Pandemics Aren't Just for People: How Disease Can Affect Crops and the Food Supply

On the most unlucky of days in 1844, a fungus now referred to as *Phytophthora infestans* made its way through the rolling hills of Ireland after ravaging American farms in the years immediately prior. Believed to have crossed the Atlantic on US ships bound for European ports, the disease is a water mold which blights not only potatoes, but potentially tomatoes as well. But it was the Irish potato crop which fell victim as the disease moved eastward into continental Europe, destroying food production along the way. By 1852, more than 1 million of Ireland's 8 million men, women, and children were dead. Another million were on their way off the island. This migration set the stage for a Gaelic exodus which would color North America for the rest of the 19th century into modern day. Some historians refer to that famine and death toll in genocidal terms due to a political system which they say enabled it. Blended into the songs, stories, and traditions brought to America by those Irish immigrants was a legacy of fear and loss, a legacy mixed into the American melting pot as much as shamrocks on St Patrick's Day (1).

And so, as a new strain of wheat stem rust (UG99) marches through developing nations from its discovery point in Uganda, world food experts are in the midst of an ongoing battle which remains un-noticed amid popular culture. But the fight is fierce nonetheless, and experts agree the toll inevitably taken by UG99 will be high. For a variety of reasons, it is unlikely America will suffer the same fate as Ireland, but for those same reasons it bears an important study. Experts interviewed predicted a rise in cost and perhaps a shift in diet for most Americans as the disease moves this way, but those in the developing countries could suffer famine, starvation, and forced migration, as they have before.

And of course, while the threat of UG99 is yet being combated, history suggests other diseases are already on the way to replace it.

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UG99

Stem, black, or cereal rusts are known to the scientific world as *Puccinia graminis* and have been problematic to farmers since Roman times. But in 1999, a new strain of stem rust was discovered in Uganda, caused by the fungus *Puccinia graminis f. sp. tritici* (2). To date, it has succeeded in destroying the harvests of entire regions in its spread. The disease moves as spores are carried by the wind, and in the 10 years since its discovery it has travelled from East to North Africa, and into the Middle East as far as Iran. Infected regions have suffered catastrophic losses. And whether or not UG99 makes it to American shores is not the question, it's rather one of when.

"It is a very real, very significant problem," Tom Creswell, PhD, said while sitting in his office inside Purdue University's Lilly Hall. "If you're asking for the single biggest threat, this is it."

Creswell is a plant pathologist who specializes in diagnosing plant diseases and serves as director of the university's Plant and Pest Diagnostic Laboratory in West Lafayette, IN. As such, he participates within the global network of specialists whose job it is to observe, report, and combat infectious diseases threatening Earth's food supply.

Tucked back within the halls of a building on Purdue's west side, Creswell chuckled at the remark that many within the general public might not know his profession exists. "I can't tell you how many times I go to a party and tell someone what I do and they say, 'plants get diseases?' Yes, they get diseases just like we do." Studying, identifying, and helping remedy those diseases is part of what he does in addition to participation in the National Plant Diagnostic System.

Wheat is a staple for most of the world, used to create everything from flour to pasta, bread, crackers, and cereals. The picture of a sheaf tied together represents the essence of food to many. This in mind, the threat of a wind-blown fungus threatening the 160-million-acre stretch from the Middle East to Asia has had Creswell's colleagues in full gear since UG99's discovery. That swath of land alone accounts for a quarter of the Earth's wheat production (2).

In 2005, the Global Rust Initiative was formed for the sole purpose of fighting UG99 (2). The initiative was spear-headed by Norman E. Borlaug, PhD, a researcher who won the Nobel Prize in 1970 for breeding high-yield wheat varieties resistant to stem rust. Currently the drive is being led by two international organizations, the International Maize and Wheat Improvement Center in El Batan, Mexico, and the International Center for Agricultural Research in Dry Areas out of Aleppo, Syria. Cooperative agencies and research institutions range in geography and political ideology from Australia to Kenya.

In 2008, Creswell's lab received about 2,125 samples of diseased or damaged plants from farmers and gardeners throughout Indiana. Growers, homeowners, and hobbyists alike generally utilize their local Purdue University Extension Educator's office as a starting point for questions varying as widely as "what is this fungus killing my corn" to "why is my tree dying," he said. Once sent to his

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lab, the material is documented and either identified or sent on for further study. Every state has some form of this system in place.

In a hypothetical scenario where UG99 was identified in one of America's wheat-producing capitals, such as Kansas, the identifier would send a sample to the US Department of Agriculture's (USDA's) Animal and Plant Health Inspection Service identification lab in Maryland for confirmation. After confirmation, notification would begin for state department of agriculture officials, university scientists, and administrators and regulatory officials within the USDA.

As media releases and educational materials were being prepared to alert grain producers, Creswell said the affected area would be immediately quarantined and the battery of fungicides which have come into being during the decade since the disease's discovery would be used. Should the pathogen survive the winter, government and industrial resources would be employed to contain it to that locale and prevent its spread. New varieties of rust-resistant wheat have been undergoing tests since UG99's discovery. They have come a long way but might not be ready for immediate use.

The fact that the disease spreads through the air is well-documented. "That's why it's so dangerous, because it can blow so far," said Creswell.

Still, all of the world's developed nations have some form of emergency plan regarding epidemic plant diseases, he said. One of the hallmarks of undeveloped countries is they do not.

"It would present a huge threat, but I think the agricultural industry would adapt to it because we're constantly working on these things," Creswell said of the United States.

The United States and its particular climates and seasons have not met with UG99, and so it's difficult to predict how fast the spread would be, but soybean rust could be used for a comparison, he said.

A different species of rust, the Asian soybean rust has significantly hiked the cost of production in America since 2005, Creswell said. This particular disease caught the attention of researchers when it was found in Hawaii in 1994 and became problematic in Kenya, Rwanda, and Uganda. The first Western Hemisphere detection was in Paraguy in 2001. By 2003, Brazil lost about 5% of its soybean crop to the disease (3). Spores were blown into Louisiana during a hurricane in 2000, and the disease quickly became problematic in farms along the Gulf Coast, Creswell explained.

"It causes the most damage in the south," Creswell said. If there is good news about the disease, it's that it doesn't survive the winter in most of the United States. Each year it begins its spread from the southern tip of Gulf Coast state farms and works its way north. By the time it's blown to Kentucky or Indiana, plants are mature enough to avoid real damage. Soybean producers in Indiana have had no real need to spray for it, he said. However, the progress of the disease is monitored each year by university researchers in all major soybean growing regions. Should it spread unusually fast in a given year, soybean farmers would be warned to spray fungicides on still-developing crops.

One of the reasons a crop-specific disease such as UG99 is so devastating is the lack of genetic diversity within commercial farm production.

If soybean rust moves from Louisiana to Tennessee within one growing season, it is conceivable UG99 might spread at a similar rate and would likely follow a pattern of annual movement similar to other known strains of wheat stem rust in the United States. And in the 15 years since this strain of soybean rust was discovered, the agricultural industry has invested considerable time and money in learning how to combat it. These methods include new fungicides as well as work on new hybrids resistant to the disease. While that adds up to higher production costs and eventually higher prices, the chance of a nationwide wipe-out is very slim, Creswell said.

Wheat is considerably more integral to the human diet than soybeans, he pointed out, noting the efforts to combat UG99 are likewise stronger. When the disease makes it to America, Creswell predicts substantial losses at a regional level in the first year. And while this will drive prices up and perhaps alter some people's dietary source of cereal grains, it shouldn't yield a long-term or widespread famine in America. The system, he explained, has grown up to prevent that, not just in wheat but all food plants.

NEW VARIETIES

One of the reasons a crop-specific disease such as UG99 is so devastating is the lack of genetic diversity within commercial farm production. One pathogen targeting one plant hybrid can yield considerable damage in fields planted with homogeneous breeds.

Dan Egel, PhD, an extension plant pathologist in Purdue University's southwest agriculture program, noted the historical context of such diseases from his office surrounded by the commercial melon fields of southern Indiana's Knox County. "In a lot of cases, I think the biodiversity is there, but I don't think we've made very good use of it," he said.

This is particularly the case with melons, one of the crops in which Egel specializes. The lack of diversity seen in commercial melon farms makes the crop very susceptible to disease, a problem best remedied by researchers going back to the original, wild varieties of melons which he said modern American shoppers wouldn't recognize. Taking those original varieties and creating new hybrids would yield higher diversity and thus more resistance to disease, but it could also take 20 years. Commercial growers can't afford that time scale, he said, noting "table vegetables" and fruits—such as green beans and watermelons—are not eligible for federal crop subsidies like those for corn, soybeans, and wheat.

Watermelon producers spend between $1,000 and $1,500 per acre preharvest, Egel said, adding a good yield is about 45,000 lb per acre with prices fluctuating around the 10-cent

per pound mark. These figures offer a higher potential profit than row crops such as corn, but a much greater risk if something like fusarium wilt takes over an entire field and renders the preharvest costs a total loss. Still, weighed against the cost of developing new hybrids, the economies of scale have led to bigger farms with bigger fields with less variety, he said.

But in the face of a crop-threatening disease such as UG99, new hybrids are as much the answer as new chemicals, USDA officials have apparently concluded.

According to plant pathologist J. Michael Bonman, PhD, with the department's Agriculture Research Service (ARS) (4), the answer to the new disease might be found in old seeds and varieties still used in small locales. Working out of the ARS Small Grains and Potato Germplasm Research Unit in Aberdeen, ID, Bonman has 25,000 different kinds of "local" wheat seeds already at hand. These seeds are part of 60,000 total wheat types stored there.

Most of these breeds have fallen out of favor with commercial producers for a variety of reasons, and Bonman noted the local wheats, as opposed to those used as commercial wheats, offer a share of drawbacks. "They tend to be too tall for what we need in modern agriculture," he said, adding the breeds are generally best-suited to the soils and climates in which they were originated and used.

Still, they're much closer to being market-ready than any move back to ancestral plants might yield. "If you crossbreed, or hybridize, a local wheat with a commercial wheat, you'll be closer to getting a market-ready wheat than if you started by crossing a wild wheat with that same commercial wheat."

Records going back to a 1988 project at the ARS's Cereal Disease Laboratory in St Paul, MN, include an 8,500-specimen sample selected for rust resistance by retired plant pathologist Don. V. McVey, PhD. Bonman credited that work as an extremely relevant starting point for developing breeds resistant to UG99. Computerized, math-based models analyzing 10 telling traits of nearly 3,000 local wheats have pinpointed more than 200 with between 50% and 70% probabilities of being resistant to stem rust, Bonman said.

While unseen to the average consumer, the battle against crop disease, Egel noted, is hardly new. Ancient Roman farmers, he said, sacrificed red animals during wheat farming to appease what might be referred to as the gods of rust. And when that didn't work with desired regularity, they began the slow turn to science still in progress today.

BALANCING THE WARNINGS

The level of impact from various plant diseases hinges greatly on where one lives. Egel recalled the wave of corn leaf blight which decimated American corn producers in the 1970s.

"We lost a boatload of corn," he said. But growing up as a kid in that era, he doesn't remember going hungry, nor was a famine recorded. Consumers probably paid more at the store for corn products and beef, but if the price was too high they had other foods from which to choose.

But that luxury of supply, choice, and relatively low cost is enjoyed by developed nations only, and in its extremity it is uniquely American. Elsewhere in the world, diseases such as UG99, or the blight which affected Ireland's potato crops, can drive entire regions to starvation. But those, Egel said, are issues as political as scientific.

Earlier this May, Egel spent 2 weeks in Afghanistan working with the Ministry of Agriculture and local universities. The population of Afghanistan survives largely through subsistence farming, and what commercial food production exists is transported regionally at best. Wheat, there as in the United States, is a staple crop. And for areas in Afghanistan, UG99 could cause starvation, and in all probability, heightened violence and increased opium production, says Egel.

"Obviously some of the people grow vegetables, and that's where I came in," Egel said, explaining that US officials hope that improving Afghani agriculture will lead to a more stable political structure. In an agrarian economy based on subsistence farming, as crops fail jobs are lost and workers have neither food nor money. Citizens gravitate toward the profitable poppy crop and its end-products of opium and heroin. If they're not growing it, they're protecting, stealing, or selling it. The snowball affect of narcotic traffic, terrorism, and poor subsistence farming winds up affecting developed nations in more ways than one, he said.

"It adds to the instability of the world at large," Egel said, describing Kabul in 2009 as a safe place to be "unless you're crossing the street."

In addition to military concerns, UG99 arose from Afghanistan's economic peer, Uganda. Given the lack of education and food safety mechanisms in those places, they make for ripe birthing grounds of disease.

What countries such as Afghanistan lack is the bureaucracy dedicated to food safety present throughout nations in Europe, Canada, and the United States. Afghan regulations are lax or nonexistent, meaning farmers who buy fertilizer have no guarantee that what's in the bag is what's on the label. The same goes for seeds and hybrids promising disease-resistance. Scams are rampant, and if the magic beans don't work as promised, the farmer is out of the luck, food, and money that season, Egel said.

While there, Egel encountered the Afghani "melon fly," an insect which lays its eggs on melons. The eggs hatch into maggots which bore into the melon and eat it from the inside out. When invasive insects such as that make their way into the United States, Egel said crop damage results. But pesticides are developed and strategies enacted to combat them, usually holding the damage to regional levels. If the watermelon crop in Florida is destroyed, produce from Michigan is a few months down the road. Transportation and distribution systems are in place to ensure its arrival. In southern Indiana, heavy rains during the spring of 2009 resulted in a strain of head blight on wheat there, he said. But even if that fungus is unchecked in the field, it's tested for at the grain elevator after harvest. Once caught, it's removed from the food supply and the process of notification and elimination begins. This doesn't occur everywhere in the world.

"We hop on it pretty quickly," Egel said, offering a contrast to what occurs in other areas where insects and

diseases fester while spreading and gaining strength.

A CASE FOR DIVERSITY

Kelly D. Horton, MS, RD, spoke of her concern that the agricultural/industrial complex may contribute to the environments in which these diseases flourish. If the threat of a killer wheat pathogen leads researchers further down the path of genetically-engineered "mono-crops," then nutrition value and biodiversity will continue to be lost and more diseases will always lurk around the corner. "Definitely, that is a concern," she said.

And it's a concern which seems to be shared by others as well.

In a report on biodiversity and its impact on health conducted in conjunction with Harvard Medical School, the impact of narrow genetics has a well-documented history of negative results (5).

"Many historical examples can be cited to prove that monocultural stands or concentrations of crops and livestock with uniform genetic traits, though they may be more productive in the short run, entail the risk of succumbing, sooner or later, to changing conditions," researchers noted. "Among the many examples of disastrous outbreaks are the infestation of red rust on wheat in Roman times, the mass poisoning of ergot-tainted rye during the Middle Ages in Europe, the failure of the vaunted vineyards of France in the late 19th century, and the potato famine that hit Ireland in the 1840s and 1850s" (5).

Without an assortment of plant varieties in the ecosystem, humans roll proverbial dice in their hopes to avoid destructive outbreaks.

According to a position paper published by the American Dietetic Association, "Loss of genetic diversity makes food production vulnerable to widespread crop losses caused by pests, disease, pathogens, and environmental changes" (6).

But politics aside, among the many suggestions offered in the position paper, registered dietitians (RDs) are encouraged to help combat the problem by encouraging diets that support variety among the food groups. Supporting farmers' markets and other regional food sources which offer variety is one way for RDs to make this style of production economically feasible to continue (6).

Gardeners and hobbyists are encouraged to remember the heirlooms. "Heirloom varieties, for example, are garden plants that have been passed down through generations. They are not bred for commercial production, but each variety is genetically unique with natural resistance to pests and disease. Heirloom varieties serve as gene banks for commercial producers and can be used to infuse new traits into genetically narrow commercial varieties, helping to ensure sustained production" (5).

Education and awareness are needed to not only combat UG99, but to prevent diseases like it from threatening the food supply.

Horton chairs the Hunger and Environmental Nutrition dietetic practice group of the American Dietetic Association, and is also founding director of Connect Nutrition. She is currently serving as a Health and Aging Policy Fellow in Washington, DC, and emphasized the need for RDs to keep nutrition and food quality in the minds of policymakers as they decide funding levels for all avenues of agricultural production. In this capacity, she hopes to offer balance to discussions and relay the agricultural community's work against UG99 and other topics back to the dietetic community.

"We're not always at the table when food policy is discussed," she said, noting those decisions are traditionally dominated by corporate farmers and the chemical industry. "As scientists, we need to understand how politicians work."

The key is to make policy work for science.

Given that fluctuations in the world's grain supply will undoubtedly lead to correlating price changes, Horton said multiple goals can be simultaneously achieved by taking food back to the basics.

"I would say we need to teach people how to grow their own food," she said. The "Victory Gardens" of World War II are coming back in vogue as community gardens, an idea worth capitalizing upon, she said. And while home gardening is often seen as a leisure hobby practiced by the middle and upper-middle classes, it's the lower-income families who could benefit most. "Unfortunately, people have lost these skills," she said, rattling off a number of practices, such as canning and preserving, which could lower a family's overall food costs while increasing the overall nutrition value. Horton herself spoke of "salad gardens" and "pizza gardens" she's grown herself for those specific purposes, a twist that makes the labor more fun.

Education and awareness are needed to not only combat UG99, but to prevent diseases like it from threatening the food supply. At a recent meeting sponsored by the USDA, Horton said officials are already working on programs designed to support small and mid-size farms. Matching regional growers with restaurants, government agencies, and schools, she said, will help those smaller operators continue to produce, thus holding the monocrops of mega farms at bay.

At the same time, US dependence on chemicals might be trimming its own future production drop by drop. Floods during the summer of 2008 sent runoff fertilizer downstream into the Louisiana Basin, creating what Horton referred to as a "dead zone" of nitrogen waste unsuitable for agricultural production. The near wipe-out of the wild US honeybee population is another example of the negative impact created by increased chemicals and decreased diversity, Horton said. "I think it's really important to consider the global impact," she said of endemic plant diseases here and overseas. Ecosystems aren't governed by borders, and the constant flow of global trade makes everyone interconnected.

THEN AND NOW

The potato famine couldn't have come at a worse era in the island's history. Controlled by England, Irish farms were owned by British landlords who sold the produce grown there. History has shown that Irish sharecroppers

starved while the untainted produce—foods other than potatoes—was shipped back to England. The potato harvest was integral to the Irish farmers' incomes, and without it, poverty ensued, something remembered there to this day, as it has for more than a century marked by strife and violence (1).

As wheat crops fail across North Africa and throughout the Middle East, regions intertwined with terrorism, food shortages, and poverty, UG99 continues onward. While most agree that the United States, like 19th century Britain, will not suffer the same starvation levels seen by the 19th century Irish, those in Third World nations might. In the end, more diversity seems needed within the world's food system. Otherwise, history may continue to repeat itself.

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