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Rust, Risk, and Germplasm Exchange: The Borlaug Global Rust Initiative

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Global food security depends on the free movement and open sharing of plant genetic resources. Some of the best examples of what can be achieved are the dwarf varieties of wheat and rice that contributed to the Green Revolution in India – genetic resources that came from Mexico, Japan, China, India and elsewhere.

Plant breeders and seed industries have contributed to the prosperity of the world's agricultural sector by identifying and deploying genetic resources through the processes of selective breeding. They have improved yield, disease resistance, and resistance to abiotic stresses, including many traits influenced by climate change. Their work has played a huge role in rural development and food security.

The Borlaug Global Rust Initiative

The Borlaug Global Rust Initiative (BGRI) and the Durable Rust Resistance in Wheat (DRRW) project that serves as the BGRI's secretariat are excellent examples of the importance of free germplasm exchange. Beginning in 1999, the ability of the world's farmers to meet current and future demand for wheat was gravely threatened by new strains of stem rust disease emerging out of East Africa. Stem (or black) rust of wheat, caused by the fungus *Puccinia graminis,* is the most feared of the rusts of wheat. Stem rust can rapidly reduce a healthy looking crop to a black tangle of broken stems and shriveled grain in a matter of weeks. Historically, wheat farmers have suffered enormous losses from rust diseases: from the Romans who prayed to a "stem rust god" called Robigus, to US and Canadian farmers in the 1950s, who saw yield losses of 40% across spring wheat growing areas. The success of wheat breeders led by Norman Borlaug protected wheat farmers from the scourge of rust diseases from the middle to the end of the last century, and certainly contributed to the stable yield gains of the Green Revolution.

The Problem was Urgent: about 90% of the wheat grown around the world was vulnerable to severe damage to the new types of stem rust disease emerging out of East Africa. Stem rust variant Ug99, identified in Uganda in 1999, was the only known type of *P. graminis* that has virulence against historically durable resistance genes used in breeding programmes, notably *Sr31*.

The Problem was Spreading: stem rust Ug99 was spreading out of East Africa via airborne spores. In early 2007, Ug99 was detected in Yemen and Sudan. Ug99 is now known to be as far north as Iran. Based on prevailing wind patterns, the spores are likely to migrate to other regions of Asia including India and Pakistan, although exact timing of dispersal is difficult to predict. Colonization of North Africa by Ug99 is also likely. International travelers could also spread rust spores on their clothing: similar rapid spread by (inadvertent) human transport has been documented for other plant diseases, including yellow rust of wheat.

The Problem is Becoming More Severe: stem rust is continuing to evolve in East Africa. New derivatives of Ug99 have been isolated that can overcome resistance genes *Sr24* and *Sr36*, both important sources of disease resistance for international breeding programmes.

The Problem is Being Solved: breeders do have access to a limited number of undefeated stem rust resistance (*Sr*) genes from various wheat varieties, landraces and wild relatives. Some of these sources of resistance are "minor" genes that are additive and need to be deployed together in one variety to provide effective protection (also known as Adult Plant Resistance, APR). A small group of elite high-yielding breeding

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lines possessing resistance are being tested already in several countries. Other sources, particularly from wild relatives, need to be "cleaned up" by having linked deleterious traits (linkage drag) removed before they can be used effectively in wheat breeding programmes. Marker assisted technologies can speed up these breeding approaches. The DRRW project (2008-2016) and its subsequent project, Delivering Genetic Gain in Wheat (DGGW) (2016-2020), envisions multiple approaches to achieve long-lasting stem rust resistance, from traditional breeding, to marker assisted selection (MAS) and high-end basic science explorations. This combination of approaches has been judged highly likely to succeed by a panel of 10 diverse external experts who reviewed the proposal for the Bill & Melinda Gates Foundation and the Department for International Development of the UK (DFID) who fund the DRRW and DGGW.

Resource-poor Farmers are Especially Vulnerable: commercial wheat farmers can access chemical protection again rust diseases, although available fungicides are expensive (estimated at $40 per crop cycle to protect one hectare in Kenya) and pose risks to human health and the environment. Chemical protection offers, at best, a limited short-term fix and is unlikely to be accessible to vulnerable resource-poor farmers in countries like Ethiopia, Pakistan, India and Nepal in a timely manner. We can protect the livelihoods and food security of these farmers by supporting development and delivery of improved, resistant wheat varieties that do not require additional inputs for crop protection.

Protecting Wheat Supplies is Important for Global Food Security: wheat represents approximately 30% of the world's production of grain crops. The FAO predicts that 598 million tons of wheat will be harvested this year on 220 million hectares of land. Nearly half of that production will be harvested in developing countries. On average, each person in the world consumes 68.2 kilograms of wheat each year. That equates to about 630 calories per day per person, or 1/3 to 1/2 of the minimal energy requirements of most adults – numbers that are even higher in many developing countries.

The DRRW and the DGGW breeding efforts to improve wheat focus on Africa, a continent that imports about 9 million tons of wheat a year (more than 80% of its wheat needs) – a gap predicted to increase steadily in the future. Poor consumers in Africa and elsewhere are particularly vulnerable to price increases related to wheat – vulnerability that contributes to social instability.

Increases in wheat productivity were a major driver for the Green Revolution, especially in India and Pakistan. In India, wheat yields grew from a total production of 12 million tons (MT) in 1965, to 76.37 MT in 2000. The Government of India has projected that wheat demand could grow to 109 MT by 2020. Crop shortfalls are also occurring in other key wheat producing nations, such as Australia, where recurring droughts in recent years have reduced production.

Using a very conservative estimate of 10% loss in regions hit by Ug99, annual global losses could be devastating in the absence of germplasm and effective breeding programmes. The largest target market would be the 50 million farming families in the Indo-Gangetic plain who rely on wheat production, who would stand to lose over 7 million tons of annual production ($2.3 billion) for each 10% drop in yield. The reality could be much more frightening since much higher losses are possible. Between Rabat and Vladivostok, there are over 100 million hectares of wheat under cultivation, most of it genetically susceptible to Ug99. The 1953 rust epidemic in North America resulted in average yield losses of 40% across US and Canadian spring wheat growing areas.

Constraints on Germplasm Exchange

Increasingly, however, what was previously a free and open exchange of wheat germplasm has become mired in forms and legal documents associated with the multilateral Convention on Biological Diversity[1] and its series of attendant treaties and conventions – particularly the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), the Nagoya Protocol[2], and the Access and Benefit-sharing Clearing House (ABS)[3]. Increasingly, the burden is on the researchers to determine that the germplasm they are deploying has been acquired legally.

The Convention on Biological Diversity affirms that states (countries) have sovereign rights over their own biological resources. Each state draws up its own

1 Convention on Biological Diversity https://www.cbd.int

2 Nagoya Protocol https://www.cbd.int/abs/

3 Access and Benefit-sharing Clearing-House: https://www.cbd.int/abs/theabsch.shtml

regulations. Some are particularly draconian, protective and punitive.

The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilisation to the Convention on Biological Diversity aims to share the benefits arising from the utilisation of genetic resources in fair and equitable ways. It was ratified on 12 October 2014. Since then, it has become the means by which plant breeders and the seed industry are increasingly subject to legal wrangling.

The Access and Benefit-sharing Clearing-House (ABS Clearing-House, within the Nagoya Protocol) is a platform for exchanging information on access and benefit sharing established by Article 14 of the Protocol, as part of the Convention on Biological Diversity. The ABS Clearing-House is a key tool for facilitating the implementation of the Nagoya Protocol, by enhancing legal certainty and transparency on procedures for access and benefit-sharing, and for monitoring the utilisation of genetic resources along the value chain, including through the internationally recognized certificates of compliance.

"Legal certainty," "access and benefit-sharing" and "monitoring the utilisation of genetic resources along the value chain" brings international lawyers, accountants and bankers with little to no background in plant breeding onto the playing field of crop improvement as referees.

Previously plant breeders in the CG system and public sector universities freely exchanged germplasm for plant improvement and did not assess monetary "value" along the "value chain" particularly since some of the "value" did not become evident until genes were used in combination, stacked and/or otherwise proven in performance trials. But, today, without the right "forms" all along the value chain, anyone from CEOs of seed companies to researchers employed by public research institutions can be charged and arrested for violating any one of many protocols.

There are certain provisions of the Convention on Biological Diversity that have merit. It is an important tool to protect various bio-resources for end uses like: drugs, industrial enzymes, food flavors, fragrance, cosmetics, emulsifiers, oleoresins, colors, extracts, and genes used for improving crops and livestock by means other than conventional breeding or traditional practices.

But stringent regulations and country-specific control are stifling the germplasm exchanges critical to agriculture and horticulture, including development of hybrids, introgression breeding for introgressing transgenic traits, and seed production including hybrid seeds. It is not only the improved seeds that are subject to regulation, but isolates of country-specific disease organisms such as Ug99 stem rust that move between collection sites worldwide and biosafety testing labs in Minnesota, Denmark and Canada, and that are subject to the Convention on Biological Diversity because they are "bio-resources."

Sustaining the Delivery of Genetic Gain in Wheat

Exchanges of seed and germplasm and even disease organisms between and among countries are critical to global plant breeding programmes. Wheat germplasm and pathogen exchanges have been essential in the Durable Rust Resistance in Wheat (DRRW) project and will be even more so under the Delivering Genetic Gain in Wheat (DGGW) project as plant breeders broaden their investigation to deliver new traits for wheat that fight diseases, pests, drought and other challenges brought about by global climate change.