At an experimental station in Njoro, Kenya, a researcher looks for plants that are resistant to wheat rust, a disease that is threatening crops in Africa and Asia.

G. VAIDYANATHAN

THE WHEAT STALKER

Scientists are fighting damaging wheat fungi from East Africa, but breeding new crops won't help unless farmers plant them.

BY GAYATHRI VAIDYANATHAN

David Cheruiyot noticed that his wheat fields were turning the wrong colour. The stems of the plants took on a sickly brown hue, and when he peeled open the heads there was no grain inside. "If you go to inspect it, there is nothing but dust," he recalls.

Ug99, a virulent fungus that causes a disease called stem rust, arrived on Cheruiyot's farm in Kenya in 2007. It devastated wheat fields in the country that season, slashing yields by as much as 80% in some regions. Since that epidemic, Cheruiyot has sprayed his wheat three times a season with fungicide, something that few farmers in Africa can afford.

Stem rust has plagued farmers for millennia, but Ug99 is a new superstrain that overcomes defensive genes in 90% of the wheat crops planted around the globe. Since it was first detected in 1998, spores of the fungus have spread from East Africa into Yemen and Iran. If the disease continues its march eastwards, hitting the breadbasket of south Asia and China, it will threaten the food supply of hundreds of millions of people.

Yet there are potential defences against the scourge, growing in a field just a few kilometres from Cheruiyot's farm. At the Kenya Agricultural Research Institute in Njoro, plant scientists have screened more than 200,000 lines of wheat for variants that are resistant to fungal attack. By combining genes using traditional breeding methods, the researchers have already developed 20 types of wheat that can withstand an attack from Ug99. Some countries are testing and starting to distribute these varieties.

But that is only half the battle. There is a large gap between the controlled world of agricultural research and the farming communities of developing nations. In the case of wheat, governments and farmers have been slow to adopt agricultural advances, especially in Africa. There are problems on both sides: farmers tend to be inherently conservative, but researchers do not always know which crops will appeal most. Farmers look not only for high yields, but also for by-products such as straw that can double as animal feed, or stalks for thatching roofs, so researchers must take that into account when designing wheat varieties. It can take years of work — and millions of dollars — to get new seeds to catch on.

The divide between research and farming was thrown into sharp relief this year by a different epidemic. A related fungal disease — yellow rust — swept through parts of Africa and the Middle East, cutting yields in half in some places. In hard-hit countries such as Ethiopia, farmers were unprepared, and are only now seeking out seeds that can resist the disease. But the varieties that are widely available are not the newest and best that science has to offer.

Getting the right seeds to farmers — and convincing them to try them — is a major challenge in Africa and the rest of the developing world. "It's not just putting seed in a storeroom where you sell it," says Ravi Singh, head of irrigated bread-wheat improvement at the International Maize and Wheat Improvement Center (CIMMYT), based in Mexico City, which developed the new wheat varieties. "It has to do with proper demonstration and publicity so farmers come to see it. Seeing is what counts in the end."

BLACK RUST

In the developing world, wheat is second only to rice as a staple food. More than 4.5 billion people worldwide depend on wheat, and forecasts suggest that demand for the grain will soar by as much as 60% in the developing world by the middle of this century. At the same time, climate change is expected to reduce wheat production in the developing world. A shock to the system in the form of a devastating new race of wheat rust — whether stem or yellow rust — could push millions into food insecurity.

When spores of the stem-rust fungus *Puccinia graminis* land on wheat plants, they form brown

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Kenyan farmer David Cheruiyot sprays his fields with fungicide to save his harvest from wheat stem rust, but not all farmers can afford such measures.

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pustules and suck up nutrients meant for the developing grain. Soon, the plant is enveloped in reddish-brown or black pustules, leading to the disease's other name, black rust.

In the 1960s, agronomist Norman Borlaug and his colleagues at CIMMYT bred varieties of wheat to contain genes that conferred resistance to rust, including one gene called *Sr31*, or stem rust 31. His team tested many of their plants in nurseries in Njoro, because wheat fungi thrive in the East African climate all year round. The new varieties also had other desirable traits, such as high yields and a compact size to resist winds. Those were some of the key advances that sparked the Green Revolution in agricultural production, and in 1970 Borlaug won a Nobel Peace Prize for his efforts.

Then people forgot about stem rust. With the disease under control, wheat supplies and prices stabilized, and money drained away from rust-resistance research. The Njoro nursery was shut down. CIMMYT continued breeding wheat, but switched its focus to properties such as increased yield. In 1990, scientists created a high-yielding wheat called Attila, which soon dominated fields in North and East Africa, the Middle East and parts of south Asia. About 20 million hectares of the developing world is now planted with this monoculture.

Meanwhile, *P. graminis* continued to evolve in the warm, humid climes of East Africa. In 1998, CIMMYT scientists in Uganda noticed a highly virulent type of stem rust that ruined wheat varieties containing the *Sr31* gene, including Attila. The new strain was dubbed Ug99, after the place in which it was found and the year it was formally identified.

Since then, seven variants of Ug99 have been found, each of which can overcome different sets of resistance genes. The spores travel by wind, hopping across nations and waiting for humid and hot weather to spark an epidemic.

In 2005, after hearing about the stem-rust resurgence, Borlaug mobilized scientists in a project that came to be known as Durable Rust Resistance in Wheat (DRRW), spearheaded by plant researchers at Cornell University in Ithaca, New York, and CIMMYT. Screening programmes resumed in Njoro, and scientists from research institutes and universities around the world started sending their wheat lines to Kenya for testing. In February this year, the DRRW received a US$40-million donation from the UK Department of International Development and the Bill & Melinda Gates Foundation in Seattle, Washington.

BREEDING IMMUNITY

Twice each year, plant researchers from nations including Mexico, Canada, Australia, the United States and India converge on Njoro to inspect the crops. Ignoring their hunger and jet lag, they don white protective bodysuits and rush to a 3-hectare wheat field surrounded by acacia trees and barbed wire.

To the untrained eye, all the plants in the field look the same. But this season, 17,000 distinct lines of wheat have been planted there. The traits of each need to be examined, scored, selected and — where desirable — bred into successive generations.

Julio Huerta-Espino, a senior geneticist and pathologist with CIMMYT's irrigated wheat-breeding programme, screens plants by touch. He runs his thumb and forefinger down the stem of a plant that looks clean, but tiny bumps alert him to the early stage of a rust infection. On a disease scale up to 100, Huerta-Espino scores these particular plants as 70 — or almost completely susceptible — and snaps the stems in half. He tags plants that have fewer pustules, about a ten on the scale, with blue tape.

He will take these plants to CIMMYT's centre in Mexico and select them for other qualities that make the perfect wheat variety — such as a large head that yields a lot of grain, many heads per plant and resistance to yellow rust and another related disease, leaf rust. Singh will then choose which of the plants to cross, and send their offspring back to Njoro to make sure that the new generation has inherited sufficient resistance to stem rust.

Scientists use this old-fashioned 'shuttle' breeding in large part because it is difficult to genetically modify wheat. The plant is hexaploid, having three copies of its chromosome pairs. Its genome is five times larger than the human genome, making regions of interest hard to pinpoint and manipulate. The wheat genome has been sequenced, but scientists have yet to annotate it. And relatively few markers have been identified, so it is difficult to map genes and link them to traits.

In the past, scientists have sought to protect wheat by breeding for 'major' genes — such as *Sr31* — that confer significant protection against a particular strain of fungus. The genes are thought to code for effector proteins that recognize the invading fungus and trigger plant defences. Over time, though, the fungus can mutate and evade the plant's recognition or defence systems. That was how Ug99 was born.

Scientists at CIMMYT are now harnessing 'minor' genes, which offer broader, but less powerful, defences. Each reduces the severity of disease by only 10% or 20%. But a combination of minor genes, stacked up in one plant,

can form an effective shield — and is harder for the fungus to evade, because it would need to evolve resistance to several genes at once.

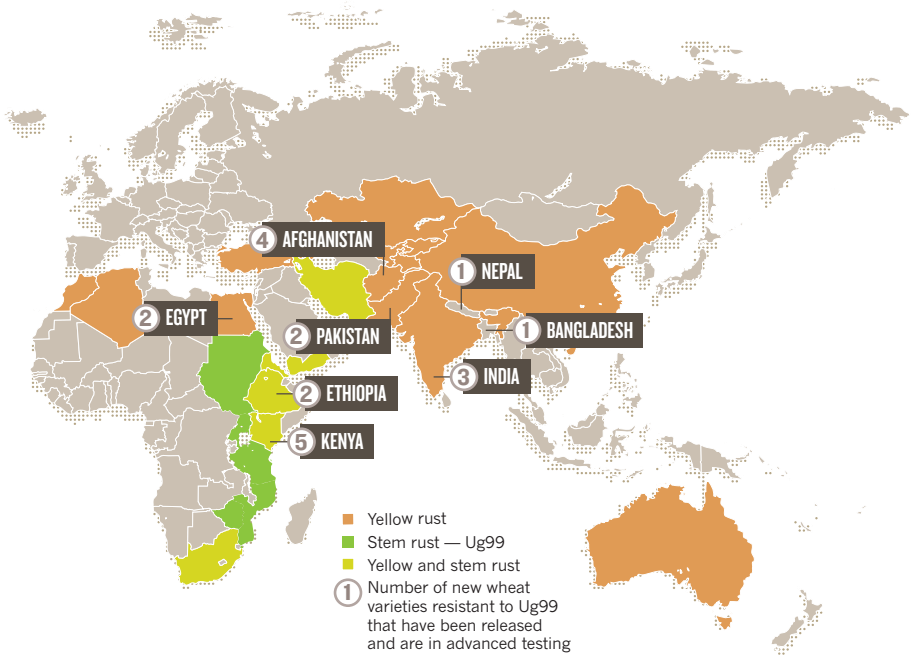
Scientists in Canada and Australia, affiliated with the DRRW, are taking a different approach, stacking major resistance genes and identifying new ones. Others are searching for genetic markers linked to minor and major genes, to ease future gene-based selection. The researchers want to keep developing more types of resistant varieties in case the fungus, which is always present in East Africa, evolves a way to defeat the minor-gene protection.

"This is what challenged us with Ug99," says Ronnie Coffman, an agricultural biotechnologist at Cornell and vice-chairman of the Borlaug Global Rust Initiative, an advocacy and research-coordination programme. The protection afforded by *Sr31* lasted for 30 years. "People began to assume it would endure," he says. Coffman believes that once the wheat genome has been annotated, it will be easier for scientists to use genetic tools to screen for the ultimate multiple-disease-resistant wheat variety.

Meanwhile, scientists with CIMMYT have spent years screening varieties bred with minor genes, and have produced 20 resistant types, which have been released to national breeding programmes in eight nations in Africa and Asia, including Kenya and Ethiopia (see 'Wheat's worst enemies').

WHEAT'S WORST ENEMIES

Previously unknown strains of wheat-rust fungi have attacked crops in Africa, Asia and Australia in recent years. Researchers have developed new varieties of wheat that are resistant to the devastating Ug99 race of stem rust, and governments are now testing and multiplying those seeds.



EVOLVING THREAT

Stem rust is not the top threat to farmers in the Munesa district of Ethiopia, 1,100 kilometres north of Njoro. Although Ug99 is present here, these wheat-growing regions are usually too cool for stem rust, there has been no major outbreak since 1993. But last year, yellow rust significantly cut wheat yields in Munesa and other parts of Ethiopia. Researchers suspect that last year's outbreak was caused by Yr27, a new race of the yellow-rust fungus, which also devastated fields in North Africa and the Middle East. First seen in south Asia in 2002, Yr27 has the potential to defeat popular types of wheat, including Attila. So plant scientists quickly bred varieties resistant to it.

But farmers and seed multipliers in Ethiopia had no interest in the new varieties, because they liked the high yields from Attila. So, without much demand, the seeds never became widely available.

This is a familiar story. Since 2006, the Ethiopian Institute for Agricultural Research (EIAR) in Addis Ababa has been promoting a type of wheat called Digalu, which is resistant to Ug99 and has some resistance to yellow rust. Researchers with the EIAR convinced a few farmers to plant the seed, but it did not gain much traction against the high-yielding Attila.

All that changed last year. The yellow-rust epidemic hit fields of Attila hard, but areas planted with Digalu were untouched. Seeing healthy plants amid sickened fields, farmers finally started seeking out the new seeds.

But Digalu is not the best variety out there. Its resistance to Ug99 is based on a single major gene rather than a set of minor genes, so at some point it will fall prey to the constantly evolving stem-rust fungus. If farmers take to Digalu, they may reject better varieties that have minor-gene resistance when they become available.

In 2010, the Ethiopian government approved two new Ug99-resistant varieties from the 20 developed by the DRRW programme, and one of them is also resistant to yellow rust. Although both varieties yield more grain than Attila and should appeal to farmers, neither is yet available for purchase, because they are in the preliminary stages of seed multiplication.

The situation should improve if the multipliers can produce a large crop of the seeds, says Singh. If all goes well, nearly 8% of Ethiopia's bread-wheat area will be planted with the two new varieties by 2013, he says. "To me, this is a major achievement in a short time period."

That is a best-case scenario. It takes time to build up support for a variety, and success depends on many factors, such as whether governments have enough funding and agents to demonstrate the new seeds to farmers. Ethiopia has long been lacking in these areas, but this year it received $3 million from the US Agency for International Development to multiply seeds, including the two DRRW varieties.

Scientists recognize the difficulty of getting plants with desirable traits into wide circulation, so they are now bringing farmers into the experimental nurseries and asking them which traits would be most valuable in the real world. Ethiopian agricultural officials used such advice from farmers to select which Ug99-resistant varieties to release in their country.

Bedada Girma, coordinator for the DRRW programme in Ethiopia and a scientist at the EIAR, then recruited influential farmers to try out the new seeds. Last year, Girma asked Manza Hamda, a farmer in the Oromia region, to grow one of the wheat varieties, called Kakaba. Hamda planted the seed on 0.25 hectares of his 3-hectare farm.

When yellow rust came, Kakaba fared much better than Attila did. Other farmers noticed, and asked Hamda for some of the resistant seed. He had enough to sell to one of his neighbours, who plans to plant Kakaba in his fields in the next few weeks. Slowly, one farmer at a time, the fruits of science are starting to take root in East Africa. ■

Gayathri Vaidyanathan *is an International Development Research Center fellow at* Nature.

A NEW RACE OF WHEAT RUST COULD PUSH MILLIONS INTO FOOD INSECURITY