



# Fighting a “Shifty Enemy”

## The international collaboration to contain wheat rusts

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**W**heat, one of the world’s staple food crops, is under constant attack in farmers’ fields from diseases, insects, and weeds. Rust diseases, which have plagued wheat since ancient times, are among the most destructive plant pathogens in the world, especially to cereals.

Rust was found on specimens of wheat from the Late Bronze Age, around 3300 BC, and ancient Romans described rust damage to their crops. In 19th century Prussia, the losses for all cereal crops from rust diseases were estimated to be almost one-third of the total value of the crops.<sup>1</sup> In India, estimated losses on occasion reached 50 percent or more, exceeding the losses from all other pests and diseases. Under epidemic conditions, they can cause crop losses of 60–100 percent, trigger famines, and even ruin whole economies.<sup>2</sup>

During the past 50 years, an international effort to identify and breed wheat varieties that not only have high yields, but also are resistant to rust, has helped protect and improve wheat yields and feed millions. The success of the effort depended on a remarkable network of national and international agricultural research centers, gene banks, and nursery programs, underpinned by a free and open worldwide system of exchanging information and plant genetic materials.

### The Threat to Wheat

In 2003, wheat was consumed in 175 countries and met more than one-third of the minimum food requirements of the average adult. Wheat is a particularly important crop in many poor countries

in terms of both production and consumption: in 2007, farmers in 76 developing countries produced wheat, while consumers in 52 developing countries consumed more than 50 kilograms per capita.<sup>3</sup>

Diseases are an ever-present threat to this essential crop, and rusts, a group of fungi species, are among the most virulent. Wheat is susceptible to three types of rust: stem (black) rust, leaf (brown) rust, and stripe (yellow) rust. Although infection may occur on any part of the plant that is above ground, cereal rusts generally attack the stem and leaves and thus reduce yields. Rust disease has many stages, but its most obvious one is indicated by rust-colored spots that contain millions of infectious propagules, or spores of the fungus, that aid in the dispersal of the disease. Rust pathogens can produce billions of wind-borne spores that are then carried thousands of miles, and they have an excellent ability to vary through mutation or sexual reproduction; in this way, they overcome any resistance that a wheat variety might have.

Although the frequency and severity of rust epidemics have been reduced with the widespread use of modern wheat varieties, losses can still be severe (see Table 2.1). Dozens of rust epidemics occurred in Africa and Asia between 1970 and 1995.<sup>4</sup> Notable ones include the Pakistan rust epidemic of 1977–78, which caused losses of more than 1 million metric tons; epidemics in India between 1970 and 1973, losses from which are valued at US\$118–222 million; a wheat leaf rust epidemic in 1976–77 in a region of Mexico that was responsible for more than 70 percent of the

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**Table 2.1—Developing country losses due to wheat rust diseases**

Rust type	Yield losses in susceptible varieties		Endemic areas as proportion of total wheat areas (%)	Number of recent epidemics (1970–85)	Hot spots (areas where disease is most severe)
	Average in endemic area (%)	Average in epidemic (%)			
Stem rust	40	Up to 100	50	7	Highlands of Kenya and Ethiopia; Parana State, Brazil; South India
Leaf rust	15–20	Up to 50	90	8	Mexico; India; Pakistan; Bangladesh; China
Stripe rust	40	Up to 100	33	18	Highlands of South America and East Africa; North Africa; Middle East; Indo-Gangetic Plains of India and Pakistan

Source: Adapted from Hanson, H., N. E. Borlaug, and R. G. Anderson. 1982. *Wheat in the Third World*. Boulder, Colo., U.S.A.: Westview Press; Saari, E.E., and J.M. Prescott. 1985. World distribution in relation to economic losses. In *The cereal rusts, vol. II, Diseases, distribution, epidemiology, and control*, ed. A.P. Roelfs and W.R. Bushnell. Orlando: Academic Press.

country’s wheat crop; and a stem rust epidemic in one part of Ethiopia in 1993–94 that contributed to severe food shortages for more than 300,000 people.<sup>5</sup>

## In Pursuit of Rust-Resistant Wheat

In the summer of 1950, a virulent type of stem rust known as race 15B began to spread in the wheat fields of Mexico and the United States. Concern immediately arose in the U.S. Department of Agriculture (USDA) and similar agencies in Canada, Mexico, and several other Latin American

countries. Representatives from these agencies held a conference in St. Paul, Minnesota, in November 1950 to address what they saw as a real threat to food security in the region.

Although countries had informally exchanged genetic materials for breeding wheat for years, during the St. Paul meeting participants decided to formalize the search for rust-resistant wheat varieties through an international nursery program—that is, they decided to collect a set of genetic materials from a variety of countries with the specific purpose of finding improved rust resistance.

Initially seven countries—Argentina, Chile, Canada, Colombia, Ecuador, Mexico, and the United States—participated in the new International Spring Wheat Rust Nursery (ISWRN) program.<sup>6</sup> Testing immediately got underway on a sizable scale: the ISWRN screened more than 1,000 wheat lines a year for rust resistance in each participating location, sharing germplasm (plant genetic material) and information freely with all interested parties. The spread of stem rust race 15B culminated in a wheat rust epidemic in North America in 1953–54, but thanks to the rust-resistant varieties identified by the ISWRN and distributed to farmers, the disease was brought under control by the mid-1950s.

A great deal of the wheat-breeding work that contained the epidemic took place through the Mexico-Rockefeller Foundation International Agriculture Program, a leading center of wheat



*Wheat infected with stem rust*

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## The Birth of the International Agricultural Research System

The Mexico-Rockefeller program was an international agricultural development program founded in 1943 to help Mexico increase food production. Under the leadership of Norman Borlaug, the wheat program began employing the principles of free and open exchange of information and germplasm to promote cooperation in agricultural research. By the late-1950s, the Mexico-Rockefeller wheat program had gathered about 50,000 nursery entries. In 1960, the Mexican-Rockefeller program was superseded by the Inter-American Food Crop Improvement Program and expanded to include potatoes. It became home to the International Spring Wheat Yield Nursery (ISWYN) in 1964. During the next few decades, wheat research programs in other countries included their wheat-breeding materials in the ISWYN. In this way, Mexico became an international center for information and exchange of spring wheat germplasm.

Also in the early-1960s, the Ford Foundation and the Rockefeller Foundation helped create the International Rice Research Institute (IRRI) in the Philippines. On a world tour in 1963, Mexican President Adolfo Lopez Mateos, impressed by what he saw in the Philippines, became convinced of the need for more such institutions. Many countries noted the success of wheat in Mexico, and Lopez Mateos told the Rockefeller Foundation that Mexico would support a wheat and maize institute similar to IRRI. Thus Mexico became the home of the International Maize and Wheat Improvement Center (known by its Spanish acronym, CIMMYT). The wheat gene bank at CIMMYT is now one of the largest wheat collections in the world. CIMMYT is now one of 15 research centers that together make up the Consultative Group on International Agricultural Research (CGIAR). The principle of free sharing of germplasm, which underpinned the success of the rust-resistance breeding work, became the hallmark of this international network of centers.

research (see box above) led by plant breeder Norman Borlaug. It was here that Borlaug and his team developed new breeding techniques that helped bring about rapid advances in wheat breeding.

In the mid-1940s, for example, Borlaug realized that Mexico's traditional wheat-growing highland areas could not produce enough wheat to make the country self-sufficient in wheat production. Scientists at the Mexico-Rockefeller program looked to areas of northern Mexico where irrigation systems were being used—such as the Yaqui Valley in the state of Sonora—to accelerate the breeding process with a system called shuttle breeding. They planted test crops in May in the highlands around Mexico City and harvested the wheat in October. Then in November they planted the crops in the Yaqui Valley and harvested the wheat in April. Despite the prevailing dogma of the time that said shuttle breeding could not work, the technique succeeded. By allowing scientists to grow two crops a year, shuttle breeding cut the time required to breed rust-resistant varieties in half, from 10–12 years to 5–6 years. With the use of shuttle breeding, promising varieties were made more rapidly available to wheat farmers than was

previously thought possible. As a result, when race 15B became epidemic in North America, it was conquered within a few short years, mitigating a true food crisis.

However, the story did not end here. Genetic resistance to wheat rust can take one of two main forms: race-specific resistance, which generally does not last long, and non-race-specific resistance, which is longer lasting or durable. Rust can overcome specific resistance in about 5–6 years, causing boom and bust cycles in wheat production.<sup>7</sup> This unpredictability accelerated the search for more long-lasting, non-race-specific resistance. Under the Mexico-Rockefeller program, researchers used materials from the United States, Kenya, and South America, where resistant varieties were known to exist. During the 1970s, scientists were able to release new varieties with non-race-specific resistance in Mexico that soon spread to other countries.

Rust resistance was only one of the characteristics that scientists were pursuing in their wheat-breeding efforts. Once plant scientists in the Mexico-Rockefeller program released the new rust-resistant varieties of wheat, they continued to look for ways to produce better yields. They found



*Farmer harvests wheat, India*

that with good soil fertility and irrigation, tall wheat varieties fell down under the weight of their heavy grains. Borlaug had heard about dwarf wheat being developed at Washington State University and the USDA using Japanese materials and thought it a good approach for the growing conditions in northern Mexico. In the 1960s, Borlaug and his team released new high-yielding, semi-dwarf wheat varieties that were short and sturdy enough to hold up their grains. Several varieties were sent to India and Pakistan, where they launched the Green Revolution (see Chapter 3). These modern, high-yielding, semi-dwarf varieties were the vehicle for delivering improved rust resistance to farmers, and they were widely and rapidly adopted. By 2002, nearly 95 percent of the developing world’s wheat was planted with modern varieties.<sup>8</sup>

## Worldwide Benefits for Wheat Farmers and Consumers

As wheat is one of the world’s most significant crops—with total production in 2005 of 607 million metric tons—the benefits of wheat rust resistance have also been global in scale.<sup>9</sup>

About half of the world’s population living in poverty is located in the large irrigated areas of South Asia alone; these irrigated areas have received the overwhelming proportion of the benefits of rust resistance.<sup>10</sup> Many of these farmers, as well as millions of others in developing countries, rely heavily on wheat for their livelihoods and nutrition. For them, the benefits of rust resistance include higher yields, more stable yields, and better grain quality.

Moreover, rust resistance inherently favors low-income and small-scale farmers, who are less able to use fungicides because they are unavailable or expensive in local markets. Indeed, evidence suggests that for every 1-percent increase in the productivity of wheat, the extent of poverty has been reduced by 0.5–1.0 percent.<sup>11</sup> The availability of effective rust-resistant wheat varieties in developing countries, especially those with food deficits, has also reduced the need for food aid imports.

One dimension of the benefits of modern semi-dwarf varieties incorporating rust resistance is the gain in per capita calorie consumption in developing countries, and the reduction in the percentage of malnourished children. Researchers estimate that calorie consumption per capita in develop-

ing countries increased by about 13–14 percent between 1960 and 2000. That improvement led to corresponding gains in health and life expectancy, reducing the share of malnourished children by about 7 percent, or more than 30 million children.<sup>12</sup> Researchers have also attributed a wheat price reduction of 35–66 percent to the increased production resulting from semi-dwarf varieties.<sup>13</sup> If rust resistance was responsible for 30 percent of the increase in global wheat production from semi-dwarf varieties, then it has made a significant impact on both nutrition and lower food prices.<sup>14</sup>

Several studies have tried to put a dollar figure on the benefits of wheat rust resistance, but it is difficult to untangle its impact from the impact of modern, semi-dwarf varieties of wheat and the Green Revolution. One study estimates that the value of leaf rust resistance to developing countries is equivalent to \$0.92 billion a year in 2006 dollars.<sup>15</sup> Another study estimates that the additional worldwide production resulting from international wheat-breeding research is equivalent to \$2.24–6.84 billion in 2006 dollars.<sup>16</sup> Thus, if rust resistance accounts for 30 percent of the value of all wheat varieties, then the benefits of all rust resistance would be \$0.67–2.05 billion a year. Similarly, it is difficult to determine the cost of rust resistance for developing countries as distinct from the cost of the rest of their breeding activities; however, it is estimated that the total cost for rust resistance is \$59–98 million in 2006 dollars.<sup>17</sup> Because rust resistance is essentially embedded within high-yielding wheat seeds, the direct cost to farmers has been low.

## Lessons Learned

The effort to breed rust-resistant wheat offers a number of important lessons. First, germplasm and information were exchanged openly and freely, and this spirit of collaboration informed the development of the international nursery system. Without the free exchange of germplasm and information, and the nursery system as the vehicle, the worldwide incorporation and distribution of durable rust resistance would likely not have happened.

Second, the practice of testing wheat in multiple locations has broadened the gene pool of the wheat program. This approach began with shuttle breeding in Mexico and then expanded to testing in more than 100 sites around the world.

Third, the training and development of young scientists was an important component of the effort. An undertaking this large requires many well-trained, field-oriented scientists.

Fourth, regional programs and partnerships played an important role. International staff members lived in the relevant regions and frequently interacted with national staff members, who were consequently able to participate in selecting national and international germplasm.

Fifth, the wheat program kept a clear focus on food production, despite pressures to take on tangential activities.

Sixth, the long-lasting support of agricultural research in developing countries by the Rockefeller Foundation, which allowed many breeding programs to bear fruit, was another factor for success in wheat rust resistance. This long-term commitment was essential to achieving an impact in agricultural research and development.

## Fighting New Rust Diseases with Less Funding

Because rust continually evolves to overcome existing genetic resistance, no form of resistance lasts forever. Today, a new threat from wheat rust looms. In 1998, William Wagoire, a scientist in Uganda, found that rust-resistant wheat in the country had become susceptible to a new race of stem rust. This new race, known as Ug99, has now become endemic in Kenya and Ethiopia. In 2005, an expert panel report declared Ug99 to be a threat to world wheat production because it was predicted to migrate to areas that produce 19



*Farmers loading wheat onto bull-drawn cart, India*

percent of the world’s wheat.<sup>18</sup> Scientists are now testing new germplasm in many key areas, but the new race is mutating and spreading as feared. Wind currents or inadvertent transport may eventually carry Ug99 to North Africa, Europe, West Asia, China, Australia, and the Americas.

A large effort is needed to achieve resistance to Ug99, but official international development support for agriculture has fallen drastically since 1980. In addition, donor fatigue in funding agricultural research has shifted funds for agricultural development away from work on breeding and rust resistance. Many national agricultural research systems have also let their systems for producing and distributing seeds deteriorate.

## Conclusion

The collaborative international effort that successfully developed rust resistance in wheat had a tremendous impact on world food supplies. It is estimated that modern rust-resistant wheat varieties account for about 30 percent of the increase in wheat production worldwide, with consequent benefits for food production, poverty reduction, and food security. These varieties now account for 95 percent of the wheat in developing countries.

This impressive achievement came about through a system of extensive research based on free and open exchange of information and genetic material that was followed by a system for delivering rust-resistant, high-yielding wheat varieties to farmers. The lessons of this experience are critical as the world faces new threats from Ug99 and other evolving diseases. ■

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