WIRED

/ MAGAZINE

FEATURES 18.03

Red Menace: Stop the Ug99 Fungus Before Its Spores Bring Starvation

By Brendan I. Koerner February 22, 2010 | 12:00 pm | Wired March 2010

Riding the winds, Ug99 has breached the best defenses science can offer.
Photo: Gallery Stock

As they queue to fill water jugs from a rusty communal tap, the women of Njoro can't help but gawk at the odd scene across the road. In a wheat field ringed by barbed wire, a dozen men wearing white polyethylene jumpsuits stand in a tight huddle, eyes fixed on the green-and-amber stalks that graze their knees. They chat in foreign tongues — Urdu, Farsi, Chinese — that are rarely heard here amid the acacia trees and donkey carts of Kenya's Rift Valley. The men's hazmat-style safety gear suggests they might be hunting down one of the infamous viruses that flourish in this part of the world — Ebola, perhaps, or Marburg.

Then the leader of the huddle, Harbans Bariana, a rotund Australian in an undersize safari hat, begins reading aloud from his clipboard: "Wylah?" he asks.

His colleagues bend down to examine some flaccid plants flecked with red splotches. A lanky Pakistani with a salt-and-pepper beard rakes a finger along one of the mottled stalks; an iodine-like residue rubs off on his skin. "40 S," he calls out.

The men move three steps right to a slightly more robust clump of wheat. The Australian asks: "Yandanooka?"

"25 MR?" comes the tentative reply from a mustachioed Nepali in a green baseball cap. They slide over to inspect another stalk, and then another.

To the women at the tap, faces scrunched in puzzlement, the call-and-response sounds like gibberish — and to most of the world, it is. But to the jumpsuited strangers in East Africa — a group of elite plant pathologists — these codenames and numbers are a lingua franca, describing just how badly a crop has been ravaged by disease. These specialists have come to Njoro on this autumn afternoon to study a scourge that is destroying acres of Kenyan fields. The enemy is Ug99, a fungus that causes stem rust, a calamitous disease of wheat. Its spores alight on a wheat leaf, then work their way into the flesh of the plant and hijack its metabolism, siphoning off nutrients that would otherwise fatten the grains. The pathogen makes its presence known to humans through crimson pustules on the plant's stems and leaves. When those pustules burst, millions of spores flare out in search of fresh hosts. The ravaged plant then withers and dies, its grains shriveled into useless pebbles.

Stem rust is the polio of agriculture, a plague that was brought under control nearly half a century ago as part of the celebrated Green Revolution. After years of trial and error, scientists managed to breed wheat that contained genes capable of repelling the assaults of *Puccinia graminis*, the formal name of the fungus.

But now it's clear: The triumph didn't last. While languishing in the Ugandan highlands, a small population of *P. graminis* evolved the means to overcome mankind's most ingenious genetic defenses. This distinct new race of *P. graminis*, dubbed Ug99 after its country of origin (Uganda) and year of christening (1999), is storming east, working its way through Africa and the Middle East and threatening India and China. More than a billion lives are at stake. "It's an absolute game-changer," says Brian Steffenson, a cereal-disease expert at the University of Minnesota who travels to Njoro regularly to observe the enemy in the wild. "The pathogen takes out pretty much everything we have."

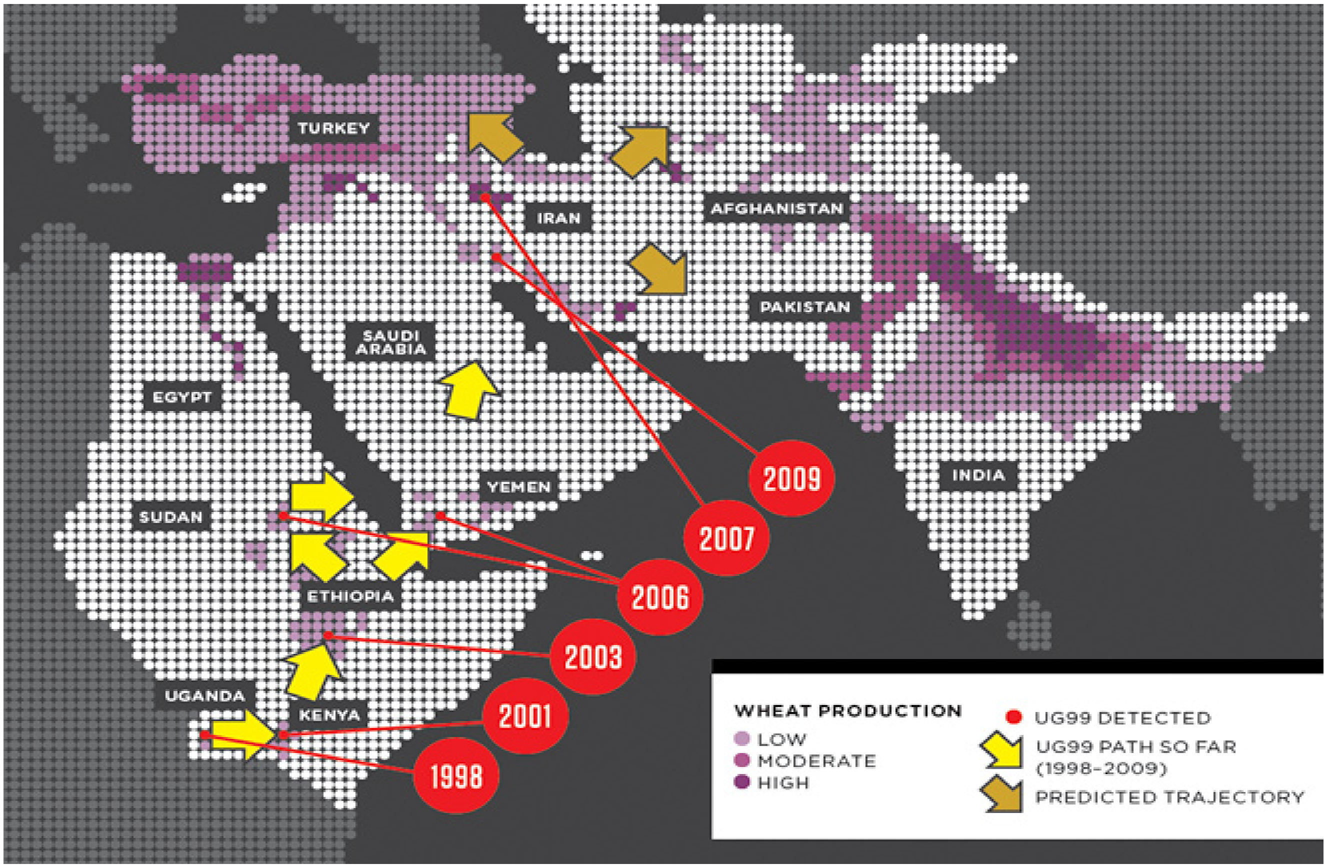
Indeed, 90 percent of the world's wheat has little or no protection against the Ug99 race of *P. graminis*. If nothing is done to slow the pathogen, famines could soon become the norm — from the Red Sea to the Mongolian steppe — as Ug99 annihilates a crop that provides a third of our calories. China and India, the world's biggest wheat consumers, will once again face the threat of mass starvation, especially among their rural poor. The situation will be particularly grim in Pakistan and Afghanistan, two nations that rely heavily on wheat for sustenance and are in no position to bear added woe. Their fragile governments may not be able to survive the onslaught of Ug99 and its attendant turmoil.

The pathogen has already been detected in Iran and may now be headed for South Asia's most important breadbasket, the Punjab, which nourishes hundreds of millions of Indians and Pakistanis. What's more, Ug99 could easily make the transoceanic leap to the United States. All it would take is for a single spore, barely bigger than a red blood cell, to latch onto the shirt of an oblivious traveler. The toll from that would be ruinous; the US Department of Agriculture estimates that more than 40 million acres of wheat would be at serious risk if Ug99 came to these shores, where the grain is the third most valuable crop, trailing only corn and soybeans. The economic loss might easily exceed $10 billion; a simple loaf of bread could become a luxury. "If this stuff gets into the Western Hemisphere," Steffenson says, "God help us."

He and his fellow scientists around the world are scrambling to halt the pathogen. To do so, they must figure out a way to reach deep within the wheat genome and create genetic barriers that Ug99 cannot overcome. And they must do so quickly, before the pestilence moves on to the next continent, and then the one after that — wreaking havoc on the world's food supply.

Deadly Migration

Since it was discovered a dozen years ago, Ug99 has steadily crept north and east out of Uganda. Wind patterns could soon carry it to the Punjab region on the border of India and Pakistan — one of Asia's most crucial breadbaskets. In the next few years, the pathogen could also travel through Iran to Afghanistan, as well as into Turkey. — *B.I.K.*



Map: Emily Dubin

William Wagoire loves wheat. "Wheat is what made me what I am," he says as he strolls through the Njoro plot of grain. For Wagoire, an agricultural researcher from neighboring Uganda, this field is a sort of heaven. It is where the world's top wheat breeders send thousands of their most promising plants, genetically souped-up varieties with an array of curious nicknames: Babax, Kingbird, Pastor, Khvaki, Circus, Milan. The breeders hope that one of these wheats will someday prove to be the One — the variety capable of withstanding Ug99. Every few yards, Wagoire passes a white sign staked neatly into the ground, indicating a row's country of origin: Iraq, Iran, Afghanistan, Pakistan, Nepal, Australia.

Wagoire, 55, was once a wheat breeder of some renown, having studied at the University of Cambridge and apprenticed under the late Norman Borlaug, a Nobel-laureate agronomist who revolutionized modern farming. But even though he hasn't worked full-time on wheat for years, Wagoire will forever have a place in cereal lore as the man who discovered the Ug99 race of *P. graminis*.

Wagoire earned that distinction several millennia after mankind's first run-in with stem rust. Wheat fragments bearing traces of *P. graminis* have been found at a Bronze Age archaeological site in Israel. And the Romans worshipped a minor god named Robigus, who had the power to stave off rust. Every April 25, as part of a festival called Robigalia, they would curry favor with the deity by sacrificing red-haired dogs.

P. graminis proved to be a prolific killer throughout the ensuing centuries, regularly tormenting both Old World and New. Certain death by starvation awaited European peasants whose crops were struck, while Mesoamerican Indians learned to fear the plague they called *chahuistle*. And the first English settlers in Massachusetts were aghast when rust wiped out their cereal crops in the 17th century, almost causing them to starve.

After the pustules burst through the wheat stem, the plant withers and dies.
Photo: University of Minnesota

In the US, stem rust was the bane of the Great Plains, which endured frequent epidemics throughout the 19th and early 20th centuries. One of the most disastrous episodes occurred in the middle of World War I, when *P. graminis* obliterated 200 million bushels of wheat — one-third of the nation's annual consumption. Countless Midwestern families scrambled to survive on nutrient-poor corn mush. "There is and has been for the last six months very wide and extended suffering upon the part of the poor people of this country for want of food," an Idaho senator declared in the spring of 1917, as the crisis reached its peak. Soon after, the spooked federal government ordered the eradication of barberry, the plant upon which *P. graminis* rests and reproduces when wheat is scarce. The epidemics abated, but they didn't stop: A two-year outbreak in the mid-1950s, for example, caused $3 billion worth of damage to the Great Plains' crops.

In the early 1940s, after the onset of World War II made it impossible to conduct philanthropic works in either Europe or China, the Rockefeller Foundation turned its attention to Mexico, where destitute campesinos suffered from chronic malnutrition. The foundation dispatched 30-year-old agronomist Norman Borlaug to Mexico in 1944 to lead a project aimed at ending the nation's hunger. When Borlaug first arrived south of the border, Mexico was reeling from a three-year bout with stem rust, which had cut wheat production in half. Borlaug resolved to breed a variety of wheat that *P. graminis* could not kill. Thus began the Green Revolution, the lifesaving agricultural movement that would earn him the Nobel Peace Prize in 1970.

There was no high tech trick to Borlaug's work, just countless hours of experimentation that he would later describe as "mind-warpingly tedious." The Iowa native collected cereals from around the world, bred them with one another, and then took copious notes on the physical characteristics of the resulting crosses that fared well in Mexico's fields. After many years of selecting and refining the top performers, he identified several genes capable of frustrating *P. graminis*. The most impressive was dubbed Stem Rust 31, or *Sr31*, a gene that several of Borlaug's colleagues had bred into wheat from a rye chromosome.

Not only did *Sr31* successfully fend off the pathogen, it also vastly improved grain yields. Farmers clambered to plant wheat that bore *Sr31*, which quickly became the world's predominant rust-prevention gene. Developing nations in particular adopted the seeds, which they obtained from Borlaug's International Maize and Wheat Improvement Center, or Cimmyt (pronounced "SIM-it").

The creation of rust-resistant wheat was one of the cornerstone achievements of Borlaug's Green Revolution, which produced multiple disease-proof, high-yielding crops capable of feeding once-hungry populations. By 1970, stem rust was no longer a threat to nations that relied on wheat as a dietary mainstay. It is impossible to calculate how many lives *Sr31* and other disease-resistance genes saved, but hundreds of millions would be a fair guess. Finally able to feed their burgeoning populations, developing countries like India were able to grow and prosper beyond all expectations. Two generations of farmers and agronomists came of age never having witnessed a stem-rust infection in the wild, and *P. graminis* largely ceased to be of interest to anyone except Cold Warriors: The US and Soviet militaries spent years trying to weaponize the pathogen. (America developed a cluster bomb containing turkey feathers smeared with spores; the stockpile was eventually destroyed after President Nixon renounced the use of offensive bioweapons.)

Stem rust thus beaten back, Wagoire was understandably amazed when he inspected the open-air fields at Uganda's Kalengyere Highland Crop Research Centre in November 1998. As one of

Borlaug’s many disciples, Wagoire had spent part of 1998 at Cimmyt headquarters in Mexico, breeding wheat designed to resist yellow rust, a comparatively mild disease caused by the *Puccinia striiformis* fungus. When he returned to southwest Uganda, he planted his lines on a hillside at Kalengyere, where yellow rust ran rampant. But while conducting a routine check of his maturing plants, Wagoire received a nasty surprise. Instead of being dusted with the jaundiced streaks indicative of yellow rust, the crop was pocked with scaly crimson pustules: stem rust.

Wagoire thought he had been careful to breed wheat that carried the *Sr31* gene, but now he wasn’t so sure. Had the Ugandan veteran somehow made a rookie mistake?

He fired off an anxious email to Ravi Singh, chief wheat breeder at Cimmyt. “I said, ‘Look, I think maybe I selected the wrong materials. All this stuff, it has all fallen down from stem rust,’” he recalls.

Singh wasn’t buying it. There was just no way a breeder as accomplished as Wagoire had failed to breed *Sr31* into his lines. The likelier scenario was that the Ugandan had mistakenly written “stem rust” when he meant “stripe rust” (a synonym for yellow rust).

But a second pass through the Kalengyere fields only confirmed that the pustules were the unmistakable handiwork of *P. graminis*. Wagoire realized there was just one logical conclusion: A new race of the stem-rust pathogen had somehow evolved undetected in a secluded region of Uganda, and it was capable of defeating the formerly invincible *Sr31* gene.

Still, Cimmyt wanted a second opinion before sounding the alarm that *Sr31* had been breached. The organization contacted Zak Pretorius, a plant pathologist at the University of the Free State in Bloemfontein, South Africa, and asked him to analyze a live sample of the pathogen. Pretorius agreed, even though doing so would place him in legal jeopardy — importing *P. graminis* spores into South Africa was strictly forbidden. “It was wrong for me to receive the samples,” he admits, “but I decided to test them anyway.”

Virulent pests have attacked our crops before

Potato (1845-1849)

Disease Water mold (*Phytophthora infestans*)
Impact The pathogen obliterates Ireland’s mainstay crop, leading to a million famine-related deaths and mass emigration.
Response It takes 36 years, but scientists develop a mold-killing chemical mixture.

Grape (1860-1900)

Disease Grape phylloxera (*Daktulosphaira vitifoliae*)
Impact Bugs infest a third of France's grapes and ravage the vineyards in Germany and Italy.
Response French vines are grafted onto aphid-resistant root stock from the US, saving the European wine industry.

Corn (1970)

Disease Southern corn leaf blight (*Helminthosporium maydis*)
Impact Some 710 million bushels of corn are lost after a mutated fungus rips through stalks from Iowa to Maine.
Response Imported seeds and rigorous crop screening quell the outbreak.

Cassava (1989-1997)

Disease Cassava mosaic virus
Impact The virus decimates Uganda's cassava crop, which provides up to half the caloric intake in the war-torn country.
Response By 1992, plant geneticists succeed in breeding a disease-resistant variety.

To get the illicit sample to Pretorius in early 1999, Wagoire used a method that in retrospect seems slightly reckless: He clipped a few infected stalks, sealed them in a plain white envelope, and dropped it off for DHL delivery.

Most of the spores died en route to Bloemfontein, but Pretorius was able to scrape together just enough to carry out his verification. He sprayed the surviving spores on several *Sr31* wheats. Sure enough, those plants were quickly plastered with red — *P. graminis* had evolved, and it could now overcome *Sr31* with astonishing ease.

Uganda's tabloid press jumped on the story. Kampala newspapers manipulated the facts to demonize Wagoire, making it appear as though he had somehow synthesized Ug99 in a lab. Accustomed to hearing tales of how Western scientists had invented HIV, the Ugandan public was all too willing to swallow the sci-fi narrative. "The local politicians and the general populace, they do not know about the evolution of diseases," Wagoire says. "All they know is that research scientists work in laboratories and that diseases are in laboratories. So in this case, the story was 'Wagoire has created a disease which is going to wipe out all the wheat in the world!' That was a very trying time for me." Uganda's government shuttered its wheat research program soon after, and Wagoire moved on to an administrative post. (Wagoire maintains that the program was dropped purely for economic reasons.)

Beyond Uganda's borders, however, the discovery was mostly greeted with a collective shrug. "We do not anticipate that the newly discovered virulence to *Sr31* poses an important threat to wheat production in the US," the USDA announced in April 1999, pointing out that several other effective resistance genes — notably *Sr24* and Sr36 — were present in much of the nation's wheat. Besides, the pathogen had been detected only in an isolated corner of Uganda, near the Rwandan border. The odds of its spreading to neighboring countries, to say nothing of beyond East Africa, seemed slim.

But those who dismissed Ug99 as a mere anomaly would soon be proven dreadfully wrong.

A quarter mile from the state fairgrounds in St. Paul, where 1.8 million Minnesotans gather each summer to inhale corn dogs and ride the Zipper, there's a one-story brick structure that could easily be mistaken for a post office. But no dead letters are stored within this building's vault — only live pathogens.

This is the USDA's Cereal Disease Laboratory, where 30,000 enemies of wheat, barley, and oats are held captive so their malevolent secrets can be learned. And among these pathogens are numerous samples of Ug99, sent here from nations already infiltrated by the new strain of *P. graminis*.

The CDL is one of only two labs in the world legally permitted to analyze live *P. graminis* spores imported from abroad. The critical work of dealing with live cultures takes place for three months each year, December through February. Should any particles of *P. graminis* escape, the theory goes, they will find no wheat in Minnesota's frozen fields to infect and will thus perish before causing any lasting damage. (The other lab that handles live stem-rust spores is in similarly frigid Winnipeg, Manitoba, for precisely the same reason.)

After the winter session, the CDL puts its Ug99 in suspended animation, so the pathogen can be reanalyzed for years to come. For the other *P. graminis* samples, many of which date back to the 1950s, this is done by placing vials of spores together in vats filled with liquid nitrogen. But Ug99 is accorded special treatment: Its spores are sealed in a dedicated freezer set to -112 degrees Fahrenheit. Solitary confinement is necessary to prevent a careless researcher from unleashing the enemy. "We wouldn't want someone to mistakenly grab the wrong tube out of the liquid nitrogen," says Les Szabo, a research geneticist at the CDL.

A gangly man with a calm yet serious demeanor, Szabo is the world's leading *P. graminis* guru, having dedicated 22 years to studying what makes the pathogen tick. Prior to the emergence of Ug99, when stem rust was considered a relic, Szabo labored in obscurity — to specialize in *P. graminis* in the latter part of the 20th century was akin to being a Sovietologist after the fall of the Berlin Wall. But Szabo has suddenly found his esoteric expertise much in demand, turning him into something of an ag-science rock star.

Szabo didn't grow up with farming in his blood. He was raised in the Seattle area, where his father was a Boeing engineer, his mother a biochemist. But for reasons he can't quite pinpoint, Szabo has always been fascinated by the ways in which parasites bend hosts to their will. In 1988, when the USDA posted a seemingly undesirable job studying *P. graminis*, Szabo leapt at the opportunity to work in what he cheerfully terms "the backwater of science."

"One of the cool things about rust is its really intricate development process," says Szabo, who comes alive when describing *P. graminis*' craftiness. "It doesn't use the slash-and-burn approach, where you just kill tissue and live off that. It establishes itself and coexists with the host, then causes its damage. That balance, that ability to take over but coexist — it's a lot more sneaky."

The fungus is also an efficient traveler: A single hectare of infected wheat releases upwards of 10 billion spores, any one of which can cause the epidemic to spread. The circumstances have to be just right, though — the prevailing winds must blow toward an area of wheat cultivation, and the *P. graminis* spores must survive the airborne journey.

That is precisely what happened in the case of Ug99. Two years after its initial discovery at Kalengyere, the pathogen drifted into the fields of central Kenya, where it caused major losses and wreaked havoc on thousands of subsistence farms. The pathogen's next stop was Ethiopia, sub-Saharan Africa's biggest wheat producer, followed by eastern Sudan. (So far, those two countries have escaped major damage thanks largely to dry weather, which tends to hinder *P. graminis*.) By 2006, the pathogen had hopped over the Red Sea into Yemen, a disturbing migratory milestone. "I look at Yemen as the gateway into the Middle East, into Asia," says David Hodson, former chief of Cimmyt's Geographic Information Systems unit and now with the Food and Agriculture Organization in Rome, where he tracks global wheat rusts.

In 2005, Hodson was asked to develop a model for predicting the spread of Ug99 based on global wind patterns. The climactic data he gathered suggested that airborne particles from Yemen would inevitably alight in Iran or Iraq. And sure enough, in 2007 and then in 2009 Iran endured successive Ug99 infections, suggesting that a full-blown epidemic is possible.

This spread to the Islamic Republic tracks neatly with what Hodson terms "Route A," the likeliest scenario for Ug99's migration. If his model continues to hold, the pathogen should steadily move toward the Punjab over the next few years — almost an exact repeat of the migratory path taken by a novel form of yellow rust, which was first detected in Kenya in 1986, then arrived in India a decade later.

But Hodson is suspicious of just how predictable Ug99 has been so far. “Maybe one of the most surprising things for me is that we haven’t yet seen a random jump, a very long-distance jump,” he says. In rare instances, fungal spores have been known to ride the winds across oceans — a sugarcane rust that first appeared in Florida in 1978, for example, is thought to have blown in from Cameroon. Hodson’s greater fear is that Ug99 will spread via the “747 route” — hitching rides on human travelers. This is how yellow rust first got to Australia in 1979, tucked into the clothing of a farmer who had vacationed in the French countryside.

Ug99 isn’t just on the march. It’s mutating, too: It has developed the ability to overcome resistance genes that were being used to combat it. At least four variants of the pathogen have been discovered to date, and each has the ability to knock out resistance genes once thought to be worthy substitutes for *Sr31*. The most troubling of these variants, first detected in Kenya in 2006, tears through *Sr24*, the gene that so many North American wheat producers rely on to keep *P. graminis* at bay. Another variant shreds Sr36, commonly used in the winter wheats of the Great Plains.

That’s why the USDA has suddenly become so alarmed over Ug99 and why Szabo now finds himself a very busy (and well-funded) scientist. Armed with banks of high-speed polymerase chain reaction machines, he’s in the midst of a two-year project to sequence the Ug99 genome. He hopes to identify the pathogen’s effector genes — the genes that actually do the dirty work of destroying wheat. If these genes can be cloned and inserted into bacteria that will produce the corresponding proteins, then new breeds of wheat could be screened for Ug99 resistance in a lab, eliminating the need to ship them to Njoro for exposure in the wild.

The CDL is especially busy during the winter months, when Szabo can devote time to his shipments of live *P. graminis*. He gets first crack at the foreign spores, so he can comb through their genetic material in search of microsatellites. These are stretches of DNA in which a reference *P. graminis* genome is known to contain a very simple sequence — say, 18 consecutive pairs of a cytosine (C) followed by an adenine (A). But “slippage” tends to creep into such repetitive strands when new races like Ug99 evolve — an extra repeat might plop down in the middle of the CACACA monotony. That error becomes a DNA fingerprint for the race.

Using the microsatellite method, Szabo needs only 48 hours to determine whether a *P. graminis* sample is Ug99. But given what’s at stake for US wheat, he wants to ensure that precious days aren’t wasted in sending samples to and from St. Paul. So he’s developing a 24-hour DNA test called a TaqMan PCR, which can be used by regional pathology labs that regularly analyze infected wheat. The faster a Ug99 invasion can be detected, the better the odds of containing its damage: Fungicides can be applied immediately. (However, due to their expense, scarcity, and negative environmental impact, such fungicides are considered only a stopgap measure.)

But Szabo wants to do more than just play post-invasion defense. He also dreams of using his genomic intel to figure out elegant new ways of countering Ug99. When a *P. graminis* spore lands on a leaf, for example, it shoots out a germ tube that searches for a stomata — a portal into the plant’s innards. The spore maximizes its chances of finding such an aperture by somehow sensing the topography of the leaf, then launching its probe perpendicular to the long axis of the surface cell. What if there were a way to give wheat a gene capable of scrambling the spores' topographical sense, so they could never burrow inside?

Szabo is a font of such ambitious, sometimes half-formed ideas for turning the tide against Ug99: He also has vague notions of transplanting resistance genes from rice, interrupting the pathogen's sugar intake, or using RNA to gunk up effector genes. But all of these strategies depend on learning more about what makes the fungus so aggressive in the first place. For now, the questions vastly outnumber the answers. "Having the genome is certainly going to give us some tools, but it's still going to take a long time to understand this organism," Szabo says. "It's much more than any one person can do in a career."

Cereal-disease expert Brian Steffenson inspects Ug99-infected wheat.
Photo: University of Minnesota

Back in Njoro, Bariana, the clipboard-toting Australian geneticist from the University of Sydney, leans down to inspect Diamondbird, one of his heartiest specimens. He likes what he sees — stem rust has chewed up only a modest 20 percent of the surface area. Though there are a few red dots on the plant's stem, the pustules don't look too angry, like blisters about to pop.

There is no single gene that has helped Diamondbird escape the worst of Ug99's punishment. The plant is protected instead by a combination of so-called minor genes, which work in tandem to slow the enemy rather than stop it cold. This pragmatic approach to engineering resistance is now much in vogue among breeders keen to make *P. graminis* irrelevant once more.

The Green Revolution defeated stem rust by relying on single "major" genes like *Sr31* and *Sr24*, which bestowed near-blanket immunity to *P. graminis*. "But the thing about major genes is that they either work or they don't — it's black or white," Bariana says. So once Ug99 started beating the majors, the vast majority of the world's wheat immediately lost protection and became completely vulnerable.

Having been burned by this all-or-nothing strategy, breeders are now borrowing an idea from cryptography: They're trying to stack up minor genes that offer only partial resistance. By itself, a single minor gene does scant good — it can only slow down Ug99 so the pathogen is able to destroy just, say, 85 percent of a plant before harvest, instead of the customary 100 percent. But if five or six such genes can be crammed into a variety pack, the cumulative effect should be akin to that of a major gene. "It's a bit like adding one more number in the lottery," says Ronnie Coffman, international professor of plant breeding at Cornell University. The addition of each semi-resistance gene makes it exponentially tougher for the fungus to win out. This piecemeal approach may not be as sexy as discovering the next *Sr31*, but it's by far the most promising approach to ending the crisis.

Breeders are scouring the globe in search of useful minor genes, combing locations from Central Asia's grasslands to dusty museum storerooms. Bariana, for example, is sifting through the vintage collection of A. E. Watkins, a University of Cambridge breeder who gathered wild wheat varieties from the far corners of the British Empire during the 1930s.

When a minor-gene plant like Diamondbird proves to be a "slow ruster" in Njoro, the next step is to analyze its DNA. This is done to find markers linked to genes that control resistance. If such markers can be identified, breeding becomes an order of magnitude easier: Seedlings can be screened in the lab to make sure they carry the desired gene combo and only the best candidates sent to Kenya. As a result, Bariana estimates that minor-gene wheats possessing near-immunity to Ug99 could be ready for widespread planting in three to four years.

Yet innovation can do only so much. The other half of the equation is politics — and PR: persuading tens of millions of farmers to switch to new wheats, especially in nations that have yet to suffer Ug99's wrath. Minor-gene wheats must therefore offer something more than just stem-rust resistance. They must also produce better grain and more of it than their predecessors, the *Sr31* and *Sr24* wheats that farmers have happily relied upon for decades. Therein lies a problem for breeders: Fiddling with one portion of a genome tends to have unpredictable effects on another. And the more slow-rusting genes that are brought into a plant's genome, the tougher it can be to control unrelated traits like yield, height, and color.

As the breeders keep tinkering, South Asia is bracing for impact. The CDL recently tried to get its hands on a suspicious *P. graminis* sample from Pakistan that is said to knock out *Sr31*. But the country is reluctant to share: "Some countries regard isolates of their pathogens as part of their genetic heritage," CDL director Marty Carson says. "I guess there's a fear that we'll patent something off of it." Preliminary analysis of dead spores indicates that the pathogen is not directly related to Ug99, but a Canadian lab is now in the process of doing a proper race analysis.

Meanwhile, for every Diamondbird there are a dozen setbacks. One autumn afternoon in Njoro, Steffenson, the cereal-disease expert from the University of Minnesota, strolled through the test field, checking on barley that was grown from seed he'd developed in his St. Paul greenhouse. It was a dispiriting affair. "Boy, these are getting spanked," Steffenson muttered as he passed by row after row of plants pocked by red pustules. "Blasted, just blasted." The victims included a variety whose genetic resilience he had prematurely extolled in a journal article just weeks before.

But there's no time to mourn these losses. Across the field from Steffenson, Bariana was busy evaluating hundreds of plants downwind of Diamondbird. His routine never varied: Bend at the waist, inspect the stalk, jot down the score on his clipboard. Few plants were faring well; Ug99 was having its way with the bulk of Bariana's creations. But the Australian kept at his tedious task for hours, until the sun began to set behind the acacia trees. He and his colleagues will do this again and again and again, until one of them finds the genetic hurdle that the enemy cannot clear.

Contributing editor Brendan I. Koerner (Brendan_Koerner@wired.com) *wrote about smart grids in issue 17.04.*