Washington Grain Commission
Wheat and Barley Research Annual Progress Report

Project #: 5682

Progress Report Year: 3 of 3 (2018)

Title: Control of Rusts of Wheat and Barley

Cooperators: K. Campbell, A. Carter, R. Higginbotham, S. Hulbert, K. Murphy, M. Pumphrey, & D. See

Executive summary: During 2018, studies were conducted according to the objectives of the project proposal and all objectives specified for the third 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 reasonably forecasted in 2018. 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 significant yield losses under the severe stripe rust epidemic. 2) We identified 19 (including 11 potentially new) races of the barley stripe rust pathogen and 27 (including 3 new) races of the wheat stripe rust pathogen in the US, of which 14 and 25 were detected in Washington, respectively. Seven of the new barley stripe rust races and all three new wheat stripe rust races were from Washington. The virulence information is used to guide breeding programs for using effective resistance genes in developing resistant varieties. 3) We sequenced 30 wheat stripe rust mutant isolates and used the data to identify candidate virulence genes. 4) We evaluated more than 40,000 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 2018, we collaborated with breeders in releasing, pre-releasing, or registered 12 wheat 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 characterization and molecular mapping of resistance genes in PNW wheat varieties Madsen, Eltan, and Skiles, mapped 6, 5, and 6 genes for stripe rust resistance, respectively, and determined the genetic mechanisms of the durable but different levels of resistance in these varieties. 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 31 fungicide treatments for control of stripe rust on both winter and spring wheat and provided the data to chemical companies for registering new fungicides. 8) 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. 9) In 2018, we published 26 journal articles and 10 meeting abstracts.

Outputs and Outcomes:

WGC project number: 5682				
WGC project title: Control of Rusts of Wheat and Barley				
Project PI(s): Xianming Chen				
Project initiation date: 7/1/2016				
Project year: 3 of 3 (2018)				
Objective	**Deliverable**	**Progress**	**Timeline**	**Communication**
1. Conduct disease forecast and field survey for guiding disease management	**1) Stripe rust predictions.** 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. **2) Field disease monitoring updates and recommendations.** Disease updates and recommendations will allow growers to implement appropriate control.	All planned studies for the project in 2018 have been completed on time. There is no any delay, failure, or problem in studies to this objective. 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, the times of first observations of stripe rust were about normal in various locations and stripe rust epidemic levels were also about normal in the moderate level in commercial fields with necessary fungicide application in fields of susceptible and moderately susceptible varieties. However, in our experimental fields near Pullman, stripe rust developed to extremely severe level in winter wheat plots and severe level in spring wheat plots, causing 70.5% and 66.4% yield losses in winter and spring wheat plots, respectively. 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, similar to 2017. Leaf rust of wheat was normal in western and observed in eastern PNW; leaf rust of barley in the western PNW was less than the previous years, but absent in the eastern PNW. Stem rust of wheat and barley was absent in the PNW in 2018.	All studies and services were completed on time.	The rust forecasts and survey data were communicated to growers and other researchers through e-mails, telephones, websites, 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).

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) Information on distribution, frequency, and changes of all races and virulence factors. 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 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 2018, we collected and received 314 stripe rust samples throughout the country and 70% of the samples were from Washington. We have completed about 90% of the race ID work for the 2018 samples as scheduled by this time. So far we have detected 27 wheat stripe rust races (including 3 new races) and 19 barley stripe rust races (including 11 new races), of which 25 wheat and 14 barley stripe rust races have been 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 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 have used molecular markers developed in our lab to study the stripe rust pathogen and determined the population changes in the past and present. We sequenced more isolates of the stripe rust pathogen and developed more SP-SNP markers to study rust pathogen populations and identify virulence genes.	The race identification work for the 2018 stripe rust samples will be completed by late February, 2019, as scheduled. The race ID work for 2019 samples will start in March. Molecular work of the 2017 samples and DNA extraction of the 2018 samples will be completed by June, 2019 as scheduled.	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).
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 with stripe rust resistance combined with other desirable traits for growers to grow.	In 2018, we evaluated more than 40,000 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 2018, we collaborated with public breeding programs in releasing and registered 12 wheat varieties. Varieties developed by private breeding programs were also resulted from our germplasm screening program.	All 2018 germplasm tests were completed and the data were provided to collaborators on time. The 2018-19 winter wheat nurseries were planted in September and October 2018. The 2019 spring crop nurseries will be planted in March-April, 2019. The greenhouse tests have been conducted during the winter, and will be completed by May, 2019.	The data of nurseries were sent to growers and collaborators through e-mails, websites, Seed Buyer's Guide, and variety registration journal publications

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 2018, We completed characterization and molecular mapping of resistance genes in PNW wheat varieties Madsen, Eltan, and Skiles, mapped 6, 5, and 6 genes for stripe rust resistance, respectively, and determined the genetic mechanisms of the durable but different levels of resistance in these varieties. 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 9 papers on molecular mapping and mechanisms of stripe rust resistance genes. 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 a few US breeding programs. In 2018, we phenotyped 40 mapping populations for stripe rust responses to map stripe rust resistance genes.	All experiments scheduled for 2018 were successfully completed. Mapping populations of winter wheat were planted in fields in October 2018 and those of spring wheat will be planted in April, 2019 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 2019.	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)

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 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 2018, we evaluated 31 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. On winter wheat, 30 treatments significantly reduced rust severity and increased grain yield. The treatments with only the late (Feekes 8) application produced the better control results than those of only early application (Feekes 5). Twenty two treatments significantly increased test weight compared to the non-treated check. Seven treatments, which all had only the early application, did not significantly increase yield compared to the non-treated check, while the remaining 24 treatments produced significantly higher grain yield. On spring wheat, all 31 fungicide treatments significantly reduced stripe rust severity. Twenty two treatments significantly increased grain test weight compared to the non-treated check. Thirty treatments significantly increased grain yield, and the increases ranged from 9.1 bushel per acre (26%) to 60 bushes (172%). Best treatments were identified. In 2018, 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 70.5% yield loss on the susceptible check and from 0 to 40.7% (average of 10.1%) on commercially grown varieties. Fungicide application increased yield by 0 to 40.2% (average of 12.4%) on commercially grown varieties. For spring wheat, stripe rust caused 66.0% yield loss on the susceptible check and from 0 to 47.5% (average 13.8%) yield losses on commercial varieties. Fungicide application increased grain yields by 0 to 90.6% (average 20.1%) 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.	For this objective, all tests scheduled for 2018 were successfully completed. For the 2018-19 growing season, the winter wheat plots of the fungicide and variety yield loss studies were planted in October, 2018 and the spring plots will be planted in April, 2019. The tests will be completed in August (for winter wheat) and September (for spring wheat), 2019.	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).

Publications:

<u>*Scientific Journals*</u>:

Wu, J. H., Wang, Q. L., Xu, L. S., **Chen, X. M.**, Li, B., Mu, J. M., Zeng, Q. D., Huang, L. L., Han, D. J., and Kang, Z. S. 2018. Combining SNP genotyping array with bulked segregant analysis to map a gene controlling adult-plant resistance to stripe rust in wheat line 03031-1-5 H62. Phytopathology 108(1):103-113.

Yuan, C. Y., Wang, M. N., Skinner, D. Z., See, D. R., Xia, C. J., Guo, X. H., and **Chen, X. M**. 2018. Inheritance of virulence, construction of a linkage map, and mapping of virulence genes in *Puccinia striiformis* f. sp. *tritici* by virulence and molecular characterization of a sexual population through genotyping-by-sequencing. Phytopathology 108(1):133-141.

Kidwell, K. K., Pumphrey, M. O., Kuehner, J. S., Shelton, G. B., DeMacon, V. L., Rynearson, S., **Chen, X. M.**, Guy, S. O., Engle, D. A., Baik, B.-K., Morris, C. F., and Bosque-Pérez, N. A. 2018. Registration of 'Glee' hard red spring wheat. Journal of Plant Registrations 12(1):60-65.

Chen, J. L., Wheeler, J., Zhao, W. D., Klassen, N., O'Brien, K., Marshall, J., Jackson, Ch., Schroeder, C., **Chen, X. M.**, and Higginbotham, R. 2018. Registration of 'UI Sparrow' wheat. Journal of Plant Registrations 12(1):79-84.

Johnson, J., Chen, Z., Buntin, G., Babar, M. A., Mason, R., Harrison, S., Murphy, P., Ibrahim, A., Sutton, R., Simoneaux, B., Bockelman, H., Baik, B., Marshall, D., Cowger, C., Browng, G., Kolmer, J., Jin, Y., **Chen, X. M.**, Cambron, S., and Mergoum, M. 2018. 'Savoy': an adapted soft red winter wheat cultivar for Georgia and the south east regions of the USA. Journal of Plant Registrations 12(1):85-89.

Belcher, A., Cuesta-Marcos, A., Smith, K. P., Mundt, C. C., **Chen, X. M.**, and Hayes, P. M. 2018. TCAP FAC-WIN6 elite barley GWAS panel QTL. I. Barley stripe rust resistance QTL in facultative and winter six-rowed malt barley breeding programs identified via GWAS. Crop Science 58(1):103-119.

Godoy, J., Rynearson, S., **Chen, X. M.**, and Pumphrey, M. 2018. Genome-wide association mapping of loci for resistance to stripe rust in North American elite spring wheat germplasm. Phytopathology 108(2):234-245.

Wang, L., Zheng, D., Zuo, S. X., **Chen, X. M.**, Zhuang, H., Huang, L. L., Kang, Z. S., and Zhao, J. 2018. Inheritance and linkage of virulence genes in Chinese predominant race CYR32 of the wheat stripe rust pathogen *Puccinia striiformis* f. sp. *tritici*. Frontiers in Plant Science 9(2):120.

Tao, F., Wang, J. J., Guo, Z. F., Hu, J. J., Xu, X. M., Yang, J. R. **Chen, X. M.**, and Hu, X. P. 2018. Transcriptomic analysis reveals the molecular mechanisms of wheat higher-temperature seedling-plant resistance to *Puccinia striiformis* f. sp. *tritici*. Frontiers in Plant Science 9(2):240.

Chen, X. M., Evans, C. K., Sprott, J., and Liu, Y. M. 2018. Evaluation of foliar fungicide treatments for control of stripe rust on winter wheat in 2017. Plant Disease Management Reports 12:CF073.

Chen, X. M., Evans, C. K., Sprott, J., and Liu, Y. M. 2018. Evaluation of foliar fungicide treatments for control of stripe rust on spring wheat in 2017. Plant Disease Management Reports 12:CF074.

Chen, X. M., Evans, C. K., Sprott, J., and Liu, Y. M. 2018. Evaluation of Pacific Northwest winter wheat cultivars to fungicide application for control of stripe rust in 2017. Plant Disease Management Reports 12:CF075.

Chen, X. M., Evans, C. K., Sprott, J., and Liu, Y. M. 2018. Evaluation of Pacific Northwest spring wheat cultivars to fungicide application for control of stripe rust in 2017. Plant Disease Management Reports 12:CF076.

Kidwell, K. K., Kuehner, J. S., Marshall, J., Shelton, G. B., DeMacon, V. L., Rynearson, S., **Chen, X. M.**, Guy, S. O., Engle, D. A., Baik, B.-K., Morris, C. F., and Pumphrey, M. O. 2018. Registration of ‘Dayn’ hard white spring wheat. Journal of Plant Registrations 12(2):222-227.

Berg, J. E., Hofer, P., Kephart, K. D., Stougaard, R. N., Lamb, P. F., Miller, J. H., Wichman, D. M., Eckhoff, J. L., Eberle, C. A., Nash, D. L., Holen, D. L., Cook, J. P., Gale, S., Jin, Y., **Chen, X.**, Moore, M. D., Kennedy, K. A., and Bruckner, P. L. 2018. Registration of ‘Spur’ hard red winter wheat. Journal of Plant Registrations 12(2):228-231.

Haley, S.D., Johnson, J.J., Peairs, F. B., Stromberger, J. A., Hudson-Arns, E. E., Seifert, S. A., Anderson, V. A., Rosenow, A. A., Bai, G. H., **Chen, X. M.**, Bowden, R. L., Jin, Y., Kolmer, J. A., Chen, M-S., and Seabourn, B. W. 2018. Registration of ‘Langin’ hard red winter wheat. Journal of Plant Registrations 12(2):232-236.

Feng, J. Y., Wang, M. N., See, D. R., Chao, S. M., Zheng, Y. L., and **Chen, X. M.** 2018. Characterization of novel gene *Yr79* and four additional QTL for all-stage and high-temperature adult-plant resistance to stripe rust in spring wheat PI 182103. Phytopathology 108(6):737-747.

Zhang, H. T., Qiu, Y. C., Yuan, C. Y., **Chen, X. M.**, and Huang, L. 2018. Fine-tuning of PR genes in wheat responding to different *Puccinia* rust species. Journal of Plant Physiology and Pathology 6:2.

Liu, L., Wang, M. N., Feng, J. Y., See, D. R., Chao, S. M., and **Chen, X. M.** 2018. Combination of all-stage and high-temperature adult-plant resistance QTL confers high level, durable resistance to stripe rust in winter wheat cultivar Madsen. Theoretical and Applied Genetics 131(9):1835-1849.

Li, M. J., **Chen, X. M.**, Wan, A. M., Ding, M. L., and Cheng J. S. 2018. Virulence characterization of stripe rust pathogen *Puccinia striiformis* f. sp. *tritici* population to 18 near-

isogenic lines resistant to wheat yellow rust in Yunnan Province. Journal of Plant Protection 45(1):75-82.

Xia, C. J., Wang, M. N., Yin, C. T., Cornejo, O. E., Hulbert, S. H., and **Chen, X. M.** 2018. Genomic insights into host adaptation between the wheat stripe rust pathogen (*Puccinia striiformis* f. sp. *tritici*) and the barley stripe rust pathogen (*Puccinia striiformis* f. sp. *hordei*). BMC Genomics 19:664.

Farrakh, S., Wang, M. N., and **Chen, X. M.** 2018. Pathogenesis-related protein genes involved in race-specific all-stage resistance and non-race specific high-temperature adult-plant resistance to *Puccinia striiformis* f. sp. *tritici* in wheat. Journal of Integrative Agriculture 17(11):2478-2491.

Xia, C. J., Wang, M. N., Yin, C. T., Cornejo, O. E., Hulbert, S. H., and **Chen, X. M.** 2018. Resource Announcement: Genome sequences for the wheat stripe rust pathogen (*Puccinia striiformis* f. sp. *tritici*) and the barley stripe rust pathogen (*Puccinia striiformis* f. sp. *hordei*) Molecular Plant-Microbe Interactions 31(11):1117-1120.

Niu, Z. X., Chao, S. M., Cai, X. W., Whetten, R. B., Breiland, M., Cowger, C., **Chen, X. M.**, Friebe, B., Gill, B. S., Rasmussen, J. B., Klindworth, D. L., and Xu, S. S. 2018. Molecular and cytogenetic characterization of six wheat-*Aegilops markgrafii* disomic addition lines and their resistance to rusts and powdery mildew. Frontiers in Plant Science 9(11):1616.

Haley, S. D., Johnson, J. J., Peairs, F. B., Stromberger, J. A., Hudson-Arns, E. E., Seifert, S. A., Anderson, V. A., Bai, G. B., **Chen, X. M.**, Bowden, R. L., Jin, Y., Kolmer, J. A., Chen, M. S., and Seabourn, B. W. 2018. Registration of ‘Avery’ hard red winter wheat. Journal of plant Registrations 12.362-366.

Cobo, N., Plfüger, L., **Chen, X. M.**, and Dubcovsky, J. 2018. Mapping QTL for resistance to new virulent races of wheat stripe rust from two Argentinean wheat varieties. Crop Science 58(6):2470-2483.

Popular Press Articles:
January 4, 2018. 2017 Fungicide and Variety Yield Loss Tests and 2018 First Stripe Rust Forecast. E-mail sent to growers and cereal groups.

March 8, 2018. Stripe Rust Forecast and Update, March 8, 2018. E-mail sent to growers and cereal groups.

April 10, 2018. Stripe Rust Update April 10, 2018. E-mail sent to growers and cereal groups.

May 8, 2018. Stripe Rust Update May 8, 2018. E-mail sent to growers and cereal groups.

June 1, 2018. Stripe rust Update June 1, 2018. E-mail sent to growers and cereal groups.

June 14, 2018. Cereal rust management and research in 2017. Pages 69-70 in: 2018 Dryland Field Day Abstracts, Highlights of Research Progress, Washington State University.

July 31, 2018. High-Temperature Adult-Plant Resistance: How Warm is Warm Enough? By Tim Murray, Wheat & Small Grains Extension, CAHNRS & WSU Extension. http://smallgrains.wsu.edu/high-temperature-adult-plant-resistance-how-warm-is-warm-enough/?utm_campaign=auto-draft&utm_source=auto-draft-2018-24&utm_medium=email&utm_content=link-17

December 20, 2018. Vogel's science legacy brings revolutionary wheat ideas to life. By Seth Truscott. https://news.wsu.edu/2018/12/19/vogels-science-legacy-brings-revolutionary-wheat-ideas-life/?utm_source=WSUNews-enewsletter&utm_campaign=wsunewsenewsletter&utm_medium=email

Presentations and Reports:

In 2018, Xianming Chen presented invited talks at the following national and international meetings:

"Stripe rust epidemiology and management and biology, genetics, functional genomics, and evolution of the stripe rust pathogen". Department of Plant Pathology, Washington State University, January 22, 2018 (about 60 people)

"Stripe rust races in the United States in 2017" at the Cereal Rust Workshop, Fargo, North Dakota, March 13, 2018 (30 people).

"Secretome of the stripe rust pathogen and genomic differences between the wheat and barley forms" at the Cereal Rust Workshop, Fargo, North Dakota, March 14, 2018 (30 people)

"Integrated control of stripe rust" in the Department of Plant Science, University of Idaho, Moscow, Idaho, March 23, 2018 (about 40 people)

"Sustainable control of stripe rust through developing wheat cultivars with durable, high-level resistance" at the Third McFadden Symposium at South Dakota State University, Brookings, South Dakota, May 2, 2018 (60 people)

"Sustainable control of stripe rust through developing wheat cultivars with high level, durable resistance." in Northwest A&F University, Yangling, Shannxi, China, May 28, 2018 (100 people).

"Virulence monitoring of wheat stripe rust in the US, China, Ecuador, Italy, and Mexico" at the Rust Surveillance Meeting during the International Congress of Plant Pathology, Boston, Massachusetts, August 2, 2018 (30 people)

"Different fungicide sensitivities and mutants of DMI target gene CYP51 identified in the *Puccinia striiformis* populations in the United States" at the 2018 International Cereal Rusts and Powdery Mildews Conference, Skukuza, South Africa, September 26, 2018 (about 160 people)

"Virulence factors of *Puccinia striiformis* f. sp. *tritici* in the United States from 1968 to 2017 and in other countries from 2013-2017" at the 2018 International Cereal Rusts and Powdery Mildews Conference, Skukuza, South Africa, September 26, 2018 (about 160 people)

"Improving Stripe Rust Control through Characterization of Genomics and Populations of the Pathogen and Diversification of Host Resistance Genes" at the 2018 Yangling International Agri-Science Forum, Yangling, Shaanxi, China, November 6, 2018 (300 people)

"Control of Stripe Rust through Understanding Pathogen Biology and Improving Cultivar Resistance" in Sichuan Academy of Agricultural Sciences, Chengdu, Sichuan, November 9, 2018 (50 people)

"Improving Control of Stripe Rust through Understanding Pathogen Biology and Improving Cultivar Resistance" in Southwestern University of Science and Technology, Mianyang, Sichuan, China, November 10, 2018 (100 people)

"Recent Progress in Stripe Rust Research in the United States" in the College of Plant Protection, Northwest A&F University, Yangling, Shaanxi, China, November 16, 2018 (50 people)

"Stripe rust management" at the 45th Annual Hermiston Farm Fair, Seminars & Trade Show, Hermiston, Oregon, November 29, 2018 (60 people)

In 2018, Xianming Chen, students, and/or associates presented posters or oral presentations at the following national and international meetings:

Poster entitled "Durable and high level stripe rust resistance in wheat cultivar Madsen conferred by five QTL for all-stage or HTAP resistance" at the 2018 Borlaug Global Rust Initiative Technical Workshop, Marrakech, Morocco, April 13-17, 2018 (300 people)

Poster entitled "Virulence characterization of *Puccinia striiformis* f. sp. *tritici* collections from China, Italy, Mexico, and Ecuador" at the 2018 International Congress of Plant Pathology, Boston, Massachusetts, July 28 - August 3, 2018 (about 2000 people)

Poster entitled "Two major and five minor QTL confer adult plant resistance to stripe rust in winter wheat cultivar Skiles" at the 2018 International Congress of Plant Pathology, Boston, Massachusetts, July 28 - August 3, 2018 (about 2000 people)

Poster entitled "Genomic basis for host adaptation in *Puccinia striiformis*" at the 2018 International Congress of Plant Pathology, Boston, Massachusetts, July 28 - August 3, 2018 (about 2000 people)