Contemporary Global Movement of Emerging Plant Diseases

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ABSTRACT: Plant diseases are a significant constraint to agricultural productivity. Exotic plant diseases pose a continued threat to profitable agriculture in the United States. The extent of this threat has increased dramatically in the 1980s and 1990s due to the expansion of international trade in agricultural products and frequent movement of massive volume of people and goods across national boundaries. Introduction of new diseases has not only caused farm losses, but has also diminished export revenue since phytosanitary issues are linked to international commerce. Plant pathogens and their vectors have also moved across national boundaries, sometimes naturally and at other times influenced by the recent changes in trade practices. Sorghum ergot, Karnal bunt of wheat, potato late blight, and citrus tristeza are some of the most recent examples of enhanced importance of diseases due to the introduction of plant pathogens or vectors.

INTRODUCTION

The thread of agriculture passes through the fabric of all human endeavors. The United States Department of Agriculture (USDA) estimates that agriculture accounts for 13.5% of the national economy, and 17% of all jobs. Modern technology and innovative farmers have helped the United States to be a food-secure nation capable of offering food security in turn to several food-deficient nations around the world. A large proportion of Americans take agriculture and food for granted due to the abundant availability of quality food and a vibrant economy. Evolution of agriculture over the centuries has led to our dependence and survival on 30 principal food crops for nourishment.[1] Important among these are wheat, maize, rice, barley, soybeans, sugarcane, sorghum, potato, and oats, which contribute 85% of the estimated edible dry matter for humans. These crops also significantly contribute to export earnings. In the event of conspicuous losses in these crops, such as those experienced due to drought in Texas in 1998, disturbing consequences occur in several sectors of society and the economy, primarily in the rural sector. Modernization

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of agriculture, to increase efficiency and profitability and to meet the food needs of increasing population, has led to some profound changes in the way agriculture is practiced. Intensification of land use, modern cultivars, new land and crop management practices, changes in food preferences and associated food policy, dynamic trade policies, and frequent international movement of goods and people have all had effects on agriculture. These changes have varying effects on different components of the agricultural system.

The full potential of agriculture is rarely achieved due to the vagaries of nature, including losses caused by plant diseases. Plant diseases as a group causes substantial losses directly and indirectly by reducing the quantity and quality of food, feed, fiber, and industrial inputs. For example, losses due to soybean diseases alone were valued at $969 million in the United States in 1994.[2] Some plant diseases also affect the quality of the environment and aesthetics around us. Examples abound in world history of the catastrophic effects of crop losses due to plant diseases. The Irish famine in the last century and the Bengal famine in this century are just two examples of the devastation associated with plant diseases. Plant diseases have sometimes upset national economies, changed food habits, caused poisoning, transformed landscapes, and caused hardships in other ways.

Diseases are ubiquitous among plants, but some diseases are more damaging than others. Within a given agroecosystem, only a few diseases cause significant damage. The more damaging diseases are most often caused by infectious agents such as fungi, viruses, bacteria, and nematodes. Not all diseases of a plant occur everywhere the plant is grown. The causal agent of a disease must challenge a host cultivar at a stage when it is susceptible and at a time when environmental conditions are favorable to the pathogen. The relative importance of a particular disease on a crop is dynamic. In some cases, an important disease may become obscure when it is controlled with new disease management technologies. In other cases, an unimportant disease may reemerge as damaging with changes in agricultural practices, and still in other cases a new disease may emerge as important in a geographic area.

The spectrum of threatening diseases has changed dramatically in recent times. The concept of global movement of plant pathogens and the subsequent threat of exotic plant pathogens to agriculture is not new. Plant pathologists recognized the importance of this threat long before even Dutch elm disease was introduced to the United States around 1930. The American Phytopathological Society (APS) recognized the importance of emerging plant diseases in late 1920s and established the Committee on Investigations of Foreign Pests and Plant Diseases in the 1930s.[3] The committee recommended that federal agencies support studies on pathogens that are not found in the United States, but have devastating potential if introduced based on experiences of other countries. The Plant Disease Research Laboratory (renamed later as Foreign Diseases and Weeds Science Research Unit) of the USDA at Fort Detrick, Maryland was established to acquire knowledge on exotic plant diseases.[4]

Much later, the National Plant Pathology Board of the APS began a project on listing emerging and reemerging plant diseases throughout the U.S. The APS held a plenary session on these diseases in its 1996 annual meeting. Subsequently, the journal *Plant Disease* commissioned feature articles on some of these and other diseases. Readers are encouraged to read some of these excellent articles.[5–10]

Threats of new and reemerging diseases occur due to several factors. The major factors are: (1) movement of a new pathogen in a production system, (2) movement of one or more new virulent strains, or emergence of a new aggressive strain in an area where the pathogen existed, (3) introduction of new vectors that can transmit a pathogen efficiently, (4) changing agronomic practices that favor one or more components of epidemics of a specific disease, (5) increased pesticide use leading to development and proliferation of pesticide-resistant strains, (6) intensification of agriculture to maximize productivity and profit, (7) changes in cultivars, and (8) consistent change in climate in the short term. Some of these factors are intrinsic to crop husbandry, while others relate to extraneous, though important, forces such as trade, policy and international exchange. In this paper, we provide specific recent examples of enhanced importance of selected plant diseases that have linkages to introduction of new pathogens, movement of new strains of established pathogens, and vectors of plant virus.

INTRODUCTION OF A NEW PATHOGEN IN A PRODUCTION SYSTEM

Several exotic pathogens have gained entry in to the United States during the past decades. Some of the new entrants are economically insignificant while others have caused significant confusion and panic in the agricultural community. We provide examples of two recent entrants that have attracted considerable attention during the last three years.

Sorghum Ergot

Sorghum ergot is the most recent example of a disease that has spread rapidly in the Americas and Australia, taking the sorghum industry by surprise. Sorghum is the second most important feed grain in the United States, with grain valued at $2.2 billion. Sorghum is a staple food in several food-deficient countries in Africa and Asia. It is also one of the major export crops in the United States, earning almost $758 million in 1996.[11] In 1995, nearly 4.88 million metric tons of sorghum grain was exported to more than 22 countries.[11] It is estimated that the United States produces nearly 40% of world's hybrid seed valued at $435 million annually (A.B. Maunder, personal communication). Unfortunately, male-sterile lines used in F_1 hybrid seed production are highly vulnerable to ergot. Losses in seed production ranging from 10–100% have been reported from various parts of the world.[12] Commercial cultivation of hybrids is also vulnerable in cooler regions. Although sorghum ergot is an old-world disease—it has been known to occur in Asia and Africa for more than 80 years—mention of its notoriety began with the introduction of hybrid seed technology in different countries. In spite of widespread use of hybrids in Australia, North America, and South America, ergot was of no consequence in these three continents due to the absence of the pathogen. That is no longer the case now.

The ergot pathogen attacks unfertilized ovaries to replace them with its own mass called sphacelia. Sphacelia exudes sweet, spore-laden, fluid, sticky honey dew. Later the fungal mass is converted into a sclerotium that contains potentially toxic alkaloids. Ergot causes crop loss by reducing the quantity and quality of seed, predisposing seeds to seedling diseases, and making harvesting and threshing difficult. Since the presence of ergot bodies increases the risk of disease transmission and toxicity, international trade of feed grain and seed are often jeopardized, as has been recently experienced with Mexico. An annual $5 million or larger increase in seed prices to producers have been projected due to new control practices to manage the disease. Additionally, potential trade implications show that every 5 cent/bushel decrease in sorghum prices costs the sorghum industry $31 million.

The global significance of the disease increased with the introduction of *Claviceps africana* in Brazil in 1995,[13] and in Australia in 1996.[14] Since then, the disease has been observed in rapid succession in other South American countries, Central America, the Caribbean, and North America. The disease spread was rapid within Brazil, Mexico,[15] the United States,[16] and Australia[12] resulting in its presence throughout the sorghum-growing areas in each country. In Brazil, ergot was found in several sorghum fields located within an 800,000 km^2 area a month after the disease was first officially recorded in the country. In Australia, the disease was confirmed in an area of 16,000 km^2 within a week of its first sighting, and after a month it had expanded to 70,000 km^2 around the locality of its first occurrence.

Ergot diffusion in South, Central, and North America and the Caribbean has been carefully monitored after the report of the disease in Brazil. By mid-1996, the disease had been recorded in Argentina, Bolivia, Paraguay, and Uruguay; by the end of 1996 in Colombia, Venezuela, and Honduras; and during the first quarter of 1997 in Puerto Rico, Haiti, the Dominican Republic, Jamaica, and Mexico. In late March 1997, ergot was observed in a sorghum field just north of the Rio Grande River near Progresso, Texas. By the end of 1997, the disease had spread throughout the sorghum-growing areas of the United States. Ergot's greatest threat to Mexico and the United States is in commercial hybrid seed production areas and in regions and situations where pre-flowering and flowering periods of sorghum extend into cool weather conditions.

The immediate impact of the ergot epidemic in Mexico and the United States was more important in the social and political aspects rather than in the agronomic. The farmers experienced the fear of the unknown. They did not know what ergot was or how it would affect their crops. The feed industry was concerned about the possibility of toxic alkaloids in the grain. Seed and feed grain exporters feared a possible shutdown of the export market in Mexico. In general, the incidence of ergot in the commercial grain sorghum fields was minimal in Mexico and the United States during the 1997 season. However, this incidence was higher than expected in some areas because the 1997 season was unique in terms of low temperatures and high relative humidity. Up to 80% incidence and 40% severity were recorded in some commercial hybrid fields in northern Tamaulipas, Mexico.[15] Growers, the seed and feed industry, researchers and extensionists have been trying to learn how to coexist with the disease and prevent it.

The ergot epidemic brought serious implications to the seed industry in Mexico and United States. Concerns about seed trade and regulation were first addressed. The seed production cost increased with the application of fungicides and additional sanitation procedures. Aerial applications of fungicides during the flowering stage are being used by the seed industry, but the efficient control of ergot has not been the best in some cases. Significant harvest problems were encountered in seed-production fields in southern Texas.

The sorghum commodity community in the U.S. met the ergot challenge remarkably well by sensitizing research administrators, policymakers, and the legislators to the importance of the disease on sorghum production and trade. Several universities, the National Sorghum Producers Association, the Agriculture Research Service, the Cooperative State Research, Education, and Extension Service (CSREES), the Foreign Agriculture Service of USDA, and state agriculture departments began funding ergot research in 1997. Research and extension activities began in several areas such as genetic resources, biology of the pathogen, epidemiology of the disease, toxicity studies, as well as control and management strategies involving phytosanitary issues, host plant resistance, chemical control, and pollen management. It is anticipated that considerable information will be available in the next few years to effectively manage and mitigate the threat of the disease in ergot endemic areas.

Karnal Bunt of Wheat

Karnal bunt of wheat is another disease that has received considerable international attention in the past few years due to issues related to quarantine and international trade. Initially restricted to India, Pakistan, Nepal, Afghanistan and Iraq, the disease was noticed in Mexico in 1972. The Animal and Plant Health Inspection Service (APHIS) began regulating wheat imports from countries with Karnal bunt in 1983 since presence of the disease in any country places it in considerable economic disadvantage from failure to export wheat. On March 8, 1996, the disease was officially recorded as present in the United States. On March 21, 1996, a “Declaration of Extraordinary Emergency” was announced by the Secretary of Agriculture to handle the disease and its repercussions. Intensive national surveys were carried out in 1996 and the disease was recorded in New Mexico, Texas, and California.[5] It is now recognized that Karnal bunt is neither a production nor quality constraint of wheat in the United States.[17] Therefore, surveys are planned again for 1998, but at 25% of the sampling rate of 1997.

Karnal bunt is a quarantine pathogen in most wheat importing countries due to limited global distribution of the disease. After the United States became a Karnal bunt–positive country, about 75 trade partner countries initially expressed concern in importing wheat from the United States. Several of these countries later allowed imports with additional phytosanitary declaration (that the grain came from an area free from Karnal bunt or where Karnal bunt is not known to occur) in good faith. As of February 1998, it was expected that almost $1 billion of the annual $6 billion wheat exports would be threatened due to curbs from importing nations because of the unresolved Karnal bunt crisis.[17] Domestically, Karnal bunt–affected areas were regulated at considerable economic cost. An economic analysis of regulation in the Imperial and Palo Verde Valleys of California showed that growers not only failed to realize nearly $77.6 million in profit from their inability to sell the grain, they also lost $57.75 million in production cost. The American Phytopathological Society, in a position statement on Karnal bunt, stated that the disease should not be regulated due to its limited agronomic consequence.[18] Nevertheless, surveillance and trade negotiations will continue to require considerable attention as long as importing nations have concerns about the disease.

MIGRATION OF NEW STRAINS

Late blight of potato is always mentioned when reviewing the impact of plant diseases on society and mankind. An epidemic of late blight in Ireland in 1845 led to famine, large-scale starvation, death, and population migration. This single event significantly changed the demography of Ireland and the United States. The late blight pathogen *Phytophthora infestans* also causes serious losses in tomato. Symptoms of the disease include blighting of the foliage resulting in defoliation and blighting of tubers (potato) and fruits (tomato). Under favorable conditions, the pathogen can spread rapidly causing severe defoliation and tuber spoilage. The pathogen survives in infected tubers and fruits and can sporulate readily on these substrates. The sexual survival structure oospore also helps overseasoning of the pathogen in parts of Europe and Mexico.

Late blight attracted the global attention again less than 150 years when it later reemerged as a devastating disease on potato and tomato worldwide. The primary reason for its reemergence in the United States is the migration of new strains of the pathogen. Extensive research[6] during the last 10 years has shown that before the 1980s a single clonal lineage of one mating type (A1) of the pathogen was dominant while the second mating type, A2, was rare or absent outside Mexico. Therefore, there was little diversity in the pathogen in the United States and Europe. Maximum diversity in the pathogen, including both mating types, occurred in the highlands of central Mexico where the pathogen and host co-evolved. Reports of the A2 mating type began to appear in the 1980s in Europe and in the 1990s in the United States and Canada. Subsequent analysis with markers such as mating type, allozyme genotype, and DNA fingerprints showed that the introduced isolates originated in Mexico. It is believed that export of potato tubers to Europe in the late 1970s and tomato fruit to the United States and Canada were responsible for long distance transport of the isolates.

Dramatic shifts in distribution of clonal lineages were noticed after the introduction of exotic strains. US-1 was the most dominant clonal lineage before the introduction of new strains. Since the early 1990s, three exotic lineages (US-6, US-7, and US-8) became increasingly important and replaced the resident strain US-1, which has not been found since 1993. US-6 and US-7 are pathogenic to both potato and tomato. US-6 became rare after 1993. The most infamous is the clonal lineage US-8. Its distribution expanded rapidly beginning with a single county in 1992 in northcentral New York, to most production regions in northeastern, southeastern, midwestern, western, and southern United States, including eastern Canada. Transcontinental shipment of potato seed tubers to distribute inocula far and wide, greater pathogenicity to foliage and tubers leading to faster establishment in a new field, and aerial spread of sporangia locally are some of the reasons for the widespread distribution of US-8. Introduction of US-8, a lineage with A2 mating type, has also created opportunities for sexual recombination with A1 mating type, thus increasing diversity in the pathogen as observed along the Pacific coast.[19] The US-8 lineage has other traits that make it dangerous and difficult to control. It has inherent resistance to metalaxyl, an effective curative fungicide, thereby making it difficult to control after the appearance of the disease. It is highly aggressive and requires more frequent sprays of protectant fungicides for disease suppression. US-8 also has unnecessary virulence genes, which suggest that it is likely to overcome newly deployed resistance genes for disease management.

The economic impact of potato late blight management has been quantified in the Columbia basin of Washington and Oregon.[20] Direct costs for late blight management, yield losses in the field, and losses in storage approached $30 million in the epidemic year 1995. Expenditure on increased frequency of fungicide use and their application alone was $25.3 million in 1995 compared to an estimated $6.6 million in 1994 when late blight was less severe. Indirect costs, such as processor costs, long-term revenue of storage facilities, etc., would further increase the losses from the disease. Psychological stress of growers and others experiencing losses is incalculable.

INTRODUCTION OF NEW VECTORS

Viruses are a major group of plant pathogens that cause serious economic losses. Vectors of different types transmit a majority of the plant viruses. Insects have been long recognized as a significant vector of plant viruses. Relationships between vector and virus vary. Some viruses are vectored by a single specific species with a high degree of specificity. However, a specific virus may also be vectored by several insect species, each varying in their efficiency to transmit the virus. Changes in distribution of specific vector species can have an impact on the economic significance of the disease caused by the virus.

Citrus Tristeza Virus

The example of Citrus brown aphid (BrCA) illustrates how introduction of an exotic vector can change the distribution of a disease from stabilized local endemics to extensive pandemics within a short period. Citrus is an important crop for the economies of several countries in South, Central, and North America and the Caribbean. Citrus tristeza virus (CTV) is one of the most economically important viral pathogens of citrus. The virus caused major declines in citrus production worldwide. Millions of citrus trees on sour orange rootstock have been killed by CTV in Argentina, Brazil, Spain, Venezuela, and the United States.[21] CTV proliferates mainly by graft transmission into new citrus growing areas. Several aphid species vector CTV in a semi-persistent manner and are responsible for secondary spread. Among these, BrCA (*Toxoptera citricida*) is the most efficient vector, followed by *Aphis gossypii* (cotton aphid). Other aphid vectors include *A. spiraecola*, *T. aurantii*, *A. craccivora*, and *Dactynotus jacae*. *Toxoptera citricida* has been shown to be at least 11 times more efficient in transmitting CTV compared to *A. gossypii*.[22] Destructiveness of CTV in South America during the 1930s and 1940s is linked to the combined presence of the virus with BrCA.[21] Similarly, devastation of the citrus industry in Venezuela during the 1980s can be linked to the introduction of BrCA. A severe decline-inducing (DI) strain of the virus was initially present in isolated areas of Venezuela. This strain of the virus was not a problem because the indigenous aphid vectors were not efficient vectors of the virus. The situation changed dramatically after the introduction of BrCA, which efficiently spread the severe strain extensively throughout the country. Due to the recent outbreaks of BrCA and the spread of severe strains of CTV, an estimated 185 million citrus trees are now highly vulnerable to CTV in the Caribbean Basin countries.[22]

CTV is not a new disease in the United States. It is present in Florida and California. Before 1996, *A. gossypii* was the major vector of CTV in both states. However, BrCA was detected in Florida in November 1995 in dooryards and small nurseries.[23] Since then, BrCA has spread rapidly in Florida despite an exhaustive eradication campaign. The U.S. citrus industry is now under a threat of CTV and the cause of the threat can be linked to the introduction of a new efficient vector.

CONCLUSIONS

Exotic plant diseases have caused appreciable losses in the agricultural sector during the 1990s. The threat from exotic plant diseases continues despite the recent spate of introduction of exotic plant diseases. The United States is still free from diseases such as tropical rust of corn and soybean rust, which are devastating diseases in countries where they occur now. Exotic pests remain exotic until they gain entry into a disease-free country. Not many diseases will remain exotic in the present climate of international trade and commerce. There is a need to stay prepared to combat the exotic diseases in case of their eventual entry into a new production system. Gaining knowledge to assess their risk and developing methods of control should receive priority at both the federal and state levels. Several universities and agencies of USDA have done a commendable job of responding to threats of emerging diseases after their entry into the United States. However, ability to conduct research on these diseases before entry of exotic diseases is seriously hampered by the lack of funding and interest from administrators and policy makers. This is because these diseases are not taken seriously until they enter the country and threaten agricultural productivity and trade. By then, much valuable time is lost. Guarding agriculture against anticipated threat of emerging plant diseases would require preparedness and an action plan based on sound research and policy issues.

Much similarity exists between factors that lead to emergence of diseases in plants and humans.[24] Evolving diseases in humans and the policies and practices to address them have justly received widespread attention.[25] With widespread consultations with several experts and associations, the Centers for Disease Control and Prevention (CDC) developed a prevention strategy for addressing emerging infectious disease threats in the United States. The strategy's four goals—surveillance and response, (applied) research, prevention and control, and strengthening infrastructure—apply to emerging diseases of plants too.

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