Executive summary: During 2017, studies were conducted according to the objectives of the project proposal and all objectives specified for the second year have been successfully completed. In addition to the major accomplishments and their impacts listed below, this project results in genetic resources and techniques for further studying the biology and genetics of the pathogens and mechanisms of interactions between the pathogen and plants.

Impact: 1) Stripe rust was accurately forecasted in 2017. Rust updates and advises were provided on time to growers based on the forecasts using prediction models and our field surveys, which effectively protected both winter wheat and spring wheat crops from potentially huge yield losses under the extremely severe stripe rust epidemic. 2) We identified 11 races of the barley stripe rust pathogen and 55 races (including 21 new) of wheat stripe rust in the US, of which 6 and 23 were detected in Washington, respectively. Seven of the new races were from Washington. The virulence information is used to guide breeding programs for using effective resistance genes in developing resistant varieties. 3) We re-sequenced seven wheat stripe rust isolates and used them together with previously sequenced stripe rust isolates to identify 923 stripe rust specific secreted protein genes and candidate virulence genes corresponding to six resistance genes. The secret protein genes can be used to study the pathogen populations and identify markers for more virulence genes. 4) We evaluated more than 35,000 wheat and 3,000 barley entries for resistance to stripe rust. From the tests, we identified new sources of resistance and resistant breeding lines for breeding programs to release new varieties for growers to grow. In 2017, we collaborated with breeders in releasing, pre-releasing, or registered 11 wheat and 2 barley varieties. The germplasm evaluation data were also used to update the Seed Buyer’s Guide for growers to choose resistant varieties to grow. 5) We completed two studies and mapped 10 genes for stripe rust resistance in two wheat lines and identified molecular markers for all mapped genes. We officially named two stripe rust resistance genes, and published 8 papers on molecular mapping of stripe rust resistance genes. We also collaborated with other programs in mapping a large number of stripe rust resistance genes in various wheat germplasm collections through the genome-wide association approach. 6) We provided seeds of our developed wheat germplasm lines to several breeding programs in the US and other countries for developing stripe rust resistant varieties. Use of these lines by breeding programs will diversify resistance genes in commercial varieties. 7) We tested 23 fungicide treatments for control of stripe rust and provided the data to chemical companies for registering new fungicides. We tested 24 winter wheat and 24 spring wheat varieties for yield loss caused by stripe rust and yield increase by fungicide application. The data of the fungicides and varieties are used for guiding
the integrated control of stripe rust. 8) In 2017, we published 27 journal articles, 9 meeting abstracts, one chapter in an extension book, and the first book (titled *Stripe Rust*) summarizing research and management of stripe rust over 100 years, which should serve as a valuable reference for future research and control of the disease.

**Outputs and Outcomes:**

Progress, Timelines, and Communication are presented in Outcome Reporting file (file name: Chen_WGC 2017 Annual Report Outcome Reporting.pdf)

**Publications:**

*Scientific Journals:*


Bruckner, P., Berg, J., Kephart, K., Stougaard, R., Pradhan, G., Lamb, P., Miller, J., Briar, S.,
Chen, C. C., Nash, D., Holen, D., Cook, J., Gale, S., Jin, Y., Kolmer, J., **Chen, X. M.**, Bai, G. H.,

and Seabourn, B. W. 2017. Registration of ‘Sunshine’ hard white winter wheat. Journal of Plant

diversity in germplasm collections by genomic selection: a case study based on quantitative adult
plant resistance to stripe rust (*Puccinia striiformis f. sp. tritici*) in spring wheat. The Plant

Han, D. J, and Kang, Z. S. 2017. Development and validation of SNP markers for QTL

Dong, Z. Z., Hegarty, J. W., Zhang, J. L., Zhang, W. J., Chao, S. M., **Chen, X. M.**, Zhou, Y. H.,
Dubcovsky, J. 2017. Validation and characterization of a QTL for adult plant resistance to stripe
rust on wheat chromosome arm 6BS (Yr78). Theoretical and Applied Genetics 130(10):2127-
2137.

Liu, W. Z., Maccaferri, M., **Chen, X. M.**, Pumphrey, M., Laggetti, G., Pignone, D., and
Tuberosa, R. 2017. Genome-wide association mapping reveals a rich genetic architecture of
stripe rust resistance loci in emmer wheat (*Triticum turgidum ssp. dicoccum*). Theoretical and

characterization and correlation analysis reveal putative pathogenicity mechanisms and identify
candidate avirulence genes in the wheat stripe rust fungus *Puccinia striiformis f. sp. tritici*.
Frontiers in Microbiology 8:2394.

**Popular Press Articles:**

January 4, 2017. First Forecast of Stripe Rust for 2017 and 2016 Fungicide and Variety Yield
Loss Tests. Xianming Chen, E-mail sent to growers and the cereal group.


March 9, 2017. Stripe rust forecast and update, March 9, 2017. Xianming Chen, Email sent to
growers and cereal groups.
March 2017. Stripe Rust Update – March 2017, Xianming Chen

March 2017. Stripe rust in PNW could be severe. By Xianming Chen.
http://www.wawg.org/stripe-rust-in-pnw-could-be-severe/

April 6, 2017. Stripe rust update, April 6, 2017. Email sent to growers and cereal groups.


May 19, 2017. Rust update, May 19, 2017. Email sent to growers and cereal groups.


June 16, 2017. Rust update, June 16, 2017. Email sent to growers and cereal groups.


Presentations and Reports:

In 2017, Xianming Chen presented invited talks at the following national and international meetings:

“Stripe Rust Research and Control in the US” at the North American Wheat Research Initiative Meeting in the CIMMYT-HQ, EL Batan, Mexico, February 14, 2017 (about 30 people)


“Unequal Contributions of Parental Isolates in Somatic Recombination of the Stripe Rust Fungus” at the 19th International Conference of Fungal Genetics. Venice, Italy, June 21, 2017 (about 40 people)
“Pathogenicity of stripe rust and its prevention and control” at the Training Course on Breeding and Production Technologies of Staple Crops in Southeast Asia, Chengdu, Sichuan, China, August 17, 2017 (about 60 people)

“Stripe Rust Research and Control in the US” at the Jinjiang Forum, Chengdu Institute, Chinese Academy of Sciences, Chengdu, Sichuan, China, August 22, 2017 (about 40 people)

“Stripe Rust Research and Control in the US” in the Institute of Crop Science, Sichuan Academy of Agricultural Sciences, Chengdu, Sichuan, China, August 23, 2017 (about 30 people)

“Stripe Rust Research and Control in the US” in the Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing China, August 24, 2017 (about 60 people)

“Stripe Rust Research and Control in the US” in the Institute of Genetics and Cell Developmental Biology, Chinese Academy of Sciences, Shijiazhuang, Hebei, China, August 25, 2017 (about 40 people)

“Stripe Rust Research and Control in the US” in the Institute of Genetics and Developmental Cell Biology, Chinese Academy of Science, Shijiazhuang, Hebei, China, August 25, 2017 (about 50 people)

“Stripe Rust Research and Control in the US” at the Chinese National Wheat Disease Management Workshop, Baoding, Hebei, China, August 26, 2017 (about 200 people)

“Biology, genetics, functional genomics, evolution, and epidemics caused by the stripe rust pathogen” at the 2nd International Conference of Mycology and Mushroom. Chicago, IL, September 25, 2017 (about 100 people)

“Biology, genetics, functional genomics, evolution, and epidemics caused by the stripe rust pathogen” in the College of Plant Protection, Northwest A&F University, Yangling, Shaanxi, China, October 11, 2017 (About 200 people).

In 2017, Xianming Chen, students and/or associates presented posters or oral presentations at the following national and international meetings:

Poster entitled “Identification of effector candidates for avirulence genes in the wheat stripe rust fungus (Puccinia striiformis f. sp. tritici) by secretome analysis” at the 29th Fungal Genetics Symposium and presented, Pacific Grove, California, March 13-17, 2017 (about 900 people)

Poster entitled “Mapping genes for and developing wheat germplasm with resistance to stripe rust” at the 13th International Wheat Genetics Symposium in Tulu, Austria, April 23-28, 2017 (more than 500 people)
Oral presentation entitled “Secretome characterization and correlation analysis reveal putative pathogenicity mechanisms in the wheat stripe rust fungus *Puccinia striiformis* f. sp. *tritici*” at the American Phytopathological Society Pacific Division meeting, June 28-29, 2017 (student: Chongjing Xia)

Oral presentation entitled “Molecular mapping of stripe rust resistance QTL in Pacific Northwest winter wheat cultivar Madsen” at the American Phytopathological Society Pacific Division meeting, June 28-29, 2017 (student: Lu Liu)

Oral presentation entitled “Virulence and molecular characterization of *Puccinia striiformis* f. sp. *tritici* mutants generated using ethyl methanesulfonate” at the American Phytopathological Society Pacific Division meeting, June 28-29, 2017 (student: Yuxiang Li)

Poster entitled “Stripe rust epidemics of wheat and barley and races of *Puccinia striiformis* identified in the United States in 2016” at the American Phytopathology Society Annual Meeting in San Antonio, TX August 5-9, 2017 (about 1600 people)

Poster entitled “Molecular mapping and comparison of *YrTr1* with other genes on chromosome 1BS for resistance to wheat stripe rust” at the American Phytopathology Society Annual Meeting in San Antonio, TX August 5-9, 2017 (about 1600 people)

Xianming Chen participated and talked about rusts, research progress, and disease management in the following field days:

- May 31-June 1, 2017. Western Wheat Workers and WEAR 97 meeting at Corvallis, OR (about 40 people)
- June 15, 2017. Lind Field Day (about 100 people)
- July 7, 2017. Farmington Field Day (about 30 people)
## Objective: Conduct disease forecast and field survey for guiding disease management

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<th>Deliverable</th>
<th>Progress</th>
<th>Timeline</th>
<th>Communication</th>
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<td>1) <strong>Stripe rust predictions.</strong> Accurate prediction before the rust season will allow growers to prepare for appropriate control measures including choosing resistant varieties to plant and possible fungicide application.</td>
<td>All planned studies for the project in 2017 have been completed on time. There is no delay, failure, or problem in studies to this objectives. Forecasts of wheat stripe rust epidemic were made in January based on the November and December weather conditions and in March based on the entire winter weather conditions using our prediction models. Further forecasts were made throughout the season based on rust survey data and past and forecasted weather conditions. These forecasts and rust updates were reported to wheat growers and researchers. Field surveys were conducted by our program and collaborators throughout the Pacific Northwest (PNW) and other regions throughout the country. In the eastern PNW, widespread infection occurred in the fall 2016 and the pathogen well survived the winter under the long snow cover, resulting in a early start of epidemic development in the spring 2017. The stripe rust favorable weather conditions in the spring and early summer made the disease an extremely severe epidemics (75% yield loss occurred on highly susceptible winter wheat varieties in our experimental fields). The timely applications of fungicides on susceptible and moderately susceptible wheat varieties prevented major yield loss. Barley stripe rust was much lower than wheat stripe rust, but relatively significant compared to the previous years. Leaf rust of wheat was normal in western but absent in eastern PNW; and leaf rust of barley in the western PNW was less than the previous years, but presented for the first time in the eastern PNW (just in three fields of barley planted in the fall of 2016 in the Walla Walla area along the Oregon border. Stem rust of wheat and barley was absent in the PNW in 2016.</td>
<td>All studies and services were completed on time.</td>
<td>The rust forecasts and survey data were communicated to growers and other researchers through e-mails, telephones, website, project reports, presentations at growers’ meetings, field days, public magazines like Wheat Life, and publications in scientific journals (for detailed information, see the lists in the main report file).</td>
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### 2. Identify races and characterize populations of the wheat and barley stripe rust pathogens for providing useful pathogen information to breeding programs for developing resistant varieties and to growers for managing diseases.

1. **New races.**
2. **Distribution, frequency, and changes of all races.**
3. **New tools such as molecular markers and population structures.**

   The information will be used by breeding programs to choose effective resistance genes for developing new varieties with adequate and durable resistance. We will use the information to select a set of races for screening wheat and barley germplasm and breeding lines. The information is also used for disease management based on races in different regions.

   In 2007, we collected and received 393 stripe rust samples throughout the country and 50% of the samples were from Washington. We have completed about 80% of the race ID work for the 2017 samples as scheduled by this time. So far we have detected 55 wheat stripe rust races (including 21 new races) and 5 barley stripe rust races, of which 23 wheat and 6 barley stripe rust races were detected in Washington. The distribution and frequency of each race and virulence factor in the US have been determined. Predominant races have been identified. The race and virulence information is used to guide breeding programs for using effective resistance genes in developing resistant varieties and selected predominant races with different virulence patterns are used in screening breeding lines for stripe rust resistance. We used molecular markers developed in our lab to study the stripe rust pathogen and determined the population changes in the past and present, and use molecular markers to tag virulence genes in the pathogen. We sequenced more isolates of the stripe rust pathogen, identified secreted protein (SP) genes as candidates for virulence genes, and developed more than 800 SP-SNP markers to study rust pathogen populations and identify virulence genes.

   - **1) New races.**
   - **2) Distribution, frequency, and changes of all races.**
   - **3) New tools such as molecular markers and population structures.**

### 3. Screening wheat and barley germplasm for supporting breeding programs to develop rust resistant varieties

1. **Stripe rust reaction data of wheat and barley germplasm and breeding lines.**
2. **Reactions to other diseases when occur.**
3. **Resistant germplasm for use in breeding programs.**
4. **New varieties for growers to grow.**

   The stripe rust data will allow breeding programs to get rid of susceptible lines or select lines for further improvement, and more importantly for releasing new varieties for with stripe rust resistance combined with other desirable traits for grower to grow.

   In 2017, we evaluated more than 35,000 wheat and 3,000 barley entries for resistance to stripe rust. The entries included germplasm, breeding lines, rust monitoring nurseries, and genetic populations from various breeding and extension programs. All nurseries were planted and evaluated at both Pullman and Mt. Vernon locations under natural stripe rust infection. Some of the nurseries were also tested in Walla Walla and Lind, WA. Germplasm and breeding lines in the variety trial and regional nurseries also were tested in the greenhouse with selected races of stripe rust for further characterization of resistance. Disease data of regional nurseries were provided to all breeding and extension programs, while data of individual breeders’ nurseries were provided to the individual breeders. Through these tests, susceptible breeding lines can be eliminated, which should prevent risk of releasing susceptible cultivars and assisted breeding programs to release new cultivars of high yield and quality, good adaptation, and effective disease resistance. In 2017, we collaborated with public breeding programs in releasing and registered 11 wheat and 2 barley varieties. Varieties developed by private breeding programs were also resulted from our germplasm screening program.

   - **1) Stripe rust reaction data of wheat and barley germplasm and breeding lines.**
   - **2) Reactions to other diseases when occur.**
   - **3) Resistant germplasm for use in breeding programs.**
   - **4) New varieties for growers to grow.**

### The race identification work for the 2017 stripe rust samples will be completed by late February, 2018, as scheduled. The race ID work for 2018 samples will start in March. Molecular work of the 2016 samples and DNA extraction of the 2017 samples will be completed by June, 2018.

The race identification work for the 2017 stripe rust samples was completed and the data were provided to collaborators on time. The 2017-18 winter wheat nurseries were planted in fields in September and October 2017. The 2018 spring crop nurseries will be planted in March-April, 2018. The greenhouse tests of the 2017 spring nurseries and the 2017-18 winter wheat nurseries have been conducting in the greenhouse during the winter, and will be completed by May, 2018.

The rust race data were communicated to growers and researchers through e-mails, website, project reports, meeting presentations and publications in scientific journals (for detailed information, see the lists in the main report file).
4. Identify and map new stripe rust resistance genes and develop new germplasm for use in breeding programs to diversify resistance genes in new varieties

1) New stripe rust resistant sources. 2) New resistance genes with their genetic information. 3) Molecular markers for resistance genes. 4) New germplasm with improved traits. The genetic resources and techniques will be used by breeding programs for developing varieties with diverse genes for stripe rust resistance, which will make the stripe rust control more effective, efficient, and sustainable.

Through the germplasm screening, we have established a collection of wheat germplasm with stripe rust resistance, which are valuable sources of stripe rust resistance for further characterization of resistance, identified new effective resistance genes, and for development of wheat varieties with effective resistance. Through our intensive testing, varieties with durable resistance to stripe rust have been developed. In 2017, we completed two studies and mapped 10 genes for stripe rust resistance in two wheat lines and identified molecular markers for all mapped genes. We officially named two stripe rust resistance genes (Yr78 and Yr79). We also collaborate with other laboratories in mapping of numerous stripe rust resistance loci in various wheat germplasm collections through genome-wide association study approach, and published 8 papers on molecular mapping of stripe rust resistance genes. We registered 29 new wheat germplasm lines with single new genes or combinations of genes for resistance to stripe rust to make them available for breeding programs and directly provided seeds to a few US breeding programs in 2017. In 2017, we phenotyped ten mapping populations for stripe rust responses and advanced progeny populations for 40 winter wheat crosses for mapping stripe rust resistance genes.

All experiments scheduled for 2017 were successfully completed. Mapping populations of winter wheat were planted in fields in October 2017 and those of spring wheat will be planted in April, 2017 for stripe rust phenotype data. Populations with adequate phenotype data are genotyped with molecular markers for mapping resistance genes. Progenies of new crosses will be advanced in fields in 2018.

New genes and molecular markers were published in scientific journals (see the publication and presentation lists in the report main file).

5. Improve the integrated control strategies by screening new chemicals and determining potential yield losses and fungicide responses of individual varieties

1) Data of fungicide efficacy, dosage, and timing of application for control of stripe rust. 2) Potential new fungicides. 3) Stripe rust yield loss and fungicide increase data for major commercial varieties. The information is used for developing more effective integrated control program based on individual varieties for growers to use to control stripe rust.

In 2017, we evaluated 23 fungicide treatments, plus a non-treated check on both winter wheat and spring wheat for control of stripe rust in experimental fields near Pullman, WA. Treatments with two applications were more effective than only one application in reducing rust and increasing yield. For winter wheat, all treatments significantly reduced rust severity and increased grain yield, and 10 of the treatment also increased test weight compared with the non-treated check. Yield increases ranged from 19 bushes (88%) to 54 bushes (242%). Similarly for spring wheat, all fungicide treatments significantly reduced rust severity and increased grain yield, and 10 treatments also increased test weight compared with the non-treated check. The yield increases of grain yield ranged from 11 bushes (26%) to 33 bushes (80%) depending upon fungicide treatments. In 2017, we tested 23 winter wheat and 23 spring wheat varieties commonly grown in the PNW, plus highly susceptible checks. For winter wheat, stripe rust caused 75% yield loss on the susceptible check and from 0 to 49% yield losses at an average of 16% on commercially grown varieties. Fungicide application increased yield by 0 to 96% at an average of 10% on commercially grown varieties. For spring wheat, stripe rust caused 48% yield loss on the susceptible check and from 0 to 22% yield losses at an average of 7% on commercial varieties. Fungicide application increased grain yields by 0 to 28% on commercial varieties at an average of 9%. These results will be used by chemical companies to register new fungicides and used by growers for selecting resistant varieties to grow and use suitable fungicide application for control stripe rust on varieties without an adequate level of resistance.

For this objective, all tests scheduled for 2017 were successfully completed. For the 2017-18 growing season, the winter wheat plots of the fungicide and variety yield loss studies were planted in October, 2017 and the spring plots will be planted in April, 2017. The tests will be completed in August (for winter wheat) and September (for spring wheat), 2018.

The results were communicated to growers and collaborators through e-mails, presentations in growers meetings, field days, plot tours, project reports and reviews, and published in scientific journals (see the publication and presentation lists in the report main file).