introduction of pathogens into new areas.

FUNGICIDE RESISTANCE.

This is an emerging area of great concern, because in recent years many pathogens of potatoes have become resistant to the fungicides used to control them. We first began having concerns about fungicide resistance potato pathogens about ten years ago. Resistance was reported before in other crops of course, but this was not an issue with any of major diseases except late blight, which had developed widespread resistance to metalaxyl in Europe. In this section, we will use the terms insensitivity and resistance somewhat interchangeably while acknowledging that in many cases there may be differences between the two terms. We began to see issues with failures to control dry rot in potatoes, and with two of my colleagues, Neil Gudmestad and Phil Nolte, we documented widespread resistance to thiabendazole (TBZ), trade name Mertect, in the fungus that causes dry rot *Fusarium sambucinum,* but not in other *Fusarium* spp. recovered from diseased potatoes. Several other studies in the United States, Canada and Europe confirmed the resistance to TBZ which had been widely used as a post harvest treatment of potatoes for the previous twenty years, and is the only post-harvest fungicide labeled for potatoes in the US. The TBZ resistant isolates were also cross resistant to thiophanate methyl (Topsin). Consequently, TBZ is seldom used as the resistance in F. sambucinum persists in the populations.

Since then, many other fungi, including many that cause disease in potatoes, have developed resistance. It has become a big issue now as we discard fungicides and new ones are getting harder to come by. Resistance to fungicides has developed in many other potato pathogens, including Helminthosporium solani, the cause of silver scurf, which has become resistant to thiabendazole and thiophanate methyl, even though it was a non-target organism which was controlled by TBZ application for dry rot control.

Phytophthora erythroseptica, the cause of pink rot, has developed resistance to mefenoxam (Ridomil, Ultraflourish) in many states in the US. In some cases, the resistance is widespread and with EC50 values of >200 ug/ml. Pink rot is a serious disease of stored potatoes in the US, and is controlled by application of the systemic fungicide mefenoxam. The fungicide is fully systemic, and is applied at planting, at hilling or as a foliar spray when tubers are approximately 10 mm in diameter. Unfortunately, mefenoxam is the only fungicide which provides control of pink rot, and to a lesser extent of leak, caused by *Pythium ultimum*. Development of resistance to mefenoxam could lead to limited lack of control and excess losses due to this disease.

Most recently, in a project led by my colleague at NDSU, Neil Gudmestad, we have seen insensitivity to azoxystrobin (Quadris), a fungicide in the strobilurin or QOI class, develop in Alternaria solani, the cause of early blight. This disease was extremely sensitive to azoxystrobin, and application resulted in almost complete control for the first two years. Insensitivity to azoxystrobin was observed in commercial fields after two years, verified in replicated field trials in subsequent years, and validated in the laboratory that showed there had bee a 10X reduction in sensitivity to azoxystrobin in two years in some isolates from fields with multiple applications. Reduction in sensitivity of *Alternaria solani* to other QOI fungicides has also been observed in laboratory studies by Dr. Gudmestad's group, including a 10X reduction to pyraclostrobin (Headline) and a 2X reduction to trifloxystrobin (Gem). This is particularly troubling because this is a new class of fungicides based on naturally occurring compounds from an allelopathic fungus, resistance was documented in only two years after commercial launch of the fungicide, and there are additional fungicides from this same class just now being registered and used. To have insensitivity develop within two years is scary. Interestingly, *Alternaria alternata,* the cause of brown spot which resembles early blight, is 10X less sensitive to azoxystrobin, and became more serious when the more sensitive and more competing *Alternania solani* was eliminated by azoxystrobin.

We also do some work with sugarbeets and fungicide sensitivity, and we see the same story there. The *Cercospora beticola* fungus has developed resistance, or at least tolerance, to triphenyltin hydroxide and thiophanate methyl in the major US sugarbeet production area in North Dakota and Minnesota.

The concern is that the resistance will persist, because we don't have many fungicides in development to defeat the resistant pathogens. In addition, since many of these pathogens cause disease in storage, we don't have any registered post-harvest fungicides to combat disease except Mertect, to which we have widespread resistance, and some disinfectants like chlorine dioxide, ozone and hydrogen peroxide which have mixed results.

SURVIVING PATHOGENS

LATE BLIGHT.

The late blight pathogen *Phytophthora infestans* is the quintessential example of a pathogen that has survived despite our collective concerted intervention and efforts for control. Management tactics include exclusion of initial inoculum sources from seed, cull and volunteers, and when late blight is present, the use of protectant fungicides. The old standard protectants, chlorothalonil and mancozeb, are still effective and widely used, and resistance has not developed to these products. Most of the newer compounds, including at least five strobilurin, or QOI, fungicides are single site in their action, which have the potential for resistance development. However, as of the present, no resistance to the QOI fungicides has been found in *P. infestans.* Resistance to the phenylamide compounds such as metalaxyl, oxadixyl and mefenoxam is widespread and these products are either not effective or have limited effectiveness in most areas. Interestingly, resistance to metalaxyl has been found in herbarium specimen isolates collected in 1977 even though metalaxyl was not issued until 1978.

The strength of *P. infestans* is its genotypic versatility that has allowed it to develop not only resistance to fungicides, but change aggressiveness, expand its host range, tolerate wider temperature ranges, enhance sporulation capability and overcome plant resistance (R) genes.
In the US, late blight has been sporadic since the 1800's and comprised of the original imported genotype US-1 (A1). Late blight has been constant since 1992 when new genotypes from Mexico were introduced. They were a mixture of genotypes and mating types, but since 1995, the US-8 (A2) genotype has dominated, and almost all potato isolates throughout the US are US-8. The US and Canada has primarily a clonal population, but some new genotypes may have arisen from sexual recombination but were displaced with the new US-8. This genotype is aggressive and resistant to mefenoxam. Existing variety resistance is only to the old US-1 isolates and potato breeding programs are working to incorporate resistance to US-8, which does not currently exist.

The situation is quite different in Europe, which has a sexual population and new new and different genotypes dominate every year. New populations of *P. infestans* are 50% sensitive to the phenylamide fungicides, but are not effective after that due to phenylamide insensitivity in the surviving population. Most varieties have some resistance to late blight, although few varieties have both foliar and tuber resistance.

The situation is different again in Chile. We have studied the population of *P. infestans* in the north of Chile, an area that grows only commercial potatoes, and where conditions are always favorable for late blight due to continuous potato production, morning dew and fog, susceptible cultivars and reliance on a single fungicide, Ridomil. In a two year study between our group at NDSU and Fernando Riveros INIA-La Serena, looking at hundreds of isolates, we found that all *P. infestans* are the old US-1 (A1) genotype and are highly resistant to metalaxyl with EC50 valuse of >300 ug/ml. The *P. infestans* population contains very simple pathotypes with an average of 1.8 virulence genes, and the complexity of the races was also simple; each race carried an average of 2.1 R genes. No new genotypes have been found due to the geographical isolation due to Chile's natural boundries.

Late blight is not common in the South of Chile, which has a large seed potato growing area. Characterization of the *P. infestans* population from south Chile has not been done, but is underway. Because the A1 mating type does not occur in at least northern Chile, and due to the natural isolation in Chile, it is strongly recommended that Chile not import potatoes, and in particular, seed potatoes, from countries where the new genotypes and A2 mating types occur.

Despite the fact that Chile has old, simple genotypes of *P. infestans*, the breeding program has developed germplasm with high levels of resistance to *P. infestans,* such as R89063-84 which appears to have resistance to all 11 known virulence genes, based on trials conducted ate NDSU in 2002 and 2003. Using a mixture of isolates containing all 11 virulence genes, this selection had less than 25% infection at the end of the season. The resistance has not been characterized.

SUMMARY

There are several areas of emerging concern for the potato industry that may have an impact on Latin America:

- Emerging diseases, including powdery scab, wart, the tuber necrotic viruses, phytoplasmas, and smut.
- Fungicide resistance, which has been found in pathogens that cause many potato diseases including dry rot, silver scurf, late blight, pink rot and early bight.
- Diseases caused by pathogens that change and adapt to new geographies such as low temperature brown rot and late blight.
- Special consideration should be given to understanding and management of late blight which has persisted for 150 years or more, has traveled throughout the world, overcome plant resistance and defeated our best efforts to control it. Special import and quarantine rules may be necessary to prevent it to moving to areas that are isolated from the new genotypes.
- There is a need for increased awareness of diseases spread by seed potatoes and a concomitant need for careful rules and regulations to prevent their global spread.
- There should be an acceptance of biogenetics for disease diagnosis and disease management to prevent disease occurrence and spread in potatoes. Technology had been developed and should be incorporated and utilized to its fullest extent.

The increased awareness of bioterrorism should be considered for potato diseases spread by seed potatoes. Many of the emerging potato pathogens have the potential as serious pathogens that can spread rapidly and globally without control.