

**Washington Grain Commission
Wheat and Barley Research Annual Progress Report**

Project #: 3144

Progress Report Year: 2 of 3 (2020)

Title: Improving Control of Rusts of Wheat and Barley

Cooperators: K. Garland Campbell, A. Carter, M. Pumphrey, & D. See

Executive summary: During 2020, 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, stripe rust resistance, and mechanisms of interactions between the pathogens and plants.

Impact: 1) Stripe rust was accurately forecasted and monitored through the 2020 crop season, and rust updates and advises were provided on time to growers, which successfully prevented a severe epidemic potentially causing yield losses of 11% on both winter and spring wheat varieties on average in Washington state. 2) We identified 19 (including 2 new) races of the wheat stripe rust pathogen and 8 (including 1 new) races of the barley stripe rust pathogen from the 2020 collection in Washington. The virulence information is useful in developing and screening resistant varieties. 3) We characterized the US stripe rust collections from 2010 to 2017 using 14 SSR markers. From 2,414 isolates, we identified 1,599 multi-locus genotypes (MLGs) and studied the genetic diversity and population differentiation. The results improve the understanding of stripe rust epidemiology and spore movement among different regions in the US. 4) We completed a study of whole genome sequencing for a sexual recombinant population of the wheat stripe rust pathogen and identified candidate genes for avirulence. Using the gene sequences, we are developing virulence-specific markers for monitoring race changes in the pathogen population. 5) We evaluated more than 25,000 wheat, barley, and triticale 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 2020, we collaborated with breeders in releasing, pre-releasing, or registered 19 wheat and 1 barley varieties. The germplasm evaluation data were also used to update the Seed-Buying Guide for growers to choose resistant varieties to grow. 6) We completed genome-wide association studies and mapped 37 genes in the spring wheat panel and 51 genes in the winter panel for stripe rust resistance. These results provide information on which genes are effective and used in breeding programs in various regions in the US, especially the Pacific Northwest. The resistance genes and their markers are useful in breeding stripe rust resistant wheat varieties. 7) We tested 19 fungicide treatments for control of stripe rust on winter and spring wheat and provided the data to chemical companies for registering new fungicides and tested 23 winter wheat and 23 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 2020, we published 30 journal articles and 6 meeting abstracts.

Outputs and Outcomes:

Project PI(s): Xianming Chen				
Project initiation date: 7/1/2019				
Project year: 2 of 3 (2020)				
Objective	Deliverable	Progress	Timeline	Communication
1. Improve the understanding of rust disease epidemiology and the pathogen populations.	1) New races. 2) Information on distribution, frequency, and changes of all races, and possible fungicide tolerant strains. 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.	All planned studies for the project in 2020 have been completed on time. There is not any delay, failure, or problem in studies to this objective. The race identification for the 2019 collection was completed and summarized. The data and summary were sent to growers, collaborators and related scientists in May 2020. In the 2020 crop season, we collected and received 350 stripe rust samples throughout the country, of which 217 samples (65%) were collected by ourselves from Washington. We have completed the race ID work for all samples of the 2020 collection and detected 19 wheat stripe rust races (including 2 new races) and 11 barley stripe rust races (including 2 new races), of which all 19 wheat and 8 (including 1 new race) barley stripe rust races were detected in Washington. The distribution and frequency of each race and virulence factor in WA and the whole country have been determined. Predominant races have been identified. The information on races and virulence factors 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 have characterized the US stripe rust collections from 2010 to 2017 using 14 SSR markers. From 2,414 isolates, we identified 1,599 multi-locus genotypes (MLGs) and studied the genetic diversity and population differentiation. Using the same set of markers, we have been genotyping the 2018 - 2020 collections. We completed a study of whole genome sequencing for a sexual recombinant population of the wheat stripe rust pathogen and identified candidate genes for avirulence. Using the gene sequences, we are developing virulence-specific markers for monitoring race changes in the pathogen population. These studies have improved the understanding the epidemiology, biology and genetics of the pathogen, and provided information and resources for improvement of monitoring and managing stripe rusts on wheat and barley.	The race identification work for the 2019 stripe rust samples was completed and summarized. The race identification work for the 2020 samples was completed, and analyses and summarization are underway. Molecular work for the population genetic studies has been completed up to the 2017 collection, and almost completed for the 2018 collection. DNA extraction of the 2019 samples has been completed and of the 2020 samples are underway.	The rust race data were communicated to growers and researchers through e-mails, websites, project reports, meeting presentations and publications in scientific journals (for detailed information, see the lists in the main report file).

<p>2. Improve rust resistance in wheat and barley varieties.</p>	<p>1) Stripe rust reaction data of wheat and barley germplasm and breeding lines. 2) Reactions to other diseases when occur. 3) New resistance genes with their genetic information and molecular markers. 4) New germplasm with improved traits. 5) New varieties for production. 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.</p>	<p>In 2020, we evaluated more than 25,000 wheat, barley, and triticale 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 2020, we collaborated with public breeding programs in releasing and registered 19 wheat varieties and 1 barley variety. Varieties developed by private breeding programs were also resulted from our germplasm screening program. Through our evaluation, 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 2020, we completed several studies for mapping stripe rust resistance genes. We mapped two major genes on chromosomes 1AL and 3BL and one minor gene on 2AL in wheat landrace PI 197734 using a doubled haploid population and developed user-friendly KASP markers for the two major genes to be used in breeding programs. We completed two whole-genome associate studies (GWAS) and mapped 37 loci in a panel of 616 spring wheat cultivars and breeding lines and identified 51 loci in a panel of 857 winter wheat cultivars and breeding lines developed in the US. We determined the frequencies and distributions of stripe rust resistance genes used in various regions in the US with the PNW had the highest number of genes. In a study involving 40 crosses of winter wheat varieties, we obtained preliminary results of identifying more than 220 SNP markers at least 73 loci for stripe rust resistance using the bulking segregation analysis and genotyping by multiplex sequencing. In 2020, we phenotyped 10 of the crosses for stripe rust reaction using the F6 generation to validate resistance loci. We selected 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 some US breeding programs.</p>	<p>All 2020 germplasm tests were completed, and the data were provided to collaborators on time. The 2020-21 winter wheat nurseries were planted in fields in September and October 2020. The 2020 spring crop nurseries will be planted in March-April 2020. The greenhouse tests of the 2020 spring nurseries and the 2020-21 winter wheat nurseries have been conducted in the greenhouse during the winter, and will be completed by May 2020. All experiments of the molecular mapping studies scheduled for 2020 have been completed. Mapping populations of winter wheat were planted in fields in October 2020 and those of spring wheat will be planted in April, 2021 for stripe rust phenotype data. Populations with adequate phenotype data are genotyped with molecular markers for mapping resistance genes.</p>	<p>The data of variety trials and regional nurseries were sent to growers and collaborators through e-mails and websites. Summary information of varieties were sent to growers and collaborators through rust updates and recommendations through e-mails, websites, Seed-Buying Guide, variety release documents. Test data of individual breeding programs were sent to the individual breeders. New genes and molecular markers were reported in scientific meetings and published in scientific journals (see the publication and presentation lists in the report main file).</p>
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<p>3. Improve the integrated management of rust diseases.</p>	<p>1) Data of fungicide efficacy, dosage, and timing of application for control stripe rust. 2) Potential new fungicides. 3) Stripe rust yield loss and fungicide increase data for major commercial varieties. 4) Stripe rust forecasts and updates. 5) Guidance for rust management. The information is used for developing more effective integrated control program based on individual varieties. Disease updates and recommendations will allow growers to implement appropriate control.</p>	<p>In 2020, we evaluated 19 fungicide treatments on winter wheat and spring wheat, plus non-treated checks, for control of stripe rust in experimental fields near Pullman, WA. On winter wheat, all fungicide treatments significantly reduced stripe rust severity compared to the non-treated check, and six of them provided the best control of stripe rust. All treatments had higher test weight than the non-treated check, and the treatments of two applications had higher test weight than those of one application. All treatments produced grain yields higher than the non-treated check with nine treatments producing the highest yields. The significant yield responses of the fungicide treatments ranged from 21.8 to 59.7 bushels per acre or 42.1 to 115.3% more grain. On spring wheat, all fungicide treatments significantly reduced overall stripe rust severity compared to the non-treated check. All 15 treatments with applications at both middle jointing stage and heading stage provided equally better control of stripe rust than the 4 treatments with only one application at the heading stage. All treatments had higher test weight than the non-treated check. All treatments produced grain yields higher than the non-treated check, and treatments with two applications generally produced higher yields than those with only one application at the heading stage. The significant yield responses ranged from 34.4 to 51.0 bushels per acre or 68.4 to 101.4% more grain. These results are useful for managing stripe rust on both winter and spring wheat crops. In 2020, 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 yield loss of 62.4 bu/A (48.6%) on the susceptible check and from 1.2 to 52.4 bu/A or 0.7 to 35.7% (average 11.6%) on commercially grown varieties. Fungicide application increased yield by 0.7 to 55.4% (average of 14.3%) on commercially grown winter wheat varieties. For spring wheat, stripe rust caused 83.8% yield loss on the susceptible check and from 0 to 62.8 bu/A or 0 to 57.7% (average 10.7%) yield losses on commercial varieties. Fungicide application increased grain yields by 0 to 136.5% (average 13.1%) on commercial varieties. These results can 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. Accurate forecast of wheat stripe rust epidemic was made based on prediction models, rust monitoring was conducted, and recommendations were made through the 2020 crop season, which successfully prevented major yield losses and saved growers millions of dollars.</p>	<p>For this objective, all tests scheduled for 2020 were successfully completed. For the 2020-21 growing season, the winter wheat plots of the fungicide and variety yield loss studies were planted in October 2020, and the spring plots will be planted in April 2021. The tests will be completed in August (for winter wheat) and September (for spring wheat), 2021.</p>	<p>The results were communicated to growers and collaborators through e-mails, presentations in growers meetings, project reports and reviews, and published in scientific journals (see the publication and presentation lists in the report main file).</p>
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Publications:

Scientific Journals:

Liu, Y., Qie, Y. M., Li, X., Wang, M. N., and **Chen X. M.** 2020. Genome-wide mapping of quantitative trait loci conferring all-stage and high-temperature adult-plant resistance to stripe rust in spring wheat landrace PI 181410. *International Journal of Molecular Sciences* 21:478(1-18). <https://doi.org/10.3390/ijms21020478>

Wang, J. H., Tian, W., Tao, F., Wang, J. J., Shang, H. S., **Chen, X. M.**, Xu, X. M., and Hu, X. P. 2020. *TaRPM1* positively regulates wheat high-temperature seedling-plant resistance to *Puccinia striiformis* f. sp. *tritici*. *Frontier in Plant Sciences* 10(1):1679(1-12). <https://doi.org/10.3389/fpls.2019.01679>

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Chen, X. M., Sprott, J., and Evens, C. K. 2020. Evaluation of foliar fungicides for control of stripe rust on winter wheat in 2019. *Plant Disease Management Reports* 14:CF065. <https://www.plantmanagementnetwork.org/pub/trial/pdmr/reports/2020/CF065.pdf>

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Li, Y. X., Xia, C. J., Wang, M. N., Yin, C. T., and **Chen, X. M.** 2020. Whole-genome sequencing of *Puccinia striiformis* f. sp. *tritici* mutant isolates identifies avirulence gene candidates. *BMC Genomics* 21:247. <https://doi.org/10.1186/s12864-020-6677-y>

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striiformis f. sp. *tritici* reveals high diversity and intercontinental migration. *Phytopathology* 110(4):933-942. <https://doi.org/10.1094/PHYTO-09-19-0355-R>

Chen, X. M. 2020. Pathogens which threaten food security: *Puccinia striiformis*, the wheat stripe rust pathogen. *Food Security* 12(2):239-251. <https://doi.org/10.1007/s12571-020-01016-z>

Zhang, G. R., Martin, T. J., Fritz, A. K., Regan, R., Bai, G. H., Chen, M.-S., Bowden, R. L., Jin, Y., **Chen, X. M.**, Kolmer, J. A., Chen, R. Y., and Seabourn, B. W. 2020. Registration of ‘KS Venada’ hard white winter wheat. *Journal of Plant Registrations* 14(2):153-158. <https://dx.doi.org/10.1002/plr2.20026>

Xia, C. J., Lei, Y., Wang, M. N., Chen, W. Q., and **Chen, X. M.** 2020. An avirulence gene cluster in the wheat stripe rust pathogen (*Puccinia striiformis* f. sp. *tritici*) identified through genetic mapping and whole-genome sequencing of a sexual population. *mSphere* 5:e00128-20. <https://doi.org/10.1128/mSphere.00128-20>

Wang, N., Fan, X., Zhang, S., Liu, B., He, M. Y., **Chen, X. M.**, Tang, C. L., Kang, Z. S., and Wang, X. J. 2020. Identification of a hyperparasitic *Simplicillium obclavatum* strain affecting the infection dynamics of *Puccinia striiformis* f. sp. *tritici* on wheat. *Frontiers in Microbiology* 11(6):1277. <https://doi:10.3389/fmicb.2020.01277>

Tao, F., Hu, Y. S., Su, C., Li, J., Guo, L. L., Xu, X. M., **Chen, X. M.**, Shang, H. S., and Hu, X. P. 2020. Revealing differentially expressed genes and identifying effector proteins of *Puccinia striiformis* f. sp. *tritici* in response to high-temperature seedling-plant resistance of wheat based on RNA-seq. *mSphere* 5(3):e0009620. <https://doi.org/10.1128/mSphere.00096-20>

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Chen, J., Wheeler, J., Klassen, N., Zhao, W., O’Brien, K., Jackson, C., Marshall, J. M., Schroeder, K., and **Chen, X. M.** 2020. Release of ‘UI Bronze Jade’ hard white winter wheat. *Journal of Plant Registrations* 14(3):357-364. <https://doi:10.1002/plr2.20029>

Berg, J. E., Kephart, K. D., Lamb, P. F., Davis, E. S., Eberly, J. O., Miller, J. H., Chen, C., Pradhan, G. P., Torrion, J. A., Ramsfield, R., Nash, D. L., Holen, D. L., Cook, J. P., Gale, S., Jin, Y., **Chen, X.**, and Bruckner, P. L. 2020. Registration of ‘StandClear CLP’ hard red winter wheat. *Journal of Plant Registrations* 14(3):365-370. <https://doi.10.1002/plr2.20052>

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Yao, F. J., Long, L., Wang, Y. Q., Duan, L. Y., Zhao, X. Y., Jiang, Y. F. Pu, Z. E., Li, W., Jiang, Q. T., Wang, J. R., Wei, Y. M., Ma, J., Kang, H. Y., Dai, S. F., Qi, P. F., Zheng, Y. L., **Chen, X. M.**, and Chen, G. Y. 2020. Population structure and genetic basis of the stripe rust resistance of 140 Chinese wheat landraces revealed by a genome-wide association study. *Plant Science* 301:110688. <https://doi.org/10.1016/j.plantsci.2020.110688>

Liu, L., Yuan, C. Y., Wang, M. N., See, D. R., and **Chen, X. M.** 2020. Mapping quantitative trait loci for high adult-plant resistance to stripe rust in spring wheat PI 197734 using a doubled haploid population and genotyping by multiplexed sequencing. *Frontiers in Plant Science* 11(11):596962. <https://doi.org/10.3389/fpls.2020.596962>

Popular Press Articles:

January 7, 2020. 2020 First Stripe Rust Forecast and 2019 Fungicide and Variety Yield Loss Tests. Xianming Chen. E-mail sent to cereal group. <https://striperust.wsu.edu/2020/01/21/2020-first-stripe-rust-forecast-and-2019-fungicide-and-variety-yield-loss-tests-january-7-2020/>

January 9, 2020. Stripe rust expert predicts ‘severe epidemic’ of the disease. Matthew Weaver. *Capital Press*.

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January 9, 2020. WSU: Stripe Rust Expected To Be Severe To Epidemic In 2020. Glenn Vaagen. Pacific Northwest Ag Network. <https://www.pnwag.net/2020/01/09/wsu-stripe-rust-expected-to-be-severe-to-epidemic-in-2020/>

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May 15, 2020. Stripe Rust Update, May 15, 2020. Xianming Chen. E-mail sent to cereal group. <https://striperust.wsu.edu/2020/05/18/stripe-rust-update-may-15-2020/>

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June 6, 2020. Expert: Next Two Weekes ‘Critical’ for Stripe Rust. Matthew Weaver, *Capital Press*. https://www.capitalpress.com/ag_sectors/grains/expert-next-two-weeks-critical-for-stripe-rust/article_24506056-a75a-11ea-ad2f-b79cf104905b.html

June 8, 2020. Latest Use of Fungicides and Other Concerns. Xianming Chen. E-mail sent to cereal group. <https://striperust.wsu.edu/2020/07/06/latest-use-of-fungicides-and-other-concerns-june-8-2020/>

July 1, 2020. Rust Update, July 1, 2020. E-mail sent to cereal group. Xianming Chen. <https://striperust.wsu.edu/2020/07/06/stripe-rust-update-july-1-2020/>

July 16, 2020. Rust Update, July 16, 2020. E-mail sent to cereal group. Xianming Chen. <https://striperust.wsu.edu/2020/07/17/stripe-rust-update-july-16-2020/>

July 16, 2020. Stripe rust report 07/16: In general, stripe rust under control and season over. Washington Association of Wheat Growers. <http://www.wawg.org/stripe-rust-report-07-16-in-general-stripe-rust-under-control-and-season-over/>

September 17, 2020. New study identifies wheat varieties that resist the destructive stripe rust disease. By American Phytopathological Society. <https://phys.org/news/2020-09-wheat-varieties-resist-destructive-stripe.html>

October 8, 2020. 2020 Variety Yield Loss Tests. Xianming Chen, Kent Evans, and Jason Sprott. E-mail sent to cereal group. <https://striperust.wsu.edu/2020/10/08/2020-variety-yield-loss-tests/>

Presentations and Reports:

In 2020, Xianming Chen presented invited talks at the following national and international meetings:

“Stripe rust epidemics of wheat and barley and races of *Puccinia striiformis* identified in the United States in 2019.” Poster presentation (authored by Wang, M. N. and Chen, X. M.) at the 2020 American Phytopathological Society Annual Meeting, August 9-12, 2020 (Virtual meeting)

“Stripe rust resistance genes in U.S. wheat cultivars and breeding lines identified by molecular markers and genome-wide association studies.” Poster presentation (authored by Liu, L., Mu, J. M., Liu, Y., Wang, M. N., See, D. R., and Chen, X. M.) at the 2020 American Phytopathological Society Annual Meeting, August 9-12, 2020 (Virtual meeting)

“Population differentiation, diversity, and dynamics of stripe rust pathogen *Puccinia striiformis* on wheat and barley in the United State from 2010 to 2017.” Student oral presentation (authored by Bai, Q., Wan, A. M., Wang, M. N., See, D. R., and Chen, X. M.) at the 2020 American Phytopathological Society Annual Meeting, August 9-12, 2020 (Virtual meeting)

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