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Washington State University Wheat and Barley Research Progress Reports

WASHINGTON GRAIN COMMISSION

2015-2016 Fiscal Year

2015-16 WSU Wheat & Barley Research Progress Reports to the Washington Grain Commission

Washington Grain Commission
Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: **3019-3425**

Progress Report Year: 3 of 3

Title: **Weed Management in Wheat**

Researcher(s): Ian C. Burke and Drew J. Lyon

Cooperators: Derek Appel and Henry Wetzel, Associates in Research

Executive summary: Weed control is one of the major challenges facing wheat growers in the PNW. To address this problem, the Weed Science Program conducts a multi-disciplinary field, greenhouse, and laboratory research project to address the critical issues that Washington wheat growers face. One aspect of this work is the evaluation of herbicides, both registered and nonregistered, for crop tolerance and weed control in wheat production systems. This work is often, but not always, conducted in partnership with agricultural chemical companies. These field studies allow us to make better recommendations to growers, and they provides us the opportunity to work with the various companies to better refine their labels for the benefit of Washington wheat growers. The results from these studies were summarized in the WSU Weed Control Report, which was shared with the Washington Grain Commission and posted on the WSU Extension Small Grains website annually. The Weed Science Program continues to look at the biology and ecology of troublesome weeds including downy brome and Russian-thistle.

Impact: The WSU Weed Science Program impacts wheat and barley production in Washington and the Pacific Northwest by producing timely, accurate, non-biased weed control and weed biology information. That information is most commonly extended to consumers in the form of presentations, extension publications, news releases, and the Internet. In terms of value, herbicide inputs are typically the second costliest a grower faces, and using the most economical and effective treatment will improve the net income and long term durability of any operation

- The project provided data and local insights to BASF and FMC that assisted these companies label their new pyroxasulfone-containing herbicide products for Italian ryegrass and rattail fescue control in wheat. Our work was also critical in getting these companies to label higher use rates and preemergence applications in the PNW, contrary to what is labeled for the rest of the country.
- The results of our research on feral rye and downy brome control in wheat were incorporated into two new PNW Extension publications on these two troublesome weeds. A third Extension publication on prickly lettuce control, currently in review, also incorporates research from this research program. A fourth on mayweed chamomile will likely be submitted before the end of the currently funded project.
- Combined, Drs. Burke and Lyon have presented the results of this research program at ~127 events over the 3 years of this project, including the WSU Weed Science Field Day, the Lind Field Day, the Wheat Academy, and Far West Agricultural Associates meeting, and numerous county meetings.

WGC project number: 3019-3425
WGC project title: Weed Management in Wheat
Project PI(s): Ian C. Burke and Drew J. Lyon
Project initiation date: July 1, 2013
Project year: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
Evaluate herbicides	Efficacy and crop injury data to support use recommendations, new labels, and label changes to benefit WA small grain growers.	The 2015 WSU Weed Control Report was published in January of 2016 and distributed to the Washington Grain Commission, County Extension Educators in eastern Washington, and sponsoring chemical companies. The published studies will also be posted on the WSU Extension smallgrains website and discussed at winter Extension meetings.	Annually, in time for winter meetings.	Annual weed control report; articles in Wheat Life, trade magazines and/or posted to WSU smallgrains website; field days; winter Extension meetings; decision support system tools.
		The first year of a field study looking at smooth scouringrush control was completed near Rearden and the second year of the study was initiated. Only one treatment, Glean + MCPA-ester, provided significantly improved control compared to the nontreated check. A field study was initiated in the fall of 2015 near Lacrosse to look at the control of rush skeletoonweed in wheat following CRP. Buckwheat seed was spread in teh fall of 2015 at a field site near Pasco in preparation for a volunteer buckwheat control study in irrigated spring wheat.	The data from the first year of the scouringrush study will be combined with data from a simliar study initiated in 2015 in Oregon. The data from the two sites will be used in a stduent M.S. thesis and submitted for publication in 2017. We will complete the second year of teh scouringrush study in 2017 and initiate a second site near Omak in 2016. We will complete the first year of work on the rush skeletonweed and volunteer buckwheat studies in 2016.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles
		Multiple field studies were conducted in association with agrichemical companies to investigate efficacy and crop tolerance to a range of grass and broadleaf weed control products. These studies allow us to evaluate new chemistries or new uses of old chemistries and also help us modify company labels to better suit our region.	Field studies were completed in the summer of 2015 and new winter wheat studies initiated in the fall of 2015.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles
Evaluate cultivars	Support release of new cultivars with superior tolerance to herbicides that provide effective weed control in WA small grains. Identify traits that confer resistance or suceptibility in wheat or the primary gene pool.	Several 2-gene imi-resistant winter wheat lines were screened in the field and greenhouse for tolerance to Beyond plus sulfonylurea herbicides.	Annually, in time for cultivar release committee meetings.	Journal articles; Supplemental reports for use by the variety release committee; field days; winter Extension meetings.

Evaluate weed biology & ecology	Weed biology and ecology to aid in the design of effective and economic control strategies for troublesome weeds in WA small grain crops; decision support system database development.	A Russian-thistle common garden was grown in Pullman and Central Ferry. Accessions were sprayed with glyphosate and paraquat. No differential responses were observed to paraquat, but some variation in response to glyphosate was observed.	Genetic analysis of the accessions will be completed early in 2016 and these results will be combined with 2015 field results to design a field study to ascertain if genetic differences in herbicide response are evident.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles
		Downy brome accessions were collected from across the wheat production region of the PNW. A subset of 96 accessions representing the spatial and climatic range of the PNW were chosen to investigate differences in maturation rate and genetic diversity. Common garden studies were conducted in 2013 and 2014, with an additional ongoing experiment taking place in 2015. The purpose of the common garden experiments were to identify differences in rate of mature downy brome seed set across the PNW. Results indicate downy brome can set mature seed from early May to early July depending on climate and downy brome accessions present. Using next generation sequencing technologies, five distinct downy brome populations were identified from the accessions used in the common garden studies. Ongoing research is being conducted to provide a map of spatial distribution of downy brome populations along with development thresholds for mature seed set and optimal timing of herbicide applications.	Genetic analysis of the accessions were completed in 2015. Work on seed dormancy continues and should be completed in 2016.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles.
Evaluate cultural & mechanical management	Data to support recommendations for integrated weed management systems to control troublesome weeds in WA small grains.	Data from two years of field work on windrow burning to control Italian ryegrass were evaluated and a refereed journal article was submitted to Weed Technology. The paper was accepted for publication and will be published in early 2016.	Project completed in 2015.	Journal article and extension presentations. Data will be used to support future grant proposals on harvest weed seed control.

Washington Grain Commission
Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: 3193

Progress Report Year: _3_ *of* _3__

Title: Field Breeding Hard White and Red Winter Wheat

Investigator/Cooperators: **AH Carter,** TD Murray, XM Chen, KG Campbell, CF Morris

Executive summary: One hard red winter wheat line was released in 2015. WA8180 is a standard height hard red winter wheat targeted to the <12" rainfall zones of Washington. This line has good end-use quality, average protein content, very good test weight, good stripe rust resistance, and good yield potential. What makes this line stand out from other lines is its ability to emerge from deep planting and dry soils. Evaluation under crusting conditions has demonstrated this line can emerge through moderate crusting events. Trials under very low water potential done by Dr. Schillinger have shown this line to emerge very quickly from soils with very low water potential. This line will be a benefit to growers in the low rainfall zones in moisture limiting conditions. Apart from this line, there are additional lines being testing in variety testing for release potential, under both low and high rainfall conditions. After extensive selection of crosses targeted for the high rainfall zones of the state, the first material derived from DH is in statewide testing. This material comes through crossing to European material and is well adapted to Washington with high yield potential. We are very excited about these crosses. Continued emphasis has been placed on selecting breeding lines with superior quality and disease resistance. We also have a strong interest in developing hard lines with excellent emergence capabilities, and continually screen material to this end. Efforts have been initiated and are ongoing to develop hard cultivars with herbicide tolerance, snow mold resistance, and aluminum tolerance. After some renewed interest in hard white wheat, we had increased our efforts for crossing, but after further discussion with the Commission, have reduced this again due to a market shift. We maintain about 10% of the hard material as hard white and apply heavy selection pressure to ensure adapted material is advanced.

Impact: Hard winter wheat is an important crop to farmers and the Ag economy in Washington State. For the past five years, hard red winter wheat production in the state has been fairly steady at about 220,000 acres. Minimal increases are seen until new markets are developed or improved cultivars released. Input costs are constantly increasing, thereby lowering the return on crop production. Due to the extreme environmental conditions in this part of the state, average grain yield potentials are difficult to calculate. However, as an example, a modest increase in average grain yield of two bushel per acre of $5.00 wheat would mean nearly $2.2 million more per year for these growers and the state's economy. Enhanced disease resistance such as Fusarium dryland foot rot and aluminum tolerance, and increased agronomic adaptability and emergence potential, along with improved nitrogen use efficiency would yield similar dollar benefits. Our measurable impact in 2015 was the release of WA8180 with excellent emergence potential, which has garnered a lot of interest in growers and seed dealers, with interest in year-in-advance sales of this line.

WGC project number: 3193
WGC project title: Development of hard red winter wheat
Project PI(s): AH Carter
Project initiation date: July 1, 2013
Project year: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
Develop hard red and white winter wheat cultivars	New cultivars released for production in WA	Sprinter was released in 2013 and was grown on about 13,000 acres in 2015. In 2014, WA8184, a hard white winter wheat line was approved for release. This line has a modest increase of seed in 2015 and limited seed was sold the fall of 2015 for production in 2016. We have 6 hard red breeding lines in statewide testing for consideration under low rainfall production systems and 3 hard red in statewide testing for consideration under high rainfall production. We have over 4,000 plots and 20,000 rows of hard material under evaluation at various stages of the breeding process.	Each year we evaluate germplasm at each stage of the breeding process. Each year lines are entered into statewide testing for final release consideration. A cultivar is released, on average, every two years.	Progress is reported through field days, grower meetings, commission reports, popular press, and peer-reviewed manuscripts, and through the annual progress reports
	Agronomic traits	Field trials and agronomic data was conducted and collected at 20 locations in 2015. This includes emergence, winter survivability, heading date, test weight, plant height, and grain yield. Our Kahlotus and Ritzville trial gave a very good screen for emergence potential Lind crusted with minimal lines emerging and had to be replanted. With this data combined, very good selection was made for important agronoimc traits in 2015.	Evaluation is done annually at multiple locations across the state	
	Disease resistance	Lines were screened for snow mold, stripe rust, eyespot foot rot, Cephalosporium stripe, SBWMV, and aluminum tolerance	Evaluation is done annually at multiple locations across the state	
	End-use quality	All breeding lines with acceptable agronomic performance in plots were submitted to the quality lab. Those with acceptable milling characteristics were advanced to baking trials. Lines with inferior performance will be discarded from selection in 2016.	Each year, all head rows are evaluated for end-use quality and lines predicted to have superior quality advanced. Each yield trial is submitted for quality evaluations and those with high performance are advanced in the breeding process.	
	Herbicide resistance	Trials were conducted in Lind, Walla Walla, and Pullman for herbicide resistance.	Evaluation is done annually at multiple locations across the state	

Field test adapted germplasm with novel genes introgressed for essential traits	Incorporation of novel genes into adapter germplasm for evaluation under WA environments			Progress is reported through field days, grower meetings, commission reports, popular press, and peer-reviewed manuscripts, and through the annual progress reports
	Rht genes	Populations have been developed and are under field evaluation for Rht1, 2, and 8.	Crosses made through the project #5195 will be evaluated under field conditions upon MAS completion	
	Stripe rust genes	Multiple different stripe rust resistance genes have been introgressed into out germplasm which are under evaluation in Mount Vernon, Central Ferry, and Pullman.	Crosses made through the project #5195 will be evaluated under field conditions upon MAS completion	
	Foot rot genes	Pch1 has been selected for and is under evaluation in field trials in Pullman.	Crosses made through the project #5195 will be evaluated under field conditions upon MAS completion	
	GPC-B1 and Bx7oe	These two genes have been incorporated into many hard breeding lines. These are being tested for agronomic performance in the field.	Crosses made through the project #5195 will be evaluated under field conditions upon MAS completion	

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Washington Grain Commission
Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: 3672

Progress Report Year: _2_ *of* _3__

Title: Graduate student training

Investigator/Cooperators*:* **AH Carter,** KG Campbell, M Pumphrey, I Burke

Executive summary: The training of new graduate students in plant breeding and related fields ensures the viability and longevity of this discipline. Additionally, projects established to assist in the graduate training can be tailored to have a direct impact on the wheat growers of Washington. The objective of this project is to establish graduate student projects that have direct impact on developing new cultivars for the state of Washington, while simultaneously recruiting and training the best students to be the future plant breeders of the world. Four students have already been recruited with these funds. Austin Case (now a PhD student in Minnesota) identified DNA markers associated with the stripe rust resistance from Coda. These markers are currently being used to introgress resistance into new breeding lines. Shiferaw Gizaw is completing research in both spring and winter wheat on drought tolerance. He has identified spectral readings that can help indirectly select for higher yield potential under drought conditions. Megan Lewien is in her third year of research working on spectral indices for heat tolerance and other selected traits. Research involves both phenotypic and spectral data under greenhouse and field conditions. Caleb Squires is in his third year and is working on screening wheat germplasm and core collections for both resistance and susceptibility to different herbicides. Paul Mihalyov is completing research identifying new genes for stripe and stem rust resistance in wheat. Tara Burke is in her first year and working to develop genetic populations to dissect the genetics underlying specific herbicide resistance traits.

Impact: The number of graduate students interested in plant breeding and cultivar development efforts have been declining in the US over the past decade. Additionally, the number of research projects which are being funded at the federal level are turning away from applied research efforts and more focused on basic research. As a result, the amount of research being conducted directly toward cultivar development is limited. Initiation of research efforts with direct application toward the release of new cultivars ensures productivity, stability, and competitiveness of cultivar development efforts. Students have targeted projects which have direct application toward wheat production in the state. The conclusion of their research allows direct application toward cultivar develop efforts through more efficient selection and development of novel traits. As a result of these projects, breeding efforts have been enhanced to select for both biotic and abiotic stress resistance, either through the use of molecular markers or phenotypic screening. Lines in breeding programs are being advanced through the use of these data. Additionally, we have been able to leverage over $4,000,000 in external grant support through use of these preliminary data. This support is for projects which will directly benefit breeding programs at WSU and the USDA, as well as expedite cultivar development for traits of economic importance in the PNW.

WGC project number: 3672
WGC project title: QTL identification through graduate student training
Project PI(s): AH Carter
Project initiation date: July 1, 2013
Project year: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
Identify and recruit graduate students and accompanying projects with interest in aplpied plant breeding	Excellent students trained in applied plant breeding	We have identified and fuknded six excellent students in the previous years funding. Austin Case (graduated), Shiferaw Gizaw (graduated), Megan Lewien, Caleb Squires, Paul Mihalyov, and Tara Burke. We are in the process of reviewing applications for the 2016 year and upon notice of the successful award, will make an offer.	Student applications are reviewed in January, with offers extended early March.	Students will be introduced to the wheat commission through field days and research reviews
To develop projects which have direct application to the wheat breeding programs to expedite release of superior wheat germplasm	New tools/processes available to plant breeders to more effectively and efficiently breed and release superior wheat varieties	Previous year's funding has resulted in markers for cold tolerance genes, stripe rust resistance, drought resistance, and foot rot resistance. Additionally, students are working on developing herbicide tolerance and susceptibility, as well as identifying phenotypic correlations for heat tolerance using spectral reflectance measurements. Project funding has allowed use to leverage $4,000,000 in USDA funded support to enhance breeding projects at WSU that are directly impactful to the PNW. The most recent grant will allow us to improve the breeding process by fully incorporating high-throughput phenotyping and genomic selection into multiple breeding programs at the USDA and WSU.	Projects are developed within the first semester the student is at WSU, with focus on projects directly relevant to the breeding programs.	Student projects will be reviewed through field days, research reviews, printed press, and other venues as requested

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Washington Grain Commission
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Project #: 3673

Progress Report Year: *_2_ of _3_*

Title: Increasing Genetic Opportunities for Stripe Rust Resistance

Investigator/Cooperators: **AH Carter, KG Campbell, M Pumphrey,** X. Chen, S. Hulbert, D. See

Executive summary: Work has been completed identifying markers linked to *Yr5*. This manuscript has been submitted for publication and will allow breeders the ability to more effectively track this important gene. Fine mapping populations for the *YrCoda* gene have been completed. Phenotyping will begin in 2016. Additional work on this region has redeveloped the genetic map to better clarify this region. The additional work on the QAM panel has clarified there are multiple genes for resistance in this region. The resistance genes from tetraploid wheat are in the process of being transferred to spring wheat for use in breeding. Crosses have been made and additional backcrosses need to be made to recover the 42 chromosomes of hexaploid wheat. The JD/Avocet S and Finch/Eltan populations have been tested in the field for QTL analysis. The JD/Avocet S population is undergoing genotyping to complete the analysis. The Finch by Eltan work is completed and we have identified markers associated with each of these genes. Results have been published. Association mapping has been completed on various panels and a list of resistance loci, markers, and germplasm containing each resistance source has been identified. These lines are in the process of being crossed to other breeding material and marker assisted selection will take place to carry forward breeding lines with multiple sources of resistance. The spring wheat, winter wheat, and USDA breeding programs are all using different sets of markers to move stripe rust resistance genes into their respective germplasm bases. Additional studies are being conducted to further evaluate selected sources of resistance to better characterize these genes.

Impact: Throughout the project, we identified SNP markers which showed significant association with novel resistant genes and known resistant genes. We are now able to add them in our MAS protocols and routinely screen for these resistance genes in our breeding material. We also have developed SNP markers linked to the Louise and Coda resistance and successfully have applied them in MAS. It is a significant accomplishment to develop elite wheat cultivars with durable rust resistance in PNW wheat breeding programs. The impact of identifying new SNP markers will allow all breeding programs the ability to use and pyramid useful stripe rust resistance genes into new germplasm. The effective use of resistance genes will mitigate the damage caused by the stripe rust pathogen as well as the amount of fungicides applied each year. Wheat producers in Washington have access to wheat cultivars with better stripe rust resistance than they did three years ago. Progress is measured by the excellent stripe rust resistance that has been incorporated into recent releases such as Puma, Jasper, Melba, Seahawk, Alum, and Chet. These lines are gaining in popularity in part due to their rust resistance.

WGC project number: **3673**
WGC project title: **Increasing Genetics Opportunities for Stripe Rust Resistance**
Project PI(s): **A Carter, K Garland-Campbell, M Pumphrey**
Project initiation date: **July 1, 2015**
Project year: **2 of 3**

Objective	Deliverable	Progress	Timeline	Communication
Use DNA markers to pyramid stripe rust resistance into PNW breeding material	Breeding lines and cultivars with multiple resistance genes conferring both seedling and adult plant resistance	Asociation mapping using PNW soft white winter wheat ('QAM panel') has been carried out and new QTL and consistent QTL from previous panel ('SNP panel') have been identified. Lines carrying these QTL have also been identified. In some cases, crosses have already been made to these lines and populations are being developed for selection such as a cross between 'Bitterroot X WA8115'. In other cases, crosses have been initiated with lines carrying the desired QTL such as a cross between 'Coda X WA8115'.	Markers will be used to verify that these lines carry target resistance along with field and/or greenhouse phenotyping in 2016. Coda X WA8115 lines will be tested for few races in greehouse.	Results will be communicated through field days, grower meetings, seminars, journal articles, annual progress reports, and the wheat research review, as well as through other venues as requested. Association mapping with 'SNP panel' has been published in Theoritical and Applied Genetics 128: 1083-1101 A integrated work from association mapping with 'QAM panel' and QTL mapping in 'Coda X Brundage' will be presented in Plant and Animal Genome conference in 2016.
Transfer resistance genes from Emmer wheat into hexaploid wheat	Additional novel genes currently effective against PNW stripe rust races moved into new breeding lines and cultivars	22 of BC1F2 populations have been tested in field. Only two out of these showed segregation on disease response. These two BC1F2 are being adavanced in greenhouse.	Unsuccessful crosses will be repeated in 2016. The advanced populations will be tested in field again, and DNA markers will be used to identify progeny with stripe rust resistance genes of interest to confirm resistance. These lines will be further used to introgress this resistance into other PNW germplasm.	Results will be communicated through field days, grower meetings, seminars, journal articles, annual progress reports, and the wheat research review, as well as through other venues as requested.
Develop 'near-perfect' markers for Yr5, Yr15, and YrCoda that can be used for marker-assisted selection.	DNA markers associated with genes resistant to currently known stripe rust races in Washington	Near perfect' markers for Yr5 have been developed and verified their usefullness with other germplasm. Re-mapping for Coda X Brundage population with additional SNP markers was carried out and verified YrCoda is novel. A popuation derived from a cross between JD (potentially carrying YrCoda and other resistance) and Avocet S was phenotyped in field and genotyping by sequencing has been completed. Populations developed for Yr15 showed complex segregation and markers did not seem to be associated with Yr15.	Fine-mapping for YrCoda will be carried out using backcross populations which currently being developing. 'JD X Avocet S' will be phenotyped in field again and QTL mapping will be carried out in 2016.	Results will be communicated through field days, grower meetings, seminars, journal articles, annual progress reports, and the wheat research review, as well as through other venues as requested. 'Near perfect' markers for Yr5 have been presented in Borlaug Global Rust Initiative workshop in 2015 and currently prepared for manuscript.

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Washington Grain Commission
Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: 5195

Progress Report Year: *_1_ of _3__*

Title: Use of biotechnology for wheat improvement

Investigator/Cooperators: **AH Carter,** KG Campbell, D See, M Pumphrey

Executive summary: In 2015 we continued our effort to advance breeding lines as quickly and efficiently as possibly by employing both molecular marker analysis and doubled-haploid technology. The traits of main focus for marker-assisted selection are foot rot resistance, stripe rust resistance, herbicide tolerance, and end-use quality. These are our primary focus due to very good markers having been developed and the importance of these traits in Washington. Additional traits include aluminum tolerance, SBWMV, dwarfing genes, photoperiod sensitivity, and nematode resistance. Over 1,500 lines were tested to confirm presence of desired genes based on marker profiling. These have been advanced to field testing to confirm presence of the selected genes. Markers were also used to screen all advanced breeding lines to identify presence of known genes. This information was used for selection and advancement purposes (in conjunction with field data) as well as for selecting lines which should be cross-hybridized to create future populations. The process of marker-assisted selection is an ongoing process, and at any given point we either have lines planted for analysis, in the laboratory undergoing marker profiling, or on increase in the greenhouse after selection to advance seed into field evaluations. Our genomic selection efforts are proceeding and we have completed our third year of phenotypic evaluations in the field. We submitted the 2015 and 2016 breeding lines for GBS analysis. Genomic selection models have been developed and will be updated as new data becomes available.

In the greenhouse, we made approximately 1,100 crosses consisting mainly of soft white, hard white, and hard red germplasm. These are being advanced to the F2 generation. We planted 200 DH plants in the field in 2015 for evaluation. The remaining DH lines are undergoing increase in the greenhouse and nearly 2,500 lines will be ready for yield evaluation in 2016. 100 additional crosses have been submitted for DH production.

Impact: This project covers all market classes and rainfall zones in the state of Washington, with about 70% of the effort on soft white crosses. This work will improve end-use quality, genetic resistance to pests and diseases, and agronomic adaptability and stability of released cultivars. All cultivars released have benefited through this project by incorporation of disease and end-use quality genes. These lines have gain popularity and are growing in demand in part due to the gene combinations they were selected for. Continued success will be measured by increases in acreage of these lines as well as enhanced cultivar release through DH production and marker-assisted and genomic selection.

WGC project number: 5195
WGC project title: Use of biotechnology for wheat improvement
Project PI(s): AH Carter
Project initiation date: July 1, 2012
Project year: 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
Marker-assisted selection				Results are presented through annual progress reports, the research review, field tours, and grower meetings
	Foot rot resistant lines	In 2015, 61 populations were screened for the Pch1 gene for foot rot resistance. Of these, lines with the gene were advanced in the greenhouse and field selection will occur this coming year.	Each year new crosses are made to Pch1 containing lines. These are subsequently developed, screened, and advanced to state-wide yield trials. At any given time, lines are in every stage of development	
	Stripe rust resistant lines	In 2015, 26 populations for Yr5 and Yr15 were screened for and selected upon for upcoming field testing. An additional 63 populations were screened for various other rust genes of interest.	Each year new crosses are made to stripe rust resistant lines. These are subsequently developed, screened, and advanced to state-wide yield trials. At any given time, lines are in every stage of development	
	End-use quality lines	In 2015, 48 F2 populations were screened for the genes Gpc-B1 and Bx7oe. Multiple F4 populations were selected in the field for these two genes as a resuklt of previous marker efforts. These lines are now in yield testing to determine agronomic adaptability. Additional lines were screened for GBSS genes (waxy) and the glutenin genes.	Each year new crosses are made to lines containing unique end-use quality genes. These are subsequently developed, screened, and advanced to state-wide yield trials. At any given time, lines are in every stage of development	
	Reduced height lines	In 2015, 14 populations were screened for incorporation of various Rht genes. Previous populations were planted at Lind to be screened for emergence potential.	Each year new crosses are being made to incorporate different Rht genes into the breeding program. We also verify presence of dwarfing genes in all material to assist with selection of lines with enhanced emergence potential.	

	Genomic selection	With the assistance of Dr. Zhang, we have begun genomic prediction model building in 2015. Lines from teh 2015 and 2016 breeding program will be genotyped and added to the model development. We have moved away from using training panels for model development and will now use the breeding program material.	Each year we will continue to phenotype the training panel, add more lines to the training panel (and genotype them), and refine the prediction model	Results are presented through annual progress reports, the research review, field tours, and grower meetings
Genotyping advanced breeding lines	Provide useful information regarding genetic diversity and gene profiles to better estimate crossing potential	In 2015, the advanced germplasm was screened with DNA markers for about 20 traits of interest. This information was used to enhance selection of field tested material, as well as assist in parent cross-combinations to develop populations with desired traits of interest.	This is done annually	Results are presented through annual progress reports, with the outcomes of this research being realized in new cultivars
Greenhouse				Results are presented through annual progress reports, with the outcomes of this research being realized in new cultivars
	Hybridization and propagation	In 2015 we made approximately 1100 crosses which were targeted for herbicide resistance, low rainfall and high rainfall production, and specific gene introgressions. These crosses were advanced to the F2 stage.	This is done annually, with the number of crosses/populations varying	
	Single-seed descent	10 SSD populations were started and are being advanced for herbicide resistance.	This is done annually, with the number of crosses/populations varying	
	Doubled haploid	In 2015 we submitted 100 crosses for DH production. We are advancing roughly 3,000 DH lines in the greenhouse to get enough seed to plant in yield plots in the fall of 2016. We have another 2,000 which are being increased for the first time. More crosses will be submitted in 2016 for DH production.	This is done annually, with the number of crosses/populations varying	
	Trait Introgression	We made crosses to germplasm containing resistance to snow mold, stem rust, stripe rust, end use quality, foot rot resistance, preharvest sprouting, Al tolerance, Ceph Stripe, SBWMV, vernalization duration, and certain herbicides. The populations are being increased in the greenhouse for field selection. Currently there are no markers for many of these genes, although some are in development. The idea was either to select based on field conditions or have populations ready once the markers were identified. These will be planted in 2015 as rows at various locations and stages of development, depending on the trait of interest.	This is done annually, with the number of crosses/populations varying	
Trait assessment				Results are presented through annual progress reports, with the outcomes of this research being realized in new cultivars

	Coleoptile length	All advanced breeding lines are screened and selected for coleoptile length (funded by the Amen Foundation)	Screening and selection will be completed in 2015. Superior lines will be planted in the field and crossed back into the breeding program.	
	Foot rot	Advanced populations are being screened for foot rot resistance. Resistant lines will be used in the breeding program to incorporate this trait through a diversity of backgrounds	Screening and selection will be completed in 2015. Superior lines will be planted in the field and crossed back into the breeding program.	
	Cold Tolerance	All advanced breeding lines are screened for cold tolerance through the USDA funded WGC grant.	Screening and selection will be completed in 2015. Superior lines will be planted in the field and crossed back into the breeding program.	
	Stripe rust	An advanced population was screened for stripe rust resistance and that analysis is now complete. We identified over 20 QTL in PNW germplasm, about half of which appear to be novel. These lines are now being crossed to additional breeding lines and cultivars, and selection will be done with the recently identified markers to incorporate this resistance through a diversity of backgrounds.	Screening and selection will be completed in 2015. Superior lines will be planted in the field and crossed back into the breeding program.	

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Washington Grain Commission
Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: 6195

Progress Report Year: *_1_ of _3__*

Title: Field Breeding Soft White Winter Wheat

Investigator/Cooperators: **AH Carter,** TD Murray, XM Chen, KG Campbell, CF Morris

Executive summary: A new club cultivar, developed in coordination and collaboration with the USDA breeding program, was approved for release in 2015 and will be named Pritchett. This is targeted to replace Bruehl, with improved disease resistance, yield potential, and cold hardiness. In the 2015 VT trails, Jasper was in the top five yielding lines in production zones with greater than 12" annual precipitation. All foundation seed was sold of this line. Puma was in high demand in the fall of 2015 and thousands of bushels were sold for commercial production. Puma was in the top three yielding cultivars across the four production regions determined by the Variety Testing program, and was the number one yielding line in the 12-16" and 16-20" rainfall zones. We are excited to see this line in production in 2016. Otto, a 2011 release from this program, continues to grow in demand. In 2015 it was estimated to be planted on 221,000 acres, making it the most widely planted cultivar in the state. Eleven advanced breeding lines were entered into WSU's Variety Testing (VT) Program, five in the low rainfall zones and six in the high. Over 1,000 unreplicated yield-trial plots were evaluated at either Pullman or Lind and thousands of F4 head rows were evaluated in Pullman, Lind, and Waterville. High selection pressure is continually placed on disease resistance, emergence, flowering date, end-use quality, straw strength, etc. Multiple screening locations have been established to evaluate germplasm for: stripe rust resistance, foot rot resistance, snow mold resistance, good emergence, aluminum tolerance, soil borne wheat mosaic virus resistance, Cephalosporium tolerance, and nematode resistance. The program has also employed efforts to develop herbicide resistant cultivars and advanced lines have been entered into Variety Testing. Many lines have been performing every well and some are on breeders seed increase in preparation for variety release proposal. We continue to put a strong emphasis on soft white wheat in the program, and have begun to modify our breeding schemes to account for marker-assisted selection, genomic selection, and doubled-haploid production.

Impact: Traditionally, over 85% of the wheat crop in our state is winter wheat. Even very small reductions of required grower input and/or increases in productivity can mean millions of dollars to the growers, grain trade and allied industries. By providing genetic resistance to diseases and increasing agronomic adaptability, input costs will be reduced and grain yield increased. WSU white cultivars are grown on approximately 35% of the acres. This continues to increase each year. Measured impact is demonstrated with the strong growth of Otto, becoming the #1 cultivar in the state after three years. The interest in Puma and Jasper for production also measures the impact of the program. Not only do these lines provide high yield potential, but also excellent end-use quality and genetic resistance to major diseases.

WGC project number: 6195
WGC project title: Field Breeding Soft White Winter Wheat
Project PI(s): AH Carter
Project initiation date: July 1, 2012
Project year: 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
Develop soft white winter wheat cultivars	New cultivars released for production in WA	We released Otto in 2011. Puma (WA8134) was released in 2012. Jasper was released in 2014. Otto became the #1 grown cultivar in the state in 2015, replacing much of the Eltan acres. Puma was sold in high demand in the fall of 2015 and will be on commercial production in 2016. Jasper was sold out of foundation seed in 2015 and prodcution and interest continues to increase. Released lines have high yield potential, excellent disease resistance, and very good end-use quality. We also co-released a club line in 2015 in collaboration with the USDA. This line is intended to replace Bruehl. We have 5 breeding lines in statewide testing for consideration under low rainfall production systems and 6 in statewide testing for consideration under high rainfall production. One of these lines is a two-gene imazamox resistant lines. We have over 10,000 plots and 40,000 rows of soft white material under evaluation at various stages of the breeding process.	Each year we evaluate germplasm at each stage of the breeding process. Each year lines are entered into statewide testing for final release consideration. A cultivar is released, on average, every two years.	Progress will be reported through field days, grower meetings, commission reports, annual progress reports, and peer-reviewed manuscripts
	Agronomic traits	We have 20 locations across the state representing diverse climatic zones in which advanced breeding lines are evaluated for agronomic characteristics. Early generation material is selected for in Lind and Pullman. Specifically, this year we added head rows for selection at Lind due to the ability to screen for emergence and cold tolerance along with extra location near Waterville to screen for snow mold.	Evaluation is done annually at multiple locations across the state.	
	Disease resistance	Disease resistance is recorded on our 20 breeding locations as disease is present, with certain locations being selected specifically for disease pressure (Waterville for snowmold, Pullman for stripe rust, etc.). Additional locations are planted in cooperation with plant pathologists to screen other diseases of importance in WA	Evaluation is done annually at multiple locations across the state.	

	End-use quality	All F4 and greater material is subjected to end-use quality screens to evaluate performance. Lines with poor quality are discarded from the breeding program and from selection in 2016.	Each year, all head rows are evaluated for end-use quality and lines predicted to have superior quality advanced. Each yield trial is submitted for quality evaluations and those with high performance are advanced in the breeding process.	
	Herbicide resistance	Multiple soft white lines have been developed for herbicide resistance and are being evaluated under replicated trials across the state. Two lines have shown very good promise and are on increase for seed production in 2016.	Evaluation is done annually at multiple locations across the state.	
Introgress novel genes for essential traits	Incorporation of novel genes into adapted germplasm for evaluation under WA environments			Progress will be reported through field days, grower meetings, commission reports, annual progress reports, and peer-reviewed manuscripts
	Rht and photoperiod genes	Crosses have been made to include non-traditional Rht and photoperiod genes into our soft white winter wheat germplasm for testing under PNW conditions.	Crosses made through the project #5195 will be evaluated under field conditions upon MAS completion.	
	Stripe rust genes	We constantly have material coming out of the MAS program for stripe rust. In 2015 we evaluated multiple populations in both early and preliminary yield trials. Material includes new genes identified from Eltan, Coda, and novel genes.	Crosses made through the project #5195 will be evaluated under field conditions upon MAS completion.	
	Foot rot genes	We have many populations being screened for foot rot resistance.	Crosses made through the project #5195 will be evaluated under field conditions upon MAS completion.	
	Cephalosporium	No markers are currently being used for this introgression. All selection is being done under field conditions. We recently completed an association mapping study, and have identified numerous markers which can be used for selection, as well as germplasm which can be used for crossing and pyramiding QTL together.	Evaluation will be done in field locations in WA in 2014	
	Aluminum tolerance	Field screening of breeding lines for aluminum tolerance is being conducted under field conditions. We recently completed an association mapping study, and have identified numerous markers which can be used for selection, as well as germplasm which can be used for crossing and pyramiding QTL together.	Evaluation will be done in field locations in WA in 2014	

	End-use quality	Seed of bi-parental mapping populations have been submitted for quality analysis and an association mapping panel for end-use quality was grown for analysis in 2015.	Seed will be collected in 2014 and sent for quality evaluations, after which analysis will be performed and markers identified.	

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Washington Grain Commission
Wheat and Barley Research Annual Progress Report

Project #: 5665

Progress Report Year: 3 of 3 (2015)

Title: Control of Wheat and Barley Rusts

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

Executive summary: During the third year (2015) of the project, 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 accurately forecasted in 2015. Rust updates and advises were provided on time to growers based on the forecasts using prediction models and field surveys, which reduced disease pressure in the early spring and prevented unnecessary use of chemicals in the late growth season the State of Washington. 2) We identified 28 races of wheat stripe rust and 2 races of barley stripe rust in the US, of which 21 and 2 were detected, respectively in Washington. The 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. 3) We used molecular markers developed in our lab to study the stripe rust pathogen and determined the population changes in the past and present. 4) We evaluated more than 35,000 wheat and 2,000 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 2015, we collaborated with breeders in releasing, pre-releasing, or registered 6 wheat and 4 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 studies for mapping 6 genes for stripe rust resistance in two wheat lines and identified molecular markers. We officially named one stripe rust resistance gene, and published 6 papers on molecular mapping stripe rust resistance genes in 6 wheat varieties. 6) We provided seeds of our recently developed new 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 19 fungicide treatments for control of stripe rust and provided the data to chemical companies for registering new fungicides. We tested potential yield loss due to stripe rust and increase from fungicide application for 23 winter wheat and 15 spring wheat varieties currently grown in Washington. The data of the fungicides and varieties are used for guiding the integrated control of stripe rust. 8) We published 21 journal articles and 8 meeting abstracts in 2015.

Outputs and Outcomes:

Progress, Timelines, and Communication are presented in Outcome Reporting file (file name:

Chen_WGC 2015 Annual Report XMChen Outcome Reporting.pdf)

Publications:

Scientific Journals:

Murphy, K. M., Ullrich, S. E., Wood, M. B., Matanguiham, J. B., Guy, S. O., Jitkov, V. A., and **Chen, X. M.** 2015. Registration of 'Lyon', a two-row, spring feed barley. Journal of Plant Registrations 9:6-9.

Maccaferri, M., Zhang, J. L., Bulli, P., Abate, Z., Chao, S. M., Cantu, D., Bossolini, E., **Chen, X. M.**, Pumphrey, M., Dubcovsky, J. 2015. A genome-wide association study of resistance to stripe rust (*Puccinia striiformis* f. sp. *tritici*) in a worldwide collection of hexaploid spring wheat (*Triticum aestivum* L.). 3G: Genes, Genomics, Genetics 5:449-465.

Zhou, X. L., Zhang, Y., Zeng, Q. D., **Chen, X. M.**, Han, D. J., Huang, L. L., and Kang, Z. S. 2015. Identification of QTL for adult plant resistance to stripe rust in Chinese wheat landrace Caoxuan 5. Euphytica 204:627-634.

Chen, X. M., Evans, C. K., Liu, Y. M., and Heath, M. 2015. Control of stripe rust of winter wheat with various foliar fungicides, 2014. Plant Disease Management Reports 9:CF021.

Chen, X. M., Evans, C. K., Liu, Y. M., and Heath, M. 2015. Control of stripe rust of spring wheat with various foliar fungicides, 2014. Plant Disease Management Reports 9:CF016.

Chen, X. M., Evans, C. K., Liu, Y. M., and Heath, M. 2015. Effects of fungicide application on control of stripe rust on winter wheat cultivars in 2014. Plant Disease Management Reports 9:CF017.

Chen, X. M., Evans, C. K., Liu, Y. M., and Heath, M. 2015. Effects of fungicide application on control of stripe rust on spring wheat cultivars in 2014. Plant Disease Management Reports 9:CF018.

Carter, A. H., Kidwell, K. K., DeMacon, V., Balow, K. A., Shelton, G. B., Higginbotham, R. W., **Chen, X. M.**, Engle, D. A., Baik, B., and Morris, C. F. 2015. Registration of 'Sprinter' hard red winter wheat. Journal of Plant Registrations 9:196-200.

Talajoor, M., Jin, Y., Wan, A. M., **Chen, X. M.**, Bhavani, S., Tabe, L., Lagudah, E., and Huang, L. 2015. Specificity of a rust resistance suppressor on 7DL in the spring wheat cultivar Canthatch. Phytopathology 105:477-481.

Vazquez, M. D., Zemetra, R., Peterson, C. J., **Chen, X. M.**, Heesacker, A., and Mundt, C. C. 2015. Multi-location wheat stripe rust QTL analysis: Genetic background and epistatic interactions. Theoretical and Applied Genetics 128:1307-1318.

Hou, L., **Chen, X. M.**, Wang, M. N., See, D. R., Chao, S. M., Bulli, P., and Jing, J. X. 2015. Mapping a large number of QTL for durable resistance to stripe rust in winter wheat Druchamp using SSR and SNP markers. PLoS ONE 10(5):e0126794.

Ma, L. J. Qiao J. X., Kong X. Y., Zou Y. P. Xu, X. M., **Chen, X. M.**, and Hu, X. P. 2015. Effect of low temperature and wheat winter-hardiness on survival of *Puccinia striiformis* f. sp. *tritici*. PLoS One 10(6):e0130691.

Han, D. J., Wang Q. L., **Chen, X. M.**, Zeng, Q. D., Wu, J. H., Xue, W. B., Zhan, G. M., Huang, L. L., and Kang, Z. S. 2015. Emerging *Yr26*-virulent races of *Puccinia striiformis* f. sp. *tritici* are threatening wheat production in the Sichuan Basin, China. Plant Dis. 99:754-760.

Ibrahim, A. M. H., Rudd, J., Devkota, R., Baker, J., Sutton, R., Simoneaux, B., Opeña, G., Herrington, R., Rooney, L., Dykes, L., Awika, J., Nelson, L. R., Fritz, F., Bowden, R. L., Graybosch, R. A., Jin, Y., Seabourn, B. W., **Chen, X. M.**, Kolmer, J., and Duncan, R. 2014. Registration of ‘TAM 305’ hard red winter wheat. Journal of Plant Registrations 9:325-330.

Zhao, J., Zhao, S. L., **Chen, X. M.**, Wang, Z. Y., Wang, L., Yao, J. N., Chen, W., Huang, L. L., and Kang, Z. S. 2015. Determination of the role of *Berberis* spp. in wheat stem rust in China. Plant Dis. 99:1113-1117.

Yin, C. T., Downey, S. I., Klasges-Mundt, N. L., Ramachandran, S., **Chen, X. M.**, Szabo, L. J., Pumphrey, M., Hulbert, S. H. 2015. Identification of promising host-induced silencing targets among genes preferentially transcribed in haustoria of *Puccinia*. BMC Genomics 16:579.

Zhou, X. L., Han, D. J., **Chen, X. M.**, Mu, J. M., Xue, W. B., Zeng, Q. D., Wang, Q. L., Huang, L. L., and Kang, Z. S. 2015. QTL mapping of adult-plant resistance to stripe rust in wheat line P9897. Euphytica 205:243-253.

Feng, J. Y., Wang, M. N., **Chen, X. M.**, See, D. R., Zheng, Y. L., Chao, S. M., and Wan, A. M. 2015. Molecular mapping of *YrSP* and its relationship with other genes for stripe rust resistance in wheat chromosome 2BL. Phytopathology 105:1206-1213.

Murphy, K. M., Ullrich, S. E., Wood, M. B., Matanguihan, J. B., Jitkov, V. A., Guy, S. O., **Chen, X. M.**, Brouwer, B. O., Lyon, S. R., and Jones, S. S. 2015. Registration of ‘Muir’ spring feed barley. Journal of Plant Registrations 9:283-287.

Wang, M. N., Wan, A. M., and **Chen, X. M.** 2015. Barberry as alternate host is important for *Puccinia graminis* f. sp. *tritici* but not for *Puccinia striiformis* f. sp. *tritici* in the U. S. Pacific Northwest. Plant Disease 99:1507-1516.

Wang, M. N., and **Chen, X. M.** 2015. Barberry does not function as an alternate host for *Puccinia graminis* f. sp. *tritici* in the U. S. Pacific Northwest due to teliospore degradation and barberry phenology. Plant Disease 99:1500-1506.

Popular Press Articles:

January 8, 2015. First Forecast of Stripe Rust for 2015 and 2014 Yield Losses. Xianming Chen E-mail sent to growers and the cereal group.

February 2015. Washington's early stripe rust forecast. Xianming Chen. Page 12 in *Wheat Life* February 2015.

March 5, 2015. Stripe Rust Forecast and Update, March 5, 2015. Xianming Chen. E-mail sent to growers and the cereal group.

April 3, 2015. Stripe rust forecast "Severe" for Northwest wheat. Matthew Weaver. Capital Press. April 3, 2015

April 10, 2015. Stripe Rust Update, April 10, 2015. Xianming Chen. E-mail sent to growers and the cereal group.

April 29, 2015. Stripe Rust Update, April 29, 2015. Xianming Chen. E-mail sent to growers and the cereal group.

May 1, 2015. PNW stripe rust update, by Xianming Chen. *Wheat Life*, May 2015. Pages 12-14.

May 5, 2015. A different kind of rust belt. By Scott A. Yates. *Wheat Life*, May 2015. Pages 50-53.

June 11, 2015. Stripe Rust Update, June 11 2015. Xianming Chen. E-mails sent to growers and the cereal group.

June 25, 2015. Stripe Rust Update, June 25 2015. Xianming Chen. E-mails sent to growers and the cereal group.

July 2015. PNW stripe rust update by Xianming Chen, pages 14-15. *Wheat Life*, July, 2015.

September 4, 2015. Hot, dry weather keeps stripe rust levels low, by Matthew Weaver, *Capital Press*. September 4, 2015.

All 2015 nursery data were sent to growers, cereal group, and/or collaborators.

Presentations and Reports:

Xianming Chen, February 9, 2015, presented "Recent Progress in Stripe Rust Research" in the WSU Department of Plant Pathology, Pullman, WA (about 70 people)

Xianming Chen, June 5, 2015, presented "Agriculture, Plant Protection, and Stripe Rust Control in the United States" in Tianshui Agricultural Bureau of Gansu Province, Tianshui, Gansu (about 200 people); and Tianshui Agricultural College and Wheat Institute of Gansu Academy of Agricultural Sciences, Tingshui, Gansu (about 150 people).

Xianming Chen, July 6, 2015, presented "Why Are Alternate Hosts Important for Stem Rust, but Not for Stripe Rust in the US Pacific Northwest?" at the 14^{th} International Cereal Rusts and Powdery Mildew Conferences, July 5-8, 2015, Helsingør, Demark (about 150 people)

Xianming Chen, July 5-8, 2015, presented three posters: 1) "Virulence and Molecular Characterization of the Wheat Stripe Rust Pathogen (*Puccinia striiformis* f. sp. *tritici*) in the United States and Other Countries"; 2) "Molecular Mapping and Identification of Wheat Genes for Effective All-stage Resistance and High-temperature Adult-plant Resistance to Stripe Rust"; and 3) "Development of an Integrated System for Control of Stripe Rust in the United States" at the 14^{th} International Cereal Rusts and Powdery Mildew Conferences, July 5-8, 2015, Helsingør, Demark (about 150 people)

Xianming Chen, August 1-5, 2015, presented "Development of SP-SNP Markers and Use Them to Characterize Populations of the Stripe Rust Pathogen and Identify Markers Associated to Avirulence Genes" with his graduate student, and 3 posters: 1) "Studying Aeciospores and Survival of Teliospores Revealed No Sexual Reproduction of *Puccinia striiformis* f. sp. *tritici* in the Pacific Northwest", 2) "Stripe Rust Epidemics of Wheat and Barley and Races of *Puccinia striiformis* Identified in the United States in 2014", and 3) "Fungicide Sensitivity of the Wheat Stripe Rust Pathogen (*Puccinia striiformis* f. sp. *tritici*)" with post-doctors.

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

- 6/13/2015: Lind Field Day (about 200 people)
- 6/24/2015: Dayton Field Day (talk) (about 30 people)
- 7/14/2015: Spillman Field Day, present field research and stripe rust control (about 200 people)

WGC project number: 5665

WGC project title: Control of Wheat and Barley Rusts

Project PI(s): Xianming Chen

Project initiation date: 7/1/2013

Project year: 3 of 3 (2015)

Objective	Deliverable	Progress	Timeline	Communication
1. Predict and monitor rust epidemics and provide best available control recommendations on a yearly basis; further study the biology of the rust pathogens, identify races and determine population changes of the stripe rust pathogens of wheat and barley; and collaborate in race identification of the leaf rust and stem rust pathogens.	**1) Rust forecasts and updates.** Stripe rust was accurately forecasted in 2015. Rust updates and advises were provided on time to growers during the crop season based on the forecasts and field surveys, which reduced the disease pressure in the early spring and prevented unneccessary use of fungicides in the late growth season. 2**) Stripe rust races.** We identified 24 races of wheat stripe rust and 2 races of barley stripe rust in the US, and 28 and 2 of them were detected respectively in Washington. The 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. 3**) Molecular markers for studying stripe rust populations.** We used molecular markers developed in our lab to study the stripe rust pathogen and determined the population changes in the past and present.	All planned studies for the project in 2015 have been completed on time. There is no any delay, failure, or problem in studies to this objectives. In 2015, stripe rust, leaf rust and stem rust of wheat and barley were monitored throughout the Pacific Northwest (PNW) through field surveys and disease nurseries. Prediction of wheat stripe rust epidemic was made using our forecasting models. Stripe rust forecasts were reported to wheat researchers and growers as early as in early January and continued as the season was progressing. Stripe rust started early in eastern PNW but normal in western PNW. The early started stripe rust created high disease pressure for winter wheat crop in the early season. Early application of fungicides kept the disease under control. During the later growth season, the weather was hot and dry, which makes the second fungicide application unnecessry for most of the winter crops and aslo fro spring crops. Leaf rust of wheat was normal in western but absent in eastern PNW; and leaf rust of barley was normal in western but absent in eastern PNW. Stem rust of wheat and barley was absent in the PNW in 2015. The forecasts and updates implemented the necessary early fungidie application on winter wheat in some areas and prevented or reduced unnecessary use of fungicide in the late season for winter wheat and also for spring wheat. A total of 369 stripe rust samples were obtained throughout the country in 2015 and 194 (53%) of them from Washington. We have completed about 95% of the race ID work for the 2015 samples as scheduled by this time. So far we have detected 28 wheat stripe rust races and 2 barley stripe rust races, of which 24 and 2 were detected respectively in Washington. The frequencies and distribution of the races were determined. We completed molecular characterization of stripe rust populations of 2012 and 2013 and more than 900 samples from 1968 to 2009 using 17 co-dominant simple sequence repaet markers and 97 single-nucleotide polymorphism markers.	All studies and services were completed on time. The race identification work for the 2015 stripe rust samples will be completed by late February, 2015, as scheduled, and the race ID work for 2016 samples will start in February. Molecular characterization of the 2013-2014 samples and DNA extraction of the 2015 samples will be completed by June, 2016.	The rust forecasts, survey results, and race data were communicated to growers 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).

2. Support breeding programs for developing rust resistant varieties; identify and develop new rust resistant germplasm; and map new resistance genes and develop molecular markers for stripe rust resistance genes.	**1) Stripe rust reaction data of various wheat and barley nurseries.** In 2015, we tested more than 35,000 wheat and 2,000 barley entries for resistance to stripe rust, and provided the data to breeding programs to eliminate susceptible lines, select rust resistant lines for developing new varieties and mapping resistance genes. **2) New rust resistant sources.** Through the germplasm screening, we identified new resistant sources and characterized the types of resistance. **3) New wheat varieties.** Through the tests, we collaborated with breeders to release new varieties. In 2015, we collaborated with breeders in releasing, pre-releasing, or registered 6 wheat and 4 barley varieties. The germplasm evaluation data were also used to update the Seed Buyer's Guide for growers to choose resistant varieties to grow. **4) Stripe rust resistance genes mapped and molecular markers developed.** In 2015, we completed studies for mapping 6 genes for stripe rust resistance in 2 wheat lines and identified molecular markers, and officially named one new gene for stripe rust resistance and published 6 papers on mapping stripe rust resistance genes and developing molecular markers. **5) Supplied seeds of germplasm to breeding programs.** In 2015, we provided seeds of our newly developed wheat germplasm lines to several breeding programs in the US and other countries for developing stripe rust resistant wheat varieties.	In 2015, we evaluated more than 35,000 wheat and 2,000 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. 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 2015, we collaborated with public breeding programs in releasing and registered 6 wheat varieties and 4 barley varieties. Varieties developed by private breeding programs were also resulted from our germplasm screening program. In 2015, we completed studies for mapping stripe rust resistance genes in two wheat lines and developed mapping populations for 10 crosses and made 40 new crosses with winter wheat germplams.	All germplasm tests were completed and the data were provided to collaborators on time. The 2015-16 winter wheat nurseries were planted in fields in September and October 2015. The 2015 spring crop nurseries will be planted in March-April, 2016. The greenhouse tests of the 2015 spring nurseries and the 2015-16 winter wheat nurseries have been conducting in the greenhouse during the winter, and will be completed by May, 2016	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, website, Seed Buyer's Guide, variety release documents. Test data of individual breeding programs were sent to the individual breeders. New genes and molecular markers were published in scientific journals (see the publication and presentation lists in the report main file).

3. Determine effectiveness of fungicides for rust control and develop more effective strategies for integrated rust management.	**1) New fungicides and information on appropriate use of fungicides.** In 2015, we tested 20 fungicide treatments for control of stripe rust in both winter and spring wheat, and provided the data to collaborators. Chemical companies will use the data for registeration of new fungicides. **2) Yield loss by stripe rust and yield increase by fungicide application of major grown varieties.** The potential yield loss due to stripe rust and increase from fungicide application for 23 winter wheat and 15 spring wheat varieties commonly grown in the PNW, plus susceptible checks, were studied in 2015. The data, together with such studies in the past, are used to guide stripe rust management on the individual variety basis. **3) Integrated control strategies.** From the fungicide and variety studies, together with race information, we developed an integrated control strategy consisting of primarily growing resistant varieties and secondarily using fungicides.	In 2015, we evaluated 20 fungicide treatments for control of stripe rust in experimental fields near Pullman, WA. Susceptible winter wheat varieties 'PS 279' and spring wheat 'Lemhi' were used in the studies. The tests were conducted as a randomized complete block design with four replications in each experiment. Fungicides were applied at different rates and different stages of crop growth. Stripe rust severities were recorded five times in both winter wheat and spring wheat during the rust season. Grains were harvested and weighted for each plot. Rusts and yield data were analyzed to determine the efficacy for each fungicide treatment. For winter wheat, 17 of the 19 fungicide treatments significantly reduced rust severity; all 19 treatments significantly increased test weight; and the 17 treatments significantly increased yield. Due to the hot and dry weather conditions in the summer, stripe rust did not developed to adequate level to determine fungicide effectiveness in the spring wheat tests. In 2015, we tested 23 winter wheat and 15 spring wheat varieties commonly grown in the PNW, plus highly susceptible checks. The experiments were in a randomized complete split-blot design with four replications. For each blot, a half was sprayed with a fungicide to control stripe rust and the other half was not sprayed to allow stripe rust to develop. Stripe rust data were recorded four times during the growing season. Grain yield and test weight were recorded at harvest. The data were used to determine stripe rust resistance level, yield loss caused by stripe rust, and yield increase by fungicide application for each variety. The results were used to estimate damage by stripe rust and also used to guide growers for selecting cultivars to grow and determine whether fungicide application is needed based on individual varieties. Very good results were obtained from the winter wheat experiment, but not from the spring wheat experiment due to the hot and dry weather conditons in the summer.	For this objective, all tests scheduled for 2015 were successfully completed, especially for winter wheat. For the 2015-16 growing season, the winter wheat plots of the fungicide and variety studies were planted in October, 2015 and the spring plots will be planted in April, 2016. The tests will be completed in August (for winter wheat) and September (for spring wheat), 2016	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).

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Washington Grain Commission
Wheat and Barley Research Final Report

Project #: 5665

Progress Report Years: 3 years (2013-2015)

Title: Control of Wheat and Barley Rusts

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

Executive summary: During the three years (2013-2015) of the project, studies were conducted according to the objectives of the project proposal and all objectives specified for the three years 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, and also provided new wheat germplasm with new stripe rust genes to breeding programs for developing commercial varieties.

Impact: 1) Stripe rust was accurately forecasted in 2013-2015. Rust updates and advises were provided on time to growers based on the forecasts using prediction models and field surveys, which prevented major losses and unnecessary use of chemicals in the State of Washington. 2) We identified 34, 33, and 28 wheat stripe rust races and 6, 5, and 2 barley stripe rust races in 2013, 2014, and 2015, respectively in the US. In Washington State alone, we detected 26, 28, and 21 wheat stripe rust races and 3, 3, and 2 barley stripe rust races in 2013, 2014, and 2015, respectively. The 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. 3) During the three years, we developed 35 single sequence repeat (SSR) markers and over 100 single nucleotide polymorphism (SNP) markers for the stripe rust pathogens and used the markers to study the rust biology and characterize various stripe rust populations. 4) By doing virulence tests and using molecular markers, we determined a) the stripe rust pathogen is asexually produced in the Pacific Northwest (PNW), b) barberry plays essential role for stem rust epidemics, but plays no role for stripe rust, c) the stripe rust pathogen have the highest diversity in the PNW in the US, d) the pathogen disperses among epidemiological regions in the US at different rates, and e) changes in virulence and race for the stripe rust pathogen populations over the last 48 years. 5) In each of the three years, we evaluated more than 30,000 wheat and 2,000 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. During the three years, we collaborated with breeders in registration of 15 wheat and 2 barley varieties, in addition to more than 10 varieties that have been released, but to be registered. The germplasm evaluation data were also used to update the Seed Buyer's Guides for growers to choose resistant varieties to grow. 6) During the three years, we mapped more than 30 stripe rust resistance genes to wheat chromosomes with molecular markers, permanently named 6 genes, and published 13 papers on molecular mapping and identification of stripe rust resistance genes.

7) We provided seeds of our recently developed new wheat germplasm lines to more than 30 breeding and research 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. 8) In each of the three years, we tested 19-30 fungicide treatments for control of stripe rust and provided the data to chemical companies for registering new fungicides. Now about 15 fungicides are available for growers to use for control of stripe rust. The large number of fungicides not only provides growers more options and keeps fungicide price low, but also potentially reduces possibilities of fungicide resistance. We determined that there is no obvious fungicide-resistant rust stain, but identified significant differences in fungicide sensitivity among stripe rust isolates. 9) We tested potential yield losses due to stripe rust and increase from fungicide application for 23 winter wheat and 15 spring wheat varieties currently grown in the Pacific Northwest, especially in Washington. The data of the fungicides and varieties are used for guiding the integrated control of stripe rust. 10) During 2013-2014, we published 71 papers in scientific journals and 32 abstracts of professional meetings.

Outputs and Outcomes:

Progress, Timelines, and Communication are given in Outcome Reporting file (file name: Chen_WGC 2013-2015 Final Outcome Reporting.pdf)

Publications:

Scientific Journals:

Sharma-Poudyal, D., **Chen, X. M.**, Wan, A. M., et al. 2013. Virulence characterization of international collections of the wheat stripe rust pathogen, *Puccinia striiformis* f. sp. *tritici*. Plant Disease 97:379-386.

Xu, L. S., Wang, M. N., Cheng, P., Kang, Z. S., Hulbert, S. H., and **Chen, X. M.** 2013. Molecular mapping of *Yr53*, a new gene for stripe rust resistance in durum wheat accession PI 480148 and its transfer to common wheat. Theoretical and Applied Genetics 126:523-533.

Huang, X. L., Ma, J. B., **Chen, X. M.**, Wang, X. J., Ding, K., Han, D. J., Qu, Z. P., Huang, L. L., Kang, Z. S. 2013. Genes involved in adult plant resistance to stripe rust in wheat cultivar Xingzi 9104. Physiological and Molecular Plant Pathology 81:26-32.

Campbell, K. G., Allan, R. E., Anderson, J., Little, L. M., Pritchett, J., Blake, N., Burke, A., Hoagland, C., Walker, C., **Chen, X. M.**, Morris, C., Guy, S. Murray T., See, D., Engle, D., Wetzel, H., and Wood, D. 2013. "Cara" soft white winter club wheat. Journal of Plant Registrations 7:75-80.

Christopher, M. D., Liu, S. Y., Hall, M. D., Marshall, D. S., Fountain, M. O., Johnson, J. W., Milus, E. A., Garland-Campbell, K. A., **Chen, X. M.**, and Griffey, C. A. 2013. Identification and mapping of adult plant stripe rust resistance in soft red winter wheat cultivar 'USG 3555'. Plant Breeding 132:53-60.

Chen, X. M., Coram, T., Huang, X. L., Wang, M. N., and Dolezal, A. 2013. Understanding molecular mechanisms of durable and non-durable resistance to stripe rust in wheat using a transcriptomics approach. Current Genomics 14:111-126.

Chen, X. M., Evans, C. K., Garner, J. P., and Liu, Y. M. 2013. Control of stripe rust of spring wheat with foliar fungicides, 2012. Plant Disease Management Reports 7:CF031.

Chen, X. M., Evans, C. K., Garner, J. P., and Liu, Y. M. 2013. Control of stripe rust of winter wheat with foliar fungicides, 2012. Plant Disease Management Reports 7:CF032.

Chen, X. M., Evans, C. K., Garner, J. P., and Liu, Y. M. 2013. Evaluation of chemical seed treatments for control of stripe rust in wheat under controlled conditions. Plant Disease Management Reports 7:ST003.

Chen, X. M., Evans, C. K., Garner, J. P., and Liu, Y. M. 2013. Evaluation of chemical seed treatments for control of stripe rust in spring wheat, 2012. Plant Disease Management Reports 7:ST012.

Chen, X. M., Evans, C. K., Garner, J. P., and Liu, Y. M. 2013. Evaluation of chemical seed treatments for control of stripe rust in winter wheat, 2012. Plant Disease Management Reports 7:ST013.

Chen, X. M. 2013. High-temperature adult-plant resistance, key for sustainable control of stripe rust. American Journal of Plant Sciences 4:608-627.

Christopher, M. D., Liu, S. Y., Hall, M. D., Marshall, D. S., Fountain, M. O., Johnson, J. W., Milus, E. A., Garland-Campbell, K. A., **Chen, X. M.**, and Griffey, C. A. 2013. Identification and mapping of adult plant stripe rust resistance in soft red winter wheat VA00W-38. Crop Science 53:871-879.

Carlson, G. R., Berg, J. E., Stougaard, R. N., Eckhoff, J. L., Lamb, P. F., Kephart, K. D., Wichman, D. M., Miller, J. H., Riveland, N. R., Nash, D. L., Grey, W. E., Jin, Y., Kolmer, J. A., **Chen, X. M.**, Bai, G., and Bruckner, P. L. 2013. Registration of ‘Bearpaw’ wheat. Journal of Plant Registrations 7:180-183.

Carlson, G. R., Berg, J. E., Kephart, K. D., Wichman, D. M., Lamb, P. F., Miller, J. H., Stougaard, R. N., Eckhoff, J. L., Riveland, N. R., Nash, D. L., Grey, W. E., Jin, Y., Kolmer, J. A., **Chen, X. M.**, Bai, G., and Bruckner, P. L. 2013. Registration of ‘Judee’ wheat. Journal of Plant Registrations 7:191-194.

Carter, A. H., Jones, S. S., Lyon, S. R., Balow, K. A., Shelton, G. B., Higginbotham, R. W., **Chen, X. M.**, Engle, D. A., Baik, B., Guy, S. O., Murray, T. D., and Morris, C. F. 2013. Registration of ‘Otto’ wheat. Journal of Plant Registrations 7:195-200.

Cantu, D., Segovia, V., MacLean, D., Bayles, R., **Chen, X. M.**, Kamoun, S., Dubcovsky, J., Saunders, D. G. O., and Uauy, C. 2013. Genome analyses of the wheat yellow (stripe) rust pathogen *Puccinia striiformis* f. sp. *tritici* reveal polymorphic and haustorial expressed secreted

Wang, M. N., and **Chen, X. M.**, 2013. First report of Oregon grape (*Mahonia aquifolium*) as an alternate host for the wheat stripe rust pathogen (*Puccinia striiformis* f. sp. *tritici*) under artificial inoculation. Plant Disease 97:839.

Xi, K., **Chen, X. M.**, Capettini, F., Falconi, E., Yang, R. C., Helm, J., Holtz, M., Juskiw, P., Kumar, K., Nyachiro, J., and Turkington, T. K. 2013. Multivariate analysis of stripe rust assessment and reactions of barley in multi-location nurseries. Canadian Journal of Plant Science 93(2):209-219.

Chen, J., Wheeler, J., Clayton, J., Zhao, W., O'Brien, K., Jackson, C., Marshall, J. M., Campbell, K., **Chen, X. M.**, Zemetra, R., Guttieri, M., and Souza, E. J. 2013. Registration of 'UI Stone' spring wheat. Journal of Plant Registrations 7:321-326.

Zhao, J., Wang, L., Wang, Z. Y., **Chen, X. M.**, Zhang, H. C., Yao, J. N., Zhan, G. M., Chen, W., Huang, L. L., and Kang, Z. S. 2013. Identification of eighteen *Berberis* species as alternate hosts of *Puccinia striiformis* f. sp. *tritici* and virulence variation in the pathogen isolates from natural infection of barberry plants in China. Phytopathology 103:935-940.

Zheng, W. M., Huang, L. L., Huang, J. Q., Wang, X. J., **Chen, X. M.**, et al. 2013. High genome heterozygosity and endemic genetic recombination in the wheat stripe rust fungus. Nature Communication 4:2673.

Graybosch, R. A., Baenziger, P. S., Santra, D., Regassa, T., Jin, Y., Kolmer, J., Wegulo, S., Bai, G. H., Amand, P. S., **Chen, X. M.**, Seabourn, B., Dowell, F., Bowden, R., and Marshall, D. M. 2014. Release of 'Mattern' waxy (amylose-free) winter wheat. Journal of Plant Registrations 8:43-48.

Zeng, Q. D., Han, D. J., Wang, Q. L., Yuan, F. P., Wu, J. H., Zhang, L., Wang, X. J., Huang, L. L., **Chen, X. M.**, Kang, Z. S. 2014. Stripe rust resistance and genes in Chinese wheat cultivars and breeding lines. Euphytica 196:271-284.

Case, A., Naruoka, Y., **Chen X. M.**, Garland-Campbell, K. A., Zemetra, R. S., Carter, A. H. 2014. Mapping stripe rust resistance genes in a Brundage x Coda winter wheat recombinant inbred line population. PLoS ONE 9(3): e91758.

Zhou, X. L., Wang, M. N., **Chen, X. M.**, Lu, Y., Kang, Z. S., and Jing, J. X. 2014. Identification of *Yr59* conferring high-temperature adult-plant resistance to stripe rust in wheat germplasm PI 178759. Theoretical and Applied Genetics 127:935-945.

Chen, X. M., Evans, K. C., and Liu, Y. M. 2014. Control of stripe rust of winter wheat with various foliar fungicides. Plant Disease Management Reports 8:CF023.

Chen, X. M., Evans, K. C., and Liu, Y. M. 2014. Control of stripe rust of spring wheat with various foliar fungicides. Plant Disease Management Reports 8:CF034.

Chen, X. M., Evans, K. C., and Liu, Y. M. 2014. Control of stripe rust on winter wheat cultivars with foliar fungicide in 2013. Plant Disease Management Reports 8:CF35.

Chen, X. M., Evans, K. C., and Liu, Y. M. 2014. Control of stripe rust on spring wheat cultivars with foliar fungicide in 2013. Plant Disease Management Reports 8:CF036.

Zeng, Q. D., Yuan, F. P., Xu, X., Shi, X., Nie, X. J., Zhuang, H., **Chen, X. M.**, Wang, Z. H., Wang, X. J., Huang, L. L., Han, D. J., Kang, Z. S. 2014. Construction and characterization of a bacterial artificial chromosome library for hexaploid wheat line 92R137. BioMed Research International. Volume 2014, Article ID 845806, 9 pages.

Chen, W. Q., Wellings, C., **Chen, X. M.**, Kang, Z. S., and Liu, T. G. 2014. Wheat stripe (yellow) rust caused by *Puccinia striiformis* f. sp. *tritici*. Molecular Plant Pathology 15:433-446.

Lu, Y., Wang, M. N., **Chen, X. M.**, See, D., Chao, S. M., and Jing, J. X. 2014. Mapping of *Yr62* and a small effect QTL for high-temperature adult-plant resistance to stripe rust in spring wheat PI 192252. Theoretical and Applied Genetics 127:1449-1459.

Sharma-Poudyal, D., **Chen, X. M.**, and Rupp, R. 2014. Potential oversummering and overwintering regions for the wheat stripe rust pathogen in the contiguous United States. International Journal of Biometeorology 58(5):987-997.

Basnet, B. R., Ibrahim, A. M. H., **Chen, X. M.**, Singh, R. P., Mason, E. R., Bowden, R. L., Liu, S. Y., Devkota, R. N., Subramanian, N. K., and Rudd, J. C. 2014. Molecular mapping of stripe rust resistance QTL in hard red winter wheat TAM 111 adapted in the US high plains. Crop Science 54:1361-1373.

Berg, J. E., Hofer, P., Davis, E. S., Stougaard, R. N., Kephart, K. D., Lamb, P. F., Wichman, D. M., Eckhoff, J. L., Miller, J. H., Nash, D. L., Grey, W. E., Jin, Y., **Chen, X. M.**, and Bruckner, P. L. 2014. Registration of ‘SY Clearstone 2CL’ wheat. Journal of Plant Registrations 8:162-164.

Haley, S. D., Johnson, J. J., Peairs, F. B., Stromberger, J. A., Hudson-Arns, E. E., Seifert, S. A., Valdez, V. A., Kottke, R. A., Rudolph, J. B., Bai, G. H., **Chen, X. M.**, Bowden, R. L., Jin, Y., Kolmer, J. A., Chen, M.-S., Seabourn, B. W., and Dowell, F. E. 2014. Registration of 'Antero' wheat. Journal of Plant Registrations 8:165-168.

Haley, S. D., Johnson, J. J., Peairs, F. B., Stromberger, J. A., Hudson, E. E., Seifert, S. A., Kottke, R. A., Valdez, V. A., Nachtman, J. J., Rudolph, J. B., Bai, G. H., **Chen, X. M.**, Bowden, R. L., Jin, Y., Kolmer, J. A., Chen, M-S., and Seabourn, B. W. 2014. Registration of 'Cowboy' wheat. Journal of Plant Registration 8:169-172.

Berg, J. E., Lamb, P. F., Miller, J. H., Wichman, D. M., Stougaard, R. N., Eckhoff, J. L., Kephart, K. D., Nash, D. L., Grey, W. E., Gettel, D., Larson, R., Jin, Y., Kolmer, J. A., **Chen, X. M.**, Bai, G., and Bruckner, P. L. 2014. Registration of 'Warhorse' wheat. Journal of Plant Registration 8:173-176.

Dugan, F. M., Cashman, M. J., Wang, M. N., **Chen, X. M.**, and Johnson, R. C. 2014. Differential resistance to stripe rust (*Puccinia striiformis*) in collections of basin wild rye (*Leymus cinereus*). Plant Health Progress doi:10.1094/PHP-RS-14-0002.

Chen, X. M. 2014. Integration of cultivar resistance and fungicide application for control of wheat stripe rust. Canadian Journal of Plant Pathology 36:311-326.

Sthapit, J., Newcomb, M., Bonman, J. M., **Chen, X. M.**, and See, D. 2014. Genetic diversity for stripe rust resistance in wheat landraces and identification of dual resistance to stem rust and stripe rust. Crop Science 54:2131-2139.

Carter, A. H., Jones, S. S., Cai, X., Lyon, S. R., Balow, K. A., Shelton, G. B., Higginbotham, R. W., **Chen, X. M.**, Engle, D. A., Baik, B., Guy, S. O., Murray, T. D., and Morris, C. F. 2014. Registration of 'Puma' soft white winter wheat. Journal of Plant Registrations 8:273-278.

Berg, J. E., Wichman, D. M., Kephart, K. D., Eckhoff, J. L., Stougaard, R. N., Lamb, P. F., Miller, J. H., Nash, D. L., Grey, W. E., Johnston, M., Gettel, D., Larson, R., Jin, Y., Kolmer, J. A., **Chen, X. M.**, Bai, G., and Bruckner, P. L. 2014. Registration of 'Colter' wheat. Journal of Plant Registrations 8:285-287.

Cheng, P., Xu, L. S., Wang, M. N., See, D. R., and **Chen, X. M.** 2014. Molecular mapping of genes *Yr64* and *Yr65* for stripe rust resistance in hexaploid derivatives of durum wheat accessions PI 331260 and PI 480016. Theoretical and Applied Genetics 127:2267-2277.

Millet, E., Manisterski, J., Ben-Yehuda, P., Distelfeld, A., Deek, J., Wan, A., **Chen, X. M.**, and Steffenson, B. J. 2014. Introgression of leaf rust and stripe rust resistance from Sharon goatgrass (*Aegilops sharonensis* Eig) into bread wheat (*Triticum aestivum* L.). Genome 57:309-316.

Wan, A. M., and **Chen, X. M.** 2014. Virulence characterization of *Puccinia striiformis* f. sp. *tritici* using a new set of *Yr* single-gene line differentials in the United States in 2010. Plant Disease 98:1534-1542.

Cheng, P., and **Chen, X. M.** 2014. Virulence and molecular analyses support asexual reproduction of *Puccinia striiformis* f. sp. *tritici* in the U.S. Pacific Northwest. Phytopathology 104:1208-1220.

Zhou, X. L., Han, D. J., **Chen, X. M.**, Gou, H. L., Guo, S. J., Rong, L., Wang, Q. L., Huang, L. L., and Kang, Z. S., 2014. Characterization and molecular mapping of stripe rust resistance gene *Yr61* in winter wheat cultivar Pindong 34. Theoretical and Applied Genetics 127:2349-2358.

Zhan, G. M., Tian, Y., Wang, F. P., **Chen, X. M.**, Jiao, M., Guo, J., Huang, L. L., and Kang, Z. S. 2014. First report of a novel fungal hyperparasite of *Puccinia striiformis* f. sp. *tritici*, the causative agent of wheat stripe rust. PLoS ONE 9(11):e111484.

Murphy, K. M., Ullrich, S. E., Wood, M. B., Matanguiham, J. B., Guy, S. O., Jitkov, V. A., and **Chen, X. M.** 2015. Registration of 'Lyon', a two-row, spring feed barley. Journal of Plant Registrations 9:6-9.

Maccaferri, M., Zhang, J. L., Bulli, P., Abate, Z., Chao, S. M., Cantu, D., Bossolini, E., **Chen, X. M.**, Pumphrey, M., Dubcovsky, J. 2015. A genome-wide association study of resistance to stripe rust (*Puccinia striiformis* f. sp. *tritici*) in a worldwide collection of hexaploid spring wheat (*Triticum aestivum* L.). 3G: Genes, Genomics, Genetics 5:449-465.

Zhou, X. L., Zhang, Y., Zeng, Q. D., **Chen, X. M.**, Han, D. J., Huang, L. L., and Kang, Z. S. 2015. Identification of QTL for adult plant resistance to stripe rust in Chinese wheat landrace Caoxuan 5. Euphytica 204:627-634.

Chen, X. M., Evans, C. K., Liu, Y. M., and Heath, M. 2015. Control of stripe rust of winter wheat with various foliar fungicides, 2014. Plant Disease Management Reports 9:CF021.

Chen, X. M., Evans, C. K., Liu, Y. M., and Heath, M. 2015. Control of stripe rust of spring wheat with various foliar fungicides, 2014. Plant Disease Management Reports 9:CF016.

Chen, X. M., Evans, C. K., Liu, Y. M., and Heath, M. 2015. Effects of fungicide application on control of stripe rust on winter wheat cultivars in 2014. Plant Disease Management Reports 9:CF017.

Chen, X. M., Evans, C. K., Liu, Y. M., and Heath, M. 2015. Effects of fungicide application on control of stripe rust on spring wheat cultivars in 2014. Plant Disease Management Reports 9:CF018.

Carter, A. H., Kidwell, K. K., DeMacon, V., Balow, K. A., Shelton, G. B., Higginbotham, R. W., **Chen, X. M.**, Engle, D. A., Baik, B., and Morris, C. F. 2015. Registration of 'Sprinter' hard red winter wheat. Journal of Plant Registrations 9:196-200.

Talajoor, M., Jin, Y., Wan, A. M., **Chen, X. M.**, Bhavani, S., Tabe, L., Lagudah, E., and Huang, L. 2015. Specificity of a rust resistance suppressor on 7DL in the spring wheat cultivar Canthatch. Phytopathology 105:477-481.

Vazquez, M. D., Zemetra, R., Peterson, C. J., **Chen, X. M.**, Heesacker, A., and Mundt, C. C. 2015. Multi-location wheat stripe rust QTL analysis: Genetic background and epistatic interactions. Theoretical and Applied Genetics 128:1307-1318.

Hou, L., **Chen, X. M.**, Wang, M. N., See, D. R., Chao, S. M., Bulli, P., and Jing, J. X. 2015. Mapping a large number of QTL for durable resistance to stripe rust in winter wheat Druchamp using SSR and SNP markers. PLoS ONE 10(5):e0126794.

Ma, L. J. Qiao J. X., Kong X. Y., Zou Y. P. Xu, X. M., **Chen, X. M.**, and Hu, X. P. 2015. Effect of low temperature and wheat winter-hardiness on survival of *Puccinia striiformis* f. sp. *tritici*. PLoS One 10(6):e0130691.

Han, D. J., Wang Q. L., **Chen, X. M.**, Zeng, Q. D., Wu, J. H., Xue, W. B., Zhan, G. M., Huang, L. L., and Kang, Z. S. 2015. Emerging *Yr26*-virulent races of *Puccinia striiformis* f. sp. *tritici* are threatening wheat production in the Sichuan Basin, China. Plant Dis. 99:754-760.

Ibrahim, A. M. H., Rudd, J., Devkota, R., Baker, J., Sutton, R., Simoneaux, B., Opeña, G., Herrington, R., Rooney, L., Dykes, L., Awika, J., Nelson, L. R., Fritz, F., Bowden, R. L., Graybosch, R. A., Jin, Y., Seabourn, B. W., **Chen, X. M.**, Kolmer, J., and Duncan, R. 2014. Registration of 'TAM 305' hard red winter wheat. Journal of Plant Registrations 9:325-330.

Zhao, J., Zhao, S. L., **Chen, X. M.**, Wang, Z. Y., Wang, L., Yao, J. N., Chen, W., Huang, L. L., and Kang, Z. S. 2015. Determination of the role of *Berberis* spp. in wheat stem rust in China. Plant Dis. 99:1113-1117.

Yin, C. T., Downey, S. I., Klasges-Mundt, N. L., Ramachandran, S., **Chen, X. M.**, Szabo, L. J., Pumphrey, M., Hulbert, S. H. 2015. Identification of promising host-induced silencing targets among genes preferentially transcribed in haustoria of *Puccinia*. BMC Genomics 16:579.

Zhou, X. L., Han, D. J., **Chen, X. M.**, Mu, J. M., Xue, W. B., Zeng, Q. D., Wang, Q. L., Huang, L. L., and Kang, Z. S. 2015. QTL mapping of adult-plant resistance to stripe rust in wheat line P9897. Euphytica 205:243-253.

Feng, J. Y., Wang, M. N., **Chen, X. M.**, See, D. R., Zheng, Y. L., Chao, S. M., and Wan, A. M. 2015. Molecular mapping of *YrSP* and its relationship with other genes for stripe rust resistance in wheat chromosome 2BL. Phytopathology 105:1206-1213.

Murphy, K. M., Ullrich, S. E., Wood, M. B., Matanguihan, J. B., Jitkov, V. A., Guy, S. O., **Chen, X. M.**, Brouwer, B. O., Lyon, S. R., and Jones, S. S. 2015. Registration of 'Muir' spring feed barley. Journal of Plant Registrations 9:283-287.

Wang, M. N., Wan, A. M., and **Chen, X. M.** 2015. Barberry as alternate host is important for *Puccinia graminis* f. sp. *tritici* but not for *Puccinia striiformis* f. sp. *tritici* in the U. S. Pacific Northwest. Plant Disease 99:1507-1516.

Wang, M. N., and **Chen, X. M.** 2015. Barberry does not function as an alternate host for *Puccinia graminis* f. sp. *tritici* in the U. S. Pacific Northwest due to teliospore degradation and barberry phenology. Plant Disease 99:1500-1506.

Popular Press Articles:

January 4, 2013. First Forecast of Stripe Rust for the Pacific Northwest in 2013. Xianming Chen, E-mail sent to growers and cereal group.

February, 2013. Warmer winters raise rust threat. By Scott Yates, *Wheat Life*, February 2013, Page 47,

March 8, 2013. Stripe rust forecast and update. Xianming Chen, E-mail sent to growers and cereal group.

April 4, 2013. Stripe rust update. Xianming Chen, E-mail sent to growers and cereal group.

May 3, 2013. Stripe rust update. Xianming Chen, E-mail sent to growers and cereal group.

May 24, 2013. Rust update May 24, 2013. Xianming Chen, E-mail sent to growers and cereal group.

June 4, 2013. Cooler weather could usher in stripe rust, researchers say. By Matthew Weaver. Capital Press. http://www.capitalpress.com/content/mw-Stripe-rust-060313

June 27, 2013. Rust update June 27, 2013. Xianming Chen, Email sent to growers and cereal group.

August 7, 2013. Rust Update August 9, 2013. Xianming Chen, E-mail sent to growers and cereal group.

All Rust updates and nursery data in 2013 were sent to growers, breeders, and/or other collaborators, and posted in the stripe rust website (http://striperust.wsu.edu)

January 3, 2014. First Forecast of Stripe Rust for 2014 Wheat Crop. Xianming Chen. E-mail sent to growers and cereal group.

March 13, 2014. Stripe rust forecast and update. Xianming Chen. E-mail sent to growers and cereal groups.

March 2014. Low level of stripe rust predicted for 2014 wheat crop. Xianming Chen. *Wheat Life* April Pages 8-10.

April 25, 2014. Stripe Rust Update, April 25, 2014. Xianming Chen. E-mail sent to growers and the cereal group.

April 29, 2014. OSU wheat variety lacks rust resistance gene. Matthew Weaver. Capital Press. http://www.capitalpress.com/Washington/20140429/osu-wheat-variety-lacks-rust-resistance-gene

May 23, 2014. Stripe Rust Update, May 23, 2014, Xianming Chen. E-mail sent to growers and the cereal group.

June, 2014. Control of Rusts of Wheat and Barley in 2013. Xianming Chen and associates, Pages 65-66 in: 2014 Dryland Field Day Abstracts, Highlights of Research Progress, Department of Crop and Soil Sciences Technical Report 14-1. Washington State University Extension,

June 13, 2014. Stripe Rust Update, June 13, 2014, Xianming Chen. E-mail sent to growers and the cereal group.

July 3, 2014. Stripe Rust Update July 3, 2014, Xianming Chen. E-mail sent to growers and the cereal group.

August 2014. "No rust, no fuss". Page 56 in *Wheat Life*, August/September, 2014.

November 16, 2014. Researchers isolate stripe rust resistance markers in barley by John O'Connell. Capital Press.

All 2014 nursery data were sent to growers, cereal group, and/or collaborators.

January 8, 2015. First Forecast of Stripe Rust for 2015 and 2014 Yield Losses. Xianming Chen E-mail sent to growers and the cereal group.

February 2015. Washington's early stripe rust forecast. Xianming Chen. Page 12 in *Wheat Life* February 2015.

March 5, 2015. Stripe Rust Forecast and Update, March 5, 2015. Xianming Chen. E-mail sent to growers and the cereal group.

April 3, 2015. Stripe rust forecast "Severe" for Northwest wheat. Matthew Weaver. Capital Press. April 3, 2015

April 10, 2015. Stripe Rust Update, April 10, 2015. Xianming Chen. E-mail sent to growers and the cereal group.

April 29, 2015. Stripe Rust Update, April 29, 2015. Xianming Chen. E-mail sent to growers and the cereal group.

May 1, 2015. PNW stripe rust update, by Xianming Chen. *Wheat Life*, May 2015. Pages 12-14.

May 5, 2015. A different kind of rust belt. By Scott A. Yates. *Wheat Life*, May 2015. Pages 50-53.

June 11, 2015. Stripe Rust Update, June 11 2015. Xianming Chen. E-mails sent to growers and the cereal group.

June 25, 2015. Stripe Rust Update, June 25 2015. Xianming Chen. E-mails sent to growers and the cereal group.

July 2015. PNW stripe rust update by Xianming Chen, pages 14-15. *Wheat Life*, July, 2015.

September 4, 2015. Hot, dry weather keeps stripe rust levels low, by Matthew Weaver, *Capital Press*. September 4, 2015.

All 2015 nursery data were sent to growers, cereal group, and/or collaborators.

Presentations and Reports:

Xianming Chen, May 11, 2013, presented "Genetics of Disease Resistance: Theory and Practice; Past, Current, and Future", Colleges of Plant Protection and Life Sciences (>50 people).

Xianming Chen, May 14, 2013, presented "Stripe rust research and control in the U.S." Colleges of Life Sciences and Plant Protection. Henai Agricultural University (>40 people).

Xianming Chen, June 18, 2013, presented "Our current understanding of stripe rust and effective management" at Canadian Phytopathological Society Meeting in Edmonton, Canada (>100 people).

Xianming Chen, August 9-14, 2013, presented "Population structure and genomics of the stripe rust pathogen and interactions with its host plants" at the American Phytopathological Society and Mycological Society of America joint meeting in Austin, TX (About 60 attendees); and presented 5 posters "Stripe rust epidemics of wheat and barley and races of *Puccinia striiformis* identified in the United States in 2012", "Association mapping for stripe rust resistance of spring wheat lines originating from global collections", "Association of single nucleotide polymorphism markers based on secreted protein genes of *Puccinia striiformis* f. sp. *tritici* to avirulence genes", "QTL mapping of resistance to stripe rust in spring wheat PI 182103", and "Functional analysis of conserved genes from rust fungi *Puccinia graminis* f. sp. *tritici*" (about 2,000 participants).

Xianming Chen, August 22, 2013, presented "Virulence, population structures and genomics of *Puccinia striiformis* and interactions with its plant hosts" at the 3rd International Conference on Biotic Plant Interactions. August 19-22, 2013, Yangling, China. (About 300 participants).

Xianming Chen, August 22-25, 2013, presented a poster "Stripe rust epidemiological regions, virulence dynamics, pathogen reproduction modes, yield losses, forecasting models, and management in the United States" in Beijing, China (About 100 participants)

Xianming Chen, August 25-30, 2013, presented a poster "Mapping QTL for resistance to stripe rust in spring wheat PI 192252 and winter wheat Druchamp", Beijing, China (More than 2,000 participants).

Xianming Chen, August 30, 2013, presented "Molecular characterization of plant pathogens and mechanisms of host resistance using genomics approaches" at Shenyang Agricultural University, Shenyang, China (About 50 attendees).

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

- 6/13/2013: Lind Field Day (>100 people)
- 6/26/2013: Dayton Field Day (24 people)
- 7/10/2013: Colton Field Day (15 people)
- 7/11/2013: Spillman Farm Field Day (about 130 people)
- 7/16/2013: Farmington Field Day (35 people)
- 7/16/2013: St. John Field Day (18 people)

Xianming Chen, June 22, 2014, presented "Integrated management of stripe rust" at Northwest A&F University, Yangling, China (about 100 people)

Xianming Chen, June 28, 2014, presented "Understanding fungal pathogen biology using a genomics approach" at the 4th BIT International Congress of Microbiology, Dalian, China (about 50 people).

Xianming Chen, August 10-13, 2014, presented 3 posters titled "Stripe rust epidemics of wheat and barley and races of *Puccinia striiformis* identified in the United States in 2013", "Regional differences in genetic structure of *Puccinia striiformis* f. sp. *tritici*, the wheat stripe rust pathogen, in the U.S. revealed by SSR markers", and "Molecular mapping of *YrSP*, a wheat gene for resistance to stripe rust" (about 2,000 participants).

Xianming Chen, November 7-14, 2014, presented "Genetics of Plant Resistance – Theory and Practice; Past, Present, and Future Perspective", "Molecular Plant-pathogen Interactions", and "Genetics of Plant Resistance – Stripe Rust as an Example", Northwest A&F University. Yangling, Shaanxi, China (about 60 people).

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

- 6/12/2014: Lind Field Day   (about100 people)
- 7/16/2014: Farmington Field Day (about 30 people)
- 7/16/2014: St. John Field Day (about 15 people)
- 7/16/2014: Lamont Field Day (about 20 people)

Xianming Chen, February 9, 2015, presented “Recent Progress in Stripe Rust Research” in the WSU Department of Plant Pathology, Pullman, WA (about 70 people)

Xianming Chen, June 5, 2015, presented “Agriculture, Plant Protection, and Stripe Rust Control in the United States” in Tianshui Agricultural Bureau of Gansu Province, Tianshui, Gansu (about 200 people); and Tianshui Agricultural College and Wheat Institute of Gansu Academy of Agricultural Sciences, Tingshui, Gansu (about 150 people).

Xianming Chen, July 6, 2015, presented “Why Are Alternate Hosts Important for Stem Rust, but Not for Stripe Rust in the US Pacific Northwest?” at the 14th International Cereal Rusts and Powdery Mildew Conferences, July 5-8, 2015, Helsingør, Demark (about 150 people)

Xianming Chen, July 5-8, 2015, presented three posters: 1) “Virulence and Molecular Characterization of the Wheat Stripe Rust Pathogen (*Puccinia striiformis* f. sp. *tritici*) in the United States and Other Countries”; 2) “Molecular Mapping and Identification of Wheat Genes for Effective All-stage Resistance and High-temperature Adult-plant Resistance to Stripe Rust”; and 3) “Development of an Integrated System for Control of Stripe Rust in the United States” at the 14th International Cereal Rusts and Powdery Mildew Conferences, July 5-8, 2015, Helsingør, Demark (about 150 people)

Xianming Chen, August 1-5, 2015, presented “Development of SP-SNP Markers and Use Them to Characterize Populations of the Stripe Rust Pathogen and Identify Markers Associated to Avirulence Genes” with his graduate student, and 3 posters: 1) “Studying Aeciospores and Survival of Teliospores Revealed No Sexual Reproduction of *Puccinia striiformis* f. sp. *tritici* in the Pacific Northwest”, 2) “Stripe Rust Epidemics of Wheat and Barley and Races of *Puccinia striiformis* Identified in the United States in 2014”, and 3) “Fungicide Sensitivity of the Wheat Stripe Rust Pathogen (*Puccinia striiformis* f. sp. *tritici*)” with post-doctors.

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

- 6/13/2015: Lind Field Day (about 200 people)
- 6/24/2015: Dayton Field Day (talk) (about 30 people)
- 7/14/2015: Spillman Field Day, present field research and stripe rust control (about 200 people)

WGC project number: 5665
WGC project title: Control of Wheat and Barley Rusts
Project PI(s): Xianming Chen
Project initiation date: 7/1/2013
Project year: All three years (2013-2015)

Objective	Deliverable	Progress	Timeline	Communication
1. Predict and monitor rust epidemics and provide best available control recommendations on a yearly basis; further study the biology of the rust pathogens, identify races and determine population changes of the stripe rust pathogens of wheat and barley; and collaborate in race identification of the leaf rust and stem rust pathogens.	**1) Rust forecasts and updates.** Stripe rust was accurately forecasted in 2013-2015. Rust updates and advises were provided on time to growers during the crop seasons of 2013-2015 based on the forecasts and field surveys, which controlled the disease and prevented unneccessary use of fungicides. 2**) Stripe rust races.** We identified 34, 33, and 28 wheat stripe rust races and 6, 5, and 2 barley stripe rust races in 2013, 2014, and 2015, respectively in the US. In Washington State alone, we detected 26, 28, and 21 wheat stripe rust races and 3, 3, and 2 barley stripe rust races in 2013, 2014, and 2015, respectively. The 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. 3**) Molecular markers for studying stripe rust populations.** In 2013-2015, we developed 35 single sequence repeat (SSR) markers and over 100 single nucleotide polymorphism (SNP) markers for the stripe rust pathogens and used the markers to study the rust biology and characterize various stripe rust populations.	All planned studies for the project in 2013-2015 have been completed on time. There is no any delay, failure, or problem in studies to this objectives. In the three years, stripe rust, leaf rust and stem rust of wheat and barley were monitored throughout the PNW through field surveys and disease nurseries. Prediction of wheat stripe rust epidemic was made using our forecasting models. Stripe rust forecasts, monitoring data and recommendations were reported to growers during the growing seasons for implementing necessary fungicide applications and preventing unneccessary applications based on the stripe rust situations. For race identification, We identified 34, 33, and 28 wheat stripe rust races and 6, 5, and 2 barley stripe rust races in 2013, 2014, and 2015, respectively in the US; and 26, 28, and 21 wheat stripe rust races and 3, 3, and 2 barley stripe rust races in 2013, 2014, and 2015, respectively in Washington. In 2013-2015, we developed 35 single sequence repeat (SSR) markers and over 100 single nucleotide polymorphism (SNP) markers for the stripe rust pathogens and used the markers to study the rust biology and characterize various stripe rust populations. Using the molecular markers together with virulence tests, we determined a) the stripe rust pathogen is asexually produced in the PNW, b) barberry plays essential role for stem rust epidemics, but plays no role for stripe rust, c) the stripe rust pathogen have the highest diversity in the PNW in the US, d) the pathogen disperses among epidemiological regions in the US at different rates, and e) changes in virulence and race for the stripe rust pathogen populations over the last 48 years. These studies has led to a better understanding the biology of the stripe rust pathogen and epidemiology of the disease.	All studies and services were completed on time. The race identification work for the 2013 and 2014 were completed and the 2015 stripe rust samples will be completed by late February, 2015, as scheduled, and the race ID work for 2016 samples will start in February. Molecular characterization of the 2013-2014 samples and DNA extraction of the 2015 samples will be completed by June, 2016.	The rust forecasts, survey results, and race data were communicated to growers 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).

2. Support breeding programs for developing rust resistant varieties; identify and develop new rust resistant germplasm; and map new resistance genes and develop molecular markers for stripe rust resistance genes.	**1) Stripe rust reaction data of various wheat and barley nurseries.** In each of the three years (2013-2015), we tested more than 30,000 wheat and more than 2,000 barley entries for resistance to stripe rust, and provided the data to breeding programs to eliminate susceptible lines, select rust resistant lines for developing new varieties and mapping resistance genes. **2) New rust resistant sources.** Through the germplasm screening, we identified new resistant sources and characterized the types of resistance. **3) New wheat varieties.** During the three years, we collaborated with breeders in registration of 15 wheat and 2 barley varieties, in addition to more than 10 varieties that have been released, and to be registered. The germplasm evaluation data were also used to update the Seed Buyer's Guides for growers to choose resistant varieties to grow. **4) Stripe rust resistance genes mapped and molecular markers developed.** During the three years, we mapped more than 30 stripe rust resistance genes to wheat chromosomes with molecular markers, permanently named 6 genes, and published 13 papers on molecular mapping and identification of stripe rust resistance genes. **5) Supplied seeds of germplasm to breeding programs.** We provided seeds of our recently developed new wheat germplasm lines to more than 30 breeding and research programs in the US and other countries for developing stripe rust resistant varieties.	In each of the three years, we completed evaluation of more than 30,000 wheat and more than 2,000 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. 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. Varieties with durable resistance to stripe rust have been developed. We collaborated with breeders in registration of 15 wheat and 2 barley varieties, in addition to more than 10 varieties that have been released, but to be registered. Varieties developed by private breeding programs were also resulted from our germplasm screening program. During the three years, we mapped more than 30 stripe rust resistance genes to wheat chromosomes with molecular markers, permanently named 6 genes, and published 13 papers on molecular mapping and identification of stripe rust resistance genes. We also made numerous crosses and developed new mapping populations for identify new resistance genes.	All germplasm tests were completed and the data were provided to collaborators on time in each year. The 2015-16 winter wheat nurseries were planted in fields in September and October 2015. The 2015 spring crop nurseries will be planted in March-April, 2016. The greenhouse tests of the 2015 spring nurseries and the 2015-16 winter wheat nurseries have been conducting in the greenhouse during the winter, and will be completed by May, 2016	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, website, Seed Buyer's Guide, variety release documents. Test data of individual breeding programs were sent to the individual breeders. New genes and molecular markers were published in scientific journals (see the publication and presentation lists in the report main file).

3. Determine effectiveness of fungicides for rust control and develop more effective strategies for integrated rust management.	**1) New fungicides and information on appropriate use of fungicides.** In each of the three years (2013-2015), we tested 19-30 fungicide treatments for control of stripe rust in both winter and spring wheat, and provided the data to collaborators. Chemical companies will use the data for registeration of new fungicides. **2) Yield loss by stripe rust and yield increase by fungicide application of major grown varieties.** The potential yield loss due to stripe rust and increase from fungicide application for 23 winter wheat and 15 spring wheat varieties commonly grown in the PNW, plus susceptible checks, were studied in each year. The data, together with such studies in the past, are used to guide stripe rust management on the individual variety basis. **3) Integrated control strategies.** From the fungicide and variety studies, together with race information, we developed an integrated control strategy consisting of primarily growing resistant varieties and secondarily using fungicides.	In each of the three years (2013-2015), we evaluated 19-30 fungicide treatments for control of stripe rust in experimental fields near Pullman, WA. Susceptible winter wheat varieties 'PS 279' and spring wheat 'Lemhi' were used in the studies. The tests were conducted as a randomized complete block design with four replications in each experiment. Fungicides were applied at different rates and different stages of crop growth. Stripe rust severities were recorded five times in both winter wheat and spring wheat during the rust season. Grains were harvested and weighted for each plot. Rusts and yield data were analyzed to determine the efficacy for each fungicide treatment. The data were used by chemical companies to register new fungicides and also used by us for guiding control of stripe rust with fungicides. In each year, we also tested 23 winter wheat and 15 spring wheat varieties commonly grown in the PNW, plus highly susceptible checks. The experiments were in a randomized complete split-blot design with four replications. For each blot, a half was sprayed with a fungicide to control stripe rust and the other half was not sprayed to allow stripe rust to develop. Stripe rust data were recorded four times during the growing season. Grain yield and test weight were recorded at harvest. The data were used to determine stripe rust resistance level, yield loss caused by stripe rust, and yield increase by fungicide application for each variety. The results were used to estimate damage by stripe rust and also used to guide growers for selecting cultivars to grow and determine whether fungicide application is needed based on individual varieties.	For this objective, all tests scheduled for each year were successfully completed. For the 2015-16 growing season, the winter wheat plots of the fungicide and variety studies were planted in October, 2015 and the spring plots will be planted in April, 2016. The tests will be completed in August (for winter wheat) and September (for spring wheat), 2016	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).

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Project #: 3043-3697

Progress Report Year: 2 of 2

Title: Wireworm Control in Wheat-Based Cropping Systems

Cooperators: David Crowder (WSU Entomology); Aaron Esser (WSU Extension); Stephen Guy (WSU Crop Sciences); Kevin Murphy (WSU Crop Sciences); Ryan Higginbotham (WSU Crop Sciences)

Executive Summary: In FY 2016 our team made excellent progress on each objective related to improving wireworm management in cereal crops. Major accomplishments of our team include:

(1) Sampling 160 crop fields for wireworms, with over 3,200 wireworms collected and identified in total. We also collected data on factors influencing wireworms in each field. These data have provided a clear picture of how wireworms vary across the state both in terms of species present and their abundance. We have submitted two academic publications and published one extension bulletin detailing the results of these trials.
(2) Conducting trials for over 40 new insecticidal products for wireworm management at two locations in Washington State. Data from these trials will aid registration of new products, particularly novel chemistries that are not neonicotinoids. We have also aided chemical companies in trying to get an exemption to use Fipronil in wheat.
(3) Evaluation of the effectiveness of Gaucho in protecting wheat from wireworms at 16 variety testing locations. Data shows the extent of damage caused by three major wireworm species, and the economic returns provided by insecticides. Results will be published in 2016
(4) Large-scale experimental trials of the susceptibility of wheat, barley, and oats to wireworms. Preliminary results show that wheat is far more susceptible than barley and oats.
(5) Delivery of over 25 extension talks on wireworms

Impact: Based on previous work of our team, we estimate that wireworm management provides economic benefits exceeding $10 million/yr for the state for spring wheat crops alone. If we factor in other crops affected by wireworms (winter wheat, barley, etc) this estimate would be much higher. Our project will identify management strategies combining cultural and insecticidal controls for wireworms that can provide maximum economic benefit for growers depending on their location, the crops they produce, and the wireworm species present in their field(s). Our results have now provided a clear picture on how growers should modify their management strategies based on the wireworm species present in their field. Optimizing wireworm control could provide economic benefits in the millions annually for growers throughout Washington.

Our team also delivered over 10 extension talks in 2015 concerning wireworms, including the wheat academy. With a conservative estimate of 50 attendees per talk our team thus directly communicated results to approximately 500 growers and industry representatives in the past year. Our development of extension bulletins and content for the smallgrains.wsu.edu website is allowing us to communicate information broadly to growers throughout the state.

WGC project number: 3043-3697
WGC project title: Wireworm Control in Wheat-Based Cropping Systems
Project PI(s): David Crowder and Aaron Esser
Project initiation date: July 1, 2014
Project year: 2

Outputs and Outcomes:

Objective	Deliverable	Progress	Timeline	Communication
1 - Determine effects of climate, tillage, soil, and crop rotations on wireworms in cereal crops and develop a predictive model for wireworms	Data on wireworm distributions throughout Washington state; academic publications on predictive models for wireworms	We sampled over 160 fields in the past two years for wireworms (80 spring wheat, 40 winter wheat, 40 CRP). From these fields we collected wireworms from bait traps and identified all individuals to species (over 3,200 individuals were collected). We also collected data on 10 environmental and management factors associated with wireworms from each field. From these data we were able to discern the geographic delineations of the three major wireworm species in Washington (Limonius infuscatus, Limonius californicus, Selatosomus pruininus) and the factors that mediate their abundances. For L. infuscatus and S. pruininus we found that abundances were lowest in winter wheat, but the same was not true for L. californicus. This suggests this species is the only one of primary concern for growers in winter wheat, and growers may be able to move away from neonicotinoids in winter wheat for other species. We also found that soil moisture is strongly associated with wireworm and abundance. Growers in higher rainfall areas are likely to have more preferable conditions for wireworms. We have submitted two publications based on results from these studies.	The final year of sampling was completed in 2015. Two academic publications which contain these results were submitted for publication in scientific journals, and we hope to have them published in 2016 and post the results to the smallgrains.wsu.edu website.	We communicated the information gained in this objective with growers and scientific audiences at grower meetings, field days, the Wheat Academy, and academic conferences to communicate information from this objective. In spring 2015 we published an extension bulletin on the major wireworm species of economic significance in Washington. This bulletin also contains information on how to sample and identify wireworms, and describe the significance of each major species in reducing wheat and barley yields. Information on website will be uploaded as available on a page on wireworms at the WSU Small Grains Website, which contains information for growers about wireworm management (smallgrains.cahnrs.wsu.edu)
1 - Determine wireworm species of economic significance in Washington	Extension bulletin	We published an extension bulletin that provides details on the biology of the three most damaging wireworm species in Washington, along with a pictoral guide to identifying these species. The bulletin was reviewed and published and is available through WSU Extension or on the small grains website.	Completed in 2015	The bulletin is available on the small grains website. We have discussed the results in the bulletin at field days and the Wheat Academy to make growers aware of it.

2 - Conduct trials to support registration of new insecticides	Data on 40 or more new insecticides for wireworm control. These data will be shared with chemical companies to support registration of new products that improve upon industry standards and support mode of actions besides neonicotinoids. We are the only research group conducting these trials in the Pacific Northwest	We completed a second year of trials with 40 insecticide entries at two locations in Washington in FY 2016. Chemical companies have been pleased with our results, and reported to PI Esser that our trials "were the best in the country". Preliminary data indicate that several new products with novel modes of action might improve on current industry standards.	As the chemical companies ultimately control registration of new products, estimating a timeline for new product registration is difficult. However, we know that without the data we are generating that new products will not be approved. Results will be communicated with growers at at grower meetings, field days in 2016.	While we can't reveal names of products in development, we have shared results of the trials with growers at field days, and grower meetings. We will continue to communicate with the chemical companies to provide necessary data to support new products.
2 - Conduct trials to support registration of new insecticides	Documents supporting an exemption for Fipronil to be used in wheat	Fipronil is a broad-spectrum insect neurotoxin that has shown good efficacy against wireworms in other crops besides cereals. We have worked with a company to try and get an exemption for Fipronil in wheat, which could provide a key new option for growers	It remains unclear if the exemption to allow the use of Fipronil will be granted, so a timeline is hard to estimate	We have communitied with the company involved and provided letters of support for the registration of Fipronil in wheat
2 - Evaluate Gaucho in variety testing trials on Louise and Glee	Data on effectiveness of Gaucho and tolerance of Louise and Glee to various wireworm species throughout variety trials	In cooperation with Ryan Higginbotham, we completed the second year of trials in summer 2015. Plots of the varieties Louise and Glee, with or without Gaucho, were tested for wireworm damage at 12 of the variety testing locations throughout Washington State. Each plot was monitored for wireworms (species present and their abundance) four times over the course of the season. Higginbotham has provided the team with data on yield and wheat quality at each location. These data are in the process of being analyzed to determine yield loss with and without Gaucho insecticide in both wheat varieties.	The second year of experiments was completed in Fall 2015. We have two years of excellent data on varieties and treatment options that provide optimal control for the three major wireworm species in Washington state. These data are currently being analyzed and we will publish the results in Spring 2016.	Data from these experiments will be incorporated into an extension bulletin in Spring 2016 that documents effectiveness of Gaucho on different wheat varieties for each major wireworm species. We have preseted preliminary results from these trials to growers at field days and grower meetings. Finally, all of our data will be uploaded to the small grains website (smallgrains.wsu.edu) to provide an easy option for growers to view it.

3 - Examine tolerance of wheat, barley, and oats to wireworms	Data on tolerance of spring wheat compared to barley and oats to wireworms. Data on effectiveness of insecticides in each crop	We have made extensive progress on this objective. In cooperation with collaborator Murphy, we finalized a second year of experiments evaluating damage from wireworms to wheat, barley, and oats, and the effectiveness of Gaucho in protecting these crops from wireworms. At each location we monitored the wireworm populations four times over the course of the season in 2015. Murphy has provided the team with data on yield and wheat quality at each location. These data will complement similar data collected in 2014. Data from these trials are currently being analyzed, although preliminary results show that oats are the most tolerant crop, followed by barley and then wheat.	The second year of experiments was completed in Fall 2015 and data are currently being analyzed. In spring 2016 we will analyze all the data and publish the results.	Data from these trials will be developed into an extension bulletin by Spring 2016. This bulletin will document the relative tolerance of barley, oats, and spring wheat to wireworms. We have presented preliminary results from these studies at grower meetings and field days in 2015. Similar presentations will be made to grower groups in 2016.
4 - Develop extension materials for wireworms	Two extension bulletins, multiple academic publications, and information on the smallgrains.cahnrs.wsu.edu website	First extension bulletin was published in spring 2015. The second extension bulletin will be published by spring 2016. Two academic publication were submitted to scientific Journals in winter 2015 and are currently beeing under review. Two more publications will be submitted by spring 2016. We have uploaded our first extension bulletin and information on wireworm sampling and management to the small grains website. Throughout the life of the project we will continue to upload materials to the smallgrains website to make them easily accessible to growers	Second extension bulletin will be published in spring 2016. Two academic publications will be submitted by spring 2016. Information on website will be uploaded as available.	We have described these upcoming bulletins and academic publications at grower meetings and field days. When they are published we will also print out copies and deliver them to growers during presentations at field days and grower meetings. We are in the process of building a dynamic webpage that informs growers of wireworm management through the small grain website.

Washington Grain Commission
Wheat and Barley Research Annual Progress Reports and Final Reports

PROJECT No.: 30109-6345
Progress report year: *3 of 3 (maximum of 3 year funding cycle)*
Title: CLUB WHEAT BREEDING

Researchers: K. Garland Campbell, A.H. Carter,
Cooperator: M. Pumphrey,
Emeritus Advisor: R.E. Allan

Executive summary: A new club wheat cultivar, Pritchett, was released in 2015, named after John Pritchett a valued and long serving technician for the USDA-ARS club wheat breeding program. Pritchett was jointly developed by the USDA-ARS and WSU winter wheat breeding programs and has significantly better grain yield and grain test weight over multiple locations in <15 inch annual precipitation environments than Bruehl, the cultivar that it is targeted to replace. Pritchett has better milling quality, producing larger diameter cookies and greater volume sponge cake than Bruehl. Pritchett has highly effective adult plant resistance to stripe rust (*Puccinia striiformis* f. sp. *tritici*) based on a combination of multiple loci for resistance to that disease. Pritchett has moderate resistance to Cephalosporium stripe disease, similar to Bruehl. Pritchett carries the *Pch1* gene for resistance to eyespot, is moderately susceptible to that disease, but more resistant that Bruehl. Pritchett has excellent emergence from deep sowing with coleoptile lengths averaging 95cm and carries the *Rht-B1b* allele for reduced plant height. Fifteen samples of Pritchett from the 2014 and 2015 crop years have been graded by FGIS and 13 of them were graded as white club with the other two graded as western white. Pritchett was released because of its superior agronomic productivity in the targeted region, and superior end use quality combined with resistance to multiple diseases and abiotic stress.

The USDA-ARS Wheat breeding program managed field testing locations at Central Ferry, Lind, Harrington, Pullman, and Farmington WA and at Pendleton OR and Genesee ID. We also evaluated breeding lines at Walla Walla, St. Andrews, Mansfield, Ritzville, Kahlotus, WA and Corvallis OR in collaboration with the WSU Winter Breeding program, the WSU Cereal Variety Testing Program, OSU-CBARC, the OSU Wheat Breeding program, the University of Idaho and Syngenta. We focused club wheat development on two major goals: 1) Development of a replacement club wheat for Bruehl with excellent resistance to snow mold, eyespot, stripe rust, sprouting and good emergence and winter hardiness and 2) Development of early maturing club wheat for the high rainfall region with excellent resistance to eyespot, cephalosporium stripe, stripe rust, aluminum toxicity and good straw strength, high yield, and good test weight. Pritchett meets goal number 1 and several new breeding lines have potential to meet goal number 2.

The club wheat ARS Crescent is a complement to Pritchett in the higher rainfall regions. In the 2015 WSU Cereal Variety Trials, ARS Crescent was the best performing wheat in the >20 in. precipitation region and this cultivar has achieved stable high performance across rainfall zones over multiple years. In addition, club wheat breeding lines have been highly competitive with soft white wheat cultivars in multiple rainfall zones during the past three harvest seasons. The club breeding line ARS010263-10-3C was a top performer in the 16-20in precipitation zone.

The breeding lines ARS20060123-31C, ARS06135-9C, and ARS010679-1C were in among the top performers in the 12-16in rainfall zone and ARS06135-9C and ARS20060123-31C were also highly competitive in the <12 inch rainfall zone.

For 2016, we entered ARS20060123-31C and ARS06135-9C into the WA State Extension <16 in rainfall zone trials and we entered ARS20060123-31C and ARS06136-49C into the >16 in rainfall trials. We also entered ARS20060123-31C and ARS06136-49C into the Oregon Winter Elite Yield Trial. We also entered five breeding lines, ARS010679-1C, ARS06132-45C, ARS06135-9C, ARS20040150-2-0-2 and ARS20060194-0-10L into the Western Regional Soft Winter Wheat Trial. These club breeding lines are all products of crossing with soft wheat from the Eastern US as additional sources of resistance to rusts, Hessian Fly and BYDV. We have added an additional head row purification and selection step to the breeding program in order to provide Washington Foundation Seed with quality Breeder seed in a timely manner.

We have greatly expanded our use of genotyping and are in the process of genotyping all our the entries in 2014 -2016 yield trials using the genotyping by sequencing (GBS) procedure in the USDA Western Small Grains Genotyping laboratory so that we can implement genomic selection for cold tolerance and disease resistance in 2016. In conjunction with Arron Carter and Yukiko Naruoka, we have identified markers associated with the club wheat gene and with the durable stripe rust resistance currently present in the club wheat germplasm. Marker assisted selection using KASP and SSR markers was used to select for resistance to Preharvest sprouting, BYDV, eyespot, stripe rust and dough strength.

We evaluated several hundred doubled haploid lines in disease nurseries and unreplicated trials and have advanced several to our Elite replicated trials. Early generation quality testing using the Micro-mill and solvent retention capacity tests was performed on all early generation selections in order to continue to maintain and improve club wheat milling quality. Coleoptile testing and survival from freezing was assayed on all breeding lines. All breeding lines were selected for resistance to stripe rust, eyespot, cephalosporium stripe, and Fusarium in inoculated nurseries.

Impact

Club wheat acreage represents a small but significant part of the total WA wheat market. The excellent disease resistance of the club wheat is a built-in premium for growers because the reduced need for fungicides. Because of their disease resistance, club wheat cultivars have been used to incorporate stripe rust resistance and eyespot resistance into other wheat classes. The combination of excellent end use quality, disease resistance, and cold tolerance of new club wheat cultivars allows growers to make planting decisions based on market demands and to maximize choice in marketing strategy. The club wheat breeding program works collaboratively with several other WGC funded projects including the Winter and spring wheat breeding projects, the disease resistance and quality projects, and the drought and preharvest sprouting projects to integrate their results and methods into production of quality cultivars for PNW growers.

D. Communication

Presentations:

a. "Club Wheat for Dry Cropping Regions", Lind Field Day-WSU Agricultural Experiment Station, Lind WA, June 13, 2013.
b. "USDA-ARS Club Wheat Breeding", Spillman Farm Field Day – WSU Dept. of Crops and Soil Sci., Pullman WA., July 11, 2013.
c. Report of Progress: Washington Grains Commission Research Review, "Club Wheat Breeding", Pullman WA, Feb. 2013.
d. Invited by Coordinating Committee, Plant Breeding Academy, Univ. of California at Davis, CA. to lecture on "Breeding Self-Pollinated Crops". Sept 16, 2013.
e. Plot and field day tours speaking to approximately 15-30 growers and industry representatives per tour during May, June and July, 2013: Connell WA, Harrington WA, St. Andrews WA.
f. "Club Wheat for Dry Cropping Regions", Lind Field Day-WSU Agricultural Experiment Station, Lind WA, June 12, 2014.
g. Report of Progress: Washington Grains Commission Research Review, "Club Wheat Breeding", Pullman WA, Feb. 2014.
h. Plot and field day tours speaking to approximately 15-30 growers and industry representatives per tour during June, 2014: Harrington WA. St. Andrews WA.
i. "Club Wheat for Dry Cropping Regions", Lind Field Day-WSU Agricultural Experiment Station, Lind WA, June 11, 2015.
j. Report of Progress: Washington Grains Commission Research Review, "Club Wheat Breeding", Pullman WA, Feb. 2015.
k. Invited by Coordinating Committee, Plant Breeding Academy, Univ. of California at Davis, CA. to lecture on "Breeding Self-Pollinated Crops". Sept 16, 2015.
l. Plot and field day tours speaking to approximately 15-30 growers and industry representatives per tour during June, 2015: Harrington WA, Reardan WA, Ritzville WA.
m. "Breeding Wheat for Functionality and Grading" Invited talk to American Association of Cereal Chemists International, Minneapolis MN, Oct. 19, 2015.
n. Breeding Wheat for End use Quality" Invited talk to Advanced Plant Breeding Class, Colorado State Univ. Ft. Collins, CO, Nov 20, 2015.

Refereed manuscripts with applications to this project.

Christopher**, M. D., S. Liu**, M. D. Hall**, D. S. Marshall, M. O. Fountain, J. W. Johnson, E. A. Milus, K. A. Garland-Campbell, X. Chen, and C. A. Griffey. 2012. Identification and mapping of adult-plant stripe rust resistance in soft red winter wheat cultivar USG 3555. Plant Breeding. Doi:10.1111/pbr.12015.

Christopher, M.D., Liu, S., Hall, M.D., Marshall, D.S., Fountain, M.O., Johnson, J.W., Milus, E.A., Garland-Campbell, K.A., Chen, X., Griffey, C.A., 2013. Identification and Mapping of Adult Plant Stripe Rust Resistance in Soft Red Winter Wheat VA00W-38. Crop Science. 52:871-879.

Case AJ, Naruoka Y, Chen X, Garland-Campbell KA, Zemetra RS, Carter, A.H. 2014. Mapping Stripe Rust Resistance in a BrundageXCoda Winter Wheat Recombinant Inbred Line Population. PLoS ONE 9(3): e91758. doi: 10.1371/journal.pone.0091758

Martinez, S.A., Schramm, E.C.,Harris, T.J., Kidwell, K.K.,Garland-Campbell, K., Steber, C.M., 2014. Registration of Zak Soft White Spring Wheat Germplasm with Enhanced Response to ABA and Increased Seed Dormancy. J. Plant Reg. 8:217-220.

Guy, S.O., Wysocki,D.J., Schillinger, W.F., Chastain,T.G., Karow,R.S., Garland-Campbell,K., Burke,I.C., 2014. Camelina: Adaptation and Performance of Genotypes. Field Crops Research 115:224-232.

Graybosch, R.; Bockelman, H. E; Garland-Campbell, K. A; Garvin, D. F; Regassa, T; 2014. Wheat. pp 459-488 In Specht, J., and Carver, B., (Eds).Yield Gains in Major US Field Crops. American Society of Agronomy, Inc., Crop Science Society of America, Inc., and Soil Science Society of America, Inc.

Garland Campbell, K., Thompson, YM, Guy, SO, McIntosh, M, Glaz, B., 2015. *Is*, or *is not*, the two great ends of Fate": Errors in Agronomic Research. Agron. J. 107: 718-729.

Piaskowski, JL, Brown, D, Garland Campbell, K. 2016 NIR Calibration of Soluble Stem Carbohydrates for Predicting Drought Tolerance in Spring Wheat. Agron J. 108:285-293. doi:10.2134/agronj2015.0173

Popular Press:

Campbell, K., 2015. "Welcome to the Club" WheatLife 58:53-55.

WGC project number: **3019-6345**
WGC project title: **Club wheat breeding**
Project PI(s): **Kimberly Garland-Campbell, Arron Carter, Mike Pumphrey**
Project initiation date: **7/1/13**
Project year: **Year 3**

Objective	**Deliverable**	**Progress**	**Timeline**	**Communication**
Objective 1. Conduct crossing program to improve resistance to stripe and leaf rust, cold tolerance, strawbreaker foot rot, Cephalosporium stripe and Fusarium crown rot. Also to identify and improve resistance to cereal cyst and lesion nematodes, and barley yellow dwarf virus.	New populations with novel combinations of important genes.	Best by Best crossing blocks from 2012,-2015 are being advanced in the greenhouse. DNA has been extracted from all parents and breedling lines for 2014-2015 to better predict good cross combinations.	Sept 2013-August 2015	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review.
Objective 2.. Develop doubled haploid and backcross populations and conduct early generation selection in disease and cold tolerance screening systems in the WSU plant growth facility.	Several hundred doubled haploids developed. Backcross popualtions using germplasm resources from outside of PNW developed.	Doubled haploid lines were evaluated at Central Ferry, Spillman, or Lind, depending on the breeding objectives for the population. Additional DH populations are being	Sept 2013-August 2015	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review.
Objective 3. Analyze information from the two training panels of adapted winter wheat that we have genotyped to develop genomic selection prediction equations. Conduct marker assisted selection and recombine the best selections to reduce breeding cycle time.	Prediction equations for club wheat quality and agronomic performance. New breeding lines identified using marker assisted selection.	Marker assisted selection using KASP and SSR markers was used to select for resistance to Preharvest sprouting, BYDV, eyespot, stripe rust and dough strength. Genomic data for advanced breeding lines has been obtained and is	By end of 2nd year and ongoing.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review.

Objective 4. Plant, manage, evalaute, and harest early generation un-replicated nurseries at Pullman WA, Pendleton OR, Lind WA as space and time permit. Evaluate resistance to multiple diseases in inoculated disease screening nurseries.	Advanced breeding lines with resistance to multiple diseases and acceptable agronomic characteristics entered into replicated trials.	The USDA-ARS Wheat breeding program managed field testing locations at 13 locations in WA, ID and OR in collaboration with the WSU Winter Breeding program, the WSU Cereal Variety Testing Program, OSU-CBARC, the OSU Wheat Breeding program, the University of Idaho and	Sept 2013-August 2015	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review.
Objective 5. Evaluate end use quality on 1500 F4 and F5 head row selections.	Breeding lines entering into unreplicated and replicated trials have been screened for quality characteristics.	Early generation quality testing conducted every year.	Sept 2013-August 2015	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review
Objective 6. Conduct laboratory, greenhouse and growth chamber evaluations of stripe rust resistance and coleoptile length. Evaluate cold tolerance in growth chamber trials	Identify germplasm with superior stripe rust resistance, coleoptile length and cold tolerance.	Seedling trials for stripe rust resistance are currently underway at the Wheat Plant Growth Facility. Coleoptile screening is underway at the Agronomy seedhouse. Cold tolerance screening was done on the 2014 yield plots and used for selection.	Sept 2013-August 2015	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review.
Objective 7. Plant, manage, evalaute and harvest advanced replicated nurseries at multi-location trials for club and soft white wheat in Eastern Washington, NE Oregon and North Idaho.	New club wheat cultivars with superior perfromance. New germplasm of other wheat classess possesing superior stripe rust resistance and quality derived from club wheat cultivars.	A new club wheat cultivar, Pritchett, was released in 2015,and was jointly developed by the USDA-ARS and WSU winter wheat breeding programs	Sept 2013-August 2015	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review.

Washington Grain Commission
Wheat and Barley Research Annual Progress Reports and Final Reports

PROJECT #: 30109-5345

Progress report year: 3 of 3

Title: Evaluation And Selection For Cold Tolerance In Wheat

Cooperators: K. Garland Campbell, D.Z. Skinner, A.H. Carter

Executive summary:

- Evaluating freezing tolerance is difficult in the field because snow cover, slope, available moisture, and soil born diseases can all affect winter survival and rating varieties can only be conducted once a year. Therefore we developed a screening system that can be conducted year round using the growth chambers at the WSU Wheat Plant Growth Facility.
- Each year for the last three years, we have rated tolerance to freezing in the Washington State Extension Winter wheat variety trials and the Western Regional winter wheat nurseries. We have rated tolerance to freezing in the spring wheat and other Regional nurseries from the rest of the US in two of these years.
- The most cold tolerant hard winter wheat in the WSU nurseries was AP503CL2, Bauermeister, Boundary, DAS1, Eltan, Finley, Farnum, IDO1103, IDO816, Norstar, UI Silver, WA8158, WA8178, WA8179, WA8180, WA8181, WA8197, WA8207, and WB-Arrowhead. The most cold tolerant soft winter wheat was ARS010262, Bitterroot, Curiosity CL, Eltan, Masami, Mela CL, Norstar, Tubbs 06, and Jasper. In the winter regional nursery, ARS010260, Eltan, IDO1101, OR2080236H, and Yellowstone had the best cold tolerance. New germplasm that has been brought into the PNW from Europe is generally less winter tolerant than needed for the PNW. The WSU Winter Wheat Variety trials were rated for winter survival after the severe 2013/2014 and 2014/2015 winter. The field survival data was closely correlated with the results of our artificial screening testing (Complete field survival data is available at http://variety.wsu.edu/).
- In the US, the best overall winter tolerance is found in the winter wheat breeding programs in CO, MT, SD, and West Texas. New sources of resistance that have been identified from regional nurseries have been crossed to PNW adapted breeding lines in order to incorporate even better winter tolerance into winter wheat.
- We have rated freezing tolerance for winter wheat breeding lines and in progeny from intercrosses within the Brundage/Coda, Finch/Eltan, and Eltan/Oregon Feed Wheat5 wheat mapping populations, and the Winter Wheat Core Nursery. Using the survival data from analysis of these mapping populations we have identified interactions among different alleles of two loci on the wheat group 5 chromosomes, *Vrn-1* and *Fr2*, that substantially improve tolerance to freezing in both spring and winter wheat. At both loci, sequence variation and copy number variation are important. The selection of varieties carrying the *FR-A2-T* allele

and three copies of the recessive *vrn-A1* allele is a good strategy to improve frost tolerance in wheat. We have developed molecular markers for these specific alleles. Most PNW adapted germplasm possessed the tolerant alleles at both genes, likely due to selection by breeders for winter tolerance. We have to continued to search for additional genes that will explain a significant proportion of the variation for cold tolerance in adapted PNW germplasm.

- We discovered that freezing, followed by a thaw cycle and subsequent refreezing to a low target temperature, increases freezing tolerance. This increased freezing tolerance occurs even at very low target temperatures like -15^{o}C. Varieties differ in their ability to take advantage of these temperature fluctuations. We are examining the sources of genetic variation for this response. These fluctuating freeze-thaw cycles occur often in nature and may actually protect the wheat plants in the field, at least to some degree.
- There are some varieties, including Otto, Coda, Farnum, ARS-Selbu, Kaseberg and Skiles, that survive better in the field than our freezing tests would predict. These results are likely due to the soil-born disease resistance that many of these lines carry. Many of our soil-born diseases infect seedlings in the fall and weaken the plants so if plants are resistant, they have more resources to handle to freezing stress.

Impact

- The data from these cold tolerance trials was published in the seed buyers guide so that farmers could select winter wheat that is less sensitive to winter kill. This data was shared with breeders and used to select for improved cold tolerance in wheat targeted to the Pacific Northwest and to support release decisions for winter wheat cultivars.
- Our results from screening the regional nurseries, which was actually done so that we could identify new sources of resistance, have been used by breeders in the Great Plains to justify release of their cultivars.
- Varieties released from the WSU winter wheat breeding program have consistently excellent cold tolerance and this tolerance has been maintained because of testing using the procedures developed by this project.
- Because of the high correlation between our artificial screening trial and winter survival in the field, we are able to incorporate better cold tolerance into our early generation breeding lines.
- Most breeding programs have both winter tolerant and less tolerant breeding lines. The identification of molecular markers associated with freezing tolerance complements our screening system and increases our current screening capacity from about 1000 varieties and breeding lines to several thousand progeny from segregating populations per year.

D. Communication:

Refereed papers

Pearce, S., Zhu, J., Boldizsar, A., Vagujfalvi, A., Burke, A., Garland-Campbell, K., Galiba, G., Dubcovsky, J., 2013. Large deletions in the CBF gene cluster at the *Fr-B2* locus are associated with reduced frost tolerance in wheat. Theor Appl Genet. 126:2683-2697.

Case, A.J., Skinner, D.A., Garland-Campbell, K.A., Carter, A.H. 2014. Freezing Tolerance-Associated Quantitative Trait Loci in the Brundage × Coda Wheat Recombinant Inbred Line Population. Crop Sci. 54. 982-992.

Zhu, J, Pearce, S., Burke,A, See, DR, Skinner, DZ, Dubcovsky, JD, Garland Campbell, K. 2014. Copy number and haplotype variation at the *VRN-A1* and central *FR-A2* loci are associated with frost tolerance in hexaploid wheat, Theor Appl Genet. DOI 10.1007/s00122-014-2290-

Skinner, D. Z. 2014. Time and temperature interactions in freezing tolerance of winter wheat. Crop Science. 54 No. 4, p. 1523-1529. doi:10.2135/cropsci2013.09.0623

Skinner, Daniel Z; Garland-Campbell, Kimberly; 2014. Measuring Freezing Tolerance: Survival and Regrowth Assays. pp 7-13 *In* Hincha, D.K., and Zuther E., (Eds) Plant Cold Acclimation: Methods and Protocols. Method in Molecular Biology. Springer New York

Cuevas, C., Bellinger, B.S., Skinner, D.Z. 2014. Membrane stability of winter wheat plants exposed to subzero temperatures for variable lengths of time. Communications in Plant Sciences. 5(1-2):9-14

Skinner, D.Z., Bellinger, B.S., Hansen, J.C., Kennedy, A.C. 2014. Carbohydrate and lipid dynamics in wheat crown tissue in response to mild freeze-thaw treatments. Crop Science. 54:1–8. DOI: 10.2135/cropsci2013.09.0604.

Skinner, D.Z. 2015. Genes upregulated in winter wheat (Triticum aestivum L) during mild freezing and subsequent thawing suggest sequential activation of multiple response mechanisms. PLoS One. 10(7):e0133166.

Abstracts

Zhu, J., Pearce, S., Burke, A., Skinner, D,Z., Dubcovsky, J., Campbell, K.A.G., 2013. Different haplotypes of Vrn-1 and Fr-2 effect the frezing tolerance of wheat. Plant Animal Genome XXI. San Diego CA Jan 12-16, 2013.

Popular Press

Garland-Campbell, K., Skinner, D., Murphy, L., Burke, A., Bellinger, B., Walker, C., 2009. The weather inside in chilly: Assessing and Enhancing Cold Tolerance in Wheat. Wheatlife:52:46-48.

Garland-Campbell, K. 2014. It's Freezing: Cold Weather Bad for Farmers but Good for Researchers. WheatLife. 57: 53-55.

Web

Garland-Campbell. Kim.. Has it Been Cold Enough to Kill my Wheat? Timely Topic. CAHNRS and WSU Extension Wheat and Small Grains. http://smallgrains.wsu.edu/

Presentations

Garland-Campbell, K.A. 2013. Dissecting Cold tolerance in Winter Wheat. Seminar to Dept. of Soil and Crop Sciences, Colorado State Univ., Nov. 18, 2013.

WGC project number: 3019-5345
WGC project title: Evaluation And Selection For Cold Tolerance In Wheat
Project PI(s): Kimberly Garland-Campbell, Dan Skinner and Arron Carter.
Project initiation date: 7/1/13
Project year: Year 3

Objective	**Deliverable**	**Progress**	**Timeline**	**Communication**
1. Evaluate Washington winter wheat variety trials.	Ratings for freezing tolerance for commonly grown and new winter wheat cultivars	Trials planted and rated each year. • The most cold tolerant hard winter wheat in the WSU nurseries was AP503CL2, Bauermeister, Boundary, DAS1, Eltan, Finley, Farnum, IDO1103, IDO816, Norstar, UI Silver, WA8158, WA8178, WA8179, WA8180, WA8181, WA8197, WA8207, and WB-Arrowhead. The most cold tolerant soft winter wheat was ARS010262, Bitterroot, Curiosity CL, Eltan, Masami, Mela CL, Norstar, Tubbs 06, and Jasper.	Sept 2012 - August 2015.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review. Published on WSU Variety Testing Web-site
2. Evaluate cold tolerance of new breeding lines in US regional nurseries in order to identify germplasm to use in crossing for better winter survival.	Ratings for freezing tolerance for advanced wheat germplasm from the US that can be used as new sources of cold tolerance for the PNW.	Trials planted and rated each year.In the winter regional nursery, ARS010260, Eltan, IDO1101, OR2080236H, and Yellowstone had the best cold tolerance.	Sept 2012 - August 2015.	Presentation at grower meetings, Wheat commission meetings, Wheat Life and Research Review. Email results to regional nursery cooperators and publish on regional nursery web sites.
3. Evaluate cold tolerance of spring wheat variety trials.	Ratings for spring wheat cultivars.	Trials planted and rated in 2013.	Sept 2012 - August 2015.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review. Published on WSU Variety Testing Web-site
4. Evaluate cold tolerance of advanced breeding lines contributed by PNW wheat breeders as well as those in the ARS breeding program	Ratings for freezing tolerance for breeding lines in regional breeding programs.	Trials planted and rated and information given to breeders. Information was used to justify cultivar release.	Sept 2012 - August 2015.	Direct communication with wheat breeders.

5. Evaluate cold tolerance of F_3-F_5 (early generation) wheat populations that are segregating for cold tolerance segregating for cold tolerance and select resistant progeny.	Populations segregating for other traits but selected to have superior cold tolerance.	The first round of selection was performed and lines are in the field for agronomioc traits.	Sept 2012 - August 2015.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review.
6. Identify genes controlling cold hardiness in winter wheat. Rate freezing tolerance in tthree mapping populations, Finch/ARS15144, Finch/ARS14142 and Finch/Eltan. All three of these populations will be genotyped with SNP markers and quantitative trait loci for cold tolerance will be	Genes responsible for cold tolerance in Eltan, ARS15144 and ARS14142 identified. The best selections from the mapping poppulations will be entered into yield trials.New markers for cold tolerance will be identified.	Populations have been screened. • We have rated freezing tolerance for winter wheat breeding lines and in progeny from intercrosses within the Brundage/Coda, Finch/Eltan, and Eltan/Oregon Feed Wheat5 wheat mapping populations, and the Winter Wheat Core Nursery. QTLs have been identified and association mapping in underway to identify additional loci.	By the end of the third year of the grant.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review. Publication in refereed journal.

Washington Grain Commission
Wheat and Barley Research Annual Progress Report

Project #: 4150-1217

Progress Report Year: *_3_ of _3__*

Title: Evaluation of Barley Varieties

Investigator: Ryan Higginbotham

Executive summary:
In 2015, the Cereal Variety Testing Program (VTP) conducted 11 variety trials across Eastern Washington. The total number of individual barley plots evaluated was 1,188. Entries in the trials included submissions from every major barley breeding program in the Pacific Northwest. Variety performance information is delivered to barley growers and other clientele through field tours (8 tours in 2015), grower meetings, the variety testing website, emails with preliminary results after harvest (over 200 recipients), the variety selection tool (located at smallgrains.wsu.edu), *Wheat Life*, seed buyers guide, annual technical report, direct contact with clientele, and reports to the Washington Grain Commission. The variety trials are used by WSU breeders for variety release decisions, by pathologists to rate disease reactions, and for county Extension programming.

Impact:
The economic impact of the WSU VTP is measured by providing information to growers and seed industry personnel that leads to variety selections that maximize profitability and minimize risk. Choosing an appropriate barley variety to plant is one of the easiest ways that a grower can increase production and decrease costs (through decreased inputs). Although current barley acreage in Washington is declining, it is important for the VTP to continue to evaluate the growing list of available barley varieties. It is also important for the program to evaluate new breeding lines for potential variety release. The trials provide a venue for growers to see what's available, and a platform to continue to promote barley production in Washington. Without the VTP, many growers in Washington would not have access to barley variety performance data in their areas of production. Growers who choose to plant barley will see an increased economic return by choosing high yielding barley varieties showcased in the WSU VTP. Some of the most direct and measurable impacts that this project had in 2015 are as follows:

1. Barley VTP field tours were attended by 208 farmers/clientele. At those tours, I highlighted each entry in the trial and presented a few details about each entry.
2. As soon as harvest results were available, they were distributed via email to a listserv with 202 members.
3. The variety testing section of the small grains website (http://smallgrains.wsu.edu/variety/) was the most visited section of the site (4,388 page views).

WGC project number: 4150-1217
WGC project title: Evaluation of Barley Varieties
Project PI(s): Ryan Higginbotham
Project initiation date: July 1, 2013
Project year: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Conduct barley variety trials in Eastern Washington	11 spring barley trials, 36 entries/trial	2015 trials complete (36 entries/trial)	Trials are planted in the spring, data results are available to growers at the end of the harvest season. Field tours in summer.	Grower Meetings: 5 in 2015; accepting invites for 2016
		2016 trials in planning		Field tours: 9 in 2015; estimate 10 tours in 2016
		The Endicott location was new in 2015.		Email list serve: results sent after processing
				Annual Report: 2015 Technical Report 15-3
				WSCIA spring seed guide
				Wheat Life article
2. Public and private entries in trials	All widely grown, commercially available varieties included in trials.	2015 barley trial: 47% WSU, 39% Private, 14% Other Public	Entries by Feb. 15	Solicit entries February 1. Maintain positive relationship with breeding programs to ensure future participation.
3. Trials and data available to other projects	Participation by other projects/programs	Data is used by breeders for variety release and promotional materials. To this point, the grain itself is not used in any further testing outside the VTP. New avenues for collaboration need to be explored.	Ongoing cooperation and collaboration that fit with timelines and other listed objectives	VTP data used for variety release
4. Extension programming	Grower Meetings	5 grower mtgs in 2015; 2 already planned in 2016	Whenever I'm invited	Grower Meetings: 5 in 2015; accepting invites for 2016
	Field Tours (with county Extension)	9 in 2015; 10 planned for 2016	May 2016 - July 2016	*Field Tours: 9 in 2015 (listed below)
	Email List serve	2015 results delivered	July 2015 - Sept. 2015	Email list serve: data sent to 200+ members
	Website	up to date with 2015 data	fall/winter	4,388 pageviews of the VTP section of the small grains website
	Annual Report	Published in December 2015	December	Annual Report: 2015 Technical Report 15-3
	WSCIA Seed Buyers Guides	in preparation	January--February	To be published in 2016
	Wheat Life	barley results in Feb. issue	February	Wheat Life: 1 article planned for 2016
	Variety Selection Tool (http://smallgrains.wsu.edu)	Selection tool updated with 2015 results. Initiating tool to track website traffic/users.	Post harvest/as data is processed	The variety selection tool has been highlighted/promoted at grower meetings and field tours.

*** 2015 PNW CROP TOUR SCHEDULE--BARLEY SITES**

Location	Date	Attendance
Fairfield	16-Jun	26
Walla Walla	23-Jun	22
Dayton	24-Jun	30
Almira	24-Jun	75
Reardan	25-Jun	20
Mayview	30-Jun	23
St. John	9-Jul	10
Lamont	9-Jul	10
Farmington	9-Jul	18
		Total = 234

Washington Grain Commission
Wheat and Barley Research Annual Progress Report

Project #: 4150-1216

Progress Report Year: *_3_ of _3__*

Title: Evaluation of Wheat Varieties

Investigator: Ryan Higginbotham

Executive summary:

In 2015, the Cereal Variety Testing Program (VTP) conducted 21 soft winter, 12 hard winter, 16 soft spring, and 16 hard spring wheat variety trials across Eastern Washington. The total number of individual wheat plots evaluated was 7,344. Entries in the trials included submissions from 10 different breeding programs/cooperators. Variety performance information is delivered to wheat growers and other clientele through field tours (18 tours in 2015), grower meetings (6 in 2015), the variety testing website, emails with preliminary results after harvest (over 200 recipients), the variety selection tool (located at smallgrains.wsu.edu), *Wheat Life* articles, seed buyers guides, annual technical report, direct contact with clientele, and reports to the Washington Grain Commission. Grain from variety trials is used to generate information on end use quality, disease reactions, market class grading, and falling numbers.

Impact:

The economic value (impact) of the WSU VTP is measured by providing information to growers and seed industry personnel that leads to variety selections that maximize profitability and minimize risk. Choosing an appropriate wheat variety to plant is one of the easiest ways that a grower can increase production and decrease costs (through decreased inputs). In 2015, there were over 2.0 million acres of wheat planted in Washington. If growers use results produced by the VTP to select higher yielding, disease resistant wheat varieties to plant on their farms, one could assume a modest average yield increase of 1 bushel/acre, resulting in 2.0 million bushels of grain. Using an average market price of $5.00/bushel, this would result in a gross increase of $10 million to the Washington grain economy. An additional impact of the VTP comes through the evaluation of breeding lines, providing valuable information to aid breeders in variety release decisions, leading to new and improved wheat varieties available to growers in Washington. Seed dealers also use VTP data to make decisions about which varieties to make available to their patrons.

Some of the most direct and measurable impacts that this project had in 2015 are as follows:

1. The inclusion of every major wheat breeding program in the VTP trials. This provided growers and industry with a head-to-head comparison of the most widely grown varieties.
2. VTP field tours were attended by 448 farmers/clientele. At those tours, I highlighted each entry in the trial and gave a few details, strengths/weaknesses about each entry.
3. As soon as harvest results were available, they were distributed via email to a listserv with 202 members.
4. The variety testing section of the small grains website (http://smallgrains.wsu.edu/variety/) was the most visited section of the site (4,388 page views).

WGC project number: 4150-1216
WGC project title: Evaluation of Wheat Varieties
Project PI(s): Ryan Higginbotham
Project initiation date: July 1, 2013
Project year: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Conduct wheat variety trials in Eastern Washington	a) 21 soft winter wheat trials; 48-60 entries/trial	a) 2016 trials planted; 2015 results finished	Trials are planted in the spring or fall, data results are available to growers shortly after harvest. Field tours throughout the summer.	Results from variety trials are communicated via Extension programming and are detailed under Objective #4.
	b) 11 hard winter wheat trials; 30 entries/trial	b) 2016 trials planted; 2015 results finished		
	c) 16 soft spring wheat trials; 24 entries/trial	c) 2016 trials in planning; 2015 results finished		
	d) 16 hard spring wheat trials; 42 entries/trial	d) 2016 trials in planning; 2015 results finished		
		An additional irrigated site was added in 2015 and an additional high rainfall spring site will be added in 2016		
2. Public and private entries in trials	All widely grown, commercially available varieties included in trials.	2016 winter trials: 35% WSU, 31% Private, 34% Other Public: Every major breeding program in the PNW is actively participating in the VTP trials. 2016 winter entries can be viewed on the variety testing website	Winter entries by Aug. 15th and spring entries by Feb. 15th	Solicit winter entries August 1 and spring entries February 1. Maintain positive relationship with breeding programs to ensure future participation.
		2015 spring wheat trials: 42% WSU, 38% Private, 20% Other Public		
3. Trials and data available to other projects	Participation by other projects/programs	Cooperation with breeders, pathologists, quality lab, FGIS, seed dealers, WSCIA, Extension	Ongoing cooperation and collaboration that fit with timelines and other listed objectives	Quality results in G&E study and preferred variety pamphlet, falling number results presented by corresponding project, disease ratings presented in seed buyers guide and variety selection tool, VTP data used for variety release and PVP applications
4. Extension programming	Grower Meetings	5 grower mtgs in 2015; 2 already planned in 2016	Whenever I'm asked to speak	Grower Meetings: 5 in 2015; accepting invites for 2016
	Field Tours (with county Extension)	20 planned for 2016	May 2016 - July 2016	*Field Tours: 18 in 2015 (listed below)
	Email List serve	2015 results delivered	July 2015 - Sept. 2015	Email list serve: data sent to 200+ members
	Website	up to date with 2015 data & 2016 maps	summer & fall	4,388 pageviews of the VTP section of small grains website
	Annual Report	Published in December 2015	December	Annual Report: 2015 Technical Report 15-3
	WSCIA Seed Buyers Guides	in preparation	spring in Feb. winter in May	To be published in 2016
	Wheat Life Article	2015 articles written by previous PI, I will write 2016 articles	spring in Feb. winter in May	Wheat Life: 2 articles planned for 2016
	Variety Selection Tool (http://smallgrains.wsu.edu)	Selection tool updated with 2015 results. Initiating tool to track website traffic/users.	Post harvest/as data is processed	The variety selection tool has been highlighted/promoted at grower meetings, field tours.

*** 2015 PNW CROP TOUR SCHEDULE--WHEAT**

Location	Date	Attendance	Crops
Horse Heaven	2-Jun	26	Winter & Spring Wheat
Ritzville	3-Jun	22	Winter Wheat
Connell	4-Jun	21	Winter Wheat
Western Whitman Co. - Dusty	4-Jun	23	Winter Wheat
Harrington	10-Jun	14	Winter Wheat
St. Andrews	12-Jun	15	Winter Wheat
Fairfield	16-Jun	26	Winter Wheat
Moses Lake	17-Jun	32	Winter & Spring Wheat
Walla Walla	23-Jun	22	Winter & Spring Wheat
N. Lincoln Co. - Creston	23-Jun	55	Winter Wheat
Dayton	24-Jun	30	Winter & Spring Wheat
Almira	24-Jun	75	Winter & Spring Wheat
Bickleton	25-Jun	6	Spring Wheat

Reardan	25-Jun	20	Winter & Spring Wheat
Mayview	30-Jun	23	Winter & Spring Wheat
St. John	9-Jul	10	Winter & Spring Wheat
Lamont	9-Jul	10	Winter & Spring Wheat
Farmington	9-Jul	18	Winter & Spring Wheat
		Total = 448	

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Updated November 2013

(Begin 1 page limit)
Project #: 3019-4387
Final Report
Title: Cultural Management of Soil Acidification and Aluminum Toxicity in Wheat-Based Systems of E. Washington
Investigators: D. Huggins, K. Schroeder and T. Paulitz

Cooperators: R. Koenig, T. Brown, C. McFarland

Executive summary:

- Field trials with different rates (100-2000 lbs/ac of $CaCO_3$) of surface applied fluid (NuCal) and dry lime (sugarbeet lime source) were established in fall 2013 on prairie (Conservation Farm and private farm near Pullman, WA) and forest (private farm near Rockford, WA) soil in long-term continuous no-till sites. Crop and soil responses to treatments were monitored. 17 months after lime application the higher rates (2000 lbs CaCO3/ac) of lime had increased soil pH in the upper 2 inches by about ½ to 1 pH unit; however, treatments failed to address stratified soil acidity located at the 4 inch depth. The fluid and dry lime had similar effects on soil pH. We concluded that movement of these surface applied fluid or dry lime sources into the soil would be slow (years) and would fail to address stratified acidity in no-tillage operations in the short term if the stratified layer was deeper than the surface 2 inches. In addition, low rates of surface applied lime (100, 200 lbs/ac) had no statistically significant measureable effect on soil pH. Failure to address stratified soil pH with surface applied lime led to the development of a new fluid lime applicator that targets stratified soil acidity at the 3-4 inch depth. The applicator consists of 30 inch sweeps with 10 fluid lime injectors per sweep. A field trial in the spring of 2015 with the prototype applicator applied 103 gal/ac of fluid lime (about 1200 lbs/ac of CaCO3) and was successful at targeting stratified soil acidity at the 3 to 4 inch depth with minimal soil disturbance. We concluded that the fluid lime applicator had potential to rapidly address stratified soil pH in no-till situations where physical incorporation of lime with tillage operations was not preferred.
- No crop (wheat, chickpea, canola, lentil) yield differences were measured comparing control to the lime treatments during the study. However, as the lime treatments failed to address the acidity issue, our results are inconclusive as to any yield benefit the lime may have achieved if the treatments had successfully adjusted soil pH to agronomically favorable levels. Field trials were coordinated with Kurt Schroeder (Univ. of Idaho) and similar treatments were established in N. Idaho. Seed-placed lime was also evaluated for spring crops at the Cook Agronomy Farm, however, no yield responses were noted. Further investigations are required to identify situations where crop yield response to lime will occur or not occur. Furthermore, future investigations should also examine other potentially beneficial effects of lime application such as increases in nutrient use efficiency, changes in herbicide carry-over characteristics and influences on biological activity such as legume nodulation, earthworm activity and residue decomposition.

- Stratification of soil acidity in the surface six inches is one source of soil pH variability and requires that soil sampling depth-increment protocols are adjusted if the stratification is to be quantified. Sampling the surface 12 inches of soil will mask stratified soil pH issues and not identify potential problems. We recommend sampling the upper six inches or 0 to 3 and 3 to 6 inch increments to adequately measure soil acidification problems in no-till operations. Soil sampling protocols can now be found on the WSU dryland wheat extension website along with other current information on soil acidification (http://smallgrains.wsu.edu/soil-and-water-resources/soil-acidification-in-the-inland-northwest/). In addition to significant variability of soil pH with depth, there is often considerable spatial variability of soil pH across the field and to a lesser extent, from season to season. Spatially distributed soil samples at the Cook Agronomy Farm showed ranges of soil pH from 4.4 to 5.4 in surface 6 inch samples. Others have also measured considerable spatial variability of soil pH within fields ranging 2 or more soil pH units (e.g. soil pH of 4.5 to 7.0 in single field). Mapping spatial soil pH was conducted via grid sampling using Veris technology in combination with traditional soil sampling and testing protocols. Limitations of Veris technology used to map soil pH were identified (poor accuracy, limited field "windows" for operation). Lime requirements derived from the soil sampling indicated that rates of lime required to achieve a target soil pH could vary significantly across a given field. Preliminary conclusions are that these data support further investigations into exploring precision application strategies for lime where application rates target soil requirements and locations where crop response may occur.
- Currently regional soil testing laboratories use various buffer tests to determine the lime requirement. Common laboratory buffer tests are Adams and Evans and SMP buffer tests. These soil buffer tests, however, had not been tested for their suitability to a broad range of soils found in the Palouse region. As buffer tests are a fundamental test required to determine what lime rates are needed to change the soil pH from its current value to an identified target pH, we conducted laboratory incubation studies using 10 common Palouse soil types to further test and develop lime requirement determinations. The lime incubation investigation was successful and quantified how regional soils would respond with respect to pH to rates of lime ranging from 100 to 20,000 lbs/ac. These results were then combined with six different soil buffer tests (Shoemaker McLean and Pratt (SMP), Adams and Evans, Modified Mehlich, Sikora, Woodruff 7, and Woodruff 6) to determine which of these tests were most suitable to use for determining the lime requirement of Palouse soils. These results showed that the Adams and Evans and SMP buffer tests were not adequate as buffer tests. However, the modified Mehlich and Woodruff buffer tests were determined to be suitable for estimating the lime requirement for Palouse soils when correlated and calibrated. It is further recommended, however, that these laboratory based results are corroborated with field tests. These investigations are currently in place but require more time to assess.
- Research results have been presented at numerous (over 40) regional and national meetings during the course of the project. In addition, a multi-disciplinary soil acidification Extension team was organized to help coordinate the many disciplinary issues that soil acidification impacts and various Extension products that would be useful for producers (see: http://smallgrains.wsu.edu/soil-and-water-resources/soil-acidification-in-the-inland-northwest/). In addition, articles in Wheat life, Crop and Soils Magazine and The Furrow have highlighted research activities.

Impact:

- Our liming trials, using novel formulations and application techniques provided growers with immediate information about the efficacy of these methods under our conditions.
- Spatial characterization of soil pH and liming requirement will help target lime applications and lead to greater economic performance of crops.
- Soil buffer tests that are well suited for determining the lime requirement for Palouse soils were identified and should replace current buffer tests used by regional soil testing labs.
- New, multidisciplinary Extension products are now available for producer and other professionals to use with further offerings to be available in the coming year.

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Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: 4150-1222

Progress Report Year: 3 of 3

Title: Extension Education for Wheat and Barley Growers

Cooperators: Timothy Murray, David Crowder, Randy Fortenbery, Haiying Tao, Ryan Higginbotham, Stephen Guy, Aaron Esser, Stephen Van Vleet, Diana Roberts, Paul Carter, Dale Whaley, and Wayne Thompson.

Executive summary: This project resulted in the development and launch of the Wheat and Small Grains website by the Extension Dryland Cropping Systems Team in January of 2014. This website consolidates WSU Extension information on wheat and barley production and marketing. The project also supported the development of several decision support tools and calculators that help growers make more informed production and marketing decisions. Some noteworthy new content for the Wheat and Small Grains website in 2015 included the Soil Acidification Implications for Management page, the Grain Growing Degree Calculator, the Wheat and Barley Insect Pest Surveys, an updated Marketing and Economics page with interactive market tools, and a Facebook page.

In addition to the website, the project supplemented registration fees to support the inaugural 2014 and 2015 Wheat Academies. In very short order, the Wheat Academy has become the educational event that Washington wheat and barley growers and crop consultants want to attend. The Wheat Academy was held on the WSU Pullman Campus on December 15 and 16. Attendance was limited to 75 people, up from 60 people in 2014, in order to keep class size small enough to allow for good hands-on activities. Within three weeks of opening registration on September 1, the Academy was full. These and other educational activities will be ongoing and will continue in some fashion, partially dependent on extramural funding, into the future.

Impact: For the six months ending September 30, 2015 the Wheat and Small Grains website had 8,672 sessions with 5,022 unique users. They viewed 19,199 pages and had an average session length of 2 minutes and 12 seconds. This is nearly a two-fold increase from the same time period from the previous year, which saw 4,481 sessions with 2,355 unique users. Additionally, the inaugural Wheat Academy was held on the WSU Pullman Campus in December, 2014. Attendance was limited to 60 people in order to keep class size small enough to allow for good hands-on activities. In August of 2015, a survey was sent to people who had attended the Inaugural Wheat Academy in December of 2014 to determine if they had increased their knowledge in the various topic areas addressed and if they had applied this new knowledge during the 2015 growing season. Those indicating that they agreed or strongly agreed to an increase in knowledge ranged from a low of 77% to a high of 100%, depending on the topic. Those indicating that they had used the knowledge gained in a topic during the 2015 growing season ranged from a low of 50% for on-farm testing to a high of 95% for soil/herbicide interactions.

WGC project number: 4150-1222
WGC project title: Extension Education for Wheat and Barley Growers
Project PI(s): Drew Lyon,
Project initiation date: July 1, 2013
Project year: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
Form Dryland Cropping Systems Extension Team	An active team focused on developing educational programming for dryland cropping systems in eastern Washington.	The team has been formed, meets regularly, and is actively planning educational programs.	The team was formed and began active planning in the summer of 2013.	Team members continue to provide educational programming as they have in the past, but are now delivering major programs under the banner of "Wheat Academy".
Develop dynamic, research-based decision support tools	Decision support tools.	Six tools are currently available on the Small Grains Website: 1) Variety Selection Tool, 2) Nitrogen Application Calculator, 3) Post-Harvest Nitrogen Calculator, 4) Spring Wheat Yield Calculator, 5) Interactive Market Tools, and 6) Grain Growing Degree Calculator. New tools proposed for development in 2016 include herbicide efficacy tables, a spray water quality tool, and an ag lime calculator.	The six identified decision support tools are currently available for public use from the Small Grains Website. We plan to have two to four new tools available on the website by the end of 2016.	The currently available decision support tools are being promoted at Extension meetings and field days, as well as through news releases and in Wheat Life magazine.
Develop enhanced, dynamic (video, audio, etc.) forms of information delivery	Enhanced dynamic information delivery	Timely Topics are regularly posted to the Small Grains Website and cover topics of current interest. Ten short videos were created at the Crop Diagnostic Clinic in July and these are available at the website. A series of three 5-minute videos on soil acidification are under development and should be avialable on the website in 2016.	We plan to develop quizzes, forums, additional videos, and possibly voiced-over Power Point presentations in 2016.	New dynamic products will be announced via Timely Topics on the website as well as at various Extension meetings and through news releases.
Develop in-depth virtual and live educational programs under the banner of "Wheat Academy"	In-depth educational programs.	The Wheat Academy was held in December of 2014 and 2015 in the Vogel Plant Biosciences Building on the WSU campus. The event has quickly become the premier educational event for growers and crop consultants.	We are considering ways to make this educational event available to more people in the future without lowering the quality of the educational experience. This very succesful event will continue into the foreseeable future.	The Small Grains Website will be mentioned at most Extension meetings. The Crop Diagnostic Clinic, when held, and the Wheat Academy School will be advertised and discussed on the Small Grains Website, in news releases, at field days and tours, through mailers, and in Wheat Life magazine.

Washington Grain Commission
Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: 4721

Progress Report Year: *3 of 3*

Title: Quality of Varieties & Pre-release Lines: Genotype & Environment-"G&E" Study

Cooperators: Ryan Higginbotham, Kim Garland-Campbell, Arron Carter, Mike Pumphrey

Executive summary: The 2013 and 2014 crop samples are complete; the 2015 harvest sample analysis is nearly complete. As in previous years, all quality data are analyzed using the *t*-Score statistic. The quality *t*-Scores for each spring hard red, hard white, soft white common and club varieties, and winter hard red, hard white, soft white common and club varieties are summarized using 'Grain', 'Milling', 'End-Product', and 'Overall' Scores. Varieties in each market class/sub-class are then ranked by the Overall Score. All varieties and advanced breeding lines with three or more years of data are included in the final listing. We will meet with regional cereal quality experts at the PNW Wheat Quality Council meeting to discuss new entries for the Preferred Variety pamphlet.

Using these results and analyses, the WWQL works closely with the WGC to develop the, *"Preferred WHEAT VARIETIES for Washington based on end-use quality"*. Completion of the spring wheat pamphlet in February represents the first significant accomplishment. We coordinate variety classification with Oregon and Idaho.

Impact: This 'G&E' project provides value to growers in two significant ways: First, it documents and highlights the quality of varieties so that growers are aware of the importance of quality and will hopefully include quality in their seed-buying decisions. Data are objective "head-to-head" results on Private and Public varieties. Secondly, the data generated by the G&E study supports in a major way the analysis of new breeding lines and the WSU Variety Release process. This program is also "highly visible" such that good end-use quality is reinforced as a priority in both private and public breeding programs throughout the region.

Outputs and Outcomes:

A. Progress: The third year of G&E samples are in the process of being completed. Complete milling and baking data are subjected to statistical analysis to generate, 1) direct comparisons with one or more checks to be used in WSU Cereal Variety Release packets. These analyses provide the breeder and the Committee an objective basis upon which to make release decisions, and 2) *t*-Scores are used to evaluate advanced and newly released varieties and provide rankings for the Preferred Variety pamphlet. This pamphlet has been highly successful in communicating to growers the relative quality of varieties and emphasized the importance of choosing better quality varieties to plant on their farms.

WGC project number: 4721

WGC project title: **Quality of Varieties & Pre-release Lines: Genotype & Environment – "G&E" Study**

Project PI(s): Craig F. Morris

Project initiation date: 1-Jul-16

Project year (X of 3-yr cycle): 1 of 3 year cycle

Objective	Deliverable	Progress	Timeline	Communication
Obtain statistically robust analysis of end-use quality of advanced breeding lines to support WSU variety release packets	Statistical analysis of experimental line versus one or more checks for each of the important end-use quality traits.	Analyses are provided for Preliminary Seed Increase and Full Release proposals when requested by the breeders	As requested, prepared for WSU Cereal Variety Release meeting (typically February)	Communication with breeder and WSU Cereal Variety Release Committee
Obtain statistical t-Scores on advanced and recently released lines to provide ranking for the Preferred Variety pamphlet	Individual t-Scores, summary t-Scores for Grain, Milling and Baking, and an overall ranking in the pamphlet	Analyses and statistics are generated early in the calendar year; the regional cereal quality leaders meet at the PNW Wheat Quality Council to discuss rankings	Preliminary scores are ready for discussion at the PNW WQC meeting	New entries are provided to the WGC for each year's new Preferred Variety pamphlet
	Wheat Life article			

Washington Grain Commission
Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: 4722

Progress Report Year: *3 of 3*

Title: Supplemental Support for Assessing the Quality of Washington Wheat Breeding Samples

Cooperators: Kim Garland-Campbell, Arron Carter, Mike Pumphrey

Executive summary: This WGC support provides for about 3 months of technician time. The additional work is devoted to evaluating breeder samples for quality from late October through mid-January.

During this period, spring wheat samples are given priority over winter wheat samples. The aim is to coordinate with the WSU Wheat Quality Program, and complete as many analyses as possible before spring planting decisions in early February. In this way, the spring wheat program is made more efficient because inferior quality lines are not planted and grown. The standing goal for WSU winter wheat breeding lines is to complete as many as possible before June 1. The extra personnel helps us meet this goal. Milling and baking evaluations of the 2014-Crop were completed and 2015-Crop testing is well under way at the Western Wheat Quality Lab.

We provide breeders with SKCS single kernel size, weight, and hardness, and the variability (SD) of each; grain protein, test weight, flour yield, break flour yield, milling score, flour ash and protein, dough mixing time and type, dough water absorption, Solvent Retention Capacity (SRC) Lactic Acid, Sucrose and Carbonate; SDS Sedimentation, cookie diameter and score, bread volume and score, sponge cake volume, and RVA (Rapid Visco Analyzer) peak pasting viscosity or Flour Swelling Volume (FSV) (RVA and FSV are for starch quality).

Impact: This work contributes directly to WSU and ARS variety development and release. New varieties need to be fully evaluated for end-use quality so that our customers can purchase predictable, high quality Washington wheat.

Outputs and Outcomes:
The Western Wheat Quality Lab has been analyzing over 4,000 breeding samples a year for complete milling and baking analyses. Obviously from these only the “best of the best” are suitable to release to growers. We work closely with breeders and try and provide them the very best, accurate and timely end-use quality data; we also provide discussions and interpretations so that the data are used in the most effective means possible.

WGC project number: 4722

WGC project title: **Supplemental Support for Assessing the Quality of Washington Wheat Breeding Samples**

Project PI(s): Craig F. Morris

Project initiation date: 1-Jul-16

Project year (X of 3-yr cycle): 1 of 3 year cycle

Objective	Deliverable	Progress	Timeline	Communication
Provide end-use quality analyses on a greater number of samples in a more timely manner	Full array of end-use quality (milling, flour and baking) analyses	This work is ongoing; we have made good progress on the 2015-crop samples	All samples are completed before early summer	Data are provided directly to the breeders so that they can make their selections
	Wheat Life article			

Washington Grain Commission: Barley Research Annual Progress Report

Project #: 3019-3009
Progress Report Year: Year 2 of 3
Title: Improving Barley Varieties for Feed, Food and Malt
Project PI: Kevin Murphy; **Cooperators:** Janet Matanguihan, Max Wood, Sachin Rustgi, Ryan Higginbotham, Xainming Chen, Deven See

Executive Summary: Significant strides were made in 2015 within each market class – feed, malting, and food – of barley. One major accomplishment in 2015 was the successful release and continued success of one new, hulless, two-row, spring ***food barley*** variety, Havener (09WA-265.5). Havener is the first hulless food barley release by the WSU Barley Breeding Program and addresses a need for higher yielding hulless varieties with an elevated β-glucan (a heart-healthy soluble dietary fiber) content. Developed specifically for human consumption, Havener contains 50 to 75% higher β-glucan than common Washington-grown varieties Lyon, Muir, Champion, Bob and Baronesse. Havener has higher yields and test weights across all eastern Washington rainfall zones than the hulless variety Meresse. Our continued field trials of the imidazolinone (IMI) ***herbicide tolerant feed barley*** germplasm also showed promise. We submitted five advanced IMI-tolerant spring barley lines in the Bob background to the WSU Variety Testing Program. In the Intermediate Precipitation Zone (16-20”), four of the top five experimental lines (out of 18 total) were our IMI-tolerant lines. Though they were all lower yielding than Lyon, the highest yielding variety across all five locations in the 16-20” precipitation zone, two of the five lines showed higher average yields than Champion and Baronesse. In the high rainfall zone location of Farmington, the top IMI-tolerant line was ranked third for yield among all 36 entries, and was statistically equal to the top two entries for yield. We currently have our top two IMI-tolerant lines growing (~1500 headrows each) in our winter breeding nurseries for purification and increase. Our intent is to submit one or both of these for pre-release in the winter Variety Release Committee meeting. Our continued breeding efforts for an IMI-tolerant spring barley include the development of hundreds of advanced feed, food and malt lines through extensive crossing and utilization of double haploid technology when appropriate to speed the breeding process. Our backcross and topcross lines show promise and will be the focus of our breeding program to expedite a release of an IMI-tolerant barley variety in the near future. Finally, low protein, high-yielding breeding lines that showed excellent potential for future release of ***malting barley*** lines were identified. Several high yielding breeding lines had low protein (6.3 to 9.5%) and significantly higher yields than both Champion and Baronesse and are currently being tested for malting quality traits.

Impact: As a newly released variety, Havener has yet to impact the market, however, due to its enhanced β-glucan contend and increased yield for a hulless barley, farmers and distributors have shown interest in the cultivation of Havener. Prices for food barley are often $70/ton higher than feed barley and $20/ton higher than malting barley. Seed of Havener is anticipated to be available from Washington State Crop Improvement Association (WSCIA) on a limited basis in 2017 (a 2014 hailstorm delayed seed availability by one year). Additionally, at present, considerable winter wheat acreage is devoted to the planting of IMI-resistant varieties, which severely hinders spring barley production due to residual herbicide damage and associated plant back restrictions. Our herbicide resistant breeding lines with the potential for varietal release in the near future would have a significant positive impact on barley acreage and production.

Outputs and Outcomes:

Objective	Deliverable	Progress	Timeline	Communication
Objective 1. Continue to develop and release high yielding, spring, two-row feed barley varieties with improved disease resistance, high protein and test weight, and excellent agronomic characteristics.	Development of disease resistant and high yielding feed barley varieties designed to improve upon Lyon and Muir continues to progress. Anticipate the pre-release of a feed barley breeding line in 2017.	Muir and Lyon continue to perform well. Lyon topped the 5-location Intermediate Precipitation Zone for yield in 2015 and Muir continues to perform well in low rainfall locations and sets the standard for stripe rust resistance. Experimental lines in our breeding program show improvements over these two varieties in terms of yield, test weight and protein content, and show excellent promise for future release.	2017	Talks and presentations at multiple field days; distribution of informative variety rack cards.
Objective 2. Continue to expedite the development and future release of barley varieties that are highly tolerant to the imidazolinone (IMI) herbicides used in winter wheat production.	Pre-release of two IMI-resistant barley varieties during the 2016 winter Variety Release Proposal Committee Meeting. Full release of at least one IMI-barley variety the following year.	Excellent progress is being made on this front. Our 5 IMI-tolerant lines in WSU variety testing performed very well and two of these lines are currently being purified and increased in our winter nurseries. Our goal is to pre-release one or both of these lines	2016-2017	Talks and presentations at multiple field days.

		in winter 2016 and fast-track their progress to expedite a full release and seed availability by spring 2017. A PVP is also being pursued at this point and will be submitted in March 2016.		
Objective 3. Capitalize on the leveraged funding from the American Malting Barley Association (AMBA) for malting barley research by focusing on the development of varieties that set new standards for malting quality.	a) Development of malting quality genetics; b)Potential release of a malting barley cultivar	We are currently in our final year of phenotyping and genotyping over 600 breeding lines for malting quality traits using genome wide association mapping. Results are expected in the spring/summer of 2016. This will be beneficial for the identification and use of markers to select for malting quality traits for both all-malt and adjunct malt market classes.	2016-2017	Talks and presentations at multiple field days, including the inagural 'Know Barley Know Beer' field and brewery day with farmers, brewers, breeders and maltsters. Wheat life article.
Objective 4. Evaluate, select and develop high-yielding, hulless, heart-healthy food barley varieties with elevated levels of beta glucan, protein, test weight, minerals and antioxidants.	2015 release of a hulless food barley, Havener, with significantly higher beta glucan, protein and test weight compared to hulled feed varieties and higher yields and test weight than other hulless varieties.	The food barley market class is in its infancy and very small compared to the malt and feed market classes. We will continue to develop hulless food barley varieties, but with our recent release, this is a low priority. We will	2016-2017	Talks and presentations at multiple field days, development of a rack card for Havener. Wheat life article.

		continue to test over 600 lines each year for beta glucan and are currently conducting a genome wide association study for beta glucan content.		

Annual Report

Project #: 4674

Progress Report Year: 3 of 3

Title: Control of Strawbreaker Foot Rot (Eyespot) and Cephalosporium Stripe in Winter Wheat

Cooperators: T. D. Murray, Plant Pathologist
A. Carter, Crop & Soil Sciences, WSU
K. Garland-Campbell, USDA-ARS

Executive summary: In 2015, data on the resistance of 40 and 45 winter wheat varieties and advanced breeding lines to eyespot and Cephalosporium stripe, respectively, was determined under field conditions. This brings the total number of lines tested for resistance to these diseases during this project to 120. This is the only program where new varieties and advanced selections from all PNW wheat breeding programs, public and private, are compared head-to-head against these diseases. Summaries of these experiments are provided to all breeders who contribute entries and made available through the WSU Wheat and Small Grains Extension website (smallgrains.wsu.edu), and the data generated from these plots is used to provide relative disease ratings in the Washington State Crop Improvement Association Seed Buyers Guide, which is revised annually.

A total of three field studies (2 in 2015 and 1 in 2013) were conducted to determine the effectiveness of registered fungicides for eyespot control. During the past 5 years, two new products were registered for eyespot control and it’s important to collect data under a range of field conditions to determine their effectiveness.

Work to transfer four new eyespot resistance genes identified in a wheat relative was begun during this project, but not completed. These genes must be transferred into a PNW-adapted wheat background and field tested to determine how effective and useful they will be in variety development. This is a long term objective and limited progress was made in transferring the genes because of personnel changes and other objectives that were considered a higher priority.

A postdoctoral scientist was hired to extend previous research on genetic variation in the Cephalosporium stripe pathogen and specifically to identify useful molecular markers. After some initial studies, we decided the most cost-effective approach was to sequence the entire genome of *C. gramineum*, which has been completed. Data analysis is in progress now to identify useful molecular markers. A set of molecular markers was identified for the eyespot fungus *O.*

yallundae that will be useful in studies of genetic variation. Work is underway to identify similar markers in the other eyespot fungus, *O. acuformis*.

Impact: The most significant and measurable impacts this project has had during this funding cycle is the evaluation of over 120 advanced selections and new varieties for their resistance to eyespot and Cephalosporium stripe. Data on variety performance under disease pressure is critical to farmers and field consultants in making decisions about which varieties to grow, and to breeders in making decisions about which selections to advance or discard. The information collected in these studies is used in the Crop Improvement Seed Buyer's Guide, which is distributed widely. Although eyespot and Cephalosporium stripe are targets in all winter wheat breeding programs in the PNW, this is the only opportunity for varieties developed for production in Washington to be evaluated and compared head-to-head. Another measurable impact during this project has been evaluation of foliar fungicides for efficacy in controlling eyespot. Although fungicide use for eyespot control has decreased over the years, there is still a substantial acreage that is treated each year. No other program in the PNW is testing foliar fungicides for control of eyespot. Such information is useful to growers and field consultants in deciding which fungicides to use.

Currently, the gene present in Madsen is the primary source of resistance in all other eyespot-resistant varieties. The new genes identified for eyespot resistance have potential to further reduce losses to this disease and broaden the genetic base of resistance available to breeders. Developing a better understanding of genetic variation in the eyespot and Cephalosporium stripe pathogens is a long-term goal that will help insure resistance genes remain stable and effective.

Results of all studies generated in this project are communicated to farmers and field consultants directly at field days and other meetings, publications such as Wheat Life and the Wheat and WSU Small Grains extension website, and to other scientists directly and through publication in appropriate journals.

WGC project number: 4674
WGC project title: Control of Strawbreaker Foot Rot (Eyespot) and Cephalosporium Stripe in Winter Wheat
Project PI(s): T. Murray, S. Hulbert, A. Carter, K. Garland-Campbell
Project initiation date: July 2013
Project year: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
To evaluate effectiveness of resistance to eyespot and Cephalosporium in advanced breeding lines and varieties in field plots.	Develop a better understanding of how existing and potential new varieties respond to each of these diseases and provide a direct comparison of variety performance under disease pressure. Provide an unbiased comparison of existing and new varieties relative to their reaction to these diseases.	**2015:** Two field studies with 40 and 45 entries were were conducted on research farms near Pullman for evaluation of resistance to eyespot and Cephalosporium stripe respectively. Emergence in both plots was very good and disease and yield data were collected on both plots. Field plots for 2015-16 were planted; emergence was also very good and both plots were inoculated in fall 2015. Data will be collected, summarized and published in 2016. **2014:** Two field studies with 40 entries each were conducted on research farms near Pullman. Emergence of the eyespot trial in fall 2013 was uneven and therefore only data on disease severity were collected; both disease and yield data were collected from the Cephalosporium plot. Field plots for 2014-15 were planted and inoculated in Fall 2014. Emergence for both plots was good and both were inoculated in Fall 2015. Data will be collected, summarized and published in 2015. **2013:** Two field studies with about 40 entries each were conducted on research farms near Pullman. Data on disease severity and yield were collected from eyespot and Cephalosporium plots in summer 2013, summarized and analyzed. Field plots for 2013-14 were planted and inoculated in	This work will be completed each year of the project. First and second year plots have been completed and third year plots have been planted and inoculated.	Results of these plots were presented at field days and other talks to grower and industry groups. Two technical reports were published and will be posted on the WSU Wheat and Small Grains website. **Presentations**: **2015:** Outlook for eyespot, Cephalosporium stripe, stripe rust and other diseases in small grains. WSU Extension, Northern Lincoln County Field Tour, Creston, June 23, Fairfield, June 16, Dusty, June 4, Ritzville, June 3, and Dayton May 20, 2015. Biology and control of eyespot disease. WSU Weed Science Tour, Pullman, WA, June 17, 2015. **2014:** Resistance to eyespot in wheat and its wild relatives. University of Minnesota, Dept. of Plant Pathology seminar, April 18, 2014. Outlook for stripe rust and other diseases in small grains. WSU Extension, Variety Testing Field Tour, Farmington, St. John, and Lamont, WA, July 16, 2014. Diagnosis and control of eyespot and Cephalosporium stripe of winter wheat. WSU Extension, Crop Diagnostic Clinic, Pullman, WA, June 26, 2014.

		Fall 2013. Emergence for the Cephalosporium plot was good, but variable for the eyespot plot due to heavy rain after seeding. Data will be collected, summarized and published in 2014.		Outlook for stripe rust and other diseases in small grains. WSU Extension, Variety Testing Field Tour, Walla Walla, WA, June 25, 2014. **Technical publications**: **2015:** Wetzel III, H.C. and T.D. Murray. 2015. Reaction of winter wheat cultivars and breeding lines to Cephalosporium stripe, 2014. Plant Disease Management Reports 9:CF013. **2014:** Wetzel III, H.C. and T.D. Murray. 2014. Reaction of winter wheat cultivars and breeding lines to Cephalosporium stripe, 2013. Plant Disease Management Reports 8:CF002. Wetzel III, H.C. and T.D. Murray. 2014. Reaction of winter wheat cultivars and breeding lines to eyespot, 2013. Plant Disease Management Reports 8:CF010. **2013:** Wetzel III, H.C. and T.D. Murray. 2013. Reaction of winter wheat cultivars and breeding lines to Cephalosporium stripe, 2012. Plant Disease Management Report 7:CF021. Wetzel III, H.C. and T.D. Murray. 2013. Reaction of winter wheat cultivars and breeding lines to eyespot, 2012. Plant Disease Management Report 7:CF004.
	Prepare an article for Wheat Life during the three-year project summarizing results to date.	**2015:** No progress **2014:** None to date	An article will be submitted in late 2015 or 2016.	
To transfer genes for eyespot and Cephalosporium stripe resistance from wild relatives to new varieties by identifying molecular markers for these genes.	Increase the number of resistance genes available to breeding programs with the ultimate goal of improving the effectiveness of resistance to these diseases.	**2015:** This objective was put on hold in favor of other priorities (seed transmission). **2014:** The student who conducted this work has returned to the lab as lab manager and is in the process of restarting the work; consequently, little progress was made toward this objective in 2014. **2013:** Crosses were made in the greenhouse beginning in 2012 to transfer newly identified eyespot resistance QTL to PNW-adapted winter wheat varieties. Progeny were being developed and advanced until the work was interupted in 2013 when the postdoctoral scientist left for another position.	This is a long-term goal that will be ongoing during this project.	Although there was no new activity on this objective in 2015, results of previous work were discussed at field days and other talks to grower and industry groups. **Journal articles published:** **2015:** Sheng, H., K. Klos, Z. Sexton and T.D. Murray. 2015. High-throughput single seed detection of *Cephalosporium gramineum* in wheat. Phytopathology [IN PRESS]. **2014:** Sheng, H., D.R. See, and T.D. Murray. 2014. Mapping resistance genes for *Oculimacula acuformis* in *Aegilops longissima* . Theoretical and Applied Genetics 127:2085-2093. **2013:** Sheng, H. and T.D. Murray. 2013. Identifying new sources of resistance to eyespot of wheat in Aegilops longissima. Plant Disease 97:346-353, doi: 10.1094/PDIS-12-11-1048-RE. Esvelt Klos, K., H. Wetzel III, and T.D. Murray. 2013. Resistance to *Oculimacula yallundae* and *Oculimacula acuformis* is conferred by *Pch2* in wheat. Plant Pathology, 63:400-404.

To insure effective fungicides for eyespot remain available by evaluating new fungicides in field plots.	Develop data that will help bring new, more effective fungicides into the marketplace by testing fungicides registered in Europe and experimental fungicides for their effectiveness in controlling eyespot in field plots.	**2015:** Foliar fungicide studies were conducted in field plots near Ralston and Dayton, WA. Each plot included the three registered fungicide treatments and a control. Priaxor, the most recently registered material, provided significantly better disease control but not a corresponding yield increase. **2014:** Fungicide studies were not conducted in 2014 due to lack of industry interest. **2013:** A field study was conducted with six treatments including the currently registered product and three other non-registered products in an inoculated plot on the plant pathology farm. One product, Priaxor,	Testing will be completed during each year of the project given industry interest and support.	Results of studies conducted in 2015 were presented in talks to grower and industry groups. **Technical article**: **2014:** Wetzel III, H.C. and T.D. Murray. 2014. Evaluation of fungicides to control eyespot in winter wheat in Washington, 2013. Plant Disease Management Reports 8:CF009. **2013:** Wetzel III, H.C. and T.D. Murray. 2013. Evaluation of fungicides to control eyespot in winter wheat, 2012. Plant Disease Management Reports 7:CF003.
To insure resistance genes for eyespot and Cephalosporium stripe remain effective by evaluating pathogen populations for pathogenic specialization.	Increase knowledge about genetic variation in these pathogens and their potential to overcome resistance genes by evaluating pathogen isolates collected from commercial fields in the PNW for genetic variation using molecular and microbiological methods.	**2015:** The genomes of *C. gramineum* and *Oculimacula yallundae* were sequenced and are being annotated. Data from the *O. yallundae* genome was mined to identify microsattelite markers that will be used in population genetic studies. Additional molecular analyses were conducted on *C. gramineum* to determine the amount of genetic variation present and the mating system. Data from the *C. gramineum* genome is being used to develop molecular markers for population genetic studies. **2014:** A postdoctoral scientist was hired and began work in April 2014. She has conducted studies examining genetic variation in three different genomic regions and found limited variation. We are currently preparing to have the genome sequenced to develop a dataset reflective of the entire genome that can be mined for useful molecular markers to advance these studies. **2013:** A study of genetic diversity in the Cephalsporium stripe pathogen based on cultural characteristics and molecular markers was completed and a paper written. Additional work is needed to fully understand genetic variation in this pathogen, but the postdoctoral scientist working on this project left to take another position. Another person has been hired	This research will be ongoing throughout the project.	Results of this work will be presented to grower, industry, and scientific audiences, published in appropriate scientific, popular and industry journals and posted on the WSU Wheat and Small Grains website. **Poster presentation:** **2014:** Klos, K.E., J.G. Evans and T.D. Murray. 2014. Genetic and phenotypic variation among, *Cephalosporium gramineum* isolates collected in the Pacific Northwest United States. Phytopathology 104(11S):S3.38. **Article in preparation:** **2015:** Esvelt Klos, D. Wafai Baaj, J.G.Evans, and T.D. Murray. 2016. Genetic and phenotypic variation among *Cephalosporium gramineum* isolates collected in the Pacific Northwest region of the United States. Phytopathology
		for this project and will begin working in April 2014.		

Progress Report

Project #: 3674

Progress Report Year: 3 of 3

Title: Enhancing Resistance to Snow Mold Diseases in Winter Wheat

Cooperators:
T. Murray, Plant Pathologist, WSU
A. Carter, Crop & Soil Sciences, WSU
D. Skinner, USDA-ARS, Pullman, WA
J. Marshall, PSES, University of Idaho

Executive summary: Development of snow mold in field plots is not predictable and doesn't occur every year in Washington. Consequently, we expanded the number of locations in Washington and began collaborating with Dr. Juliet Marshall, plant pathologist with the University of Idaho at Idaho Falls, to begin field testing at the Tetonia Research Center in southeastern Idaho. In 2013, field plots were established at three locations, two in WA near Waterville and Mansfield, and another in ID near Tetonia, to test populations from the cross Münstertaler (highly resistant) x Xerpha (susceptible) and Finch x Eltan for resistance to snow mold. A third site in Douglas County, WA was added in 2014, and both populations were planted at all locations. Three QTL and associated makers were identified in the Finch x Eltan population, and data from the Münstertaler x Xerpha population is being analyzed.

Three new doubled-haploid populations were developed between a new source of resistance, PI 173438, and PNW-adapted lines to expand the diversity of resistance genes. These populations will be field-tested beginning in 2016.

Several experiments were conducted to scale-up growth chamber testing for snow mold resistance so it can be used to screen large numbers of plants for resistance in controlled environment conditions, but results were disappointing. Consequently, graduate student Erika Kruse was recruited to work on this project. The focus of her project is both genetic and physiological, and specifically to identify QTL associated with cold-hardening and snow mold resistance, and to understand the role of fructan (a carbohydrate) metabolism in snow mold resistance. Field plots were established on Spillman farm in 2014 and 2015 to collect wheat samples and analyze them for fructan content. Studies are in progress and information gained from them will be used to improve growth chamber screening for resistance. Although we don't expect controlled environment testing to replace field testing, it will allow us to make progress on genetic studies throughout the year and eliminate very susceptible lines from field testing.

Impact:

One of the most significant and measurable impacts during this funding cycle has been the expansion of field testing within Douglas County, to three sites, and in Tetonia, ID. Snow mold developed in at least one location each year, which resulted in us being able to complete testing the Finch x Eltan and Münstertaler x Xerpha populations for snow mold resistance. New QTL and molecular markers were identified in the Finch x Eltan population, which should be useful to breeding programs.

Another measurable impact is the development of three new genetic populations with a new source of snow mold resistance with PNW-adapted lines that have potential for new resistant varieties and introduction of a new source of snow mold resistance.

Successful completion of these objectives will provide growers with a greater selection of adapted, high-yielding snow mold-resistant varieties from which to choose and the development cycle will be shorter compared to the conventional methods now used. In addition, data on variety performance under snow mold conditions is useful to farmers and field consultants in making decisions about which varieties to grow. Results generated in this project are communicated to farmers and field consultants at field days, other meetings, and publications such as Wheat Life. Results are communicated to other scientists directly and through publication in appropriate journals.

WGC project number: 3674
WGC project title: Enhancing Resistance to Snow Mold Diseases in Winter Wheat
Project PI(s): T.D. Murray
Project initiation date: 2013
Project year: 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Complete field screening of a population with new snow mold resistance genes transferred from the variety Münstertaler into Xerpha.	Test mapping populations, advanced breeding lines, and varieties under field conditions to determine their resistance to snow mold diseases.	**2015:** Field plots were planted near Mansfield and Waterville, WA and Tetonia, ID. Snowmold developed in Tetonia and in one of the Douglas County plots, which allowed us to complete field screening of the Münstertaler x Xerpha population with new snow mold resistance genes. Data analysis is in progress to identify the genes and associated molecular markers. We attempted to find another location for field testing near McCall, ID in conjunction with University of Idaho Extension personnel, but were unsuccessful. **2014:** Field plots were planted near Waterville and Mansfield, WA and Tetonia, ID in fall 2013. Not enough snow mold developed near Waterville for useful data; although snow mold was not severe near Tetonia, enough disease developed to be useful. Three field plots were planted Douglas County, two near Mansfield and one near Waterville, and one in Tetoniain fall 2014 with the same and new material for evaluation in 2015. We identified a potential farmer cooperator near McCall, ID, but were not able to establish a plot in fall 2014; we will try again in 2015. **2013:** Field plots were planted near Waterville, WA and Tetonia, ID in fall 2012. Snow mold developed at both locations and survival notes were taken in spring 2013. The data have been summarized and are being analyzed now. Field plots were planted again near these locations with the same and new material for evaluation in 2014.	Field testing will be conducted in each year of this proposal with the goal to identify another location for field testing in fall 2015.	Results of this work was presented at field days, other grower and industry talks, and on the WSU Wheat and Small Grains website. **Presentations:** **2014:** Eyespot, snow mold, stripe rust, and stem rust diseases of wheat. Wilbur-Ellis Growers Meeting, Odessa, WA, January 17, 2014. **Field Day abstracts**: **2015:** Murray, T., H. Sheng, Z. Sexton, and S. Koberstein. 2015. Eyespot, Cephalosporium Stripe, Snow Mold, and Soilborne Wheat Mosaic Diseases of Winter Wheat. Washington State University, Dept. of Crop and Soil Sciences Technical Report 15-1, p. 52. **2014:** Murray, T., H. Wetzel III, H. Sheng, D. Vera, and S. Koberstein. 2014. Eyespot, Cephalosporium Stripe, Snow Mold, and Soilborne Wheat Mosaic Diseases of Winter Wheat. Washington State University, Dept. of Crop and Soil Sciences Technical Report 14-1. **2013:** Murray, T., H. Wetzel III, and D. Vera. 2013. Eyespot, Cephalosporium Stripe, Snow Mold, and Soilborne Wheat Mosaic Diseases of Winter Wheat. Washington State University, Dept. of Crop and Soil Sciences Technical Report 13-1.
2. Identify molecular markers associated with snowmold resistance from Eltan using the Finch x Eltan mapping population.	Molecular markers that can be used in marker-assisted-selection to transfer snow mold resistance genes.	**2015:** Three QTL for snow mold resistance resistance and associated molecular markers were identified in a Finch x Eltan population . **2014:** Data from the Tetonia field plot were analyzed and used to confirm the location of QTL in the Finch x Eltan population. Growth chamber testing was planned for 2015, but a useful test is needed (see below). **2013:** Crosses were made and populations developed in the greenhouse. Plants were field-tested once with no useful results and planted again in 2012 at two locations.	Growth chamber testing of these populations will occur during 2014-15.	Results will be published in appropriate journals and communicated directly to breeders.

	Prepare an article for Wheat Life during the three-year project summarizing results to date.	**2015:** Article was published in the March issue of Wheat Life **2014:** Article is in preparation now.	An article will be submitted in February 2015	Murray, T.D. 2015. Speeding up snow mold research. Wheat Life 58(03):66-69.
3. Identify markers from PI 173438 using "Genotyping by Sequencing" and transfer this resistance into new varieties.	Molecular markers that can be used in marker-assisted-selection to transfer snow mold resistance genes.	**2015:** Three doubled-haploid populations were developed between a new source of snow mold resistance (PI 173438) and lines adapted to Washington production (WA8315, WA8137, and Farnum). Seed increase is underway in anticipation of planting these populations in the field in August 2016. **2014:** Development of doubled-haploid populations continued in the greenhouse and will be available in 2015 for genotyping, and field and greenhouse testing. **2013:** Initial crosses were made in the greenhouse and development of the doubled-haploid plants is in progress.	Doubled-haploid plants will be produced during 2013-14 and GBS will be conducted during 2015. Field and greenhouse screening will be conducted in 2015. Marker associations will be analyzed once phenotyping is completed.	Results of this work are presented at field days, and other grower and industry talks. When completed, results will be published in Wheat Life, scientific journals, and the WSU Wheat and Small Grains website.
4. Establish protocols for screening large numbers of breeding lines for snow mold resistance under controlled environment conditions.	Methods of screening for snow mold resistance in growth chambers. Data on variety reaction.	**2015**: This objective was put on hold in favor of objective 5 in an effort to develop a better understanding of cold-hardening. Experiments are planned for early 2016 to correlate field accumulation of fructans with accumulation under growth chamber conditions. **2014:** Three experiment were conducted to optimize large-scale testing of germplasm for snow mold resistance in the growth chamber. Results have been disappointing and we are reassessing how to proceed with this objective. **2013:** Four experiments were conducted to identify the best methods for testing large numbers of plants for resistance to snow mold in growth chambers based on previous research. Unfortunately, growth chamber space was not available	Growth chamber testing will occur during each year of this project.	Results of this work are presented at field days, and other grower and industry talks. When completed, results will be published in Wheat Life, scientific journals, and the WSU Wheat and Small Grains website.
5. Measure fructan concentrations in breeding populations and identify genes involved in its production to determine its association with resistance.	Methods and data that can be used to screen breeding populations efficiently and determine whether fructan accumulation can be used to indirectly select for resistance to snow mold diseases.	**2015:** Initial field collections were sampled for fructan analysis. Methods are being standardized to complete this analysis. Once methods are established, fructan concentrations will continue to be evaluated in 2016 from both field and greenhouse screening. **2014:** A graduate student was recruited to join the program with the goal of examing carbohydrate accumulation in relation to snow mold resistance. She is becoming familiar with the disease and has established field plots on Spillman farm to collect winter wheat plant samples during cold-hardening on which fructan accumulation will be measured.	This research will continue for the duration of the project.	Results of this work are presented at field days, and other grower and industry talks. When completed, results will be published in Wheat Life, scientific journals, and the WSU Wheat and Small Grains website.

Washington Grain Commission
Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: 3019-4548

Progress Report Year: 1 of 3

Title: Pre-breeding for Root Rot Resistance

Researchers: Scot Hulbert, Pat Okubara

Cooperators: Timothy Paulitz, Deven See

Executive summary:

Rhizoctonia solani AG8 and *R. oryzae*, soilborne fungal pathogens of wheat and crops used in rotation with wheat, causes root rot, stunting and bare patch. Rhizoctonia root rot is one, but not the only disease causing green bridge problems in spring cereals in the PNW. The aim of this project is to characterize resistance or tolerance to Rhizoctonia and other greenbridge-promoted diseases identified from several synthetic wheat lines and transfer the resistance to the cultivar Louise. The cultivar Louise was selected because it has a relatively good root system already, and enhancing its resistance to Rhizoctonia would create a valuable germplasm asset for the breeding programs. It is also already a popular cultivar and we could perform roughly nine generations in three years by using a spring wheat. The resistances are controlled by the additive effects of several genes in each of the sources of resistance, so backcrossing the resistance to adapted germplasm takes many more generations than backcrossing a single gene trait, like many of the rust resistance genes used in the breeding programs. After each cross to Louise, the progeny lines are advanced 3-4 generations under selection for resistance to try to collect and maintain all of the genes from the resistant parent. In addition, the sources of resistance were *synthetic* lines; artificially generated by combining the genomes of AB and D wheats (Table 1) to reconstruct the bread wheat genome. Thus, the original sources were all poorly adapted to the PNW and still exhibited some of the wild characteristics of the AB and D genome parents, (e.g. difficult threshing). We felt that at least three crosses to an adapted cultivar would be required to develop lines that could be evaluated for performance in field trials. We also used the same cultivar, Louise, as the recipient of all of the sources of resistance so that the resistances could be compared in the same genetic background. The original sources of resistance all had very different root systems making it impossible to tell which aspects of these root systems were associated with resistance. Once the resistances are transferred into the same genetic background, analysis and comparisons of the root systems would be more informative.

The project focused on five sources of resistance that are listed in Table 1 along with the progress we have made in crossing these resistances to Louise. All five sources have now been crossed to Louise at least three times. The backcross 2 (BC2) designation indicates the original cross to Louise was followed by two more crosses with multiple generations of selection in between. The F4 to F5 designation indicates the numbers of generations of self-fertilization and selection that have been conducted after the BC2 cross. For two of the sources of resistance, Synthetic 172 and CIMMYT 3104, we also advanced large BC1 derived populations of lines for mapping the resistance genes. In the past year all of the BC2 lines were screened one more time in field assays under severe green bridge conditions and the most resistant lines were amplified in the greenhouse for performance testing in field plots in Year 2 of the proposal.

Table 1. Progress in crossing resistance from five different sources into the cultivar Louise

Resistance Source	# lines	Stage in 2015	Pedigree*
Synthetic 30	4	BC2-F5:6	**CROC_1**/AE.SQ. (210)
Synthetic 182	12	BC2-F5:6	**CROC_1**/AE.SQ. (518)
Synthetic 201	9	BC2-F5:6	**68112/WARD**//AE.SQ. (369)
Synthetic 172	10	BC2-F5:6	**SNIPE/YAV79//DACK/TEAL**/3/AE.SQ. (904)
CIMMYT 3104	8	BC2-F5:6	(**CROC1**/ AE.SQ. (224)//OPATA/3/PASTOR)

* Durum wheat parent (A&B genomes) are in bold font, wild diploid parent (D genome) in shaded font.

In year 1 of the project, we completed field evaluation of two large populations of BC1-F5 derived lines from the Synthetic 172 and CIMMYT 3104 sources. They were scored in multiple years for stunting or non-stunting in fields with high levels of disease pressure. In the these field assays, we evaluated stunting by monitoring plant height in plots in which the green bridge was not controlled ("green"), and comparing them to plants grown at adjacent plots in which the green bridge was controlled by glyphosate ("clean"). Molecular diagnostics showed that *R. solani* AG8 was present at moderate to high levels and thus resistance to this pathogen was expected to be a component of resistance to the green bridge conditions. The resistance of these lines has also been evaluated in greenhouse assays. Results of disease assays with the CIMMYT 3104 x Louise population are summarized in Figure 1. Note the relative resistance of the CIMMYT 3104 and Louise parents compared to the 190 lines generated from the cross. While multiple pathogens are present in our field assays (*Pythium*, etc.) the greenhouse assays are conducted with *Rhizoctonia* only, so results differ to some extent. However the lines that perform best in the greenhouse assays generally performed well in the field assays. This supports our hypothesis that resistance or tolerance to Rhizoctonia is a major component of the resistance to green bridge conditions in the field.

In collaboration with Deven See, several hundred genetic markers were scored on the CIMMYT 3104 x Louise population using genotype by sequencing (GBS) in the past year. The marker data was then used to create a genetic map on which to integrate the resistance data. Genomic locations (QTL) on three chromosome arms were identified in which resistance from the CIMMYT 3104 parent mapped. A manuscript describing the five sources of resistance and the locations of the resistance QTL is in preparation. GBS mapping of the Synthetic 172 x Louise population has been initiated.

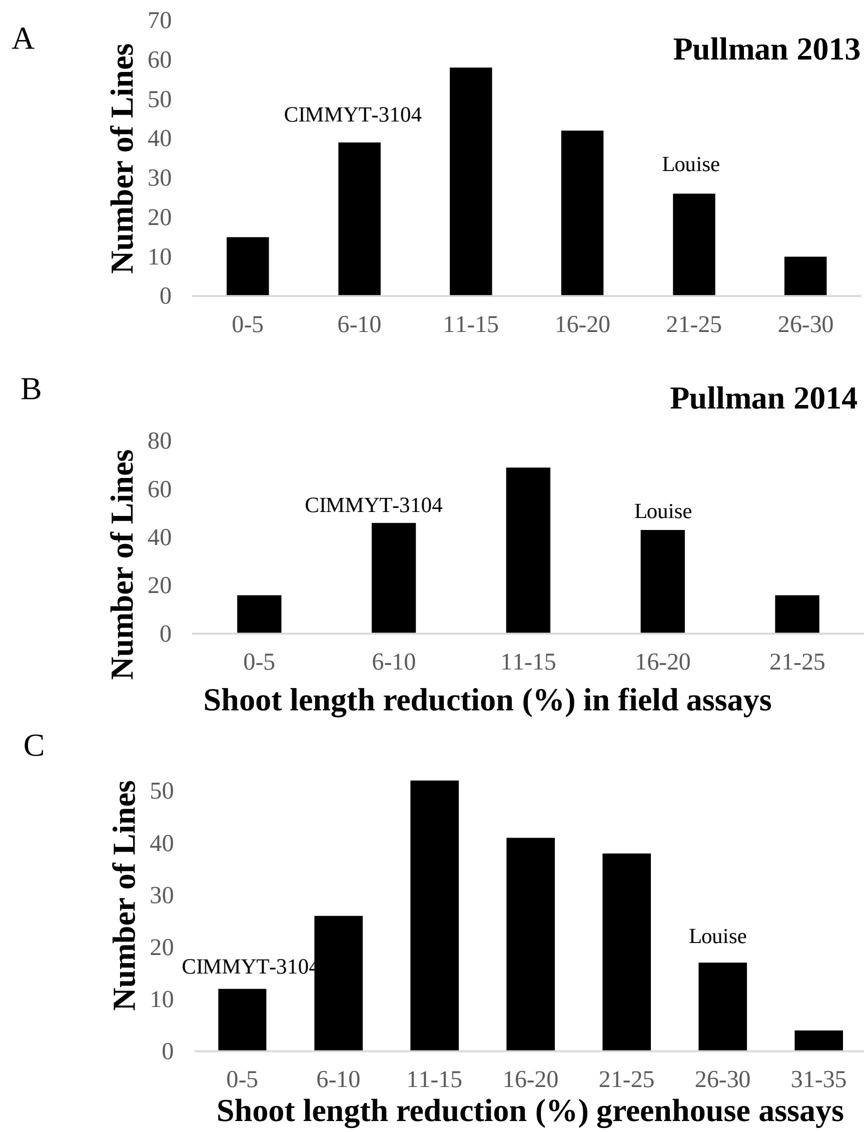

Figure 1. Root rot damage in 190 lines from a CIMMYT 3104 X Louise cross after planting in severe green-bridge field conditions (a and b) or in Rhizoctonia infested soil in the greenhouse. Root rot was estimated as % stunting compared to control rows. Results for the Synthetic 172 population were similar.

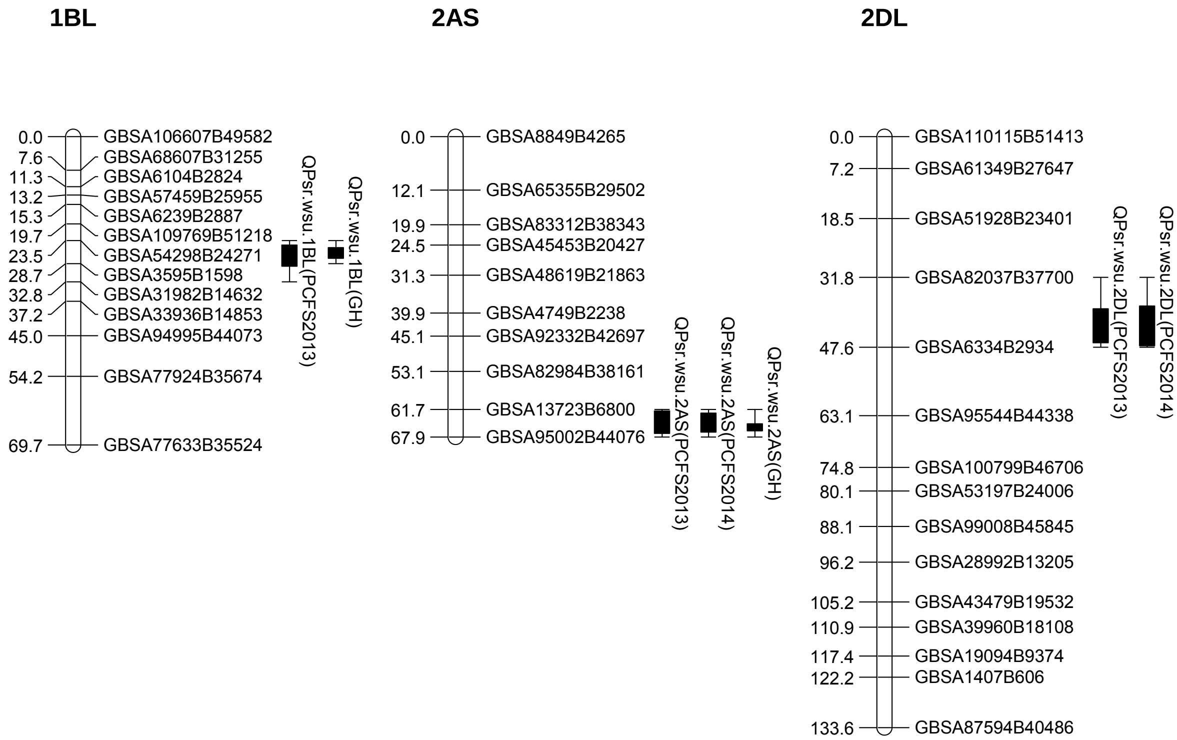

Figure 2. QTL mapping of genes contributing to resistance in the CIMMYT 3014 x Louise mapping population. The figure shows maps of three chromosome arms that carry genes that contribute to resistance or tolerance to green bridge diseases in field plots and in greenhouse assays with Rhizoctonia.

Impact:

In the past year, the main impact of project was to advance the resistance to Rhizoctonia and green bridge associated diseases to wheat lines adapted to PNW wheat production. Genetic resistance is a cost-saving resource for controlling plant pathogens, but this resource is not available to wheat breeders and growers for *Rhizoctonia* anywhere in the world. Yield loss of wheat and barley due to *Rhizoctonia* and other soilborne pathogens is estimated at 10%, but can be as high as 40% in direct seeded systems in field with high inoculum levels. Estimated yield potential to be gained from control of these pathogens would amount to over $100 million per year for the Washington wheat and barley industries. The resistance to stunting in synthetic wheats is apparently due to multiple genes with small effects, as indicated by our mapping data with the CIMMYT 3104 x Louise population. Given its multigenic nature, resistance is expected to be durable, but will not be simple to move between lines. Genetic improvement of wheat and barley resistance to root rot will contribute to current management by rotation, fungicides and green bridge control, and will enhance profitability and sustainability of dryland cereal cropping.

WGC project number: 4548
WGC project title: Pre-breeding for Root Rot Resistance
Project PI(s): Scot Hulbert & Pat Okubara
Project initiation date: July 1, 2015
Project year: Report for year 1 of 3

Deliverable	Progress	Timeline	Communication
Obj. 1. A set of novel Rhizoctonia/ green bridge associated disease resistant lines that can be used to develope PNW spring wheat cultivars. Molecular markers linked to genes controlling resistance in two synthetic lines.	Mapping of genes in the first mapping population was completed with molecular markers linked to three genes contributing to resistance. Multiple (four to 13) BC2 lines from each of the four sources of resistance were selected and amplified this year.	The BC2 lines have now been amplified and we will have sufficient seed to plant three replicate plots at two locations in year 2. We will also perform genotype-by-sequence marker generation and genetic mapping of resistance genes in the second mapping population.	Progress will be reported at the wheat research review and the Cook Chair review. An article on the synthetic lines will be submitted to *Wheat Life* if solicited. An article describing the sources of resistance and the mapping in the first mapping population will be submitted to Phytopathology in February.
Obj. 2. Multi-location yield trial data on the BC2 derived lines from each of the five sources of resistance, to identify which has/have best benefits in different types of field environments.	The BC2 lines for this objective were selected and amplified in the past year.	In year 2 and 3 of the proposal, we will identify the best performing BC2 lines that appear to be best adapted to PNW growth conditions. We will have sufficient seed for testing in two locations in year 2.	Progress will be reported at the wheat research review and the Cook Chair review.
Obj. 3. A more rapid and economical means of selecting and advancing *Rhizoctonia* resistant plants.	This objective has been completed.		A manuscript by Okubara et al. is in press in the journal Plant Disease.
Obj. 4. Information on whether the synthetic wheats carry true resistance or tolerance, and how similar or unique root morphology traits are in these lines. These will be available at the end of Year 1.	We completed the BC2 lines so the resistances are all in similar genetic backgrounds.	We will complete greenhouse resistance screens and quantification of root morphology variables for the five sources of resistance in Yeasr 2 and 3.	Progress will be reported at the wheat research review and the Cook Chair review. The BC2 lines and their root characteristics will be described in a germplasm release article.

Washington Grain Commission
Wheat and Barley Research Annual Progress Reports and Final Reports

(Begin 1 page limit)
Project #: 3061-4949
Progress Report Year: *3 of 3 (maximum of 3 year funding cycle)*

Title: Management of Nematode Diseases with Genetic Resistance
Investigators: S. Hulbert, K. Garland-Campbell, and T. Paulitz

Cooperators: R. Smiley

Executive summary:

- Over the last three years (2013, 2014, and 2015) we have screened over 300 lines from the Western Spring Regional Nursery in a field infested with cereal cyst nematode (*H. filipjevi*) near Colton, WA. **In 2013**, we identified UC 1711, AUBR3059W, SY Steelhead and WA 8163 with resistance. UC 1711 and SY Steelhead also showed resistance in our 2012 trial. **In 2014,** SY Steelhead and AUS28451 (an Iranian landrace) showed resistance. Glee (WA 8074), Glee 0W and SY605 CL showed moderate resistance. A newly tested line, Svevo, showed resistance. Ouyen, a resistant check to *H. avenae,* was susceptible, while Chara, another resistant check to *H. avenae*, showed moderate resistance to *H. filipjevi.* **In 2015,** we reconfirmed the resistance in WA 8163, UC 1711, UC 1741, SY605 CL, SY-B041418, AUS28451 and Svevo. Ouyen continues to be susceptible, while Chara and Sonmez continue to be resistant. We also identified three new lines that were completely resistant- Pretty Wheat, Soft Alzada, and SY3051-9. S346 also showed resistance. Svevo, Soft Alzada and 'Pretty wheat' are all durum.
- **In Spring, 2014**, *Heterodera filipjevi* was discovered in Washington for the first time, near Colton. This discovery required us to work with APHIS to provide information for possible regulatory action, as well as numerous talks and publications to growers. But we needed to answer the question of how far the infestation extended. We have extended our survey to cover all of Whitman County in Fall, 2014 and 2015. We developed a molecular method for species identification from a single cyst, based on ITS and 28S primers. We went back to all the soil samples we took in 2013, 2014, and 2015 to extract single cysts.
- **In 2013,** 19% of the 53 sampled fields were infected with cysts, and all were identified as *H. avenae*, except for the Colton site. **In 2014,** 10% of the 76 fields were infested with cysts, and all were *H. avenae* except for the Colton site. **In 2015,** 31% of the 81 sampled fields were infested, and all were *H. avenae* except for the Colton site and a site south of Uniontown, which had *H. filipjevi.* Surveys by Dr. Smiley in Spring 2014 also found *H. filipjevi* only in the Colton-Uniontown area, with one mixed infection north of Pullman.
- **In 2014, for the first time, we were successful in conducting greenhouse screening using infested soil collected in the spring.** This nematode is difficult to work with in the greenhouse, because it requires a cold treatment or vernalization period to break dormancy of the nematodes and allow them to hatch. We screened 112 varieties using infested soil collected in the spring 2014. SY Steelhead and AUS28451 were resistant. The resistant check for *H. avenae* Ouyen was moderately resistant to *H. filipjevi*, while

another resistant check Chara showed resistance. In addition, we discovered two additional resistant durum wheat lines, Svevo and Soft Svevo.

- **In 2015, we successfully screened soft white and hard red winter varieties for the first time in the greenhouse**. From the Winter Wheat Soft White Regional Nursery, a number of ARS lines from the program of Kim Campbell were identified with resistance, including ARS-Crescent, ARS-Selbu, ARS010719-4L, and ARS2006-126-13C. Other lines included IDN-04-1001A 03PN062-21, 03PN071-4, 4J070874-1 and Chara. From the Winter Wheat Hard Red Regional Nursery, ARS070141-18L, 09X199-0-t-4, and HE9817/1.2 were identified with resistance.
- We hypothesized that the source of resistance was *Cre5* because it is linked to the stripe rust resistance gene *Yr17* which is prevalent in PNW wheat. We assayed for the presence of *Cre5*, and discovered that *Cre5* is present in UC1711, WB Rockland, Chara, 4J070874-1, ARS2006-126-13C, ARS070141-18L, and 09X199-0-t-4, but *Cre5* is not present in Somnez, SY Steelhead, Ouyen, ARS-Crescent, ARS-Selbu, ARS010719-4L, IDN-04-1001A 03PN062-21,03PN071-4, and HE9817/1.2. **The resistance that we have identified is due to other unknown genes.**
- For root lesion nematode (*Pratylenchus thorneii* and *P. neglectus*), we have screened a collection of Iranian landraces and identified thirty two with dual resistance to both species. Six of these accessions also had moderate adult plant resistance to stripe rust in the field. A recombinant inbred line population between the dual resistant accession AUS28451 and Louise was assayed for resistance to Lesion Nematodes, other soil born diseases, and for lignin content. This population was genotyped with the 90K Iselect SNP chip and we identified QTLs associated with higher lignin content and with multiple soil borne disease resistance. We developed multiple segregating populations from a backcrosses of AUS28451 to Louise that perform well in infested field sites in Pendleton. We discovered high populations of lesion nematode at Spillman Farm in Pullman and screened the backcross populations in Pullman in 2015. The identification of screening locations in Pullman facilitates our ability to work with lesion nematodes.

Impact:

- We have now identified 10 locally-adapted spring wheat varieties and 11 winter wheat varieties with resistance to cereal cyst nematode *H. filipjevi*. These varieties may be available to growers in the next 1-2 years, allowing them to reduce the inoculum levels in their fields.
- The resistance to cereal cyst nematode that is present in these varieties is being used in crossing and breeding additional varieties in the ARS and WSU breeding program.
- *Cre5* may be useful in combination with other genes that have yet to be identified.
- We have shown that *H. filipjevi* has a restricted distribution, based on present sampling. However, more sampling is needed to detect possible mixed populations of both species which may be present.
- Resistant lines from the AUS28451/Louise backcross populations have been used as breeding lines to improve resistance to Lesion nematodes and other soil borne diseases in PNW wheat. The six dual resistance accessions with stripe rust resistance are being crossed to spring wheat breeding lines.
- **What measurable impact(s) has your project had in the most recent funding cycle?**

- **Discovery of new species of cereal cyst nematode *(H. filipjevi)*, a coarse understanding of its distribution, and a handful of spring and winter wheat varieties with resistance to this species.**

(End 1 page limit)

WGC project number: 3061-5745
WGC project title:Management of nematode diseases with genetic resistance
Project PI(s): S. Hulbert, T. Paulitz, K. Campbell
Project initiation date:7/1/2013
Project year:2014-2015

Objective	Deliverable	Progress	Timeline	Communication
Obj. 1. Conduct surveys for CCN	Maps of CCN around **all** of Eastern and Central Washington	From 2013-2015, we surveyed 210 fields in eastern Washton and the Palouse. Initially, the survey was conducted assessing white females. With the discovery of *H. filipjevi* in 2014, we developed a technique to assess the species identification of an individual cyst, based on ITS and 28S primers. Species cannot be easily distinguished from morphology. We extracted cysts from the 2013 and 2014 samples, along with soil from 2015 sampling. Almost all of the positive samples were identified as *H. avenae* . *H. filipjevi* was only found in the Colton-Uniontown area.	The species-specific survey for the Palouse has been completed. However, other areas of eastern Washington and possibly northern Idaho should be surveyed. In addition, we should use methods that have the ability to pick up mixed populations of the two species.	Paulitz, T. C. 2015. "Root Disease Research at ARS Pullman-What's New?" Spokane Farm Forum, Ag Expo, Feb. 4, 2015. (presentation). Paulitz, T. C. 2014. A new nematode on the block: Cereal cyst nematode adds a new twist to wheat farming. Wheat Life, Dec. 2014. **See attached list for communications and publications during during the 3-years of the grant.**
Obj. 2) Screen adapted PNW and US varieties in infested grower fields for resistance to CCN, identify the Cre genes involved, and use markers to incorporate this resistance into breeding programs	List of resistant US and PNW varieties and lines, knowledge of what *Cre* genes we have in our backgrounds	Conducted 3 years (2013-2015) of resistance testing in a field site in Colton, infested with *H. filipjevi.* Screened over 300 lines from the Regional Spring Wheat Nursery. Evaluated lines based on number of white females on the root. Each line was paired with the susceptible "Alpowa" in each 4-row head row.	Have completed testing of adapted varieties against *H. filipjevi* . Will need to verify resistance against *H. avenae.*	Manning-Thompson, Y,Thompson, A., Smiley,R., Paulitz,T., Garland-Campbell, K., 2016. Cereal Cyst Nematode Screening in Locally Adapted Spring Wheat (*Triticum aestivum* L.) Germplasm of the Pacific Northwest, 2015. Plant Dis Manag. Rep. SUBMITTED.
	Germplasm rated for resistance to CCN	Field trial was conducted in **summer, 2014** in Colton. This is the field where *H. filipjevi* was discovered. SY SY Steelhead continued to show resistance. Glee (WA 8074), Glee 0W and SY605 CL showed moderate resistance, with some reps showing very few cysts. These should be retested to verify. Ouyen, which is resistant to *H. avenae,* was susceptible in this field, while Chara showed moderate resistance. AUS28451, used in root lesion resistance work, showed resistance to *H. filipjevi* . We also identified Svevo with a high level of resistance. For the first time, we have identified locally adapted varieties with resistance. **In 2015,** we reconfirmed the resistance in WA 8163, UC 1711, UC 1741, SY605 CL, SY-B041418, AUS28451 and Svevo. Ouyen continues to be susceptible, while Chara and Sonmez continue to be resistant. We also identified three new lines that were completely resistant- Pretty Wheat, Soft Alzada, and SY3051-9. S346 also showed resistance.	Testing in field will continue in summer, 2016, but instead we will test crosses and populations made with CCN resistant parents and locally adapted varieties.	Manning, Thompson. Y., Thompson, A., Smiley, R., Garland-Campbell, K., and Paulitz, T. 2015. Screening for Resistance to Cereal Cyst Nematode in Locally Adapted Spring Wheat Cultivars of the Pacific Northwest 2014 Dryland Field Day Abstracts. Dept. of Crop and Soil Sciences Technical Report 15-1. Pg. 68. **See attached list for communications and publications during during the 3-years of the grant.**
	Greenhouse method of screening was successfully tested	In Spring, 2014, we were successful in greenhouse screening using soil infested with *H. filipjevi* collected from the field in April. These results confirmed field results. SY Steelhead continued to show a resistant reaction. AUS28451, used in root lesion resistance work, also showed resistance. The resistant check for *H. avenae* Ouyen was moderately resistant to *H. filipjevi,* while another resistant check Chara showed resistance. In addition, we discovered two additional resistant lines, Svevo and Soft Svevo. In Spring 2015 tested the Winter Soft White and Hard Red Nursery. We identified a number of soft wheat varieties from the ARS program with resistance, including ARS-Crescent, ARS-Selbu, ARS010719-4L, and ARS2006-126-13C. Other soft white lines with resistance included IDN-04-1001A 03PN062-21,03PN071-4, 4J070874-1. We also identifed three resistant hard red lines-ARS070141-18L, 09X199-0-t-4, and HE9817/1.2	Continue greenhouse testing of varieties in Winter and Spring, 2016. Goal is to test all WSU winter and spring varieties that are in variety testing trials.	
Obj. 3. Complete the identification of and verify QTLs associated with resistance to root-lesion nematodes in AUS28451 and select resistant breeding lines in PNW adapted backcross populations with AUS28451 as a source of resistance.		A major QTL for resistance to both species of lesion nematode was identified on chromosome 5A from AUS 28451. Validation of this QTL is being done using field trials in infested fields, and in the greenhouse. Additional markers are being placed on the linkage map.	7/2013-12/2015	Thompson, AL, Smiley, RW, Paulitz, TC, Garland-Campbell, K. 2015. Identification of dual-resistance to *Pratylenchus neglectus* and *P. thornei* in Iranian Landrace accessions of wheat. Crop Sci doi: 10.2135/cropsci2015.07.0438; Date posted: December 01, 2015
		Backcross populations with AUS28451 as a resistance source are being selected New crosses are being made with other sources of resistance. The selected best backcross lines were grown in nematode infested and drought stress locations at Pendleton and LInd in 2014.	7/2013-12/2015	Thompson, A, Smiley, RW. 2015. Registration of the LouAu (Louise/IWA8608077) Wheat Recombinant Inbred Line Mapping Population. J. Plant Regis. 9:424–429. doi:10.3198/jpr2015.01.0002crmp

Publications, Presentations, and Outputs for Nematology Grant 2013-2015

Kandel, S. L., Smiley, R. W., Garland-Campbell, K., Elling, A. A., Abatzoglou, J., Huggins, D., Rupp, R. and **Paulitz, T. C.** 2013. Relationship between climatic factors and distribution of *Pratylenchus* spp. in the dryland wheat production areas of Eastern Washington. Plant Disease 97: 1448-1456.

Manning-Thompson, Y,Thompson, A., Smiley,R., Paulitz,T., Garland-Campbell, K., 2016. Cereal Cyst Nematode Screening in Locally Adapted Spring Wheat (*Triticum aestivum* L.) Germplasm of the Pacific Northwest, 2015. Plant Dis Manag. Rep. SUBMITTED.

Manning, Thompson. Y., Pumphrey, M., Garland-Campbell, K., and Paulitz, T. 2014. Screening locally adapted spring wheat lines for resistance to cereal cyst nematode. ASA, CSA, and SSSA Annual Meeting, Long Beach, CA. Nov. 2014. (presentation)

Manning, Thompson. Y., Pumphrey, M., Garland-Campbell, K., and Paulitz, T. 2014. Screening locally adapted spring wheat lines for resistance to cereal cyst nematode. 2014 Dryland Field Day Abstracts. Dept. of Crop and Soil Sciences Technical Report 14-1. Pg. 68.

Manning, Thompson. Y., Thompson, A., Smiley, R., Garland-Campbell, K., and Paulitz, T. 2015. Screening for Resistance to Cereal Cyst Nematode in Locally Adapted Spring Wheat Cultivars of the Pacific Northwest 2014 Dryland Field Day Abstracts. Dept. of Crop and Soil Sciences Technical Report 15-1. Pg. 68.

Paulitz, T. C. 2014. A new nematode on the block: Cereal cyst nematode adds a new twist to wheat farming. Wheat Life, Dec. 2014.

Paulitz, T. C. 2013. "Root Disease Research at ARS Pullman-What's New?" Spokane Farm Forum, Ag. Expo, Feb. 3, 1013.

Paulitz, T. C. 2014. "Root Disease Research at ARS Pullman-What's New?" Spokane Farm Forum, Ag Expo, Feb. 4, 2014. (presentation).

Paulitz, T. C. 2014. Updates in Wheat Disease Research, Garfield Grange, Colfax, Washington, January 25, 2014 (presentation)

Paulitz, T. C. 2015. "Root Disease Research at ARS Pullman-What's New?" Spokane Farm Forum, Ag Expo, Feb. 4, 2015. (presentation).

Smiley, R. et al. Information on *Heterodera filipjevi* presented to APHIS in Fall, 2014.

Smiley, R. W., Marshall, J. M., Gourlie, J. A., **Paulitz, T. C.,** *Kandel, S. L.,* Pumphrey, M. O., Garland-Campbell, K., Yan, G. P., Anderson, M. D. Floers, M. D and Jackson, C.A. 2013. Spring wheat tolerance and resistance to *Heterodera avenae* in the Pacific Northwest. Plant Disease 97: 590-600**.**

Thompson, AL, Smiley, RW, Paulitz, TC, Garland-Campbell, K. 2015. Identification of dual-resistance to *Pratylenchus neglectus* and *P. thornei* in Iranian Landrace accessions of wheat. Crop Sci doi: 10.2135/cropsci2015.07.0438; Date posted: December 01, 2015

Thompson, A, Smiley, RW. 2015. Registration of the LouAu (Louise/IWA8608077) Wheat Recombinant Inbred Line Mapping Population. J. Plant Regis. 9:424–429. doi:10.3198/jpr2015.01.0002crmp

Washington Grain Commission
Wheat and Barley Research Annual Progress Reports and Final Reports

(Begin 1 page limit)
Project #: 3019-3564
Progress Report Year: *1 of 3 (maximum of 3 year funding cycle)*

Title: Fusarium Crown Rot on Wheat: Prebreeding and Development of Tools for Genetic Disease Management

Investigators: Mike Pumphrey, Kim Garland-Campbell, Timothy Paulitz

Cooperators: Yvonne Thompson, WSU, Arron Carter, WSU; Chris Mundt, OSU, Grant Poole, Syngenta

Executive summary:

- A mini-core collection of spring wheat germplasm has been developed and greenhouse screening has begun.
- Spring and winter wheat varieties are currently being evaluated in the Wheat Growth Facility. Ratings will take place in Winter-Spring 2016.
- Inoculated trials for spring wheat in Ritzville and winter wheat in Mansfield were conducted in the 2014-2015 crop year. Ratings are still being analyzed, and will be presented at the Feb. meeting.
- Because of the high levels of *Fusarium* seen in variety testing sites, ratings were taken at Creston, Reardon, Lamont, and Ritzville. Initial results from these trials have identified SY107, ORCF103, and WA8227 with more susceptibility to Fusarium crown rot. Coda, IDN-06-18102A, WA 8202, WB-1070CL, and ARS010679-1C were identified with more resistance to Fusarium crown rot than other lines. We will compare these results to the greenhouse assays to determine how predictive the greenhouse assays are of field results.

Impact:

- **What measurable impact(s) has your project had in the most recent funding cycle?**

We have just started this project, but already have a ratings of winter wheat from 4 variety testing locations. Once we combine with greenhouse and inoculated field trials, we will have useful information will be disseminated to growers via field days, seed brochures, etc to make variety selections.
(End 1 page limit)

WGC project number: 3019-3564
WGC project title: Fusarium Crown Rot on Wheat: Prebreeding and Development of Tools for Genetic Disease Management
Project PI(s): M. Pumphrey, K. Garland-Campbell, and T. Paulitz
Project initiation date: 7/1/2015
Project year: Year 1

Objective	Deliverable	Progress	Timeline	Communication
Objective 1. Perform association mapping on spring and winter core collections to identify further sources of resistance.	Resistant sources that can be used for variety development.	A mini-core collection was developed for the spring core collection. The mini-core is current being screening in the Wheat Plant Growth Facility. The initial ratings will take place in winter 2016. Additional replications may be needed and will be screening in the spring of 2016.	Greenhouse screening completed by the end of 2015. Data analysis completed by Fall of 2016.	None in 2015, first year of grant.
Objective 2. Screen all variety and regional nurseries for resistance in greenhouse screening.	Ratings of varieties for Fusarium tolerance in the the WSCIA seed buyers guide and other publications.	WSU winter variety trials are being screening in the Wheat Plant Growth Facility. These will be rated in winter 2016. The spring wheat variety trials will be evaluated in spring and summer 2016.	Ongoing, Every year. Completion of that year's greenhouse trials by August.	None in 2015, first year of grant.
Objective 3. Expand field testing to two locations, and test variety and regional nurseries. Evaluate new seed treatments, since there is little information on how seed treatments may protect against this disease.	Ratings of varieties for Fusarium tolerance in the the WSCIA seed buyers guide and other publications. Evaluation of seed treatment chemicals for efficacy against Fusarium crown rot.	Because of the widespread incidence of Fusarium crown rot in field locations in 2015, we sampled from WSU winter variety trials at Reardan, Creston, Ritzville, Harrington, Lamont and St. Andrews. We also planted an inoculated winter wheat trial at Mansfield and and inoculated spring wheat trial at Lind. These are currently being rated. Initial results from these trials have identified SY107, ORCF103, and WA8227 with more susceptibility to Fusarium crown rot and Coda, IDN-06-18102A, WA 8202, WB-1070CL, and ARS010679-1C with more resistance to Fusarium crown rot than other lines. We will compare these results to the greenhouse assays to determine how predictive the greenhouse assays are of field results.	Two locations have been planted in fall 2014. Nursery evaluation will be ongoing with data analysis compelted by Jan. of each year following the field trial.	None in 2015, first year of grant.

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Washington Grain Commission

Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: **3019 3571**

Progress Report Year: *_3___ of __3__ (maximum of 3 year funding cycle)*

Title: **Improving Spring Wheat Varieties for the Pacific Northwest**

Cooperators: Mike Pumphrey, John Kuehner, Vic DeMacon, Sheri Rynearson, Wycliffe Nyongesa

Executive summary:
The WSU spring wheat breeding program's elite material and recently released varieties continue to be the top performers is statewide variety trials and for growers. Foundation seed of Seahawk (WA8162) soft white, Alum (WA8166) hard red, Chet (WA8165) low rainfall hard red, and Melba (WA8193) spring club was produced and sold as all three were released in 2014 or 2015. Each variety has very good yield potential, a high level of stripe rust resistance, good-to-excellent end-use quality, and better straw strength compared to existing varieties. Melba club is intended to replace JD in >16" rainfall areas, with significantly shorter height and lower protein. WA8214 soft white spring wheat will be proposed for release in Feb 2016, and we expect broad adoption due to early maturity, shorter height, and top yield performance. WA8214 has aluminum tolerance, Hessian fly resistance, excellent rust resistance, and below average protein. Two-gene Clearfield variety candidates performed well in WSU variety testing trials, and we expect a release in the next one-two years.

Impact:
The WSU spring wheat breeding program is in a unique position to focus on grower opportunities and challenges, large and small. We identify and develop traits, technology, germplasm, and released varieties to meet the needs of the majority of Washington producers, whether the needs are localized or widespread. Our latest releases package excellent yields with superior quality and key yield protection traits. Glee hard red spring wheat was again a top performer in >12" through >20" precipitation areas, and was the leading hard red spring by acres in 2015. Diva, Louise, Whit, Babe and JD were collectively planted on >72% of soft spring wheat acres. Across spring wheat market classes, our varieties were planted on >57% of all spring wheat acres in 2015. These varieties were also top performers in 2015 spring wheat variety testing trials. Public wheat breeding programs at WSU and across the country payback consistently on research dollars invested. It is commonly referenced that public wheat breeding programs consistently return > ~60% on investment. With >57% of the spring wheat acres in Washington planted to WSU varieties, growers continue to realize a substantial return on research dollars invested in this program.

Outputs and Outcomes: File attached

WGC project number: 3019 3571
WGC project title: Improving Spring Wheat Varieties for the Pacific Northwest
Project PI(s): Mike Pumphrey
Project initiation date: 2013
Project year: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
Develop biotic and abiotic stress tolerant, high-yielding, and high-quality hard red, soft white, club, and hard white spring wheat varieties for diverse Washington production environments.	New spring wheat wheat varieties that are superior to existing varieties. This effort includes all four market classes of spring wheat and all precipitation regions in Washington state.	Four new spring wheat varieites were released during the 3 years of this project. In 2014, Seahawk (WA8162) SWS, Alum (WA8166) HRS, and Chet (WA8165) HRS, and in 2015, Melba (WA8193) spring club. These varieties will have a significant positive economic impact for PNW growers. Despite a few rough years due to drought and heat, our advanced experimental lines performed very well in the WSU Variety Trials. WA8214 (SWS) was the top performer across all precipitation zones in the 2014 and 2015 Variety Trials, and will be proposed for full release in Feb 2016. Other WSU Spring Wheat varieties and elite lines, including Seahawk, Louise, JD, Diva, Whit, Babe, Alum, Chet, Kelse, and WA8189 (SWS) performed well in WSU Variety Testing trials over the past 3 years. WSU spring wheat varieties accounted for >57% of spring wheat acreage in Washington State, and all have very good to excellent quality.	Recurring annually	WSU Field days attended by Pumphrey: Connell, Dayton, Farmington, Horse Heaven, Reardan, St. John, Lind Field Day, Spillman Farm Field Day. Workshops/meetings/presentations attended/given by Pumphrey: Western Wheat Workers, WSCIA Annual Meeting (presentation), WSCIA Board, WA Grain Commission, Several public-private exploratory meetings.
Improve PNW spring wheat germplasm to strengthen long-term variety development efforts/genetic gain.	Enhanced germplasm. Consistent genetic gain for many desirable traits.	A total of over 500 unique cross combinations were made for selection in field nurseries in 2015, and ~28,000 breeding lines were evaluated in field trials at 1 to 18 locations throughout Washington State. Grain samples from advanced breeding lines with superior agronomic performance were sent to the WSU/USDA-ARS Western Wheat Quality Laboratory for end-use quality assessment. A total of nearly 2600 F4 headrows were selected from the field based on plant type, stripe rust resistance and heading date. Early generation, end-use quality assessment methods were used to evaluate these selections and ~950 superior lines were retained.	The payback for this work will fully be realized for many years to come as these lines continue to be crossed into existing breeding lines. We expect this effort to result in introgression of desirable variation for yield, disease resistance, and other agronomic characters.	

Objective	Deliverable	Progress	Timeline	Communication
Discover/improve/implement scientific techniques and information to enhance current selection methods.	We will continue to leverage the efficiency of the Spring Wheat Breeding Program to enhance traits and research of direct relevance to Washington producers. Current examples that will continue are development of DNA markers for useful sources of Hessian fly and stripe rust resistance, drought and heat tolerance loci, identification of superior germplasm through association mapping, screening for tolerance to aluminum, development of facultative wheat, screening for drought and heat tolerance, development and screening of mutant populations (TILLING) and the development of high-throughput field phenomics selection methods.	In 2015 the tractor mounted spectral reflectance cameras were further implemented to obtain field-based high throughput phenotyping measures. We again planted individual rows of ALL our material, from early generation to our most advanced lines, at Rockford Wa. in a field with known low pH values and high levels of exchangeable aluminum. This information is very useful in selecting lines with aluminum tolerance and was very helpful in the release of the varieties "Alum", Seahwak, and WA8214.	This works has short, medium, and long term goals. We are already using new DNA markers discovered through this work to improve selection for quality and pest resistance.	Annual Wheat Life contributions

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Project #: **3573**

Progress Report Year: ___*3_ of _3___ (maximum of 3 year funding cycle)*

Title: **Pre-breeding pest resistance, agronomic and grain quality traits for spring wheat variety development**

Cooperators: Mike Pumphrey, John Kuehner, Vic DeMacon, Sheri Rynearson, Wycliffe Nyongesa

Executive summary:

This project is an integral component of the Spring Wheat Breeding program. The objective of this project is to support/enable the most effective and efficient selection procedures for development of superior Washington spring wheat varieties. In addition to routine early-generation grain quality selection carried out through this project, we apply DNA marker technology to elite breeding materials, and are conducting several research projects of direct relevance to our breeding efforts. This project also supports our two-gene Clearfield breeding effort, which has progressed nicely. Approximately 2600 early generation lines were evaluated for end-use quality with ~1000 retained, over 1000 marker-selected doubled haploid and backcross-derived progeny were advanced through selection in field nurseries, and molecular markers were used to characterize parental lines for disease, quality, and agronomic traits through this project in 2015.

Impact:

This project is critical to the spring wheat breeding program and works seamlessly with project 3571. Program efficiency is significantly increased, by evaluating early generation lines for quality and eliminating those with poor quality characteristics before further field testing. This allows for increased testing of superior material in the field program and protects resources from being used to further test lines that are inferior in terms of quality, lack of adequate pest resistance, and numerous other DNA-marker selectable traits. The release of a top performing 2-gene Clearfield spring wheat varieties will be of substantial economic benefit to growers in Washington State by protecting yields where Imazamox or Imazethapyr has been heavily used. Spring wheat varieties with complex stripe rust resistance, Hessian fly resistance, superior end-use quality, and broad adaptation are critical for Washington wheat producers by adding millions of dollars of annual return. *WSU varieties 'Diva', 'Louise', 'Whit', 'JD' and 'Babe' accounted for ~72% of the soft white spring wheat acres planted in the state in 2015*. WSU varieties 'Kelse' and 'Glee' were leading hard red spring wheat varieties in 2015. *In total, >57% of the 2015 Washington spring wheat acres were planted to WSU spring wheat varieties*. Over the past three years, we have released Chet, Alum, Seahawk, and Melba. Each variety is high quality, top yielding, pest and disease resistant, and have been accepted and adopted by seed dealers and farmers with increasing acres each year. Our newest soft white spring wheat, WA8214, which will be released in 2016, is a very exciting release that we anticipate broad adoption.

Outputs and Outcomes: File attached

WGC project number: 3019 3573
WGC project title: Molecular selection of pest resistance, agronomic and grain quality traits for spring wheat variety development.
Project PI(s): Mike Pumphrey
Project initiation date: 2013
Project year: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
Develop DNA markers and select breeding lines by marker-assisted selection with stripe rust resistance, Hessian fly resistance, and two-gene Clearfield™ herbicide tolerance as well as other traits when desirable.	Elite variety candidates will result, in part, due to these molecular selection activities. Many of these populations will be ideal for marker optimization, new genetic mapping studies, and potentially the basis of new competitively funded projects.	Clearfield™ spring wheat breeding lines have been developed using our most advanced and elite genetic backgrounds. Three hard red spring, WA8220, WA8241, WA8242, two spring club, WA8236 and WA8237, and one common soft white, WA8238, Clearfield+ lines were included in the 2015 Variety Trials. These lines were created using the double haploid method and marker assisted backcrossing. All performed fairly well. We have made swift progress in only a few short years and have several more candidates for the 2016 Variety Trials for hard and soft types. Seahawk soft white spring wheat Foundation seed raised in 2015 (off-season and main season). Seahawk was selected by markers to have a combination of Yr5 and Yr15 seedling stripe rust resistance genes. New DNA markers for Yr5 and Yr15 were developed and validated.	The two-gene Clearfield™ breeding effort is in full swing, ~800 lines were planted at Pullman in plots in 2015. Three Clearfield™ sites were planted in 2015 at Pullman, Dayton, and Plaza. These trials were replicated and designed using the BASF testing protocol. Several of these lines performed well and will be in the 2016 WSU Variety Testing trials.	Pumphrey attended/presented numerous WSU field days workshops/meetings, PNW wheat Quality Council, WSCIA Annual Meeting (presentation), WSCIA Board Meetings, WA Grain Commission, industry tours in Pullman.
Select early-generation breeding lines with good end-use quality potential by eliminating inferior breeding lines prior to expensive and capacity-limited yield tests.	Elimination of lines with inferior end-use quality. This ensures only lines with acceptable end-use quality are tested in the field and maximizes efficiency in field operations.	Early generation grain quality analyses were employed to select and advance experimental lines with increased likelihood of having superior quality. In 2015, ~2600 head-row selections were subjected to specific laboratory-based grain quality assays based on market class, and ~900 were retained for single seed descent and 2016 F5:F6 nursery evaluation. Current analyses include: NIR-protein, NIR-hardness, SKCS-hardness, SDS micro-sedimentation, PPO, and micro-milling.	Return on investment is realized each year, since lines with poor end-use quality are not tested in expensive and capacity-limited yield tests. This allows for additional yield testing of lines with good end-use quality and more efficient variety developement.	Nasseer, A. M., J. M. Martin, H.-Y. Heo, N. K. Blake, J. D. Sherman, M. Pumphrey, K. D. Kephart, S. P. Lanning, Y. Naruoka, and L. E. Talbert. Impact of a Quantitative Trait Locus for Tiller Number on Plasticity of Agronomic Traits in Spring Wheat. Crop Science. in press

Objective	Deliverable	Progress	Timeline	Communication
Conduct greenhouse operations required for variety development, including crossing, doubled haploid development, generation advancement, and seedling assays such as herbicide screening, and stripe rust screening.	Lines for field testing that contain desirable and novel characterisitcs. This is where new varieties are born. Greenhouse operations also allow more rapid breeding cycles by advancing F1 and F5 generations every year as part of of our routine breeding efforts. Seedling evaluation of stripe rust resistance and herbicide tolerance screening are also major greenhouse activities.	Another successful and ambitious year of greenhouse multiplication and crossing was completed, including two large crossing blocks and thousands of early generation lines tested for stripe rust and herbicide tolerance. The addition of the new wheat greenhouse facility expanded our capacity and we were not as limited by plant growth space.	Annually	Sherman, J. D., N. K. Blake, J. M. Martin, K. D. Kephart, J. Smith, D. R. Clark, M. L. Hofland, D. K. Weaver, S. P. Lanning, H.-Y. Heo, M. Pumphrey, J. Chen, and L. E. Talbert. 2015. Agronomic Impact of a Stem Solidness Gene in Near-Isogenic Lines of Wheat. Crop Science. 55:514-520.

Washington Grain Commission

Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: **3019 3574**

Progress Report Year: *_1___ of __3__ (maximum of 3 year funding cycle)*

Title: **Evaluation of WSU wheat breeding lines for management of Hessian fly and development of DNA markers for resistance breeding**

Cooperators: Mike Pumphrey, Nilsa A. Bosque-Pérez

Executive summary:
Hessian fly (HF) infestations continue to cause significant annual yield losses in spring wheat production areas of Washington and neighboring regions of Oregon and Idaho. Hessian fly is in many ways a silent problem. Moderate infestations are not visually striking, and their occurrence is somewhat variable over space and time. Nonetheless, significant reductions in grain yield and grain quality are observed across spring wheat production areas. Factors such as weather patterns, crop rotation, variety selection, and tillage or conservation practices can impact HF pressure. Infestation may also be a significant barrier to increased conservation tillage practices in the Palouse. Advanced breeding lines, new sources of resistance genes H13, H26, and two unknown resistances source, along with mapping population progeny were screened for Hessian fly resistance in 2015. Backcross populations were developed with four new sources of resistance, and progeny selfed to select homozygous resistant lines this winter. The HT080158LU/WA8076 doubled haploid mapping population was used to map a newly discovered Hessian fly resistance gene on chromosome 6A. We are currently validating and converting linked DNA markers for routine selection in our breeding efforts.

Impact:
Inventories of HF resistance in PNW spring wheat will be useful for strategically designing the breeding program. The development of tightly linked DNA markers will improve the effectiveness and efficiency of spring wheat breeding by eliminating susceptible lines earlier in the breeding process, prior to expensive yield testing and making crosses. Spring wheat production has averaged ~30 million bushels in WA in recent years. A conservative state-wide loss estimate of 2% translates to over $4,000,000 per year; yield loss due to HF in moderately to heavily infested areas often exceeds 25% and may be 100% in localized areas. In addition to protecting from $45-$104 per acre via HF resistance, improved variety development can translate to $Millions/year in WA spring wheat farm gate value.

Outputs and Outcomes:
<u>Excel file attached</u>

WGC project number: 3574
WGC project title: Evaluation of WSU wheat breeding lines for management of Hessian fly and development of DNA markers for resistance breeding
Project PI(s): Pumphrey
Project initiation date: 2015
Project year: 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
Screen WSU Spring Wheat breeding populations and advanced breeding lines for resistance to Hessian fly in the laboratory	Information on resistance of elite breeding lines on an annual basis	Twenty elite breeding lines were selected for screening in winter 2015.	Annually	Progress will be presented by M. Pumphrey and N. Bosque-Pérez at field days, plot tours, at Wheat Research Reviews for individual states. Presentations will be made to the Washington Wheat Commission and WAWG conferences upon invitation. Progress will be reported in Wheat Life magazine and data will be recorded with nursery data.
Continue to incorporate "new" Hessian fly resistance genes into breeding lines	Improved germplasm with useful sources of Hessian fly resistance	Several backcrosses have been made to known (H13, H26) and unknown resistance gene donors, using susceptible elite line "Dayn" as the initial recipient parent. BC1 populations were self pollinated to select resistant families for screening and backcrossing winter 2015. Essentially all elite crossing block populations for the breeding program were made based on known resistance of one or both parents to Hessian fly. A new resiatnce gene on chromosome 6A was mapped in an elite doubled haploid population, and DNA marker validation is underway.	Annually	

Washington Grain Commission
Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: 3667

Progress Report Year: *___2_ of _3___ (maximum of 3 year funding cycle)*

Title: **End-Use Quality Assessment of Washington State University Wheat Breeding Lines**

Cooperators: *Mike Pumphrey, Arron Carter, Craig F. Morris, Doug Engle*

Executive summary:
WSU spring and winter wheat variety development programs heavily emphasize selection for superior end-use quality. All market classes and wheat production areas of the state are affected by/included in this project. Quality evaluation of WSU breeding lines has been ongoing for over 50 years. Effective quality testing is essential for the recent release of new varieties from all market classes that are at or near the top of end-use quality rankings. This project supports a scientist to conduct thousands of quality tests per year for the WSU wheat breeding programs in conjunction with the USDA-ARS Western Wheat Quality Laboratory.

Impact:
The majority of wheat from the PNW is now being exported to overseas markets. To maintain current markets and recapture lost markets, PNW wheat must possess quality characteristics that make it suitable for use in both domestic and overseas markets. Therefore, before it is released, a new variety must be tested to determine if it is suitable for use in specific end-use products. In addition, increased competition from traditional and non-traditional exporters necessitates enhancing the end-use quality of our wheat. The loss of overseas markets will continue to cause a reduction in the demand and therefore the price of wheat, resulting in losses to Washington farmers. Concerted efforts to insure that new varieties possess superior quality traits are an essential step to recapturing lost markets and establishing new markets. Washington State University, Washington Wheat Growers, the State of Washington, and the PNW, as well as grain buyers, will benefit from the availability of wheat varieties that require less inputs and possess superior, consistent end-use quality. Otto, Puma, Glee, JD, Louise, Sprinter, Chet, Alum, Seahawk, Melba, Whit, Babe, Dayn and Diva are examples of recent top-performing lines that also have very good to excellent end-use quality.

Outputs and Outcomes: File attached

WGC project number: 3667
WGC project title: End-Use Quality Assessment of Washington State University Wheat Breeding Lines
Project PI(s): Mike Pumphrey and Arron Carter
Project initiation date: 1-Jul-14
Project year (X of 3-yr cycle): 2 of 3 year cycle

Objective	**Deliverable**	**Progress**	**Timeline**	**Communication**
Early to late generation quality testing of WSU experimental lines to aid variety development	New spring wheat and winter wheat varieties that are superior to existing varieties. This effort includes all market classes of spring and winter wheat and all precipitation regions in Washington state.	Over 1500 breeding samples were analyzed by numerous milling and baking quality tests in 2015. This is a substantial increase over previous years and has allowed enhanced selection of advanced breeding lines with good quality. Three new wheat varieties were released using this project and data.	The economic return for this work will manifest itself each breeding cycle with superior quality varieties and germplasm.	Progress will be summarized and discussed at numerous field days (>10 per year), grower meetings (~10 per year), the annual Research Review, through WSCIA meetings, Wheat Life, Variety Release Meetings, and direct communication with the WGC every year. Graduate graduate student Kendre Jernigan won the Crop Science Society of America research poster award competion in 2015 summarizing this work.
Support genetic analysis of end-use quality to identify desirable alleles and to predict end-use quality through new genotyping methods	Improved germplasm selection procedures which translate to more efficient, cost-effective, and consistent genetic gain for end-use quality.	Over 400 winter wheat lines that have been genotyped with 90K SNPs were evaluated for milling and baking. Milling and baking analysis of a bi-parental winter wheat mapping population has also been substantially completed. Eleven loci for nine different quality traits were identified in the soft white winter wheat panel and a manuscript is being submitted. This data may also be used to help predict quality before conducting any quality tests. This would be a huge advantage in variety development	The reward for this work will compound each year and will fully be realized for many years to come as these lines continue to be crossed into existing breeding lines. We expect this effort to result in routine selection of outstanding quality wheat.	

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Project #: 7768

Progress Report Year: *__1__ of __3__ (maximum of 3 year funding cycle)*

Title: A Genetic Arsenal for Drought Tolerance, Getting to the Root of the Problem

Cooperators: Karen A. Sanguinet, Camille M. Steber, Kimberly Garland Campbell, Timothy Paulitz, Scot Hulbert, Arron Carter

Executive summary: Dryland farms in eastern Washington experience yield losses due to drought stress. Improving wheat root structure can help to resist such stresses by increasing access to water. The combined issues of drought, no-till practices and the changing pathogen load affect all market classes of wheat and barley. Traditional breeding for wheat and barley has mainly focused on the health of the aboveground parts of the plant. As a result, many modern varieties have small and/or shallow root systems. The primary goal of this research project is to identify root architectures in current breeding populations of both spring and winter wheat cultivars associated with better yield under drought stress. We assessed the root structures of Hollis, Drysdale, Louise, and AUS28451, as well as the 10 best and worst yielding lines from Hollis/Drysdale population in the summer of 2015 at the Lind Dryland Research Station. Quantification of the root traits is underway, but preliminary analysis shows that the drought-tolerant genotypes tend to show deeper rooting. Winter wheat genotypes (*wt, Rht1, Rht2, Rht1 Rht2*) in the Brevor and Golden backgrounds were sown at Spillman Farm in October 2015. Scans were taken weekly until prohibited by the weather. All winter and spring cultivars are being measured in pots in the wheat greenhouse. Once all root traits have been quantified, selected genotypes, cultivars, and RIL and backcross populations will be planted at both Spillman and Lind in 2016 and 2017.

Impact: Combined drought and heat routinely experienced in the PNW can cause 20-50% losses in grain yields as experienced in recent years. The short-term impact of this research is to use root traits and overall architecture in current breeding lines under selection as an additional and crucial metric to improve drought tolerance. Previous research has shown root traits cannot be predicted or selected for using aboveground traits. The long-term impact of this research is to develop *in situ* root imaging technology for winter wheat, spring wheat, club wheat and barley cultivars under selection with the overall goal of improving the salient root traits important for drought tolerance. These could include seminal root establishment, crown root colonization, or lignin content for improving a number of root-related traits to both biotic and abiotic stresses. The ultimate goal of this research project is to improve root architecture in current breeding populations of both spring and winter wheat cultivars to improve yield under drought stress. Root imaging and phenotyping is a primary focus area and priority for federal funding agencies. This grant and support for root imaging has helped leverage a collaboration with Pacific Northwest National Labs (PNNL), which is in turn leading to the generation of proposals addressed to DOE, the USDA, and the NSF.

WGC project number: 7768
WGC project title: A Genetic Arsenal for Drought Tolerance, Getting to the Root of the Problem
Project PI(s): K. Sanguinet, C. Steber, K. Campbell, T. Paulitz **Collaborator: S. Hulbert, A. Carter**
Project initiation date:7/1/2015
Project year: 2016-2017, year 2

Objective	Deliverable	Progress	Timeline	Communication
1. Characterize the root systems of the five RIL parental lines: Louise, AUS28451, Dharwar Dry, Hollis and Drysdale using a digital in situ root imaging system to measure root traits such as root hair length and density root mass and root depth.	Methods and analysis of two key traits for drought stress: root architecture and lignin content in Louise, AUS28451, Dharwar Dry, Hollis and Drysdale (end of 2015).	We ave successfully imaged Louise, AUS28451, Hollis, and Drysdale in the field in Summer 2015. Serial scans every 3 days for Louise, AUS28451, Drysdale, Hollis, Dharwar Dry, and Alpowa are underway in the wheat greenhouse in the winter 2015-2016. Quantificaiton of root architectural traits are underway using RootSnap! software.	The first round of field trials and quantification of root architecture was completed by the end of 2015. Lignin content measurements will be performed in the greenhouse in winter 2015-16 of the parental lines.	Our findings will be reported in the July 2016 issue of Wheat Life and at the CSA meeting in Fall 2016. In addition, we attended the Lind and Spillman field days in 2015 and will do so again in 2016.
2. Examine the Hollis/Drysdale RIL population to determine if yield under drought and canopy temperature correlate with a specific root trait or traits.	Determine the link between canopy temperature, root architecture traits and yield (end of 2016).	With the aid of Dr. Hulbert, the 10 highest and lowest yielding RIL populations from Hollis/Drysdale RIL populations were sown at Lind in summer 2015. Images were taken every two weeks. We found that the 3 ft. long imaging tubes were too short and need to continue subsequent imaging in the field with 6 ft. long tubes. Nonetheless, informative data were obtained and differences in architecture and rooting depth were obsercved between Hollis and Drysdale. These analyses will be repeated in Summer 2016 at Lind and Spillman.	Field trials will be initiated in both dry and irrigated conditions in summer of 2015 of the parents and will be analyzed again in summer 2016 comparing 10 of the best yielding versus worst yielding RILs. Time and data permitting. This will be repeated again in summer 2017.	Our findings will be reported in Wheat Life and prepared for publication in a scentific journal.
3. Examine backcross lines in the Louise background with specific root traits from AUS28451 including higher root lignin, root depth, root branching, root biomass, and root hair density to improve yield under drought and to select breeding lines with vigorous roots. Also backcross lines of Dharwar Dry to Louise will be analyzed for improved drought resistance and root architecture traits.	Development of breeding lines with increased lignin and root vigor which are predicted to show enhanced drought tolerance (2018-2020).	We have begun analyzing the parental lines. With help from Dr. Garland-Campbell's group, backcrossing to Louise is advancing and we will be evaluating the Louise/AUS28451 advanced BC lines beginning in 2017.	Analysis and selection of backcross lines will commence in summer of 2015. The backcross lines will be further backcrossed to the Louise parent and will undergo several rounds of selection. The timeline for the selection of breeding lines will take 3-5 years.	Our findings will be communicated at field days at Lind and Spillman farms. In addition, we will again prepare a publication for Wheat Life.
4*. Examine root architectural traits in wild type, rht1, rht2 and rht1 rht2 dwarf winter wheat lines in the Brevor and Golden backgrounds.	Development tools and imaging to assess the importance of root growth and the rht alleles on winter wheat cultivars (2017-2028).	With the help of Dr. Carter, *wt, rht1*, *rht2*, and *rht1 rht2* lines in the Brevor and Golden backgrounds were sown in October 2015 at Spillman Farm. Imaging tubes were places after sowing. Seed will be bulked for more expansive testing in Fall 2016-Summer 2017.	Imaging and analysis of root growth of winter wheat (*wt, rht1*, *rht2*, and *rht1 rht2* will occur at Spillman Farm Winter 2015 until Summer 2016. A repetion of imaging will occur in the field in Fall 2016 to Summer 2017. to confirm and extend findings in the field. The same lines will be sown in vernalization chambers in the wheat greenhouse followed by growth in the WSU wheat greenhouse.	Our findings will be communicated at field days at Lind and Spillman farms, on the small grains website and in a publication for Wheat Life.
Expected impacts over the next 3 years: Previous data has shown that root and shoot traits are not correlated. The proposed research uses *in situ* root imaging techniques to add another metric for selection of breeding lines and determination of the supposed link between deeper rooting, canopy temperature and yield by addressing which root traits (depth, branching, thickness, angle, root hairs, lignin content) most influence yield. Once precise traits and their impact on yield are determined, this provides another tool in the breeding tool box for selection of plant traits that correlate with increased yield particuarly in drought or water-limiting conditions.				

The expected outcomes are:
1) Increasing the knowledge regarding root architecture and drought tolerance in wheat;
2) Selecting for key root architecture traits in wheat cultivars for improved drought tolerance;
3) Improving drought tolerance in the Spring White Wheat Louise in backcross populations with the landrace AUS28451 and the drought-tolerant cultivar ;
4) Determining the link between canopy temperature, yield and root architecture;
5) Determining the role of root lignin in drought stress and root pathogen resistance;
6) Development of in situ root imaging techniques for breeders as an additional metric and tool in their breeding arsenal
7)* Determine the impact of Rht mutantions on root development in winter wheat genotypes adapted to the PNW

*-new objective and outcome for year 2.

Washington Grain Commission
Wheat and Barley Research Annual Progress Report

Project #: 5389

Progress Report Year: _1__ of _3__ *(maximum of 3 year funding cycle)*

Title: Developing Washington Wheat with Stable Falling Numbers (FN) through resistance to preharvest sprouting and LMA.

Project PIs: Camille M. Steber, Michael O. Pumphrey, Arron H. Carter
Cooperators: Kimberly Garland Campbell, Ryan Higginbotham, Deven See, Craig Morris

Executive summary: The goal of this project is to breed for stable Falling Numbers (FN) in Washington wheat through selection for genetic resistance to preharvest sprouting and late maturity alpha-amylase (LMA). The previous project identified existing cultivars with sprouting and LMA problems through evaluation of the WSU cereal variety trials, and made this information available through a website enabling growers to examine FN relative to yield data from 2013 and 2014 (http://steberlab.org/project7599.php). The current project will enable breeders to select for resistance to LMA and PHS by developing and using phenotypic screens and molecular markers.

Objective 1. Screen spring and winter wheat cultivars, breeding, and mapping lines for preharvest sprouting tolerance using the spike wetting test and the Falling Number test.
Falling Number was determined for the 2014 WSU Cereal Variety Trials, and locations showing low FN were identified for the winter and spring wheat variety trial locations in 2015.

Objective 2. Improve screening for LMA susceptibility to prevent release of susceptible spring and winter varieties.
LMA is not a wide-spread problem in older northwest wheat cultivars, but LMA susceptibility is an emerging problem in our breeding programs. Greenhouse LMA testing is slow and requires considerable growth chamber space for cold treatment of whole wheat plants. LMA experiments were performed with a more efficient "cut spike" protocol for field-grown wheat. Screening detected LMA-susceptible winter breeding lines. No LMA susceptibility was detected in Avocet with and without the Yr5 and Yr15 Field cut spike experiments detected known LMA susceptible lines, but appeared to over-predict the number of LMA susceptible lines. Field cut spike assays will enable us to perform the large scale screening needed for association mapping, but will need to be confirmed by other methods.

Objective 3. Identify molecular markers linked to sprouting and LMA resistance and susceptibility genes by association mapping.
Association mapping identified molecular markers linked to preharvest sprouting susceptibility/tolerance in winter wheat. Mapping was performed using both spike wetting tests and FN on the same mapping population. Spike wetting tests did not detect many of the sprouting tolerance loci detected by FN. This suggests that if we want to breed for stable FN we will need to continue running FN assays instead of relying on the less labor-intensive spike-wetting tests. Thus, the project will continue using FN data for breeding and mapping lines grown at locations subject either to sprouting or LMA events.

Impact: Wheat in all market classes is dramatically discounted for low falling numbers (below 300s). Moreover, a consistent problem with low FN could damage the reputation of Washington wheat in foreign markets. LMA screening will prevent the release of LMA susceptible cultivars that may lower the overall FN of grain from this region.

WGC project number: 5389
WGC project title: Developing Washington Wheat with Stable Hagberg Falling Numbers
Project PI(s): C. Steber, M. O. Pumphrey, A.H. Carter
Project initiation date: 07/01/15
Project year: year 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Screen spring and winter wheat cultivars, breeding, and mapping lines for preharvest sprouting tolerance using the spike wetting test and the Falling Number test.	Knowledge about the susceptibility of spring and winter wheat cultivars and breeding lines to preharvest sprouting based on the spike-wetting test and on to FN (2015, 2016, 2017). Selection of breeding lines with higher resistance to preharvest sprouting compared to current varieties.	Year 1. Completed FN testing for the 2014 variety trials (see steberlog.org/project 7599). Conducted spike wetting tests of winter wheat breeding lines from the 2015 field season. Identified locations with low FN problems in 2015 by FN testing of known susceptible spring and winter wheat lines. Winter wheat checks had low FN in Mayview and Pullman. Spring wheat checks had low FN in Almira, Endicott, Farmington, Horse Heaven, Lamont, Lind, Pullman, and Reardan. FN will be performed on variety tirals at these locations.	Year 1, 2, and 3. Spike-wetting tests and FN testing of breeding lines, association mapping lines, and affected variety trial locations.	Results will be communicated through talks at the Wheat Research Review, annual Wheat Life articles, abstracts submitted to the Lind and Spillman Field Days, and through the project website: steberlab.org/project7599.php.
2. Improve screening for LMA susceptibility to prevent release of susceptible spring and winter varieties.	Knowledge about the susceptibility of spring and winter wheat varieties and breeding lines to LMA. Breeding of LMA resistant wheat.	Year 1. Compared the field cut-spike LMA testing with greenhouse LMA tests. The field cut spike assay detects known LMA susceptible lines, but may score mistake soem LMA resistant lines for susceptible lines. Based on FN and LMA testing data, winter LMA suspects include, Jasper, SY-Ovation, Bruehl, WA8202, 4J071246-1C, and Rosalyn. Spring wheat LMA suspects include Alturus, ARS504174, WB6341, IDO851, IDO854, Nick, UI-Stone, and WA8124.	Year 1. Perform LMA testing using both the established greenhouse and new field-based technique. Determine if the field technique gives the similar results to greenhouse. Year 2 and 3. LMA testing of breeding lines and spring association panel.	Results will be communicated through talks at the Wheat Research Review, annual Wheat Life articles, abstracts submitted to the Lind and Spillman Field Days.
3. Identify molecular markers linked to preharvest sprouting resistance and susceptibility genes by association mapping	Molecular markers for use in early selection for increased preharvest sprouting tolerance.	Year 1. Molecular markers linked to preharvest sprouting tolerance were identified based on Falling Number and spike wetting test data. The genes/loci identified by Falling Number were not identical to those identified by spike wetting test. This suggests that we need to continue to emphasize FN data when making selections in the breeding programs.	Year 1. Perform association mapping to identify loci linked with PHS tolerance. Year 2 and 3. Perform field LMA tests in preparation for association mapping. Year 3 perform LMA association mapping.	Results will be communicated through talks at the Wheat Research Review, annual Wheat Life articles, abstracts submitted to the Lind and Spillman Field Days.

Washington Grain Commission
Wheat and Barley Research Final Report

Project: 3389

Progress Report Year: __*3*__ *of* __*3*__

Title: Building a Mutation Breeding Toolbox for Washington Wheat

Project PIs: Camille Steber, Brian Beecher, Daniel Z. Skinner, Deven See, and Michael Pumphrey

Cooperators: Michael Neff, Scot Hulbert, Kimberly Garland Campbell, and Arron Carter

Executive summary:

Objective 1. Use forward genetics to screen mutagenized populations derived from the TILLING populations of Alpowa, Louise, Jagger, and Eltan for mutations involved in stripe rust resistance, heat tolerance, vernalization, and photoperiod sensitivity.

The Louise population was advanced in the field and in the greenhouse to provide an M3 population for use in screening for altered stripe rust resistance and heat tolerance. Scot Hulbert and Michael Pumphrey screened the Louise mutant population for loss of high temperature adult plant resistance to stripe rust in the field in 2015. Four lines segregating for loss of stripe rust resistance were identified, and backcrossed to wild-type Louise in the greenhouse. In order to clone a gene, one must prove that mutations in that gene result in loss of function (in this case loss of stripe rust resistance). These lines will be used in the process of cloning the Louise stripe rust resistance gene. Evaluation of the Jagger population revealed that it was not suitable for the originally planned screen for altered vernalization and photoperiod sensitivity. We are in the process of developing a new Norstar mutant population that Deven See will use for this screen. Norstar is a highly cold tolerant winter wheat with a strong vernalization requirement. This new TILLING population will be useful to the Skinner, Carter, and See research programs aimed at understanding cold tolerance and vernalization. Spring wheat mutant lines generated by this project were provided to Dr. Ian Burke's lab for use in forward genetic screens for altered herbicide resistance.

Objective 2. Generate a club wheat TILLING population in JD and generate a new forward genetics mutant population in soft white spring Alpowa+Yr5 for use to identifying and cloning stripe rust resistance genes..

Both JD and Alpowa+Yr5 seeds (M1 generation) were mutagenized and advanced in year 1. Screening of the Alpowa+Yr5 population recovered 20 mutants showing loss of the stripe rust resistance that will be used by M.Pumphrey's program for identifying the Yr5 gene. Additional JD TILLING lines were generated in year 3. This is the first club wheat mutant population. Club wheat is genetically quite different from common wheat, and contains unique genes for stripe rust resistance. This mutant population will be useful in efforts to clone genes, including stripe rust resistance genes, from club wheat.

Objective 3. Perform TILLING in the soft white winter Eltan population for mutations in cold tolerance genes *ICE1* and *ICE2*. Assist Washington researchers in TILLING for mutations in specific genes involved in coleoptile emergence, as well as cold, heat, drought, and preharvest sprouting tolerance.

TILLING was performed on the *ICE-7A1* and *ICE-7B1* genes to identify mutations that alter (improve or decrease) cold tolerance. These experiments were conducted in spring tetraploid wheat because initial screening suggested that the original Eltan population did not have a high enough density of mutations in all lines. These experiments are useful as an initial proof of concept, but ideally they should be performed in winter wheat. Successful TILLING requires a very high density of mutations (1 mutation in every 24,000 bp). New TILLING lines were generated in soft white winter Eltan using higher levels of mutagen. Several WSU researchers requested a new TILLING population in the highly freezing tolerant hard red winter line, Norstar. A seed increase of a doubled haploid-Norstar was increased in year 2. The Norstar TILLING population is under construction, and should be completed in year 3.

Impact: This project created resources for forward and reverse genetics that can allow Washington wheat researchers to transfer knowledge about gene function into superior wheat cultivars. Federal grant funding has become highly competitive, and requires extensive preliminary results. The existence of this resource has enabled WSU researchers to propose the use of existing mutant populations in grant proposals with aims involving gene cloning and wheat improvement. In the long term, this should improve the ability of WSU wheat researchers to obtain federal funding. Resources have been used by the wheat researchers: Scot Hulbert, Arron Carter, Ian Burke, Camille Steber, Deven See, Dan Skinner, and Brian Beecher.

WGC project number: 3389
WGC project title: **Building a Mutation Breeding Toolbox for Washington Wheat**
Project PI(s): Camille Steber, Brian Beecher, Daniel Z. Skinner, Deven See, Michael Pumphrey.
Project initiation date: 1-Jul-13
Project year: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Use forward genetics to screen mutagenized populations derived from the TILLING populations of Alpowa, Louise, Jagger, and Eltan for mutations involved in stripe rust resistance, heat tolerance, vernalization, and photoperiod sensitivity.	Mutant resources that can be used to understand stripe rust resistance, heat tolerance, vernalization, and photperiod sensitivity.	The Louise population was advanced to M3 in the field and greenhouse to create M3 mutant families for screening (Year 1). Jagger did not have a strong enough vernalization requirement for use in forward mutant screens for altered vernalization and photoperiod sensitivity. Eltan was chosen as an improvement, and a larger mutant population was developed (Year 2 and 3). Finally, three labs requested a Norstar mutant population because of its excellent freezing tolerance. The new objective to develop a Norstar TILLING population was undertaken in year 3.	Year 1. The Louise population was advanced, and initial analysis of Jagger population performed. Year 2. Mutagenesis of Eltan to create 1,000 additional Eltan TILLING lines. Year 3. Eltan population was advanced and genomic DNA prepared. Norstar was mutagenized. Louise mutants that lost stripe rust resistance were identified in a field screen. These Louise mutants will be used in an effort to clone an HTAP stripe rust resistance gene.	Results were reported at the Wheat Research Review and at field day presentations.
2. Generate a club wheat TILLING population in JD. Generate a new forward genetics mutant population in soft white spring Alpowa+Yr5 for use to identifying and cloning stripe rust resistance genes.	New TILLING population in JD. A new mutant population in Alpowa+Yr5.	JD was mutagenized and advanced for use in making a TILLING population. Alpowa+Yr5 was mutagenized for use in forward genetics, and 20 mutants showing loss of stripe rust resistance were recovered. These mutants will be used in mapping and cloning of the Yr5 stripe rust resistance gene.	Year 1 Alpowa+Yr5 population and screening. Year 2 and 3. Creation of JD TILLING lines.	Results will be reported at the Wheat Research Review and at field day presentations.
3. Perform TILLING for mutations in cold tolerance genes *ICE1* and *ICE2*. Assist Washington researchers in TILLING for mutations in specific genes involved in coleoptile emergence, as well as cold, heat, drought, and preharvest sprouting tolerance.	Mutations in the *ICE1* and *ICE2* genes of wheat for use in understanding and improving cold tolerance in wheat. Mutations for altered photoperiod sensitivity in the Ppd-D1 gene of wheat.	Gene-specific primers to *ICE1*, *ICE2*, and to two as yet unpublished *ICE* gene homologs. TILLING recovered 33 mutations in one *ICE* gene and 23 mutations in another that are expected to result in amino acid changes. If ICE functions in wheat freezing tolerance, then these mutations will most likely result in reduced freezing tolerance. However, some of these alleles may result in a gain-of-function increase in freezing tolerance. Preliminary screening of the original Eltan population indicated that some of the lines did not contain a high enough density of mutations for TILLING. Thus, additional Eltan lines were generated in Year 2 using a higher concentration of mutagen.	Year1. Develop ICE-gene-specific primers. Year 2 and 3. Perform TILLING of ICE genes in wheat.	Results were reported at the Wheat Research Review.

Project #: 126593

Progress Report Year: *1 of 3 years (maximum of 3 year funding cycle)*

Title: Intelligent Prediction and Association Tool to Facilitate Wheat Breeding

PI: *Dr. Zhiwu Zhang*

Cooperators: *Dr. Michael Pumphrey, Dr. Arron H. Carter, and Dr. Kimberly Campbell*

Executive summary: *We assembled forty traits collected from multiple fields over multiple years, and sixty thousand genetic markers from DNA sequencing together, to predict the genetic potentials of three hundred wheat lines. Although more than half of genetic markers were missing across the three hundred lines, our primary results demonstrated that these traits are still predictable. The Pearson correlation coefficients between the predicted and observed phenotypes averaged around 40%, and ranged from 20% to 60%. This suggested that the current molecular breeding platform is working toward improved selection accuracy and reduction of breeding cycles. The manuscript on the software to predict phenotypes from genotypes has been accepted for publication. Furthermore, we have developed a new statistical method for genomic prediction. The new statistical method improves prediction accuracy by 5~15%. The manuscript on the new prediction method is under preparation.*

Impact: *Implementation of our research findings creates the opportunity to efficiently develop varieties with high yield, high quality, and resistance to biotic and abiotic stress. In short term, breeders have more confidence to eliminate lines with low genetic potentials to reduce the cost of field trials. In long term, breeders have more chances to retain the genetic lines with desirable genes, and recombine them to create superior varieties. In our recent funding cycle, we measured our impact on how accurately we could predict phenotypes from genotypes by using cross-validation. We hided the observed phenotypes for one fifth of the total lines. We used the rest to develop predictive formula and apply to the genotypes of the one fifth lines to predict their phenotypes. Then we calculated the correlation between the predicted and the observed phenotypes. After circulating each of the one fifth, the average correlation was calculated as the overall prediction accuracy. Multiple efforts are required to continually improve prediction accuracy, including improvement of prediction methods and quality of genetic markers.*

WGC project number: 126593

WGC Project title: **Intelligent Prediction and Association Tool to Facilitate Wheat Breeding**

Project PI(s): *Zhiwu Zhang, Michael Pumphrey, Arron H. Carter, and Kimberly Campbell*

Project initiation date: 1-Jul-15

Project year: 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
1) Develop statistical methods to model gene interactions	IPAT software package in R with functions customized for wheat breeding	Based on GAPIT software developed by the PI previously for Genome-Wide Association Study (GWAS), we further improved the software particularly for genomic prediction in current funding cycle. The manuscript of second version of GAPIT was accepted for publication. We used the package to evaluate forty traits of 300 wheat lines and achieved an average accuracy of 40%. Furthermore, we developed a new genomic prediction method by using the SUPER algorithm that was developed by the PI for GWAS. The new method improves prediction accuracy by 5~15% compared with existing method. The manuscript on the new methods is under preparation. We are the in the process to integrated the new method into GAPIT.	We have met the timeline of December 31, 2015 for the development of a new statistical method to improve accuracy of genomic prediction. Currently we are integrating the new method into our existing software (GAPIT), particularly for improved genomic prediction, which is expected to be completed by June 30, 2016.	1) An article is in preparation for Wheat Life; 2) PI made a presentation to WGC in February 2015;3) The PI was invited to give a presentation at International Symposium of Agricultural Genomics (http://www.nature.com/natureconferences/ag2015/speakers.html); WGC annual meeting; and 4) One manuscript was accepted for publication by The Plant Genome.