Control of Stripe Rusts of Wheat and Barley

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Abstract: In 2005, stripe rust of wheat was the most widespread in the U.S. and also occurred unusually early and severe in the PNW. Barley stripe rust occurred in the western U.S. and was severe in some fields grown with susceptible cultivars. Stripe rusts of wheat and barley were accurately predicted. Fungicide application was implemented to control stripe rust on both winter and spring wheat crops, which prevented major losses. A total of 27 races of the wheat stripe rust pathogen and 15 races of the barley stripe rust pathogen were detected, of which six and two races were new for the wheat and barley stripe rust pathogens, respectively. PST-100 was the most predominant race of the wheat stripe rust pathogen in the PNW and throughout the country. Wheat stripe rust races PST-115 and PST-116 were increasing in frequency, which rendered several previously resistant cultivars to become susceptible. More than 16,000 wheat and 5,000 barley entries were evaluated for stripe rust resistance, from which new germplasms and advanced breeding lines with stripe rust resistance were identified. The information was provided to breeding programs for developing and releasing new cultivars with adequate resistance. Molecular markers were identified for genes conferring HTAP resistance in Alpowa wheat and Bancroft barley, which are useful for developing resistant cultivars. Genes that are important for rust development, survival, and virulences were identified in the wheat stripe rust pathogen, which leads to a better understanding of the pathogen. These genes were used to design primers for identifying markers for studying the distribution, migration, population structures, and virulence variations of the stripe rust pathogen. New effective fungicides were tested for control of stripe rust. Profitability of fungicide application on various cultivars of wheat and barley without and with different level of stripe rust resistance was determined.

1. Monitor occurrence, distribution, and severity of rusts; identify races of the wheat stripe rust; and determine population structures and factors involved in rust epidemics

In 2005, stripe rust, leaf rust, stem rust and other foliar diseases of wheat and barley were closely monitored throughout the Pacific Northwest (PNW) through field surveys and disease nurseries. Early prediction of wheat stripe rust epidemic was made using rust forecasting models based on temperatures in December 2004 and January 2005. The warmer than normal winter allowed more survival of the stripe rust fungus in infected leaf tissues, resulting in early occurrence and quick development of stripe rust in the PNW. Based on the forecast, stripe rust alert was sent to wheat workers and growers as early as in February 2005, which allowed growers to be prepared for control of stripe rust by planting resistant spring wheat cultivars and using fungicides. From March 2005, field survey was conducted periodically and rust updates on rust distributions and severities were provided to growers based on real-time rust situations. The early occurrence of stripe rust due to the warm winter and fast development due to the disease-favorable weather conditions (cool and frequent precipitations) in the late spring and early summer made the disease pressure unusually high. Advises on whether or not to use fungicides on specific cultivars and timely use of fungicides were provided to growers for minimizing yield losses and fungicide usage and maximizing profit under the severe stripe rust epidemic. The effective control of stripe rust saved the PNW wheat growers millions of dollars that could have been lost without the timely control of the disease. Based on acreages of planted resistant and susceptible cultivars and fungicide applications in the commercial fields, and data of our experimental plots, the yield losses caused by stripe rust were reduced to 2% for the winter crop and 4% for the spring crop in the state of Washington. Without fungicide application, the winter wheat crop could have suffered 5-10% yield losses and the spring wheat crop could have suffered 15-20% yield losses, and individual fields grown with susceptible cultivars could have had 40-60% yield losses.

Through cooperators in many other states, wheat stripe rust was monitored throughout the United States. In 2005, wheat stripe rust occurred in at least 35 states, which was the most widespread of the disease in the recorded US history. Severe epidemics occurred in California, Texas, Louisiana, Arkansas, Oklahoma, Colorado, Nebraska, Kansas, Alabama, Indiana, Missouri, and some other states in the southeast and Great Plains, as well as the PNW including southern Idaho, where stripe rust epidemic did not occur from 2000 to 2004.

Severe stripe rust occurred in western Washington, Western Oregon, and California. Susceptible barley varieties had up to 100% stripe rust in our experimental plots near Pullman and Mt Vernon. In the major barley growing regions of eastern Washington, a few fields of barley fields of hooded barley had severe stripe rust and trace stripe rust occurred in most commercial production fields. The light stripe rust in barley fields was mainly due to the factor that the major fields were grown with cultivars (such as Baronesse) with moderate high-temperature, adult-plant (HTAP) resistance. As a result, yield losses of barley caused by stripe rust were estimated less than 1% in 2005. However, our studies with trap plots and stripe rust nurseries and a few commercial fields showed that stripe rust could cause huge yield losses when highly susceptible varieties are grown.

In 2005, leaf rust, which was severe in the eastern and Great Plains states, occurred severely in our experimental plots in western Washington and in some irrigated fields in eastern Washington. The wide application of fungicides for controlling stripe rust also reduced risk of leaf rust. Stem rust was found in limited field spots in the late growth stage in eastern Washington, and it did not caused any significant damage.

The epidemic impact and benefit of fungicide control were assessed based on our experimental data and disease surveys throughout the state. In 2005, we evaluated yield reduction by stripe rust and yield increase by fungicide application with 24 winter wheat and 16 spring wheat cultivars in field experiments of a randomized split-block design with 4 replications. Yield losses caused by stripe rust were more than 70% on highly susceptible winter wheat and more than 60% on highly susceptible spring wheat. Fungicide spray increased yield by 2.9 times for susceptible winter cultivars and by 1.6 times for susceptible spring wheat cultivars.

Because the most widespread of stripe rust, we collected and received 518 samples from 28 states for identification of stripe rust races in 2005. Of the samples that were collected from wheat, barley, triticales, and grasses, 477 were wheat stripe rust. Nearly 46% of the wheat stripe rust samples were collected from the PNW and 21% were from the state of Washington. The stripe rust samples were tested on a set of wheat differential cultivars to identify races of the pathogen. A total of 27 wheat stripe rust races and 15 barley stripe rust races were identified by testing the isolates on 20 wheat differential genotypes and 12 barley differential genotypes, respectively. Six wheat stripe rust races and two barley stripe rust races were first identified in 2005. More than 96% of the wheat stripe rust samples belonged to the group of races (e.g. PST-78, PST-98, and PST-100) with virulences to *Yr8*, *Yr9*, and other resistance genes, which caused widespread stripe rust epidemics in the U.S. from 2000 to 2005. Race PST-100 (virulent on Lemhi, Heines VII, Produra, Yamhill, Stephens, Lee, Fielder, Express, Yr8-AVS, Yr9-AVS, Clement, and Compair), PST-102 (the same as PST-100 plus virulence on Tres), and PST-115 (the same as PST-102 plus virulence on Paha) were the most predominant races, accounting for 33.4%, 27.0%, and 14.4% of the total wheat stripe rust samples, respectively. Race PST-116 (a new race with the same virulence of PST-115 plus virulence on Moro) increased rapidly in the late growing season in the Pacific Northwest. Race PSH-56 (virulent to Topper, Hiproly, Abed Binder 12, and Bancroft) was the most predominant, accounting for 26.7% of the barley stripe rust samples.

To study functional genomics, we have constructed a full-length cDNA library from the wheat stripe rust pathogen. Of 196 sequenced cDNA clones, 37.8% had significant homology to the sequences of genes with characterized functions, 16.8% had significant homology to hypothetical proteins, 19.4% had some homology with genes, and 26.0% did not have significant homology with any sequences in other fungi. A total of 51 different protein products were identified and they are involved in growth, defense, and virulence/infection. In order to develop specific primers to differentiate rust species, formae speciales, and isolates, 28 gene-specific primer pairs were designed based on sequences of some of the identified genes. Using these primers, we have identified polymorphic markers to distinguish the stripe rust pathogen from the stem rust, wheat leaf rust, and barley leaf rust pathogens, and markers to separate the wheat stripe rust pathogen from the stripe rust pathogens of barley, bluegrass, and orchard grass. We also identified primers to detect polymorphisms among isolates of the wheat stripe rust pathogen.

2. Evaluate wheat germplasms and screening breeding lines for resistance to stripe rust, leaf rust, stem rust, and other foliar diseases; identify and develop new resistance sources, especially durable resistance, for improving resistance to rusts

In 2005, we evaluated more than 16,000 wheat and 5,000 barley entries for resistance to stripe rust and other foliar diseases. Based on different sources and purposes, the wheat materials formed 46 nurseries with entries ranging from 12 to 2,000. All the nurseries were planted and evaluated at both Pullman and Mt Vernon locations under natural stripe rust infection. The wheat entries also were evaluated for resistance to leaf rust, powdery mildew, and physiological leaf spot at the Mount Vernon field plots, where these diseases occurred. Some of the nurseries were also tested in the greenhouse with selected five races of stripe rust covering all identified virulences for further characterization of resistance. Disease data of regional nurseries were provided to all breeding and extension programs of that region, while data of individual breeders' nurseries were provided to the individual breeders. Through our testing, new wheat cultivars such as Bauermeister' (WA7939), 'MDM' (WA7936), 'Concept' (89*88D), George (GMG-Q-1), 'Rjames' (GMG-Q2), 'Eddy' (BZ9W96-788-E), and 'Sola' (DA900-229) have been or are being released. We also assisted the re-selection from heterogeneous cultivars 'Tubbs' and 'Brundage 96' to improve their resistance.

Through the germplasm screening, we have established a core collection of wheat germplasms with stripe rust resistance. The current collection has more than 5,000 entries, which will be valuable sources of stripe rust resistance for further characterization of resistance, identified new effective resistance genes, and for development of wheat cultivars with superior resistance.

3. Determine genetics of resistance, identify new resistance genes, develop molecular markers for stripe rust resistance genes for marker-assisted selection; and determine mechanisms of rust resistance and plant-pathogen interactions.

The spring wheat cultivar 'Alpowa' has both race-specific resistance and non-race specific high-temperature adult-plant (HTAP) resistance to stripe rust. To identify and map genes for the resistances, Alpowa was crossed with 'Avocet Susceptible' (AVS). In the tests of seedlings under controlled greenhouse conditions with 15 races of the pathogen, AVS was susceptible to all races and Alpowa was resistant to only PST-1 and PST-21. One partially dominant gene was identified from tests of the parents, F_1, F_2, and F_3 progeny of the cross inoculated with PST-1. This gene was mapped on chromosome 1BS. To map the quantitative trait loci (QTL) for the HTAP resistance, parents and 136 F_3 lines were tested in three locations in eastern and western Washington under natural infection of stripe rust races virulent on seedlings of Alpowa and all-stages of AVS. QTL mapping identified a QTL that explained 54.8% of the total variation based on the relative area under disease progress curve data and 48.9% of the total infection type variation. The QTL was mapped on 7BL. The chromosome locations and different race reactions indicate that the two Alpowa genes have not been previously described.

Through collaboration with Dubcovsky at UC Davis, we identified a new gene and named it *Yr36* from *Triticum dicoccoides* controlling HTAP resistance. Currently, we are testing recombinant lines to fine map the gene for cloning of *Yr36*. Through collaboration with Kim Kidwell and Kim Campbell, we identified markers for a QTL with major effect on the durable HTAP resistance in wheat variety Stephens.

We have identified barley cultivar Bancroft to have HTAP to stripe rust. To map QTL for the HTAP resistance, Bancroft was crossed with susceptible Harrington barley. The parents and F_4 and F_5 progeny of the crosses were evaluated in three locations in 2004 and 2005, respectively. Infection type and disease severity were recorded three times during the growing season. The Area under disease progress curve (AUDPC) was calculated for each line based on the disease severity data. Analysis of variance with the infection type data showed no significant differences among the locations, indicating that the HTAP resistance is non-race specific. A linkage map was constructed with eight resistance gene analog polymorphism (RGAP) markers and mapped on the long arm of barley chromosome 3H with three microsatellite markers identified using 119 F_6 lines. QTL mapping identified a single gene that explained 95%, 76%, and 71% of the total variations using the infection type, disease severity, and AUDPC data, respectively. The two flanking RGAP markers detected polymorphism in 23 of 26 barley cultivars, indicating that the markers are useful to incorporate the HTAP resistance into most of the cultivars.

4. Determine effectiveness and use of fungicides for rust control and develop strategies for integrated rust management

A total of 10 fungicide treatments were evaluated for controlling stripe rust in experimental fields near Pullman, WA. Susceptible winter wheat cultivar 'PS 279' was planted on 14 October 2004 and susceptible spring wheat cultivar 'Fielder', moderately susceptible 'Eden', and susceptible barley cultivars 'Russell' and 'Morex' were planted on 19 April 2005 using a completely randomized block design with four replications. The fungicide treatments were compared with non-treatment check. Fungicides were sprayed on 21 May in the winter wheat plots when the plants were at the late jointing stage with 20-40% stripe rust severity, and on 20 June in the spring wheat plots when the plants also were at the late jointing stage with 20-40% stripe rust severity. A second spray was only used 14 days after the first spray for one of the treatments with Quilt. Severities of stripe rust were recorded five times for the winter plots and four times for the spring plots at and after fungicide application. Area under disease progress curve (AUDPC) was calculated for each treatment and the check from the multiple sets of rust severity data, and also used for comparison of rust severities over the time period. Test weight and yield were recorded for each plot at the time of harvesting.

All fungicide treatments significantly reduced rust severity and increased yield of the wheat cultivars compared to the untreated check. All treatments also increased test weight, but only treatments of two applications of Quilt, Absolute, Sparta, and Folicur significantly increased test weight of PS 279; only Sparta, Quilt, Absolute, and Folicur significantly increased test weight of Fielder; and all treatments but Absolute significantly increased test weight of Eden. These treatments varied in duration of effectiveness, which was correlated with relative stripe rust AUDPC and yield. Based rust AUDPC data, the best treatments were two applications of Quilt, Absolute, and Folicur for winter wheat PS 279; Absolute, Folicur, Sparta, Quilt, Flutriafol, and Tilt for Fielder; and all treatments were not significantly different from each other for the moderately susceptible cultivar, Eden. Based on yield data, Absolute, Sparta, two applications of Quilt, and Folicur were the best in the tests with PS 279; Sparta, Quit, Absolute, Folicur, and Stratego were the best in the test with Fielder; and all fungicide treatments were not significantly different from each other in the tests with moderately susceptible Eden.

All fungicide treatments significantly reduced stripe rust severity on the barley cultivars at 8, 17, and 25 days after application. All treatments still remained effective 25 days after application on both Russell and Morex, while significant stripe rust (29.60% on Russell and 14.97% on Morex) developed in the plots treated with Flutriafol indicating that the effectiveness of Flutriafol did not last as long as other fungicides. All treatments significantly increased test weight of Russell, but did not significantly increase test weight of Morex. All fungicide treatments increased yield of Russell by 16 to 36% and all increases were significant except the increase by the treatment with Stratego. All treatments increased yield of Morex by 3 to 14%, but the increases were not statistically different from that of the non-treated control. The insignificance of yield increases was due to the low levels of stripe rust in the Morex plots compared to the rust levels in the Russell fields.

Compared to the disease and yield data of 2004, the 2005 data validated two applications of fungicides under the circumstances of early starting and prolonged epidemics like in 2005. In 2004, stripe rust severity was only 1% on PS 279 on 6 June when fungicides were applied at the boot stage. Untreated plot produced 66 bu/A and the best controlled plot (with two applications of Quilt) produced 110 bu/A. In contrast, in 2005 stripe rust severity had already reached 40% on 21 May when fungicides were used at the late jointing stage. The untreated plot of PS 279 produced only 13 bu/A and the same treatment (two applications of Quilt) produced 45 bu/A.

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