A nested association mapping population for wheat stem rust resistance

By DJ McCauley

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Wheat stems displaying adult plant resistance conferred by the Sr2 gene. Photo courtesy of Z.A. Pretorius.

- Wheat stem rust is found worldwide, and the possibility of virulent, recombinant strains could mean yield losses that disrupt local and global economies.
- Resistant wheat varieties are the most economical means of combatting this fungus, particularly in developing countries.
- A recent *Journal of Plant Registrations* article documents resistance genes in a unique “nested association mapping” population of 852 wheat lines with varying levels of wheat stem rust resistance.

For as long as people have cultivated wheat, they've been fighting off a nasty fungus: wheat stem rust. The ancient Romans even held a festival called “Robigalia” on 25 April each year, sacrificing dogs to the god of rust to keep the fungus away.

Thankfully for Fido, modern gene-mapping techniques coupled with the expertise of wheat breeders can help us develop resistant wheat lines to stymy outbreaks of the disease caused by the fungus *Puccinia graminis* f. sp. *tritici*.

University of Minnesota and USDA-ARS researchers designed the equivalent of an upgraded genetic map to show the locations of wheat stem rust resistance genes. The nested association mapping (NAM) population registered by the team is one of the first of its kind to examine wheat stem rust resistance genes through NAM and was published in a recent *Journal of Plant Registrations* article (**https://doi.org/10.1002/plr2.20043**).

The advances the team made in mapping the locations of adult plant resistance to the stem rust fungus will help scientists in the fight to quickly find and breed relevant genes into locally adapted wheat lines.

Wheat Stem Rust

Wheat stem rust devastates fields. The fungus spreads to a wheat plant via airborne spores, forming a brick-red, flaky, blister-like pustule. Pustules release more airborne spores that can infect other plants.

According to James Anderson, a co-author on the study and professor in the Department of Agronomy and Plant Genetics at the University of Minnesota and an ASA and CSSA member, one infection cycle only takes 7 to 10 days. A single susceptible plant can host several infection cycles in a season.

“One outbreak can have exponential growth,” Anderson says. In areas where both winter and spring wheat are grown, the fungus can pass from one crop to another without any type of alternate host.

A susceptible field response in wheat to stem rust. Photo courtesy of Z.A. Pretorius.

The airborne transmission of fungal spores has dire consequences for wheat fields across the landscape. In the United States, outbreaks in temperate areas like the South can result in the fungus overwintering in winter wheat and then traveling on the wind as spores to wheat populations farther north as the weather warms up in the spring (**https://bit.ly/2A7XFzg**).

Though many farmers use a variety of fungicides to keep disease down, they become expensive quickly.

“Fungicides can be really effective,” Prabin Bajgain says. “But we need better ways to fight this, and in many developing countries, fungicides might not be available. If they are accessible, they are often really costly.”

Bajgain worked on this project as a part of his dissertation as a Ph.D. student at UMN. He now serves as a post-doc in the Department of Agronomy and Plant Genetics.

Outbreaks of stem rust in the United States were curtailed during the first half of the 20th century by breeding resistant wheat and eradicating much of the fungus's alternate host, the common barberry bush. However, stem rust is still a major issue in areas of Africa with Kenya as a hotspot for particularly virulent strains. The most common strain, called “Ug99,” was identified in Uganda in 1999 by Zak Pretorius and his colleagues (**https://bit.ly/2BcOH45**). This strain is often used to test resistant lines.

Though the physiological methods of resistance are not well understood, resistant lines have fewer pustules, release fewer spores, and have longer infection cycles.

These factors combined slow fungus spread.

Just last year, a team in Western Europe identified wheat stem rust in the field (**https://bit.ly/2Z8o7kO**). Since virulent, recombinant strains are known to overcome resistant wheat lines, the importance of the NAM population quickly becomes evident.

One estimation predicts that a global outbreak of wheat stem rust, which can cause yield losses between 10 and 70%, could cause as much as $63.8 billion in economic losses, based on average wheat prices in 2009 (**https://bit.ly/2VipD2y**). That conservative estimate provides great incentive for wheat breeders to find and catalogue resistance genes.

Nested Association Mapping

Though breeding wheat for greater resistance isn't a new concept, creating a NAM population in wheat is. The team at the University of Minnesota (UMN) used 10 male parents, all with moderate to high levels of resistance to the common Ug99 stem rust strain.

James Anderson, co-author of a recent Journal of Plant Registrations article documenting resistance genes in a unique "nested association mapping" population of 852 wheat lines with varying levels of wheat stem rust resistance. Source: University of Minnesota Department of Agronomy and Plant Genetics.

Nine of the 10 male parents were derived from Kenyan-bread wheat lines. Since Kenya is a hotspot for new, virulent stem rust strains, it's also a great place to find resistant varieties. The team at UMN has been using Kenyan-bread wheat as sources of resistance as early as the 1950s, according to Anderson.

The tenth male parent was a hard red spring wheat cultivar called Ada, developed at UMN by Anderson's wheat-breeding program.

The 10 male parents were all crossed with the same female parent—a line from Canada called LMPG-6. The mother line is susceptible to wheat stem rust, allowing researchers to determine that any resistance is a product of the male parent's genes. The lines are "nested" within the background of the mother plant's genetics.

From these crosses, the team derived 852 distinct lines. These lines were then self-pollinated for five or six generations, creating stable lines that have resistance genes and are adapted to grow in the field.

There are two different types of resistance—seedling and adult. The team identified resistant plants by exposing seedlings to stem rust and then mapped the genes of wheat that expressed resistance as adults. The team focused on adult plant resistance (APR) because it has broader protection. Often, APR genes show resistance to more than one race of the same rust species and sometimes to other types like leaf or stripe rust.

The detailed NAM population in the Journal of Plant Registrations study makes finding and integrating resistance genes easier for plant breeders. Source: Wikimedia Commons/Carl Davies, CSIRO.

Field trials in Minnesota, Kenya, and South Africa provided resistance data for the researchers to identify and map resistance genes. As an example, if the team saw that 100 of the 852 lines showed stem rust resistance in the field, they could compare their genomes to see what loci they have in common and where those genes are located.

“This design gives you a lot more power to detect resistance genes,” Anderson says. “It's not just that we had 852 lines compared with the normal 100 to 200 from a bi-parental cross but that we were able to detect more genes because of the number of parents.”

Increasing the size of a population means that you can increase the resolution of a genetic map. For instance, by testing both in-field resistance while genotyping each line, the UMN team was able to increase their statistical power, enabling them to find more genes that confer resistance to wheat stem rust.

After the field trials, resistance genes were painstakingly mapped for all 852 lines, and the population was deposited in the USDA-ARS National Laboratory for Genetic Resources Preservation. Seed is available for any researcher interested in exploring their genomes.

“We've seen this population express resistance to other important diseases like stripe rust and leaf rust,” Bajgain says. “That's why we decided to make the whole population available in the United States germplasm collection.”

With such a detailed NAM population, finding and integrating resistance genes becomes easier for plant breeders. In the event of a new virulent strain of wheat stem rust, at least wheat breeders have a readily available selection of genes in publicly available germplasm, well mapped at high resolution, to incorporate into adapted lines and test for resistance. Thankfully, our best option isn't a celebration of Robigalia to keep stem rust at bay, but a well-documented selection of genes to confer adult plant resistance.

Dig deeper

View the original article, "Registration of KUWNSr, a Wheat Stem Rust Nested Association Mapping Population," in the *Journal of Plant Registrations* at **https://doi.org/10.1002/plr2.20043**.

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