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Washington State University Wheat and Barley Research Progress Reports

Washington Grain Commission

2014-2015 Fiscal Year

2014-15 WSU Wheat & Barley Research Progress Reports to the Washington Grain Commission

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

Project #: 3193

Progress Report Year: _2_ *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: Two hard white winter wheat lines were proposed for release in 2014. WA8184 is a hard white line targeted toward the intermediate rainfall zones of the state, but particularly, the Davenport/Reardan area. This line has good end-use quality for the domestic market, good protein content, good stripe rust resistance, and good yield potential. It has also been evaluate by ADM and found to meet their market use. This line was approved for release and foundation seed is being increased. WA8158 is a hard white line targeted to the low rainfall zones of the state and does especially well under deep-furrow planting systems. This line has very good end-use quality, good protein content, good resistance to stripe rust, and very good yield potential. The release of this line was deferred another year to continue to estimate the amount of hard white winter acres are needed before release. Two other hard red lines are on breeder seed increase. WA8180 is a standard height hard red winter line for production in the low rainfall zones under deep-furrow cropping systems. This line has good yield potential, good protein content, and good end-use quality. 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. WA8181 is a hard red winter line targeted toward production in the intermediate rainfall zones. WA8181 has good disease resistance, good yield potential, and good protein content. Apart from these lines, there are an additional seven lines being testing in variety testing for release potential. 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.

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 $8.00 wheat would mean nearly $3.4 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.

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: 2 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 is on limited acres for production in 2015. In 2014, WA8184, a hard white winter wheat line was approved for release. This line is targeted for production in the domestic market and will complement production of the already 15,000 acres of hard white spring wheat in the state. We have 6 hard red and 1 hard white breeding lines in statewide testing for consideration under low rainfall production systems and 2 hard red and 1 hard white in statewide testing for consideration under high rainfall production. We have over 12,000 plots and 40,000 rows under evaluation at various stages of the breeding process. Two lines have performed very well under the low rainfall conditions and are on breeder seed increase. One line, WA8180, has some of the quickest and best emergence we have seen.	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 16 locations in 2014. This includes emergence, winter survivability, heading date, test weight, plant height, and grain yield. Our Kahlotus trial gave a very good screen for emergence potential, and Lind gave a very good screen for cold tolerance. With this data combined, very good selection was made for these traits in 2014.	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 2015.	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: QTL Identification and Deployment through 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 second year and is working on screening wheat germplasm and core collections for both resistance and susceptibility to different herbicides. The goal of this project is to identify novel sources of resistance and susceptibility that can be used for breeding and crop rotation purposes. Erika Kruse started this past year and is working on the interaction between snow mold and cold tolerance, trying to identify the genes responsible for snow mold tolerance and their relationship to tolerance to cold temperatures.

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 numbers 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.

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: 2 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 identified four excellent studnets in the previous years funding. Austin Case (graduated), Shiferaw Gizaw, Megan Lewien, and Caleb Squires. We are in the process of reviewing applications for the 2015 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. Upon successful recruiting of a student for 2015, we will develop a project directly relevant to improving the wheat breeding process.	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
Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: 3673

Progress Report Year: *_1_ 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: Significant SNP markers associated with novel resistant genes and known genes such as *Yr17*, *Yr5* and the Coda resistance have been identified through Winter wheat and/or Spring wheat panels. Additionally, novel stripe rust resistance genes from tetraploid wheat have also been identified. Although some of these genes identified have already been described, the identification of SNP markers linked to these genes will allow breeders to more effectively transfer these useful genes into new breeding lines. The resistance genes from tetraploid wheat are in the process of being transferred to spring wheat for use in breeding. Spring wheat lines were initially chosen for speed, but will eventually be moved into winter germplasm as well. The JD/Avocet S and Finch/Eltan populations have been tested in the field for QTL analysis and we have identified the stripe rust genes from Finch and Eltan. Mutant populations for Yr5 and the Coda resistance have been developed for further analysis and were screened under field conditions in 2014. 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. We now have multiple effective sources of resistance to PNW races of stripe rust, as well as markers associated with them, to begin selecting resistant germplasm. 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. The markers identified in this project will continue to ensure that future releases from breeding programs have resistance to stripe rust, thereby maintaining or improving upon the level of resistance they already experience in current cultivars.

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, 2014**
Project year: **1 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	Association mapping has been completed and QTL 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. In other cases, crosses have been initiated with lines carrying the desired QTL. QTL have been identified which would work well to be pyramided together and population selection will begin in 2015.	Population creation and selection with DNA markers will be done annually as populations are established. Once populations have been selected upon, field screening will be completed to ensure resistance has been captured.	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.
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	37 BC1F2 populations have been made and are currently being grown in the greenhouse. DNA markers will be used to identify progeny with stripe rust resistance genes of interest and then phenotyping will be done to confirm resistance. These lines with then be further used to introgress this resistance into other PNW germplasm.	Crosses between Emmer wheat and hexaploid wheat have been completed. Additional crosses will be done as necessary and once populations are established markers will be used to select for resistance.	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	Mutation populations have been generated. Phenotyping was completed in 2014. Additional phenotyping will be done in 2015. Crosses have been made to verify if YrCoda is novel or not. Genetic linkage maps are in their final stages and new markers tightly linked to these genes are in their final stages of validation.	Phenotyping will be done for two to three years. Genotyping will be done concurrently. Markers will be identified at the end of the funding period.	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.

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

Project #: 5195

Progress Report Year: *_3_ of _3__*

Title: Use of biotechnology for wheat improvement

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

Executive summary: In 2014 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 900 lines were selected out of those tested which had the 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 this population for GBS analysis. We will begin establishing the prediction model to apply to material in the field in the summer of 2015.

In the greenhouse, we made approximately 1,000 crosses consisting mainly of soft white, hard white, and hard red germplasm. These are being advanced to the F2 generation. We planted 1,100 DH plants in the field in 2014 for evaluation in 2015. In 2014 we attempted nearly 6,000 DH crosses, of which about 3,000 were successful. These will be advanced under greenhouse conditions and planted in the field in 2015.

We continue to introgress and select for (both phenotypically and with markers) germplasm containing herbicide resistance, foot rot, cold tolerance, snow mold tolerance, end-use quality, and stripe rust resistance. Multiple tools are being used in the greenhouse to screen this material for the selected traits and prepare seed for field evaluations. For these select traits, screening in the greenhouse can help ensure germplasm advanced to field conditions has the required level of resistance needed for variety release.

Impact: This project covers all market classes and rainfall zones in the state of Washington. This work will improve end-use quality, genetic resistance to pests and diseases, and agronomic adaptability and stability of released cultivars. Incorporating novel genes into cultivars will enhance the profitability of winter wheat production. Growers will save time and money by getting superior cultivars into their hands much quicker. The full impact of this work will depend on the adoption of wheat producers to the new cultivars developed, the perceived loses avoided through genetic resistance, and the varying price of wheat and input costs.

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: 3 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 2014, 12 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 2014, 15 populations for Yr5 and Yr15 were screened for and selected upon for upcoming field testing. Additionally, crosses were made in the field with lines carry diverse stripe rust genes that survived the cold and looked to perform well in the field. Field crosses were done to expedite the development process. An additional 5 populations were screened for a rust gene from the cultivar Stephens.	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	
	GPC-B1 and Bx7oe lines	In 2013, 34 F2 populations were screened for the genes Gpc-B1 and Bx7oe. Of these, 472 lines were selected and advanced in the greenhouse. In 2014 these were selected under field conditions and lines selected are now undergoing end-use quality screening. In 2014, 12 populations for Gpc-B1 were selected upon, and additional populations have been initiated with these two traits for selection in 2015.	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 2013, 5 populations were screened for incorporation of various Rht genes. These lines were tested in 2014 for emergence potential and lines which emerged well have been planted again at Lind for further screening while proceeding through the breeding process.	In 2013 these lines will be planted and in 2014 evaluated for performance under field conditions. Once it is confirmed these lines reduce height without hindering emergence or yield potential, more crosses will be initiated to more fully incorporate into our germplasm.	
	Genomic selection	Our genomic selection training panel was genotyped with 9K SNP markers in 2011. In 2012 and 2013, we collected our additional phenotypic data. In 2014 was did GBS on this population. We have combined agronomic data on this population into one file. With the assistance of Dr. Zhang, we will begin genomic selection in 2015. Prediction model development will begin and refinement will be made as more data is added at the end of the 2015 season. Once the model is developed, we will use it to predict performance of our advanced breeding lines currently in field trials.	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 2014, the advanced germplasm was screened with DNA markers for traits of interest. In 2015 we plan to continue this screening and progress to earlier generations.	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 2014 we made approximately 1200 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	Four existing(high rainfall SWW, Lo rainfall SWW, HWW and HRW Populations) single seed decent populations were increased to the F4 generation in the green house in 2013 and evaluated in the field in 2014. Due to lack of greenhouse space we did not make additional populations for 2014 increase. We have plans to do SSD populations in 2015.	This is done annually, with the number of crosses/populations varying	

	Doubled haploid	In 2014, we planted 1100 DH plants in the field. In 2014 we attempted approximately 6,000 DH plants, of which about 3,000 were successful and will be planted in the Fall of 2015. We are currently developing DH plants for another 100 populations.	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, and vernalization duration. 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.	

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

Project #: 6195

Progress Report Year: *_3_ 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 soft white winter wheat line, WA8169, was approved for release in 2014. WA8169 has good end-use quality, resistance to stripe rust and eyespot foot rot, and excellent yield potential. WA8169 appears to have broad adaptability across the state, but is most targeted to the intermediate rainfall zones of the state. In the 2014 VT trails, WA8169 was the top producing line in six of the 20 locations, and was in the top significance group in 17 of the 20 locations. Averaged over rainfall zones, it was the highest yielding line in the >20 inch rainfall zones, was second in the 16-20 inch and 16-12 inch rainfall zones, one bu/acre and three bu/acre below Xerpha, respectively, and was second in the <12 inch rainfall zone with a yield potential similar to Otto. Foundation seed production of WA8169 is currently underway. Puma was in high demand in the fall of 2014 and is being increased to meet demand. Otto, a 2011 release from this program, was also in high demand in 2014. It was planted on roughly 125,000 acres in 2013 and production acreage is estimated to have increased for this coming year. Ten advanced breeding lines were entered into WSU's Variety Testing (VT) Program. Over 600 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 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. This program aims to provide growers with winter wheat cultivars that have far reaching positive financial and environmental impacts. Our efforts target production in the major grain growing regions of the state, and the accompanying disease pressures. Release of new cultivars with excellent agronomic performance benefits growers within the state while excellent end-use quality increases market demand and acceptance.

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: 3 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. Puma is adapted to the Palouse region of the state and has resistance to stripe rust and foot rot, tolerance to Cephalosporium and low pH soils, and has excellent end-use quality. Due to demand, this line was increased again in 2014 and will be available in 2015. We recently received approval to release WA8169, a soft white winter wheat line with very broad adaptability. This line was a top yielding line in all locations in 2014, and in the intermediate to low zones in 2013. This line is targeted to replace Xerpha acres. We have 4 breeding lines in statewide testing for consideration under low rainfall production systems and 6 in statewide testing for consideration under high rainfall production. Two of these lines are two-gene imazamox resistant lines. We have over 12,000 plots and 40,000 rows 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 16 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 was added 15,000 head rows for selection at Lind due to the ability to screen for emergence and cold tolerance.	Evaluation is done annually at multiple locations across the state.	
	Disease resistance	Disease resistance is recorded on our 16 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 2015.	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 2015.	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 will evaluate 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 is currently being 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: 2 of 3 (2014)

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 second year (2014) of the project, studies were conducted according to the objectives of the project proposal and all objectives specified for the second year were 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 2014. Rust updates and advises were provided on time to growers based on the forecasts using prediction models and field surveys, which prevented unnecessary use of chemicals in the State of Washington. 2) We identified 29 races of wheat stripe rust and two races of barley stripe rust in the US, of which 26 and one 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 identified different genetic groups in different epidemiological regions. 4) We evaluated more than 30,000 wheat and 5,000 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 2014, we collaborated with breeders in releasing or pre-releasing eight wheat and one barley varieties; and registered seven wheat varieties. The germplasm evaluation data were also used to update the Seed Buyer's Guide for growers to choose resistant varieties to grow. 5) We completed studies for mapping six genes for stripe rust resistance in two wheat lines and identified molecular markers. We officially named and published five new genes for stripe rust resistance. 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 30 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 the Pacific Northwest, especially in Washington. The data of the fungicides and varieties are used for guiding the integrated control of stripe rust. 8) We published 28 journal articles and 4 meeting abstracts in 2014.

Outputs and Outcomes:

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

WGC2014 Report XMChen Outcome reporting.pdf)

Publications:

Scientific Journals:

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.

Popular Press Articles:

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.

Presentations and Reports:

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)

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: 2 of 3 (2014)

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 2014. Rust updates and advises were provided on time to growers during the crop season based on the forecasts and field surveys, which prevented unneccessary use of fungicides. 2**) Stripe rust races.** We identified 29 races of wheat stripe rust and 2 races of barley stripe rust in the US, and 26 and 1 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 identified different genetic groups in different epidemiological regions.	All planned studies for the project in 2014 have been completed on time. There is no any delay, failure, or problem in studies to this objectives. In 2014, 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 forecast was reported to wheat researchers and growers as early as in early January and continued as the season was progressing. Stripe rust was low in eastern PNW but normal in western PNW. Leaf rust of wheat was normal in western but absent in eastern PNW; and leaf rust of barley was severe in western but absent in eastern PNW. Stem rust of wheat and barley was absent in the PNW. The forecasts and updates reduced unnecessary use of fungicide. A total of 327 stripe rust samples were obtained throughout the country in 2014 and 196 (60%) of them from Washington. We have completed about 95% of the race ID work for the 2014 samples as scheduled by this time. So far we have detected 29 wheat stripe rust races and 2 barley stripe rust races, of which 26 and 1 were detected respectively in Washington. The frequencies and distribution of the races were determined. We completed molecular characterization of stripe rust populations of 2010 and 2011 using 17 co-dominant simple sequence repaet markers and 97 single-nucleotide polymorphism markers and found the pathogen population in the PNW is more diverse that the eatsern US population and determined the differences of spore movement between epidemiological regions.	All studies and services were completed on time. The race identification work for the 2014 stripe rust samples will be completed by late February, 2014, as scheduled, and the race ID work for 2014 samples will start in February. Molecular characterization of the 2012-2013 samples and DNA extraction of the 2014 samples will be completed by June, 2015.	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 2014, we tested more than 30,000 wheat and 5,000 barley entries for resistance to stripe rust and other foliar diseases, and provided the data to breeding programs to eliminate susceptible lines and select rust resistant lines for developing new varieties. **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 2014, we collaborated with breeders in releasing or pre-releasing 8 wheat and 1 barley varieties; and registered 7 wheat 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 2014, we completed studies for mapping 6 genes for stripe rust resistance in 2 wheat lines and identified molecular markers, and officially named five new genes for stripe rust resistance. **5) Supplied seeds of germplasm to breeding programs.** In 2014, we provided seeds of our newly developed wheat germplasm lines to several breeding programs for developing stripe rust resistant wheat varieties.	In 2014, we evaluated more than 30,000 wheat and 5,000 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 under artificial inoculation and Mt. Vernon locations under natural stripe rust infection. Some of the nurseries were also tested in Walla Walla and Lind, WA . Because natural stripe rust was low in eastern WA, the artificial inoculation at the Pullman sites allowed us to have high quality data of germplasm screening nurseries. 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 superior resistance. Through our intensive testing, varieties with durable resistance to stripe rust have been developed. In 2014, we collaborated with public breeding programs in releasing 8 wheat varieties and 1 barley variety; and registered 7 wheat varieties. Varieties developed by private breeding programs were also resulted from our germplasm screening program. In 2014, we completed studies for mapping stripe rust resistance genes in two wheat lines and developed mapping populations for identification of stripe rust resistance genes in Madsen and Eltan.	All germplasm tests were completed and the data were provided to collaborators on time. The 2014-15 winter wheat nurseries were planted in fields in September and October 2014. The 2015 spring crop nurseries will be planted in April, 2015. The greenhouse tests of the 2014 spring nurseries and the 2014-15 winter wheat nurseries have been conducting in the greenhouse during the winter, and will be completed by May, 2015	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 2014, we tested 30 fungicide treatments for control of stripe rust 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 2014. 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. As stripe rust was low in 2014, the overall resistance to stripe rust in the wheat varieties grown in Washington was adequate for protecting crops from stripe rust damage.	In 2014, we evaluated 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. The experimental fields were inoculated with a spore mixture of two races predominant in the region in the previous year. 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, all fungicide treatments significantly reduced rust severity; all treatments but one significantly increased test weight; and all treatments but one significantly increased yield. For spring wheat, all treatments significantly reduced rust severity; but none of them significantly increased test weight. 23 treatments significant increased yield while the increases by the other 7 treatments were not statistically significant. In 2014, 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 three ot four times during the disease 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. The results were sent to the cereal group including growers, organizations, industries, and scientists.	For this objective, all tests scheduled for 2014 were successfully completed. For the 2014-15 growing season, the winter wheat plots of the fungicide and variety studies were planted in October, 2014 and the spring plots will be planted in April, 2015. The tests will be completed in August (for winter wheat) and September (for spring wheat), 2015	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 Annual Progress Reports and Final Reports

Project #: 3043-3697

Progress Report Year: 1 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)

Executive Summary: In FY 2015 our team made excellent progress on each of our four objectives related to improving wireworm management in cereal crops. Major accomplishments of our team include:

(1) Sampling 80 crop fields for wireworms. In each field we collected wireworms from 10 bait traps, with over 1,600 wireworms collected and identified in total. We also collected data on factors influencing wireworms in each field. These data are providing a clearer picture of how wireworms vary across the state both in terms of species present and their abundance.
(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.
(3) Evaluation of wireworm damage at 8 wheat variety testing locations. Data will show the extent of damage caused by three major wireworm species, and the economic returns provided by insecticidal treatments.
(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 20 extension talks on wireworms
(6) Development of insect management content for the WSU small grains website

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). Optimizing wireworm control could provide economic benefits in the millions annually for growers throughout Washington.

Our team also delivered over 20 extension talks in 2014 concerning wireworms. With a conservative estimate of 30 attendees per talk our team thus directly communicated results to approximately 600 growers, field consultants, 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

Outputs and Outcomes

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: 1

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; extension bulletin on major species present in Washington state	We have made extensive progress on this objective, with 80 fields sampled in 2014 for wireworms (40 spring wheat, 20 winter wheat, 20 CRP). From these fields we collected wireworms from 10 bait traps and identified all individuals to species (over 1,600 individuals were collected). We also collected data on 10 environmental and management factors associated with wireworms from each field. These data will complement similar data collected in 2013, and we plan for a final year of sampling in 2015. From these data we will be able to discern the geographic delineations of the three major wireworm species in Washington (Limonius infuscatus, Limonius californicus, Ctenicera pruinina) and the factors that mediate their abundances.	Sampling from the first year of the project was completed in summer 2014. We plan to put out an extension bulletin in spring 2015 with the preliminary data on the major wireworm species found in Washington and their geographic distributions. A final year of sampling is planned in year 2 of the project, which will allow us to continue to refine our predictive models for wireworms (see below).	The PhD student funded by this project, Ivan Milosavljevic, delivered over 10 talks at grower meetings, field days, or academic conferences to communicate information from this objective. In addition, PIs Esser and Crowder delivered results at several field days and the inaguaral Wheat Academy at WSU in December 2014. In spring 2015 we plant to releash an extension bulletin on the major wireworm species of economic significance in Washington. This bulletin will contain information on how to sample and identify wireworms, and describe the significance of each major species in reducing wheat and barley yields. We have also develop a page on wireworms at the WSU Small Grains Website, which contains information for growers about wireworm management (smallgrains.cahnrs.wsu.edu)
1 - Determine effects of climate, tillage, soil, and crop rotations on wireworms in cereal crops and develop a predictive model for wireworms	Risk calculator for wireworms	We currently have data from 160 fields on factors affecting wireworm species and their abundances, and will collect data on 40 more in FY 2016. After these data are collected in summer 2015 we will use our 200 total data points to determine the factors that promote or deter wireworms, and build regression models for each of the three major species. These models will form the basis of risk calculators that growers can use to assess their risk from wireworms based on their unique combination of field conditions and management practices. This is expected to be completed by the end of the second year of the project	We expect to be able to produce effective calculators that show risk from wireworms by end of FY 2016.	Risk calculators will be published on the small grains website (smallgrains.cahnrs.wsu.edu). Growers will be able to enter specific information about their fields (location, management practices, etc) and receive predictions of "risk" from wireworms. This will allow growers to proactively make management decisions based on their unique conditions.

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	Our team conducted trials with 40 insecticide entries at two locations in Washington in 2014. Chemical companies have been pleased with our results, and reported to PI Esser that our trials "were the best in the country". These companies have already established contact with us to continue trials in 2015. 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. We will continue to evaluate 40 or more insecticide entries at two locations in FY 2016 to support registration of these products.	While we can't reveal names of products in development, we have shared results of the trials with growers at field days, grower meetings, and the Wheat Academy. We will continue to communicate with the chemical companies to provide necessary data to support new products.
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 Stephen Guy we established plots of Louise and Glee wheat varieties, with or without Gaucho, at 8 of the variety testing locations throughout Washington State. At each location we monitored the wireworm populations (species present and their abundance) four times over the course of the season. Guy 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. Similar trials conducted in summer 2015 will provide us with two years of field data. These trials are being coordinated with cooperator Higginbotham, who is now the head of the variety testing program.	We collected meaningful data on variety x insecticide combinations that are effective for each major wireworm species in summer 2014. Experiments will be repeated in summer 2015 to control for season-to-season variability. At the end of 2015 we will have two years of excellent data on varieties and treatment options that provide optimal control for the three major wireworm species in Washington state. Growers can use these data to assess the potential returns of using Gaucho.	As the results are still being analyzed they have not been presented to growers prior to December 2014. However, in 2015 we plan to present results of our two years of trials at field days, grower meetings, and the 2015 Wheat Academy. These data will also be incorporated into an extension bulletin in 2015 that documents effectiveness of Gaucho on different wheat varieties for each major wireworm species. 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	In cooperation with collaborator Murphy we planted side-by-side trails evaluating damage from wireworms to wheat, barley, and oats at two locations (Dusty, WA and near Pullman, WA). These trails were conducted on the farms of participating growers, and including plots with each of the three crops that were treated with Gaucho or left untreated. From each plot we sampled wireworms four times in 2014 and collected yield data and crop quality at the end of the season. These data are currently being analyzed, although preliminary results show that oats are the most tolerant crop, followed by barley and then wheat. Trials will be repeated in 2015 to control for season-to-season variability.	The first year of experiments was completed in Fall 2014 and data are currently being analyzed. A second year of these trials to control for seasonal variability will be conducted at two locations in 2015. In Fall 2015 we will analyze all the data and publish the results.	Data from these trials will be developed into an extension bulletin by Fall 2015. 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 at the Wheat Academy in 2014. Similar presentations will be made to grower groups in 2015 and 2016.
4 - Develop extension materials for wireworms	Two extension bulletins, multiple academic publications, and information on the smallgrains.cahnrs.wsu.edu website	We have uploaded information on wireworm sampling and management to the small grains website. We expect to publish the first extension bulletin in spring 2015. The second extension bulletin will be published by spring 2016. Throughout the life of the project we will continue to upload materials to the smallgrains website to make them easily accessible to growers	One extension bulletins will be published by spring 2015 and the second by spring 2016. Information on website will be uploaded as available.	We have described these upcoming bulletins 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: 3557

Progress Report Year: *_1_ of _1_*

Title: Development of Basis Forecasting Strategies and Tools for Washington Wheat Producers

Project PIs: T. Randall Fortenbery

Executive summary: A significant amount of research has been devoted to identifying marketing strategies for managing volatile prices at the farm level. However, before a producer can take full advantage of various risk management strategies (including forward cash contracts, futures hedging, and options on futures contracts) he/she must be able to localize publicly reported futures prices. This involves converting a reported price for some future delivery date into a price that could be received on his or her farm in the future.

This has become more challenging as wheat prices the last several years have experienced a level of volatility unparalleled in previous years. In addition, basis levels have been more volatile than the actual prices were prior to 2008. This has made wheat marketing more difficult – a volatile and unpredictable basis makes it hard to determine what the local cash price is likely to be for a later delivery date even though the futures price for later delivery can be observed. This, in turn, makes it difficult to determine when a cash forward contract or other cash pricing opportunity is offering an attractive price for later delivery.

This is an issue with all classes of wheat produced in the Pacific Northwest (PNW), but is particularly evident in white wheat markets. This is partly because there is no white wheat futures contract. The soft red winter wheat futures contract traded in Chicago is often used to form cash price expectations for white wheat at later delivery dates, but this price relationship has become much less predictable in recent years.

The primary goal of the project was to improve the market information available to producers and merchandisers of PNW wheat. This included developing improved strategies for basis expectations, and providing continuous updates of basis forecasts across several Washington markets. This research focused on white wheat, but plans are to expand the forecast methodology web site functionality developed to other wheat varieties.

Objective 1. Develop a system of statistical models that identify the drivers of basis volatility.

This objective has been completed. A series of three different type forecasting models were developed and tested for estimating local basis levels. The models were initially developed based on two Eastern Washington locations, but are now being applied across a couple of dozen different locations. The models include a fundamental statistical model. This model attempts to account for supply/demand conditions across markets, and is similar to the type models fundamental traders' use in trading commodity markets. This model includes variables measuring economic relationships and includes local versus national wheat production, transport costs to Portland from the local market, exchange rates between the U.S. and major buyers of U.S. wheat, perceptions of crop progress, etc., as well as various measures of market emotion and momentum. The second model is a time series type model similar to those used by technical traders of commodity markets. They explain current basis behavior as a function of historical basis relationships, although the weighting and lag structures of the models are more complicated than just looking at past trends. The third model is a hybrid of the fundamental and technical models. All models have been subjected to peer review for presentation at a two professional conferences.

Objective 2. Develop a reduced form of the various identified models that can be used to forecast basis levels for up to 11 months forward. I have developed and launched a single basis forecasting model based on the combined information of the three model types described above. This is the model that generates the actual basis forecasts. The model forecasts are available from http://smallgrains.wsu.edu/marketing-and-economics/market-prices-graphing-tool/.

Objective 3. Develop a web based system that will allow produces and merchandisers to access both historical basis levels and forecasts for up to 11 months forward.

The web site has been constructed and provides regular updates to the basis forecasts. It is currently being altered to present forecast errors over previous years. The web site is a page choice under the Wheat and Small Grains Extension wheat website developed by the dry-land cropping extension team. The website receives live data feeds of local cash prices and futures prices daily, and this data is used to update the basis forecasts on a daily basis.

Impact: Completion of this project allows both producers and merchandisers of PNW wheat to make more informed decisions relative to forward pricing wheat. Further, improved basis forecasts allow for more informed decisions relative to wheat storage. The more precise the basis forecast, the easier it is to determine whether it makes sense to store wheat un-priced for later delivery, store wheat with a guaranteed price, or make immediate sales and not continue to store wheat.

WGC project number: 3557
WGC project title: Development of Basis Forecasting Strategies and Tools for Washington Wheat Producers
Project PI(s): T. Randall Fortenbery
Project initiation date: 7/1/2013
Project year: 2013

Objective	Deliverable	Progress	Timeline	Communication
1. Develop a system of statistical models that identify the drivers of basis volatility	A set of mdoels to be used for developing a reduced form, basis forecasting model.	Models have been developed and evaluated.	Completed	Progress and results have been presented at severla county meetings, including all Extension Farm Bill education programs in Fall 2014. Wheat Life article duscussing the research and its use pubulished in August/September 2014.
2. Develop a reduced form of the various identified models that can be used to forecast basis levels for up to 11 months forward.	A basis forecasting model that will run on the associated web site and deliver daiuly updates to basis farecasts by location.	This work has been completed and manuscripts are being developed for academic journals. Results were presented at two different professional meetings so peer reviewed feed back has been received	Completed	Dynamic model updatres have been implemeted and are avaiable via the web.
3. Develop a web based system that will allow produces and merchandisers to access both historical basis levels and forecasts for up to 11 months forward.	A web based information delivery system for use by growers and agribusiness. This is part of the Wheat and Small Grains Extension site developed by the dry land extension team.	I worked with Bill Bonner in the CAHNRS IT office to develop the actual web site. I purchased the feed for the automatic price downloads from Data Transmission Network (DTN). The basis forecast model is updated daily and be runs behind the website.	Completed	The web site has been promoted in Wheat Life and in grower meetings Fall of 2014.

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

PROJECT No.: 30109-6345
Progress report year: *2 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: In 2014, the USDA-ARS filled the field research technician position and we plan to fill the ARS technician position in 2015 or early 2016. We managed 7 field testing locations ourselves and four others in collaboration with the WSU Winter Breeding program, the WSU Cereal Variety Testing Program, OSU-CBARC and the OSU Wheat Breeding program and University of Idaho. We evaluated over 3000 plots and several thousand head row plots in three states. We are focusing 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. Based on the 2014 WSU Cereal Variety Trials, the best performing club wheats in the > 20 in. precipitation region were Bruehl and ARS Crescent. ARS Crescent, ARS Chrystal, and ARS 010262-1C were highly competitive with the best soft white common cultivars in the 16-20 in. rainfall zone while ARS010262-1C and 4J071366-1 performed will in the 12-16 inch region and under 12 inch region. For 2015, we entered eight breeding lines into the Washington State Extension Trials. 4J071366-1, and ARS20060123-31C for all zones; ARS010669-2C, ARS010263-10-3C and ARS20060126-35C for ithe wet locations; ARS010679-1C, ARS040335-9C and ARS06135-9C for the dry locations. We did not enter any soft white wheats into the trials. These club breeding lines are all products of crossing with soft wheats from the Eastern US as additional sources of resistance to rusts, Hessian Fly and BYDV. In addition, six breeding lines were entered into the Western regional trials. We are reselecting ARS010262-1C for club head type. 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.

We have greatly expanded our use of genotyping and and are in the process of genotyping all our the entries in 2014 and 2015 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 2015. 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. We are confirming these markers in segregating DH popualtions and in a large PNW-adapted panel. Marker assisted selection using KASP and SSR markers was used to select for resistance to Preharvest sprouting, BYDV, eyespot, and stripe rust. We are developing new KASP markers when possible because they have proved to be quite efficient.

We evaluated several hundred doubled haploid lines in disease nurseries and unreplicated trials and have advanced several to our Elite replicaited trials. Early generation quality testing was performed on all early generation selections in order to continue to maintain and improve club wheat milling quality. Coleotpile testing and winter hardiness testing was run on all breeding lines. All breeding lines were selected for resistance to stripe rust, eyespot, cephalosporioum stripe, and Fusarium in inoculated nurseries.

We updated all of our computers, and purchased a new small tractor for spraying to replace our two old tractors, both of which were at least 30 years old. We planted our yield trials at Pullman using the WSU no-till plot drill with cross-slot openers in order to select under conditions that are similar to common farm practice. This proved to be a challenge in the fall of 2014 due to the lack of rain and hard soil but as of Dec. 21, the stands were adequate. It is critically important to select under farming practices that are similar to current production practice.

We are considering 4J071366-1 as a release for the dryer rainfall zone. This line was developed in conjunction with the WSU winter wheat program.

Impact

Club wheat acreage represents a small but significant part of the total WA wheat market. The excellent disease resistance of the club wheats 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.

Project 6345 Communications:

Presentations:

a. "Club Wheat for Dry Cropping Regions", Lind Field Day-WSU Agricultural Experiment Station, Lind WA, June 12, 2013.
b. Report of Progress: Washington Grains Commission Research Review, "Club Wheat Breeding", Pullman WA, Feb. 2014.
c. Plot and field day tours speaking to approximately 15-30 growers and industry representatives per tour during June, 2014: Harrington WA.

Refereed manuscripts with applications to this project.

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.

WGC project number: **3019-6345**
WGC project title: **Club wheat breeding**
Project PI(s): **Kimberly Garland-Campbell and Arron Carter**
Project initiation date: **7/1/13**
Project year: **Year 2**

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, 2013 and 2014 are being advanced in the greenhouse. The 2015 Best by Best crossing block has been plantey. DNA has been extracted from all parents and most have been genotyped 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 evalauted at Central Ferry, Spillman, or Lind, depending on the breeding objectives for the population. Selections are in yield trials. 20 F1 populations have been designated for DH production given to the WSU DH lab with the goal of obtaining an average of 50 lines per F1 population.	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.	All germplaslm in replicated testing has been through marker assisted selection for at least one trait. Genomic data for advanced breeding lines has been obtained and is currently being analyzed.	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.	Unreplicated yield trials were planted, comprising germplasm selected from inoculated disease nurseries. These nurseries were planted at Pendleton, Lind, Harrington and Spillman.	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.	Micro quality testing has been started for 2014 crop year. We are working with C. Steber and D. Engle to screen germplasm for low falling number.	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.	Recent releases include ARS-Amber and ARS-Selbu soft white winter wheats, ARS-Crescent and ARS-Chrystal club wheat. New breeding lines have been entered into regional and state variety performance trials.	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: *2 of 3 (maximum of 3 year funding cycle)*

Title: Evaluation And Selection For Cold Tolerance In Wheat

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

Executive summary: We have rated tolerance to freezing in the Washington State Extension Winter and Spring wheat variety trials for 2014. We have also rated tolerance to freezing for the Western Regional winter wheat nurseries, and the Regional nurseries from the rest of the US. We have rated freezing tolerance for winter wheat breeding lines and in progeny from intercrosses within the Brundage/Coda wheat mapping population. The most cold tolerant hard winter wheats in the WSU nurseries were 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 wheats were ARS010262, Curiosity CL, Eltan, Masami, Mela CL, Norstar, Tubbs 06, and WA8169. In the winter regional nursery, ARS010260, Eltan, IDO1101, OR2080236H, and Yellowstone had the best cold tolerance. In the US, the best overall winter tolerance is found in the winter wheat breeding programs in CO, MT, SD, and West Texas. We reported winter survival ratings in the annual seed buyers guides published by Washington State Crop Improvement Assoc. 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. New germplasm that has been brought into the PNW from Europe is generally less winter tolerant than needed for the PNW.

These results from analysis of the mapping populations have allowed us to identify interactions among different alleles of two loci on the 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 would be a good strategy to improve frost tolerance in wheat. We have developed molecular markers for these specific alleles and screening a winter wheat panel for the presence of those loci. Most PNW adapted germplasm possessed the tolerant alleles at both genes, likely due to selection by breeders for winter tolerance. We have to continue to search for additional genes that will explain a significant proportion of the variation for cold tolerance in adapted PNW germplasm.

We identified a previously unknown cold response in winter wheat that results in some varieties surviving longer times at subfreezing temperatures better than they survive shorter times. Understanding the mechanisms behind this response will provide another tool to use in developing winter hardy wheat cultivars.

The WSU Winter Wheat Variety trials were rated for winter survival after the severe 2013/2014 winter. The field survival data was closely correlated with the results of our artifical screening testing (Complete field survival data is available at http://variety.wsu.edu/) (Fig. 4, Tables 1 and 2).

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. 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.

We have rated survival for cooperative nurseries from throughout the U.S. and around the world. Much of the U.S. experiences winters that are more severe than those in the PNW. Based on our screening, the winter wheat breeding programs with the best winter tolerance are in Montana, South Dakota, Colorado, and Illinois.

Most breeding programs have both winter tolerant and less tolerant breeding lines. The identification of molecular markers associated with freezing tolerance will complement our screening system and increase the current screening capacity from about 1000 varieties and breeding lines to several thousand progeny from segregating populations per year.

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 (Table 1). 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.

Although winter injury was a major problem for wheat growers in the state of Washington last growing season, its occurrence was beneficial to plant breeders who used the experience of winter kill in the field, combined with the freeze test screening results, to better predict the survival of their new releases and the correlation with the results of our freezing tests allows us to reliably predict the tolerance of new cultivars and breeding lines.

Communication:

Project #	**5345**
Title:	**Evaluation And Selection For Cold Tolerance In Wheat**
Researcher(s):	**K. Garland Campbell, A.H. Carter, and D.Z. Skinner**
Year Initiated:	**Date initiated: July 1, 2013** **This is year __2_ of _3__ (maximum 3 years) of the funding cycle.**

Papers:

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/s00122-014-2290-2

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.

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.

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/

WGC project number: **3019-5345**
WGC project title: **Club wheat breeding**
Project PI(s): **Kimberly Garland-Campbell, Arron Carter and Dan Skinner.**
Project initiation date: **7/1/13**
Project year: **Year 2**

Objective	Deliverable	Progress	Timeline	Communication
1. **Evaluate Washington winter wheat variety trials**.	Ratings for freezing tolerance for commonly grown and new winter wheat cultivars	The 2012-2014 trials have been evalauted and analyzed. The 2015 winter trials have been planted and will be rated during the summer. Ratings were correlated with field results from 2014.	Sept 2012 - August 2015.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review. Published on WSU Wheat 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.	The 2012-2014 trials have been evalauted and analyzed. The 2015 winter trials have been planted and will be rated during the summer.	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.	We did not rate spring wheat in 2014, but plan to do so again in 2015.	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 have been planted and will be rated during the summer. Ratings from 2012-2013 trials have been analyzed, the 2014 trials are now being analyzed.	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 and select resistant progeny.**	Populations segregating for other traits but selected to have superior cold tolerance.	The first round of selection has bene performed and selected populations were planted in the field in the fall of 2014. Another round of selection will take place during the summer of 2015.	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 identified.**	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 developed. The Finch/Eltan population was planted at Sidney MT for field screening and analyzed. All populations have been assayed for cold tolerance in artificial screening trials. Initial QTL analysis was conducted. Additional markers are being put on the linkage map.	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 Reports and Final Reports

Project #: 4150-1217

Progress Report Year: *_2_ of _3__*

Title: Evaluation of Barley Varieties

Investigator(s): Stephen Guy, Ryan Higginbotham

Executive summary:
In 2014, the Cereal Variety Testing Program (VTP) conducted 10 variety trials across Eastern Washington. The total number of individual barley plots evaluated was 1,260. Entries in the trials included submissions from Washington State University, private breeding companies, and other public breeding programs. Variety performance information is delivered to barley growers and other clientele through field tours (8 tours in 2014), grower meetings (6 in 2014), the variety testing website (over 12,000 unique visitors in 2014), emails with preliminary results after harvest (over 160 recipients), the variety selection tool (located on smallgrains.wsu.edu), *Wheat Life* article, 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 an avenue 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.

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: 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Conduct barley variety trials in Eastern Washington	10 spring barley trials, 36 entries/trial	2014 trials complete (42 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: 6 in 2014; accepting invites for 2015
		2015 trials in planning		Field tours: 8 in 2014; estimate 10 tours in 2015
				Email list serve: results sent after processing
				Annual Report: 2014 technical report 14-3
				WSCIA spring seed guide
				Wheat Life article
2. Public and private entries in trials	All widely grown, commercially available varieties included in trials.	2014 barley trial: 53% WSU, 33% Private, 14% Other Public	Entries by Feb. 15	Solicit spring entries February 1
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	Due to new PI, few mtgs. planned for 2015	Oct. 2014 - Feb. 2015	Grower Meetings: 6 in 2014; accepting invites for 2015
	Field Tours (with county Extension)	20+ planned for 2015	May 2015 - July 2015	*Field Tours: 18 in 2014 (listed below)
	Email List serve	2014 results delivered	July 2015 - Sept. 2015	Email list serve: data sent to 160+ members
	Website	up to date with 2014 data & 2015 maps	summer & fall	Website: more than 12,000 unique IP users
	Annual Report	Published in December 2014	December	Annual Report: 2014 technical report 14-3
	WSCIA Seed Buyers Guides	in preparation	spring in Feb. winter in May	To be published in 2015
	Wheat Life	spring and winter articles will be prepared	spring in Jan. winter in April	Wheat Life: 3 articles planned for 2015
	Variety Selection Tool (http://smallgrains.wsu.edu)	Selection tool updated with 2014 trial data. Tool uses 2-year average data from WSU VTP program. Selection tool has been accessed by 200+ people.	Post harvest/as data is processed	The variety selection tool has been highlighted/promoted at grower meetings, field tours, and through a Wheat Life article. The tool has been accessed by 200+ people through the website.

*** 2014 PNW CROP TOUR SCHEDULE--BARLEY SITES**

Location	Date	Attendance
Fairfield	17-June	35
Almira	18-June	110
Mayview	19-June	20
Reardan	25-June	15
Dayton	26-June	20
Farmington	16-July	38
St. John	16-July	18
Lamont	16-July	19

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

Project #: 4150-1216

Progress Report Year: *_2_ of _3__*

Title: Evaluation of Wheat Varieties

Investigator(s): Stephen Guy, Ryan Higginbotham

Executive summary:
In 2014, the Cereal Variety Testing Program (VTP) conducted 21soft winter, 12 hard winter, 17 soft spring, and 17 hard spring wheat variety trials across Eastern Washington. The total number of individual wheat plots evaluated was 7,830. Entries in the trials included submissions from Washington State University, private breeding companies, and other public breeding programs. Variety performance information is delivered to wheat growers and other clientele through field tours (18 tours in 2014), grower meetings (6 in 2014), the variety testing website (over 12,000 unique visitors in 2014), emails with preliminary results after harvest (over 6,000 email contacts per year), the variety selection tool (located on 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 2014, there were over 2.3 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 2.3 million bushels of grain. Using an average market price of $6.00/bushel, this would result in a gross increase of $13.8 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.

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: 2 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) 2015 trials planted; 2014 results finished	Trials are planted in the spring or fall, data results are available to growers shortly after harvest. Field tours throughout the summer.	Grower meetings: 6 in 2014, accepting invites for 2015
	b) 11 hard winter wheat trials; 30 entries/trial	b) 2015 trials planted; 2014 results finished		Field tours: 18 in 2014, estimate 21 tours in 2015
	c) 16 soft spring wheat trials; 24 entries/trial	c) 2015 trials in planning; 2014 results finished		Email list serve: results sent after harvest
	d) 16 hard spring wheat trials; 42 entries/trial	d) 2015 trials in planning; 2014 results finished		Annual Report: 2014 technical report 14-3
				WSCIA seed guides (spring & winter)
				Wheat Life articles
2. Public and private entries in trials	All widely grown, commercially available varieties included in trials.	2015 winter trials: 50% WSU, 32% Private, 18% Other Public: As of the fall of 2014, both Syngenta and Monsanto are active & willing participants in the VTP again. 2015 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
		2014 spring trials: 52% WSU, 30% Private, 18% 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, VTP data used for variety release and PVP applications
4. Extension programming	Grower Meetings	Due to new PI, few mtgs. planned for 2015	Oct. 2014 - Feb. 2015	Grower Meetings: 6 in 2014; accepting invites for 2015
	Field Tours (with county Extension)	20+ planned for 2015	May 2015 - July 2015	*Field Tours: 18 in 2014 (listed below)
	Email List serve	2014 results delivered	July 2015 - Sept. 2015	Email list serve: data sent to 160+ members
	Website	up to date with 2014 data & 2015 maps	summer & fall	Website: more than 12,000 unique IP users
	Annual Report	Published in December 2014	December	Annual Report: 2014 technical report 14-3
	WSCIA Seed Buyers Guides	in preparation	spring in Feb. winter in May	To be published in 2015
	Wheat Life	spring and winter articles will be prepared	spring in Jan. winter in April	Wheat Life: 3 articles planned for 2015
	Variety Selection Tool (http://smallgrains.wsu.edu)	Selection tool updated with 2014 results. The tool has been accessed by 200+ people.	Post harvest/as data is processed	The variety selection tool has been highlighted/promoted at grower meetings, field tours, and through a Wheat Life article.

*** 2014 PNW CROP TOUR SCHEDULE--WHEAT**

Location	Date	Attendance	Crops
Horse Heaven	3-June	38	Winter & Spring Wheat
Ritzville	4-June	40	Winter Wheat
Western Whitman Co. - LaCrosse	5-June	36	Winter & Spring Wheat
Connell	5-June	40	Winter & Spring Wheat
Harrington	11-June	28	Winter Wheat
Lind Field Day	12-June	250	Winter & Spring Wheat
Fairfield	17-June	35	Winter & Spring Wheat
Moses Lake	18-June	48	Winter & Spring Wheat
Almira	18-June	110	Winter & Spring Wheat
Mayview	19-June	20	Winter & Spring Wheat
Anatone	19-June	12	Winter Wheat
Reardan	25-June	15	Winter & Spring Wheat
Walla Walla	25-June	20	Winter & Spring Wheat
Dayton	26-June	20	Winter & Spring Wheat
Bickelton	26-June	15	Spring Wheat
Farmington	16-July	38	Winter & Spring Wheat
St. John	16-July	18	Winter & Spring Wheat
Lamont	16-July	19	Winter & Spring Wheat

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Wheat and Barley Research Annual Progress Reports and Final Reports
Format
Updated November 2013

(Begin 1 page limit)
Project #: 3019-4387
Progress Report Year: *_3___ of _3___ (maximum of 3 year funding cycle)*
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 fluid and dry lime were established in fall 2013 on prairie (Conservation Farm and private farm near Pullman, WA) and forest (private farm near Rockford, WA) soil. Crop and soil responses to treatments were monitored. No yield differences were measured, however, hail damage reduced the utility of these results. Soil samples revealed that treatments were only effective to a less than 1 inch depth, however, soil monitoring with depth will be continued. 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.
- Limitations of Veris technology used to map soil pH were identified (poor accuracy, limited field "windows" for operation). Spatial variability of soil pH was considerable with fields ranging 2 or more soil pH units (e.g. soil pH of 4.5 to 7.0 in single field). Similar spatial variability in soil pH was measured for soil samples from the Cook Agronomy Farm. These data support variable lime applications that target within-field differences in lime requirements.
- Laboratory studies were conducted to develop a new lime requirement determination to replace current recommendations which are not adequate.
- Farm sites in WA and ID where lime applications have been initiated were identified to further assess spatial responses of soil, yield and economic results.
- A new fluid lime applicator was developed to target stratified soil acidity at the 3-4 inch depth.

Impact:

- Our liming trials, using novel formulations and application techniques are providing 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.
- New soil tests for determining lime recommendations will replace current recommendations.

(End 1 page limit)

WGC project number: 3019-4387
WGC project title: Cultural management of soil acidification and aluminum toxicity in wheat-based systems of E. Washington
Project PI(s): David Huggins, Kurt Schroeder, Tim Paulitz
Project initiation date: 7/1/2013
Project year: Year 3

Objective	Deliverable	Progress	Timeline	Communication
Objective 1. Evaluate crop response to band and broadcast lime on low pH soil.	(a) Efficacy of relatively low quantities of banded lime and (b) effectiveness of fluid versus pelitized lime with and without soil incorporation on ameleorating adverse soil acidification effects.	Field trials with different rates (100-2000 lbs/ac of $CaCO_3$) of fluid and dry lime established in fall 2013 on prairie (Conservation Farm and private farm near Pullman, WA) and forest-derived (private farm near Rockford, WA) soil. Field trials were coordinated with Kurt Schroeder (Univ. of Idaho) and similar treatments were established in N. Idaho. Crop yields were harvested and additional soil samples collected to assess soil and crop responses to treatments. A seed-placed fluid lime study was conducted for spring pea, chickpea and wheat at the Cook Agronomy Farm. A new fluid lime applicator was developed to target stratified soil acidity. This applicator will be integrated into new field studies in 2015.	Initiate field trials in year 1, complete in year 3.	Twelve presentations (over 900 growers/industry personnel in audiences) and written products (e.g. Wheat Life article) aimed at raising awareness and understanding of soil acidification issues made to wheat industry, Soil Conservation Districts, and as a part of 2014 PNDSA conference. Extension guides addressing a suite of soil scidification issues was initiated. Preliminary results were presented at the American Society of Agronomy meetings (2014).
Objective 2. Evaluate use of soil pH sensing technology (Veris Technologies, Inc.) to map the spatial variability of soil pH and to develop management zones.	Determine effectiveness of soil pH mapping to develop useful management zones for liming.	Veris Technology used to map spatial variability of soil pH in fields and evaluated to assess strengths and limitations. Significant limitations of the equipment in terms of accuracy and adequate field "windows" for operation discovered. Spatial variability of soil pH was considerable with fields often ranging 2 or more soil pH units (for example, soil pH of 4.5 to 7.0 in single field). Soil samples were also collected and analyzed acroiss the Cook Agronomy farm which showed nearly a 2 pH unit range in variability. These data support the idea that variable lime applications may be beneficial to target differences in lime requirements. However, we initiated soil tests to determine lime requirements adequate for the Palouse region.	Evaluation of Veris technology will be completed in year 2. Development of soil pH management zone guidelines in years 2 and 3.	Five of the presentations listed under Objective 1 included data and information on the spatial variability of soil pH and use of Veris Technology to assess spatial variability.
Objective 3. Apply appropriate lime source site-specifically using soil pH maps and lime requirement and assess soil, yield and economic results.	Development and value (yield and economic) of precision agricultural liming	Farm sites in WA and ID where lime applications have been initiated were identified to further assess spatial responses in terms of soil, yield and economic results. Variable rate application of lime was established in one grower field. These data as well as results from Objective 2 will be used to develop and assess precision lime applications.	Initiate in year 2, complete in year 3	Future presentations.

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Project # 3019-5599

Progress Report Year: Third Year (2014-2015) of Three Years (2012-2015) **FINAL**

Title: Suppression of Downy Brome (Cheatgrass) in Wheat Using a Soil Bacterium

Researchers: Ann C. Kennedy, Tami L. Stubbs, Jeremy C. Hansen,
USDA-ARS, WSU, Pullman WA 509-335-1554, akennedy@wsu.edu

Cooperators: William Schillinger, Dan Harwood, Aaron Esser

Deliverables:

1. Added data collected over the past three years on the bacteria application in winter wheat to the EPA registration packet that will be submitted to EPA by ARS in January 2015. The bacterial bioherbicide should be available to growers by the fall of 2016.
2. Filed patent for the weed-suppressive bacterium (*Pseudomonas fluorescens* strain ACK55 in May 2014.
3. Scheduled to file a patent on another weed-suppressive bacterium in spring 2015.
4. Published the manuscript: Stubbs, T., Kennedy, A.C., Skipper, H. 2014. Survival of a rifampicin-resistant *Pseudomonas fluorescens* strain in nine Mollisols Applied and Environmental Soil Science ID306348, 7 pages http://dx.doi.org/10.1155/2014/306348
5. Obtained EPA Registration for our weed-suppressive bacterium (*Pseudomonas fluorescens* strain D7 in August 2014. The company who obtained the registration is Verdesian from Cary, North Carolina. We are not sure of the timeline or future of this bacterial bioherbicide.
6. Developed draft application and restoration documents for the use of bacterial bioherbicides in wheat and rangeland.

Executive Summary: Downy brome (cheatgrass) is a serious weed in wheat causing reductions in wheat yield even when only a few weed plants are present. Bacteria suppressive to downy brome have the potential to reduce downy brome populations for several years and reduce viable seed in the seed bank. If a competitive crop is maintained, downy brome will be limited and annual applications of grass-weed herbicides should not be necessary. Our objectives are to: 1.) Evaluate the impact of downy brome suppressive bacteria with or without herbicide to reduce downy brome and improve winter wheat yields; and 2.) Optimize the delivery of the bacteria for maximum downy brome reduction and increased winter wheat growth and yield. We established studies in wheat fields each fall from 2011 through 2014 to determine the effect of these weed-suppressive bacteria on downy brome populations at more than nine Washington sites with wheat in rotation. At each site, for each year, the bacteria were applied in plots designated as multiple year application plots at same sites as well as on new adjacent land. We monitor the plants in those plots in the spring of the year following application (6 months) and the subsequent springs as well. Over all sites after 3 years, the bacteria reduced downy brome an average of 89% in winter wheat studies. Application of the bacteria resulted almost complete

suppression of downy brome by 5 years, when winter wheat was in rotation or cereals continuously grown (Figure 1). Multiple year application did not necessarily increase the speed of downy brome reduction. The bacteria inhibited downy brome at most of the sites within 6 months of application, but multiple applications did not always result in greater weed reduction in the second spring. Vegetation, soil, climate, bacteria survival, and wheat growth are factors controlling the bacteria's ability to reduce downy brome and we are still analyzing the data on that part of the study.

Bacterial Information

These weed-suppressive bacteria:

- are applied in the in the fall and establish in the soil microbial community as weather cools;
- inhibit radicle formation, root growth and tiller initiation of these weeds;
- do not hurt native plants or crops;
- grow well in fall and spring coinciding with the early root growth of the fall annual weeds; and
- grow down roots and deliver the weed-inhibitory compound.

The bacterium, *Pseudomonas fluorescens* strain ACK55 (*P.f.* ACK55), inhibits only:

- cheatgrass (downy brome, *Bromus tectorum*),
- medusahead (*Taeniatherum caput-medusae)* and
- jointed goatgrass *(Aegilops cylindrica).*

Pseudomonas fluorescens strain ACK55 does not inhibit any economically important plants nor does it injure any native plant species found in the United States. Replicated field plots ($3m^2$ to 10A size) across many different years, and locations have been established by several collaborators. These field studies consistently show a minimum of 50% reduction in downy brome within three years of one bacterial application. In long-term field trials of quarter acre size in Washington, application of the bacteria resulted almost complete suppression of downy brome in 5 years, when winter wheat was in rotation or cereals continuously grown (Figure 1). Additional applications of the bacteria may be needed in 3 to 6 years if downy brome or weed-laden soil is transported into the site. With the reduction of downy brome, cereals are even more competitive and yields increased 5 to 30%. The bacteria suppress downy brome roots at a time when the weed is increasing its competitive root growth. Application of a herbicide in year 1 along with the bacteria increased the rate of downy brome reduction. In addition, no downy brome could be found in the seed bank three to seven years after a single application. Herbicides are able to kill the standing plant, but not able to work on the seed bank. The herbicide/bacterial interaction can rid a field of downy brome. These bacteria provide a novel means to reduce downy brome while limiting the need for tillage and chemical use for weed control.

The Toxicology/Pathology study by an independent lab showed that the weed-suppressive bacterium presents no mammalian toxicity or pathology. The EPA registration document for the one bacterium that inhibits cheatgrass, medusahead and jointed goatgrass will be submitted to EPA this month. The bacteria are being integrated into weed-management plans for croplands using both spray and seed coat technologies. We are developing rangeland restoration plans that include the bacteria. We have several research studies on the ground to test these plans. Other weeds that we have been studying are wild oats, Ventanta grass, bulbous bluegrass, rattail fescue, annual bluegrass, and several other emerging annual grass weeds. Because of its selectivity, this bacterium can be used in management of downy brome in rangeland, cropland, pasture, turf, sod production, golf courses, road sides and road cuts, construction sites, and right-of-ways (road, rail, pipeline, electrical).

Excerpts from a Potential Label
Active Ingredient:
***Pseudomonas fluorescens* strain ACK55**
Crop/Site: rangeland, cereal, pasture, turf, sod production, golf courses, road sides and road cuts, construction sites, and right-of-ways (road, rail, pipeline, electrical).

For selective suppression of the fall annual grass weeds cheatgrass/downy brome (*Bromus tectorum* L.), medusahead (*Taeniatherum caput-medusae* [L.] Nevski)**, and jointed goatgrass (*Aegilops cylindrica* L.) in rangeland, cereal, pasture, turf, sod production, golf courses, road sides, and road cuts, construction sites, and right-of-ways (road, rail, pipeline, electrical).**

ACTIVE INGREDIENT
0.23% *Pseudomonas fluorescens* strain ACK55; 2.6% spent medium; 97.2% water. *Pseudomonas fluorescens* strain ACK55 contains a minimum of 30 million cells mL^{-1}. This product is a naturally occurring *Pseudomonas* bacterium from soil, which selectively reduces or suppresses the growth of the weeds cheatgrass/downy brome (*Bromus tectorum* L.), medusahead (*Taeniatherum caput-medusae* [L.] Nevski), and jointed goatgrass (*Aegilops cylindrica* L.) and does not hurt crops or rangeland plants. It is a preemergent bioherbicide.

MODE OF ACTION
This bacterium specifically inhibits downy brome/cheatgrass and DOES NOT inhibit other grass and broadleaf crops and plants. The bacterium suppresses weed growth by the production of a labile secondary metabolite that inhibits root-cell elongation and tillering; reduces seedling vigor and overwintering; lowers seed production; and reduces viability of the seed bank.

Once applied to the soil surface the bacterium can be carried into the soil by rain or irrigation. The bacteria grow well on residue, seeds, and roots. The bacteria move to the roots of the target weeds, seeds, or young seedlings and inhibit root-cell elongation. The suppressive compound inhibits lipopolysaccharide production in the cell wall and membrane and reduces root-cell wall elongation. If this inhibition of cell elongation occurs early in the seedling life, tiller initiation can be reduced. Visual effects of the bacteria working are a red color of the plant leaves due to stress and anthocyanin production, stunted plants with few tillers, and few seeds produced. With application of the weed-suppressive bacterium, the soil seed bank is reduced. The bacteria need to establish in the soil and on roots for suppression. The suppression of cheatgrass, medusahead, and jointed goatgrass by this bacterium may take two to five years. Dry conditions do not allow the bacteria to grow in the soil and colonize soil, residue, seed, and roots, and result in only minor suppression of the weed.

DIRECTIONS FOR USE

This product is a preemergent bioherbicide and should be applied in late fall. For best results, make initial application in the late fall when daily high temperatures are less than 55^{o}F and more than 0.2 inches of rain is imminent or will occur within 2 weeks. Activity may be low when applied to dry soil or heavy residue. Lack of rainfall within 2 weeks of application may reduce weed suppression. Application in late spring or summer will not allow the bacterium to establish in the soil and will result in low weed suppression.

When sprayed on the soil surface or coated on seed, this product will suppress the growth of downy brome/cheatgrass, medusahead or jointed goatgrass over time and is not likely to harm other plant species. Apply 1 pint of material or the equivalent of 40 billion cells acre^{-1}) in 100 or 400 gallons of water (5 to 20 gallons acre^{-1}) with mixing and spray the solution on the soil surface. Optimum conditions for application are cool air temperatures (<50^{o}F) and wet conditions (0.25 inches of rain). Hot and dry conditions and dry soil surface limit the effectiveness of the application. For best results, apply the bacterium in the fall or very early spring before annual grass weed seed germination and when day-time temperatures are below 50^{o}F.

The coverage characteristics of the spray equipment will determine the volume of water needed. Use 5 to 30 gallons of solution acre^{-1} for conventional tillage or direct seed application. If there is dense vegetation or residue use 20 to 50 gallons acre^{-1} of spray solution. Once mixed with water use immediately.

APPLICATION METHODS

Select one of the application methods below.

Method 1: Seed

For cheatgrass, medusahead, or jointed goatgrass suppression, use 0.25 to 1 gallons of liquid acre^{-1} or a minimum of 40 billion cells acre^{-1}. Apply bacteria to seed in 16 oz. of cells for 60 lb. seed rotating in a drum. Direct drill or broadcast seed at recommended seeding rates, which should be 60 lb. acre^{-1} wheat seed or 30 lb. acre^{-1} native seed. Species of seed can be crop or native plant or other species and drilled or broadcast.

Method 2 Liquid Spray

For cheatgrass, medusahead, or jointed goatgrass suppression, use 0.25 to 1 gallons of liquid acre^{-1}. For 20 acres, apply 5 to 20 gallons of liquid acre^{-1}. Final minimum concentration would be 10 million bacterial cells square foot soil surface^{-1}. The liquid spray can be applied by back pack sprayer, ground sprayer or aerially applied.

APPLICATION INSTRUCTIONS

GENERAL: Avoiding spray drift at the application site is the responsibility of the applicator. The interaction of many equipment- and weather-related factors determines the potential for spray drift. The applicator and the grower/treatment coordinator are responsible for considering all of these factors when making decisions. Where states have more stringent regulations, they should be observed. Note: This section is advisory in nature and does not supersede the mandatory label requirements.

GROUND: Be sure to maintain agitation during mixing and application to assure uniform product suspension. Thorough coverage of the soil surface is essential for effective disease control. *Pseudomonas fluorescens* strain ACK55 can be applied with commonly used ground equipment, including hose-end, pressurized, greenhouse and hand-held sprayers. To achieve good coverage, use proper spray pressure, gallons acre^{-1}, nozzles, nozzle spacing and ground speed. Consult spray nozzle and accessory catalogues for specific information on proper equipment calibration.

AERIAL: This product can be applied by aerial application. Refer to the Aerial Drift Reduction Advisory Information section of this label for general directions and precautions. Use the application rate indicated for the appropriate crop in sufficient water to achieve thorough coverage, typically between 3 to 20 gallons of water acre^{-1} depending upon the crop. Three gallons of water acre^{-1} is the minimum.

CHEMIGATION: This product can be applied through sprinkler (center pivot, lateral move, end tow, side (wheel) roll, traveler, solid set, and hand move) or drip type irrigation systems. Refer to the Chemigation Directions for Use section of this label for general directions and precautions.

COMPATIBILITY

Do not tank mix with toluene or surfactants that are used to reduce microbial growth. This product is compatible with most herbicides and bioherbicides. Adjuvants and surfactants may reduce the viability of the bacteria.

STORAGE AND DISPOSAL

Product must be stored in the original container at temperatures less than 60^{o}F. Store the container unopened until ready to apply. Do not contaminate water, food, or feed by improper storage and disposal.

CONTAINER DISPOSAL

Do not reuse or refill the container. Dispose of empty container. Material can be sanitized with a 1:10 solution of bleach or caustic material to water or steamed or autoclaved to kill any remaining active bacterial cells.

Management Guidelines

Application guidelines and management systems are being constructed for wheat and rangeland systems.

1. **Apply the bacteria in that fall when the air temps are below 50^{o}F with rain or rain in forecast (mid October to mid November).**

2a. Treatment - An early fall application of a herbicide to get rid of any cheatgrass that germinated with late summer or early fall rains.

2b. Why-The bacteria will not inhibit the fall germinated plants. This bacterium is well suited for application after burns because the soil is exposed and the bacteria can fall onto the soil instead of the residue.

3a.Treatment - A light harrow before or after the herbicide might be beneficial.
3b. Why- to expose more seed to germination (before) and disturb the residue to expose more routes for the bacteria to enter the soil (after). Disturbing the residue or a burn can also increase the amount of weed seed germination, which is both good and bad, the residue is reduced, but the volume of seeds that germinate might be large, too large for the bacteria contact and inhibit.
4a. Treatment- Drill seed desirable plant species.
4b. Why - Desirable plant species are needed to compete further with the weed plants stressed by the bacteria.
5a. Treatment- In the spring of each year, check for broadleaf weeds and use herbicide as needed. May need to spot spray, if reasonable, to reduce the broadleaf weeds but not kill desirable broadleaf plants.
5b. Why – As cheatgrass is eliminated, voids are created, other weeds will grow in those voids.
6. Treatment - If fall germinated grass weeds are still a problem the next fall, then another application of a grass weed herbicide may be needed.
7. Treatment - Walk the land each month to see what weeds are appearing and spray when appropriate.

Delivery Systems
Delivery systems showed mixed results in cheatgrass reduction. Winter wheat coated with the bacteria and then seeded did not reduce the down brome in the first spring, but downy brome populations were reduced to near zero in subsequent years. Bacteria applied in pellets did not reduce weed numbers sufficiently in these studies and the bacteria did not spread through the soil. From these field studies, surface characteristics, laboratory analyses and weather data, we will determine the effects of interactions among bacteria, surface cover, soil disturbance, soil type, weed seed bank, seed coating, and winter wheat growth and yield on inhibition of downy brome. This research illustrates the use of these bacteria in weed management systems and hastens product development and lead the way for other weed-suppressive bacteria.

I**mpact:** Downy brome is a winter annual grass weed that thrives in all soils, is very competitive, and has a negative effect on crop growth. Its mat-like rooting system and ability to grow further into the winter than wheat allows the weed to extract much of the soil water and nutrients before wheat produces its roots in the fall. Downy brome is conservatively estimated to cost growers over 400 million dollars annually. Herbicide costs that reduce the growing downy brome, but not the seed bank can be well over \$60 $A^{-1}yr^{-1}$. Bacteria native to Washington soils reduce downy brome populations over a few years and reduce viable seed in the seed bank. If a competitive crop is maintained, downy brome will be limited and annual application of grass-weed herbicides should not be necessary. Additional field information is needed on the best methods to apply these bacteria to inhibit downy brome in wheat. Delivery methods such as seed coating, pelleting or encapsulation and raking are potential means to increase bacterial survival and are being studied.

These bacteria have the potential to reduce invasive weeds, improve winter wheat yields and restore western landscapes while reducing tillage and chemical use in crop production (5yr goal). The research provided information on these bacteria in cropland situations and hastened registration by the federal government and EPA approval of this bioherbicide. This research assisted the commercialization process for cropland use with solid scientific data on application methods and risk assessments. A long-range goal (10yr+) for this research is to pave the way for additional bioherbicides against emerging weeds such as Ventenata grass, rattail fescue, Italian ryegrass and feral rye.

Outputs and Outcomes: WGC project number: 3019-5599

WGC project title: Suppression of Downy Brome (Cheatgrass) in Wheat Using a Soil Bacterium

Project PI(s): Ann C. Kennedy

Project initiation date: July 1, 2012 Project year: 2014-2015

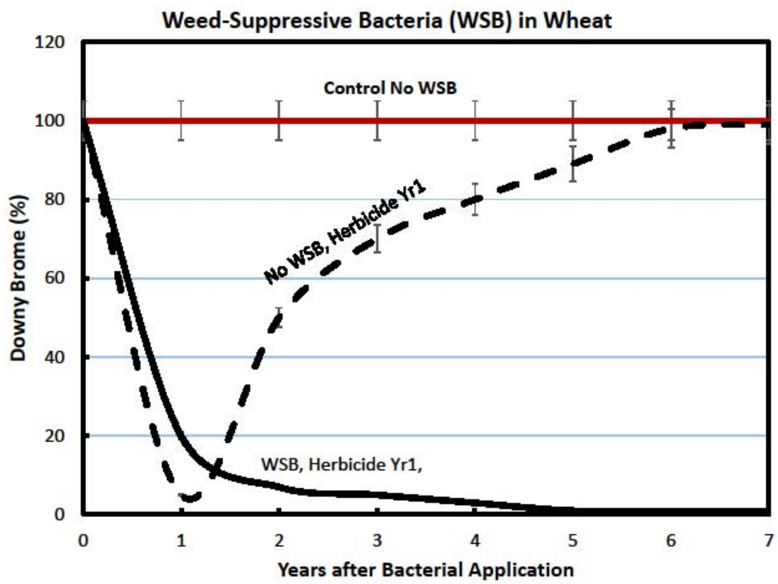
Objective 1: Evaluate the efficacy of downy brome suppressive bacteria with or without herbicide to reduce downy brome and improve winter wheat yields;

Objective 2: Optimize the delivery of bacteria for maximum downy brome reduction and increased winter wheat growth and yield.

Objective	Deliverable	Progress	Timeline	Communication
Obj.1: Downy brome suppression by the bacteria				
Field application	Information on the efficacy of downy brome-suppressive bacteria on downy brome populations.	Weed-suppressive bacteria were applied to 9 locations in the fall of 2011,2012,2013,2014 and again at same sites and new adjacent land in the fall of 2012, 2013, and 2014.	We found significant reductions in downy brome at each site over time. Data will be collected from each plot in spring and harvest 2015 and continue with monitoring in subsequent years to obtain a full data set over 3 more years.	Manuscript published: *Stubbs, T.*, Kennedy, A.C., Skipper, H. 2014. Survival of a rifampicin-resistant *Pseudomonas fluorescens* strain in nine Mollisols Applied and Environmental Soil Science 7 pages http://dx.doi.org/10.1155/2014/306348 Field data were added to the documents needed for EPA registration that will be submitted by the IR4 group who will submit the packet to EPA in January of 2015.
Monitoring of survival of applied bacteria	Data indicating the survival of the bacteria in different soils and various climatic conditions.	We monitored the bacterial populations over time. The bacteria are in soil at sufficient numbers to cause downy brome inhibition (> 10^8 cells per g soil).	We will continue to monitor the weed-suppressive bacteria in soil over time.	BLM pesticide certification classes Albuquerque, NM (2/26/14) and Boise ID (4/2/14); NRCS CIG, Pullman, WA (5/2/14).
Soil analyses	Characterization of each soil at each site and climatic data.	We are characterizing the soil at each location and have completed the analyses. The soils are silt loams and other characteristics will be analyzed using multivariate analyses not yet completed.	We collected soil and climatic data in 2011, 2012, 2013, and 2014 to characterize soil quality. We will continue to sample and analyze soil in the plots to monitor any changes in the soil for 3 more years.	Presented seminars on Weed-Suppressive Bacteria at Lind Field Day (6/12/14); Worley, ID (7/14/14); Ag Tech, Pullman, WA (7/16/14); Baker City, OR (8/22/14); Monument OR (9/29/14); Baker City, OR (9/30/14);

Cheatgrass reduction	Reduction in cheatgrass in the field.	The bacteria reduced cheatgrass an average of 89% in winter wheat studies. At all sites we found significant reductions in cheatgrass	We will continue to monitor the cheatgrass populations in these plots for 3 more years to follow the effect of the bacteria on cheatgrass populations.	Presented seminars on Weed-Suppressive Bacteria at Idaho Department of Transportation Idaho Falls, ID (11/28/14); SGI Risk Assessment webinar (2/5/14). In 2014, we presented information to over 500 growers, producers or land managers.
Obj. 2: Delivery of bacteria to soil and downy brome roots				
Spray	Survival and efficacy of downy brome-suppressive bacteria when sprayed on the soil surface.	We applied the bacteria as spray at 9 locations in 2011, 2012, 2013, and 2014.	Data will be collected in each plot each spring (downy brome) or at harvest (wheat growth and yield) for another 3 years past this funding.	Met with producers and land managers throughout the year to discuss the use of weed-suppressive bacteria as a spray.
Seed treatment	Survival and efficacy of downy brome-suppressive bacteria when coated on seed and drilled.	Bacteria were applied as a seed coat and drilled at three locations. Reduction in cheatgrass was not evident the first year.	Next fall we will coat seed with the bacteria and drill in plots. Data from plots in which seed was coated with the bacteria will be collected in each plot each spring and at harvest for the next three years past this funding.	Met with producers, grain elevator personnel, ag industry, and land managers throughout the year to discuss the use of weed-suppressive bacteria as a wheat seed treatment.
Pellets	Survival and efficacy of downy brome-suppressive bacteria when incorporated into a protective pellet and broadcast.	We impregnated pellets with the bacteria. The pellets released the bacteria into the soil directly under the pellet but no movement occurred.	We terminated this area of research as the bacteria were not distributed into the soil when pelleted.	Discontinued

Figure 1. The reduction of downy brome by weed-suppressive bacteria in winter wheat fields in Washington. Data are means of 5 replicates at each location and 9 locations.



Budget

Amount allocated by the Commission in fiscal year 2015 (July 2014 to June 2015): $ 34,191.
Amount requested for FY 2016 (July 1, 2015-June 30, 2016) $0.

Category	2012-2013	2013-2014	2014-2015	Total
Salaries[1] – 00	9,918	10,315	**10,315**	30,548
Wages[2] - 01	5,760	5,990	**5,990**	17,740
Goods/Services[3] - 03	5,730	5,959	**8,498**	19,187
Travel[4] - 04	5,950	5,950	**5,950**	17,850
Benefits[1,2] - 07	4,700	4,438	**4,438**	14,027
Total Direct Costs	32,058	33,103	**34,191**	99,352

[1] Part-time skilled personnel for field data collection $35/hr; benefits at 40%.

[2] Undergraduate wages for lab and field work $10/hr,; benefits at 2.0%

[3] Field and lab supplies, field monitoring, soil analyses.

[4] Travel to field sites for applications and monitoring, field ($0.50 per mile), lodging and MIE ($146/day).

Budget approved by Jason Croyle 12.18.2013.

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

Project #: 4150-1222

Progress Report Year: 2 of 3

Title: Extension Education for Wheat and Barley Growers

Cooperators: Drew Lyon, Stephen Guy, Timothy Murray, David Crowder, Randy Fortenbery, Ryan Higginbotham, Aaron Esser, Stephen Van Vleet, Diana Roberts, Paul Carter, Richard Koenig, Dale Whaley, Wayne Thompson, Joshua Paulsen, James Boyer, and Gerrit Hoogenboom.

Executive summary: The major accomplishments of the Dryland Cropping Systems Extension Team for 2014 were:

1) The public launch of the Small Grains Website (smallgrains.wsu.edu)
2) The development of five decision support tools for the website:
   - a) Variety Selection Tool
   - b) Nitrogen Application Calculator
   - c) Post-Harvest Nitrogen Calculator
   - d) Spring Wheat Yield Calculator
   - e) Market Price Graphing Tool
3) The Crop Diagnostic Clinic held in June at the Spillman Farm
4) The Inaugural Wheat Academy held December 16-17 in Pullman

The Team will take what they have learned in 2014 and apply it to the website and educational events for 2015. We will make a special effort to provide educational programming at sites away from Pullman in 2015.

The funds provided to this project by the Washington Grain Commission have been matched by WSU Extension, which has provided the team with sufficient resources to significantly scale up our outreach effort to growers in eastern Washington.

Impact: The Small Grains Website is the major focus for the Dryland Cropping Systems Extension Team. The following are some statistics from the website for the three-month period of September through November of 2014. The website had:

> 1) 1,481 users; 48.7% of these were new visitors and 51.3% were returning visitors.
> 2) A bounce rate of 47.8%: bounce rate is the percent of visits where only one page was looked at before the visitor left the site. Anything less than 60% is considered good, with 30% being ideal.
> 3) An average session duration of 4 minutes and 35 seconds.

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: 2 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.	Five 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, and 5) Market Prices Graphing Tool. New tools proposed for development in 2015 include tools for stripe rust prediction, downy brome seed development, herbicide efficacy tables, and herbicide resistance management.	The five 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 2015.	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. One short video was filmed at the Wheat Academy and will be edited and posted in 2015.	We plan to develop quizzes, forums, additional videos, and possibly voiced-over Power Point presentations in 2015.	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 Crop Diagnostic Clinic was held in June at the Spillman Farm in Pullman and had nearly 80 participants. The inaugural Wheat Academy School was held December 16-17 in the Vogel Plant Biosciences Building on the WSU campus. The 60 available spots were all taken a month prior to the event.	Lessons learned in 2014 will be used to improve Wheat Academy offerings in 2015. We will try to have more virtual programming available in 2015.	The Small Grains Website will be mentioned at most Extension meetings. The Crop Diagnostic Clinic 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 2014 harvest sample analysis is nearly complete. Winter wheat samples are complete; spring wheat samples still need bake data. As in previous years, all quality data will be 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.

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:

Use the <u>Excel template provided</u> to report on the following. Ideally, you simply update your spreadsheet from previous reports.

WGC project number: 4721
WGC project title: Quality of Varieties & Pre-release Lines: Genotype & Environment--"G&E" Study
Project PI(s): Craig F. Morris and Doug Engle
Project initiation date: 1-Jul-12
Project year: 3

Objective	Deliverable	Progress	Timeline	Communication
Complete milling & baking analyses	Data set complete	Winter dataset complete; spring wheat needs bake data	complete baking this month	internal
Analyzed data set for t-Scores	Grain, Milling, Baking and Overall t-Scores calculated	waiting for final data set	complete this month or early February	internal
Rank varieties, assign quality classification, deliver final consensus to WGC	Final consensus classification of cereal chemists across the PNW	We will meet at the PNW Wheat Quality Council meeting to reach consensus on classification	We have scheduled meeting for Jan. 21, 2015	Meeting with PNW cereal chemists from USDA, WSU, U of I and OSU; then communicate results to WGC

Do not use a font size less than 10 point. Let the template break over pages if necessary. The formatting will be retained when saved as a pdf file.

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 ½ months of technician time. The additional work is devoted to evaluating breeder samples for quality from 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. Milling and baking evaluations of the 2013-Crop were completed and 2014-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:

Use the Excel template provided to report on the following. Ideally, you simply update your spreadsheet from previous reports. The objectives and deliverables identified in the spreadsheet should be consistent with the original objectives and deliverables described in the project proposal.

WGC project number: 4722
WGC project title: Supplemental Support for Assessing the Quality of Washington Wheat Breeding Samples
Project PI(s): Craig F. Morris and Doug Engle
Project initiation date: 1-Jul-13
Project year: 3

Objective	Deliverable	Progress	Timeline	Communication
Complete spring wheat samples by early Feb.	Full mill & bake data delivered to breeder	Progress is good and on track	Starts at harvest when samples come in, ends with completion of last nursery	Data delivered directly to breeder; dialogue may ensue as to interpetation, selection strategy
Complete winter wheat samples by early June	Full mill & bake data delivered to breeder	Progress is good and on track	Starts at harvest when samples come in, ends with completion of last nursery	Data delivered directly to breeder; dialogue may ensue as to interpetation, selection strategy

Do not use a font size less than 10 point. Let the template break over pages if necessary. The formatting will be retained when saved as a pdf file.

Project #: 3019-3009; **Progress Report Year:** Year 1 of 3
Title: Improving Barley Varieties for Feed, Food and Malt
Project PI: Kevin Murphy; **Cooperators:** Janet Matanguihan, Max Wood, Sachin Rustgi, Stephen Guy, Xaiming Chen, Deven See, Diter von Wettstein

Executive Summary: The major accomplishment of 2014 was the continued success of two new, two-row, spring ***feed barley*** varieties, Lyon and Muir. Lyon is a broadly adapted, high yielding spring barley with stem rust resistance intended to replace Bob, Baronesse and Lenetah across high rainfall zones of Eastern Washington. Muir performs particularly well in low rainfall environments of Eastern Washington, and has the most comprehensive disease resistance package of any commonly grown spring barley variety in Washington State. In the low rainfall zone, Muir is intended to replace Bob, Baronesse and Lenetah. On a scale of 1 to 9, Muir was rated as a 1 for resistance to stripe rust across 5 sites in 2014, replacing Bob as the standard barley for stripe rust resistance (rated as a 3 for moderately resistant). One of our advanced lines, 09WA-203.21, topped the WSU Variety Testing (VT) Nursery at three locations in 2014 and will be put forth for pre-release consideration in February 2015. 09WA-203.21 performs particularly well in the intermediate rainfall zone and therefore will be a valuable complement to Lyon (high rainfall) and Muir (low rainfall). Additionally, continued field trials of the imidazolinone (IMI) ***herbicide tolerant barley*** germplasm were performed in Pullman, and our elite breeding lines showed 100% survival after being sprayed by Beyond® herbicide at 2x the recommended rate. The top five of our elite breeding lines are currently being grown out and increased in our winter breeding nursery, and will be included in the WSU VT Nursery at ~10 locations in 2015. Our continued breeding efforts for an IMI-tolerant spring barley include the development of hundreds of advanced lines, extensive crossing, and utilization of double haploid technology 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. For ***food barley***, our best hulless breeding lines entered in the WSU VT program significantly outyielded the hulless control variety Meresse by approximately 400 pounds/acre across locations and rainfall zones over two years, and had exceptional test weight, β-glucan content and protein content when compared to hulled varieties. We anticipate nominating two hulless food barley varieties for release in February 2015. 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 in collaboration with the American Malting Barley Association.

Impact: As newly released varieties, Muir and Lyon have yet to impact the market, however, due to their enhanced disease resistance and/or increased yield over currently grown spring barley varieties, we anticipate that if they are accepted by growers and grown on a large percentage of the barley acreage, their impact will be significant in terms of increased production. Seed of Muir and Lyon will be available from Washington State Crop Improvement Association on a limited basis for the first time in 2015. 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
1: Release new high-yielding two-row, spring **feed barley varieties**.	Two two-row, spring, feed barley varieties with superior yield, disease resistance, protein and agronomic characteristics were released in 2013, increased in 2014, and will be available in limited quantities in 2015.	09WA-203.21 topped all entries for yield in the 2014 WSU VT nurseries in Dayton, Reardon and Walla Walla, all intermediate rainfall zone locations. Our next feed barley release is intended to target the intermediate rainfall zone of barley to complement Lyon (high rainfall) and Muir (low rainfall). We intend to nominate 09WA-203.21 for pre-release in February 2015.	2015	Talks and presentations at field days in 2014 at Pullman, Lamont, St. John, Almira, Mayview, Fairfield, and Farmington. Informative variety rack cards of Lyon and Muir were distributed to growers at all field days. Washington State Crop Improvement Association Annual Meeting, Update of WSU Barley Breeding Program, November 10, 2014. Greater Spokane Incorporated Agribusiness Council, Overview of WSU Barley and Alternative Crop Breeding Program, Pullman, WA, October 28, 2014.
2: ***Herbicide tolerance.*** Expedite the development and future release of barley varieties that are highly tolerant to the imidazolinone (IMI) herbicides used in winter wheat production.	Development of hundreds of intermediate and advanced spring barley lines with documented tolerance to IMI-herbicides. In 2014, we selected the top five breeding lines. These we sent to our winter location to	We have hundreds of IMI-tolerant backcrossed and topcrossed lines in our breeding pipeline. In 2014, we made 58 successful crosses between spring feed, malt and food barley lines with IMI-resistant barley lines, and obtained 494 F_1	2015-2016	Talks and presentations at field days in 2014 at Pullman, Lamont, St. John, Almira, Mayview, Fairfield, and Farmington. Washington State Crop Improvement Association Annual Meeting, Update of WSU Barley Breeding Program, November 10, 2014.

	increase the seed, and we will submit these five elite herbicide tolerant breeding lines to WSU Variety Testing for multi-location evaluations across barley growing regions of Washington State in 2015.	seeds.		
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.	We have extensive malting quality data on over 500 breeding lines. We identified the very best candidates with regards to yield and malting quality for inclusion in the WSU Variety Testing Program in 2015. Success of this objective will depend primarily upon the results of these and future malt quality trials.	a) Identification of malting quality molecular markers; b)Potential release of a malting barley cultivar.	a)2015-2016 b)2017	Talks and presentations at field days in 2014 at Pullman, Lamont, St. John, Almira, Mayview, Fairfield, and Farmington. Washington State Crop Improvement Association Annual Meeting, Update of WSU Barley Breeding Program, November 10, 2014. Greater Spokane Incorporated Agribusiness Council, Overview of WSU Barley and Alternative Crop Breeding Program, Pullman, WA, October 28, 2014.
4. Evaluate, select and develop high-yielding, hulless, heart-healthy ***food barley*** varieties with elevated levels of beta glucan, protein,	We identified two superior breeding lines with over two years of Variety Testing yield and agronomic data, as well as quality data from our lab, that significantly	Our hulless, high β-glucan breeding lines are surpassing all hulless check varieties in our breeding trials and in Variety Testing trials. We quantified over	2015-2016	Talks and presentations at field days in 2014 at Pullman, Lamont, St. John, Almira, Lewiston, Mayview, Fairfield, and Farmington. Washington State Crop Improvement

test weight, and other quality and nutritional characteristics.	and substantially exceed the yield and β-glucan content of Meresse. These two will be nominated for release in February 2015.	500 breeding lines in 2014 for β-glucan content, and are working to identify molecular markers associated with quality traits of interest.		Association Annual Meeting, Update of WSU Barley Breeding Program, November 10, 2014. Greater Spokane Incorporated Agribusiness Council, Overview of WSU Barley and Alternative Crop Breeding Program, Pullman, WA, October 28, 2014.

Progress

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.

Two new feed barley varieties, 'Muir' and 'Lyon', were officially released by the WSU Barley Breeding Program in 2013, and showed continued success in 2014. For example, Lyon was the second highest yielding variety (or breeding line) over 3 years (9 location years) and 5 years (14 location years) in the WSU Spring Barley VT nursery in the high rainfall zone (Fairfield, Farmington & Pullman). Muir was the second highest yielding variety over 2 years and the third highest yielding variety over 3 years in the WSU VT nursery in the low rainfall zone. In addition, Muir is the new standard spring barley for stripe rust resistance, replacing Bob. Though these new varieties showed significant improvements in yield and disease resistance over previous WSU varieties (notably 'Bob' and 'Baronesse') and other commonly grown barley varieties, as always, there is room for improvement. Muir and Lyon now represent the best of the continuously moving target varieties that we aim to surpass each year with our elite breeding lines. We are increasing our number of crosses while improving our estimations of the breeding value of parent varieties to facilitate a larger and better group of breeding lines from which to select. Selection priorities include resistance to a wider spectrum of diseases, herbicide tolerance (see Objective 2), improved straw strength and decreased lodging, higher test weight, consistently plump kernels, tolerance to acidic soils, aluminum tolerance, and higher grain yield across a broad range of environments and rainfall zones. Our next feed barley release is intended to target the intermediate rainfall zone of barley to complement Lyon (high rainfall) and Muir (low rainfall). In 2014, three of the top four entries (10WA-106.18, 09WA-203.36 and 09WA-203.21) across the WSU VT intermediate rainfall zone locations of Dayton and St. John were WSU breeding lines. One of these lines, 09WA-203.21, also topped all entries for yield in the 2014 WSU VT nurseries in Dayton, Reardon and Walla Walla, all intermediate rainfall zone locations.

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.

In order to expedite the development of IMI-resistant barley varieties, we continue to use a combination of intensive hybridizations, doubled haploid technology, and greenhouse spray trials to get the improved, herbicide tolerant lines into the field for advanced spray and residue trials. In 2014, we made 58 successful crosses between spring feed, malt and food barley lines with IMI-resistant barley lines, and obtained 494 F_1 seeds. In the field, we use a two-pronged approach to test for and ensure herbicide tolerance. First, we continue to test our mutant backcross and topcross lines under 2x spray conditions in the field with susceptible control varieties (Bob and Champion) and one tolerant wheat variety as a resistant control. Each variety/breeding line is subjected to field sprayings of the 2X the recommended rates of Beyond® herbicide, which gives us valuable information on field resistance or susceptibility of our herbicide tolerant breeding line. The second approach is be to plant a variety trial on ground sprayed with Beyond® on the preceding winter wheat crop, which provides us with data on the yield differences between our herbicide tolerant breeding line and standard spring feed barley varieties when grown in residual herbicide conditions. These are the conditions that would occur on-farm in a typical rotation that would have spring barley follow winter wheat. Due to hail damage in 2014, we lack statistically reliable field data on our herbicide tolerant lines, but through field observations we were able to select the top five breeding lines. These we sent to our winter location to increase the seed, and we will submit these five elite herbicide tolerant breeding lines to WSU Variety Testing for multi-location evaluations across barley growing regions of Washington State in 2015. Our focus will be to bring this important trait to a variety release as soon as possible.

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.

Year	Variety or Selection	Kernel Weight (mg)	Plump (%)	Malt Extract (%)	Barley Protein (%)	Wort Protein (%)	S/T (%)	DP (°ASBC)	Alpha-amylase (20°DU)	Beta-glucan (ppm)	FAN (ppm)	Yield lb/a
2014	10WA-111.24	41.4	97.1	78.5	12.1	3.47	29.6	92	49.1	410	144	4427
2014	10WA-113.10	39.3	93.5	78.0	11.2	3.14	28.3	50	34.7	501	121	4357
2014	10WA-116.14	37.7	94.3	76.0	13.1	3.48	26.6	78	36.4	357	128	5092
2014	AC Metcalfe	32.5	78.8	79.0	13.9	4.85	36.0	151	*98.4	55	238	4102
2014	Harrington	40.5	96.9	82.4	11.7	4.66	41.2	118	83.8	66	231	3473
2013	10WA-111.24	41.5	95.0	79.3	10.9	3.57	34.8	81	58.0	263	116	5031
2013	10WA-113.10	42.1	98.0	79.4	9.6	3.38	39.4	43	44.0	219	129	4843
2013	10WA-116.14	37.3	87.0	75.7	11.6	3.55	31.1	86	41.0	140	113	4471
2013	AC Metcalfe	36.9	95.4	81.9	10.1	4.39	46.5	89	92.6	43	194	4782
2013	Harrington	41.2	97.0	82.3	11.8	4.81	44.6	104	88.9	112	225	4362

In addition to adjunct malt quality standards, which are targeted towards lager beers (i.e., Budweiser, Coors, Pabst Blue Ribbon), ***all-malt quality*** standards are now in place to represent the microbrew, or all-malt, industry. Though only ~5% of domestic consumption of beer falls into the all-malt category, over 25% of all barley malted is for this all-malt, microbrew industry. This represents a significant portion of the malting barley grown in the U.S., and the standards for this type of barley are unique. Our program is now also actively selecting barley lines for the all malt market class.

Objective 4. Evaluate, select and develop high-yielding, hulless, heart-healthy food barley varieties with elevated levels of beta glucan, protein, test weight, and other quality and nutritional characteristics.

2014 was a productive year for our hulless food barley breeding trials. In our advanced yield trials and our Preliminary State Uniform Nursery trial, we had several promising lines yield statistically equal to the high-yield check variety Champion. In these same trials, we identified lines with significantly higher yields than the hulless check Meresse, and 30-40% higher β-glucan content. Our best hulless lines in Variety Testing yielded approximately 400 pounds per acre higher than the hulless check variety Meresse in several locations. In the high rainfall zone, 09WA-265.5 outyielded Meresse by 380 lbs/acre, and had a 2.8 lbs/bu test weight advantage over Meresse over two years (six location years). In the intermediate (six location years) and low (2 location years) rainfall zones, X05013-T1 out yielded Meresse by 420 lbs/acre and 390 lbs/acre, respectively, in 2013 and 2014. In Pullman in 2014, X05013-T1 and 09WA-265.5 had 20% and 10% higher β-glucan content than Meresse. Both these lines represent significant improvements, both in yield and β-glucan content, over Meresse, and our intention is to submit these lines for pre-release in February 2015. Additional food barley traits of interest include hulless, waxy types, proanthocyanidin-free types, and types with high soluble fiber content. New crosses are being made to combine the proanthocyanidin-free trait into waxy hulless types to produce better food types in terms of desirable color and color retention. Crosses have also been made to breed for low phytic acid types to improve mineral quality of barley and reduce phosphorus waste in feeding operations.

B. **Timeline:** see Excel template above

C. **Communication:**

Refereed Publications (published and/or accepted for publication in 2014):

Meints, B., A. Cuesta-Marcos, A.S. Ross, S. Fisk, T. Kongraksawech, J. Marshall, K. Murphy, P.M. Hayes (2015, accepted). Developing winter food barley for the Pacific Northwest of the U.S. *Crop Science* (in press).

Murphy, K., S. Ullrich, M. Wood, J. Matanguihan, S. Guy, V Jitkov, X. Chen (2015). Registration of 'Lyon', a two-row, spring feed barley. *Journal of Plant Registrations* 9:6-9.

Rustgi, S.[†], J. Matanguihan [†], J. Mejias, R.A. Brew-Appiah, N. Wen, C. Osorio, N. Ankrah, K. Murphy, D. von Wettstein (2014). Assessment of genetic diversity among barley cultivars and breeding lines adapted to the US Pacific Northwest, and its implications in barley breeding for imidazoline-resistance. *PLOS ONE* 9(6):e100998.
[†]These authors contributed equally to this work

Refereed Publications (submitted in 2014):

Meints, B., A. Cuesta-Marcos, S. Fisk, A.S. Ross, K. Murphy, P.M. Hayes (in review). Registration of '#STRKR' barley germplasm. Submitted to *Journal of Plant Registrations*.

Murphy, K., S.E. Ullrich, M.B. Wood, J.B. Matanguihan, V.A. Jitkov, S.O. Guy, X. Chen, B.O. Brouwer, S.R. Lyon, S.S. Jones (in review). Registration of 'Muir', a two-row, spring feed barley. Submitted to *Journal of Plant Registrations*.

Presentations:

- **Washington State Crop Improvement Association Annual Meeting**, Update of WSU Barley Breeding Program, November 10, 2014.
- **Greater Spokane Incorporated Agribusiness Council,** Overview of WSU Barley and Alternative Crop Breeding Program, Pullman, WA, October 28, 2014.
- **Pullman Lions Club Program,** Overview of WSU Barley and Alternative Crop Breeding Program, Pullman, WA, October 27, 2014.
- **WSU Cereal Breeding Program Seed Dealer Tour,** Spillman Farm, Barley Breeding and Genetics, July 18, 2014.

2014 Field Day Presentations:

- **Lamont Variety Testing Field Day,** WSU Barley Breeding and Genetics, Lamont, WA July 16, 2014.
- **St. John Variety Testing Field Day,** WSU Barley Breeding and Genetics, St. John, WA July 16, 2014.

- **Farmington Variety Testing Field Day,** WSU Barley Breeding and Genetics, Farmington, WA July 16, 2014.
- **Mayview Variety Testing Field Day,** WSU Barley Breeding and Genetics, Mayview, WA, June 19, 2014.
- **Almira Variety Testing Field Day,** WSU Barley Breeding and Genetics, Almira, WA, June 18, 2014.
- **Fairfield Variety Testing Field Day,** WSU Barley Breeding and Genetics, Fairfield, WA, June 17, 2014.
- **Lewiston Food Barley Field Day**, Healthy Foods & Farms Program, Harvest Ridge Farm, Lewiston, ID, May 23, 2014.

Washington Grain Commission

Project #: 3019-4548

Progress Report Year: 3 of 3; Final Report

Title: Pre-breeding for Root Rot Resistance Using Root Morphology Traits

Researchers: Pat Okubara, Scot Hulbert

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. The aim of this project was to characterize resistance 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 as a spring wheat we could perform roughly nine generations in three years. The resistances appear to be 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 either *synthetic* lines (artificially generated by combining the genomes of AB and D wheats to reconstruct the bread wheat genome) or crosses between synthetics and other CIMMYT wheat lines. Thus, they 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 breeders would be comfortable crossing into their breeding populations. We also wanted to use the same cultivar, Louise, as the recipient of all of the sources of resistance to 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 F3 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. All of the populations will be screened in the field one more time before the end of the funding period (July 2015). Following selection in the field, lines from the Synthetic 30, 182 and 201 sources will be ready for amplification and comparative analysis. Lines from the other two sources will be advanced one more generation in the greenhouse.

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

Resistance Source	Current gen.	# lines	In 2015 Spring Nursery
Synthetic 30	BC2-F5	6	BC2-F5:6
Synthetic 182	BC2-F4	12	BC2-F5:6
Synthetic 201	BC2-F4	9	BC2-F5:6
Synthetic 172	BC2-F3	10	BC2-F4 (and BC1 derived mapping population)
CIMMYT 3104	BC2-F4	8	BC2-F5 (and BC1 derived mapping population)

In years 2 and 3of the project, we successfully screened two large populations of BC1-F5 derived lines from the Synthetic 172 and CIMMYT 3104 sources in the field. They were scored for stunting or non-stunting in fields with high levels of disease pressure. First, we evaluated stunting in Year 2 in the field by monitoring plant height at PCFS 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. In past years, we had difficulty in managing *Rhizoctonia* plots free of pests such as wire worm and in border effects between the green and clean plots. In years 2 and 3 of the project we produced field data we are more confident in. Because of the difficulty in measuring resistance in the field however, we plan to screen these populations one more time in Spring 2015. The resistance of these lines has also been evaluated in greenhouse assays. 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. In collaboration with Deven See, the CIMMYT 3104 population was genotyped using SSR markers. Marker analysis of both populations are now being performed with a high density of DNA markers using the newest technology, genotype by sequencing (GBS).

Impact:

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 likely to be due to multiple genes; given its multigenic nature, resistance is expected to be durable. Genetic improvement of wheat and barley 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: 3019-4548

Project PI(s): Pat Okubara, Scot Hulbert
Project initiation date: July 1, 2012
Project year: 3 of 3; final report

Objective	Deliverable	Progress	Timeline	Communication
1. Select and advance resistant wheat lines in the field and greenhouse. Transfer six sources of resistance to a common spring wheat (cultivar Louise) background.	Five different sources of resistance crossed at least three times to Louise to place them in a popular adapted wheat background. One source was dropped because resistance appeared inferior to the other five. Advanced RIL lines for two populations for mapping the resistance genes. Protocols for producing field environments in which Rhizoctonia is present or absent; protocols for scoring stunting in the field and greenhouse.	BC_1F_7 recombinant inbred line (RIL) populations derived from synthetic wheats Synthetic 172 x Louise and CIMMYT 3104 x Louise have been advanced completed and phenotyped successfully for two years. These two sources, as well as Synthetics 30, 182 and 201 have all been crossed to Louise three times and resistant line selection is underway from the backcross two progeny. CIMMYT 3220 was dropped due to poor performance.	Multiple resistant lines with three crosses to Louise in their backgrounds from five different sources of resistance will be available for amplification by the end of the year 3 funding period.	1) Okubara PA, Mahoney A, Hulbert SH (2013) Dryland Field Day Technical Report. 2) WGC Research Reviews, annually. 3) Hulbert Cook Chair review, annually. 4) PCFS Field Day 2013. 5) Okubara PA, Mahoney A, Hulbert SH (2014) Dryland Field Day Technical Report.
2. Develop molecular markers for tracking the resistance during breeding. Two of the sources of resistance are being used to make mapping populations from the breeding pedigrees developed as they are integrated into the Louise background.	Markers that can be used by breeders for tracking resistance in cultivar development; this is particularly important with traits like Rhizoctonia resistance with are difficult to track phenotypically.	The CIMMY 3104 x Louise mapping population (175 RILs), were genotyped using 162 polymorphic SSR markers. A putative QTL with a LOD score of 4.2 was identified for shoot length reduction within a 24 cM region on the long arm of chromosome 2B. Both mapping populations have been phenotyped; for two years, marker analysis of both will be complete before the end of year three funding.	Phenotyping and high density marker analysis of both populations will be complete by July 2015. Data analysis and publication will take another year.	See above
3. Evaluate and compare the nature of the tolerance or resistance from the different sources. The six sources of resistance are all very different but once these resistances are placed in the common spring wheat background, we will be able to compare them more efficiently.	Information on whether the synthetic-derived lines carry tolerance or true resistance to *Rhizoctonia;* information on whether they carry resistance to other *Rhizoctonia species, Pythium* and *Fusarium;* protocols to compare lines for resistance under controlled environments	Greenhouse scoring of the two mapping populations with Rhizoctonia was completed; data will be compared to field resistance data to see if the same genes are controlling resistance to both traits. Comparisons of root architecture between the five sources of resistance will commence once the resistant BC2-derived lines are available.	Greenhouse and field comparisons indicate they are mostly different. Final comparisons will be made once BC2-derived lines are completed and resistances are mapped in the two mapping populations.	See above
New objective in 2014: Verify that the AUS28451 line does have some level of resistance or tolerance to *Rhizoctonia* and/or *Pythium* and examine the inheritance of this resistance by planting the population in our green-clean assays in Pullman.	Possbile germplasm that can be used for breeding for multiple resistances.	We have performed preliminary tests for *Rhizoctonia* resistance on the AUS28451 and found it to be promising. We have scored approximately 120 recombinant inbred lines from a AUS28451 x Louise in the field in 2014, but they need to be scored one more time. More field testing will be performed before the end of the funding period.	We will re-score the parent line and the whole AUS28451 mapping population at PCFS this spring in our green-clean trials.	None yet

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(Begin 1 page limit)
Project #: 3061-4949
Progress Report Year: *2 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:

- We have screened 112 adapted lines from the Western Spring Regional Nursery in 2014, in a field infested with cereal cyst nematode (*H. filipjevi*) near Colton, WA. 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 Spring, 2014, *Heterodera filipjevi* was discovered in Washington, near Colton. We have extended our survey to cover all of Whitman County in Fall, 2014, with a more intensive sampling to determine the extent of this infestation. We sampled 75 sites, and are currently extracting DNA to use molecular methods to determine species identity.
- We were successful in conducting a greenhouse screen of 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 lines, Svevo and Soft Svevo.
- For root lesion nematode (*Pratylenchus thorneii* and *P. neglectus*), we have screened a collection of Iranian landraces and identified several with dual resistance to both species. We have conducted QTL analysis of resistance in a specific landrace, AUS28451. We are confirming these QTL in backcross populations of AUS28451 cross to Alpowa and to Louise. We have identified promising segregants from these backcross populations that perform well in infested field sites in Pendleton.
- AUG28451 has more root lignin that the adapted PNW cultivar, Louise. We have assayed total root lignin in the mapping population. Total lignin is correlated with nematode resistance in this population. We are currently measuring the expression of genes in the lignin pathway with the goal of identifying possible methods of selection for this trait using gene expression or QTL rather than conducting full scale resistance assays.
- A survey of plots at Spillman in 2014 revealed significant populations of lesion nematodes in several fields. We are establishing a disease screening nursery at Spillman. This nursery, which will be easily accessible, will enable us to evaluate more germplasm in the field.

Impact:

- We have now identified 6 locally-adapted spring wheat varieties with resistance to cereal cyst nematode. 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.
- The use of molecular markers will facilitate pyramiding resistance genes for cereal cyst nematode.
- The selected backcross lines with AUS28451 as the resistant parent and either Alpowa or Louise as the adapted parent, are being further topcrossed to the best current spring and winter breeding lines.

(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	Completed a survey of 52 locations in July, 2013. Found white females in 27% of locations. With the discovery of *H. filipjevi* in Washington announced in Aug. 2014, we initiated a more intensive survey of Whitman County, collecting 75 locations in Sept.-Oct. 2014. Cysts are being extracted, and we will optimize molecular methods do do species identifications, which was not done on previous surveys.	Because of new species findings, survey will extend to the end of year 3, 2015.	Paulitz, T. C. 2014. "Root Disease Research at ARS Pullman-What's New?" Spokane Farm Forum, Ag Expo, Feb. 4, 2014. (presentation). Smiley, R. et al. Information on *Heterodera filipjevi* presented to APHIS in Fall, 2014. Paulitz, T. C. 2014. Updates in Wheat Disease Research, Garfield Grange, Colfax, Washington, January 25, 2014 (presentation)
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 initial trials showing feasibility of testing in grower fields, in summer, 2012. Evaluated spring wheat using visual rating system in infested grower field in 2013 and 2014.	Testing in field will be done in summer, 2015. Cross CCN resistant lines to other sources of resistance in 2014. Screen these populations in 2015.	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)
	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.	Testing in field will continue in summer 2015.	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.
	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.	Continue greenhouse testing of lines in Winter and Spring, 2015	
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, A., Garland, Campbell, K. Paulitz, T. and Smiley, R. 2014. Rooting out defense mechanisms in wheat against plant parasitic nematodes. American Society of Plant Biologists Conference. July 12-16, Portland, Oregon (presentation)
		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	

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(Begin 1 page limit)
Project #: **3061-3548**
Progress Report Year: *_3___ of _3___ (maximum of 3 year funding cycle)*

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

Investigators: M. Pumphrey, K. Garland-Campbell, and T. Paulitz

Cooperators: R. Smiley, Yvonne Manning

Executive summary:

- We have taken the data from the *Fusarium* field surveys funded by the previous grant, and did an extensive analysis and modeling to look at relationships of species with climatic and cropping factors in the dryland area of PNW. Isolates of *Fusarium* spp. were obtained from 99% of 105 fields sampled in 2008 and 97% of fields in 2009. Results of the factor analysis showed that the distribution of *F. pseudograminearum* occurred in a greater frequency in areas of the PNW at lower elevations with lower moisture and higher temperatures, whereas *F. culmorum* occurred in greater frequency from areas at higher elevations with moderate to high moisture and cooler temperatures.
- We have screened 293 adapted spring and winter wheat lines in greenhouse trials for resistance to *F. culmorum*. In each nursery screened, we were able to identify 4-5 lines with better resistance than others. The lines with the best resistance in these trials included spring wheat lines Nick, WB-1035CL, WA8193, WA8195, LNR10-0551, WA8163, UC1742, and Louise, and winter wheat lines SY Ovation, OR2070870, and ARS010302-5C. These results will have to be confirmed with additional trials, due to the variable nature of the disease.
- A mini-core collection was developed for the Spring wheat germplasm of the National Small Grains collection. These lines were increased are being evaluated for Fusarium resistance in the greenhouse screening in 2014/2015. Genotype data is available for this collection.
- Synthetic wheat lines from CIMMYT were screened and three of them were identified as resistant. These lines have been crossed to adapted spring wheat germplasm.
- We evaluated 90 Spring breeding lines and cultivars from the Washington State spring wheat Extension Trials and the Western Regional Spring wheat nurseries for resistance to *F. culmorum* in the field and Lind. The disease pressure was lower than optimal, likely due to the drought, but we were able to discern some lines with better resistance than others, including LCS-Buck Pronto, and Otis, Patwin515, Scarlet, Tarra 2002, WA8219. WB-1035CL. WB-Fusion, and Zak. These results need to be confirmed in trials with heavier disease pressure and results need to be correlated to the greenhouse trials.

Impact:

- Fusarium crown rot is widely distributed throughout all cropping zones, in levels causing economic loss. Different zones however, have a predominance of one species. This is important information for deployment of resistance/tolerance genes in the future.
- The variability of this disease is such that multiple replications and experiments are needed to accurately rate resistance. With the further refinement of our screening systems, we are able to rate several hundred lines in greenhouse and field screening sites on a routine basis. New sources of resistance have been identified.
- Development of resistant varieties will reduce losses from Fusarium crown rot and improve the economic and environmental sustainability for Washington growers.
- Methods for field screening are essential to accurately evaluate response to root disease. We have developed a method that is working to evaluate varieties at Lind, and collaborated with others to expand the number of testing locations. With these field trials, plus our more rapid greenhouse trials, we have identified some breeding lines and cultivars with better than average resistance. These can be intercrossed to accumulate resistance genes with minor effects.

WGC project number: 3061-3548
WGC project title: Fusarium Crown Rot on Wheat: Prebreeding and Development of Tools for Genetic Disease Managemen
Project PI(s): M. Pumphrey, K. Garland-Campbell, and T. Paulitz
Project initiation date: 7/1/2012
Project year: Year 3

Objective	Deliverable	Progress	Timeline	Communication
Objective 1. Objective 1. Confirm resistance of 3B QTL against *Fusarium culmorum.*	Verification of resistance with the same gene.	Fusarium screens were conducted at the WSU Plant Growth Facility using *Fusarium culmorum* . The nurseries screened were the WSU wheat variety trials as well as the Western Regional Nurseries. We have identified approximately 40 lines with better resistance, but this disease is highly variable. We need to repeat these trials under heavier infection pressure in order to confirm resistance.	Will be completed after year 3	Articles in Wheat Life, grower presentations, abstracts, conference proceedings, refereed scientific articles . See attached page for 2013 communications.
Objective 2. Optimize field inoculation techniques (millet seed vs seed coating) and develop natural disease nurseries. Test advanced lines and PNW winter and spring wheat varieties for tolerance and resistance in inoculated field nurseries. Use the field screening sites to evaluate and select germplasm resources from other regions of the US, from the USDA-small grains germplasm bank, and from international nurseries.	Efficient screening system that mimics real life farmer experiences with Fusarium.	Inoculated field screening trials were planted at Lind. The winter wheat trial at Pullman was complicated by infection of eyepot making it difficult to rate the entries so that site was not used for Fusarium. The spring wheat trial at Lind had good infection but the disease pressure was low, likely due to the drought. For the future, we will conduct field screening for Fusarium resistance at Lind using irrigation and higher inoculum rates. We were able to distinguish some differences among varieties.	Development of screening systems will be completed after year 3 Variety testing will be ongoing.	Articles in Wheat Life, grower presentations, abstracts, conference proceedings, refereed scientific articles See attached page for 2013 communications.
Objective 3. Validate the 3B QTL in additional segregating populations with Sunco as a parent and prebreeding development of germplasm using germplasm resources from international CIMMYT nurseries introgressed into the best locally adapted winter and spring wheat cultivars.	New breeding lines with moderate resistance to Fusarium that are derived from combinations of Australian and US germplasm.	Segregating populations have been planted in the greenhouse for inoculation and screening this spring. A mini-core representing 1/100 of the National Small Grains Spring wheat collection was identified. Seed was increased and screening for Fusarium resistance is currently being conducted in the GH. The data obtained from evaluation of the spring mini-core will be used with existing genotype data to conduct association mapping for Fusarium resistance, to identify new sources of resistance.	Will be completed after year 3.	Articles in Wheat Life, grower presentations, abstracts, conference proceedings, refereed scientific articles. See attached page for 2013 communications.

Communications for Washington Wheat Commission Grant 2012-2014

Refereed Publications, Popular Press Articles (partially supported with Wheat Commission funding):

2012

G. J. Poole, G. J., Smiley, R. W., **Paulitz, T. C.** Walker, C.A., Carter, A. H., See, D. R.., and **Garland-Campbell, K**. 2012. Identification of quantitative trait loci (QTL) for resistance to Fusarium crown rot (*Fusarium pseudograminearum*) in multiple assay environments in the Pacific Northwestern US. Theoretical and Applied Genetics. 91-107.

2013

Poole, G., Smiley, R., Walker, C., Huggins, D., Rupp, R., Abatzoglou, J. **Campbell, K.** and **Paulitz, T. C.** 2013. Effect of climate on the distribution of *Fusarium* species causing crown rot of wheat in the Pacific Northwest of the US. Phytopathology 103:1130-1140.

Paulitz, T. C. 2013. Fusarium Crown Rot: What's known, what's new? Wheat Life, June, 2013.

Presentations and Reports:

2012

Paulitz, T. C., Cook, R. J., **Campbell, K.G.** and Poole, G. 2012. Fusarium crown rot research in the Pacific Northwest of the United States: A half a century of discoveries. Pg. 11. Proceedings of the First International Crown Rot Workshop for Wheat Improvement, Oct. 22-23, 2012. Narrabri, New South Wales, Australia.

Poole, G. J., Smiley, R. W., Walker, C. A., **Campbell, K. G., and Paulitz**, T. C. 2012. Distribution of *Fusarium* spp. causing crown rot in the Pacific Northwest. Pg. 22. Proceedings of the First International Crown Rot Workshop for Wheat Improvement, Oct. 22-23, 2012. Narrabri, New South Wales, Australia.

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Project #: **3019 3571**

Progress Report Year: *_2___ 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, and Chet (WA8165) low rainfall hard red was produced as all three were released in 2014. Each variety has very good yield potential, a high level of stripe rust resistance, Hessian fly resistance, aluminum tolerance, good-to-excellent end-use quality, and better straw strength compared to existing varieties. Foundation seed is sold out for 2015 seed production of these new varieties, and will be available to growers in 2016. WA8193, a shorter spring club to replace JD in >16" rainfall areas, will be proposed for release in February 2015. Glee hard red spring wheat was again a top performer in >12" through >20" precipitation areas, and will be the leading hard red spring by acres in 2015. Kelse and Glee were the two leading hard red spring wheat varieties, planted on >85,000 acres. Diva, Louise, Whit, Babe and JD are collectively planted on >75% (228,000) of soft spring wheat acres. Across spring wheat market classes, our varieties were planted on 57% of all spring wheat acres in 2014.

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. 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:

WGC project number: 3019 3571
WGC project title: Improving Spring Wheat Varieties for the Pacific Northwest
Project PI(s): Mike Pumphrey
Project initiation date: 2014
Project year: 2 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.	Three new spring wheat varieites were released in 2014, Seahawk (WA8162) SWS, Alum (WA8166) HRS, and Chet (WA8165) HRS. These varieties will have a significant positive economic impact for PNW growers. Despite a rough year due to hail and other environmental impacts our advanced experimental lines performed very well in the WSU Variety Trials. WA8214 (SWS) and WA8213 (SWS) were among the top performers across all precipitation zones in the 2014 Variety Trials. WA8193 (SWC), WA8224 (SWS), and WA 8215 (SWS) also showed very good performance in the 2014 soft white Variety Trials. WA8193 (SWC) will be proposed for release in 2015. In the 2014 hard WSU Variety Trials WA8220 (HRS) was second in the >20" zone. WA8117 (HRS) and WA8118 both performed well across all zones. WA8216 (HWS) performed well across all zones, particularly in the moderate rainfall zones and the <12" zone were it ranked #1. Other WSU Spring Wheat varieties and elite lines, including Seahawk, Louise, JD, Diva, Whit, Babe, Alum, Chet, Kelse, Scarlet, Hollis, Otis, WA8189 (SWS), and WA8195 (SWS) performed well in WSU Variety Testing trials in 2014. WSU spring wheat varieties accounted for 70% of the SWS, 100% of the SWC, and 34% of the HRS acreage in Washington State.	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. Annual Wheat Life contributions
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 429 unique cross combinations were made for selection in field nurseries in 2014, and ~30,000 breeding lines were evaluated in field trials at 1 to 18 locations throughout Washington State. Grain samples from 520 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 1,981 F4 headrows (822 SWS, 867 HRS, 137 HWS and 155 spring clubs) 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 1168 superior lines were identified. Afterwards, we implemented an additional single-seed-descent generation in the greenhouse in December 2014 and F5-derived lines will be grown at Spillman Farm in 2015.	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, identification of superior germplasm through association mapping and prediction of breeding values, 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 2014 the design and setup of tractor mounted spectral reflectance cameras was implemented to obtain field-based high throughput phenotyping. This will greatly enhance the range and amount of data that can be collected. 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 variety "Alum".	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.	

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Project #: **3019 3573**

Progress Report Year: *_2___ of __3__ (maximum of 3 year funding cycle)*

Title: **Greenhouse and laboratory efforts 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 ahead of schedule. Approximately 2000 early generation lines were evaluated for end-use quality with ~1100 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 2014.

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. Parental germplasm is characterized with DNA markers for desirable traits, which allows efficient development of high-value breeding populations and ultimately better wheat varieties. 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.

Outputs and Outcomes:

WGC project number: 3019 3573
WGC project title: Greenhouse and laboratory efforts for spring wheat variety development
Project PI(s): Mike Pumphrey
Project initiation date: 2013
Project year: 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
	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. Two hard red spring Clearfield™ lines, WA8219 & WA8220 were included in the 2014 Variety Trials. Both these lines were created using the double haploid method and marker assisted backcrossing. WA8220 performed well, and was the highest yielding hard red spring in the >20" rainfall zone, and competitive in the <12" zone. We have made swift progress in only a few short years and have several candidates for the 2015 Variety Trials for hard and soft types. Seahawk soft white spring wheat, was released and Breeder and Foundation seed raised in 2014 (off-season and main season). Seahawk was selected by markers to have a combination of Yr5 and Yr15 seedling stripe rust resistance genes.	The two-gene Clearfield™ breeding effort is in full swing, ~800 lines were planted at Pullman in plots in 2014. Three Clearfield™ sites were planted in 2014 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 2015 WSU Variety Testing trials.	Pumphrey attended/presented numerous WSU field days workshops/meetings, Western Wheat Workers, WSCIA Annual Meeting (presentation), WSCIA Board Meetings, WA Grain Commission, industry tours in Pullman. Annual Wheat Life contributions in 2013 on spring wheat breeing update.
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 was employed to select and advance experimental lines with increased likelihood of having superior quality. In 2014, ~2000 head-row selections were subjected to specific laboratory-based grain quality assays based on market class, and ~1100 were retained for SSD and 2015 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.	

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	Annually	

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Project #: **3019 3667**

Progress Report Year: *_1___ 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. Otto, Puma, Glee, and Diva are examples of top-performing lines with that also have desirable to most desirable end-use quality. Over 1300 WSU breeding samples were analyzed for milling and baking quality in 2014, involving tens of thousands of individual tests. This is large increase over previous years, and has allowed our breeding programs to handle more advanced breeding lines.

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.

Outputs and Outcomes: Excel 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: July 1, 2014
Project year: 1 of 3

Objective	Deliverable	Progress		Communication
Early to late generation quality testing of WSU experimental lines to aid variety development	New spring wheat 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 1300 breeding samples were analyzed by numerous milling and baking quality tests in 2014. This is a substantial increase over previous years and has allowed enhanced selection of advanced breeding lines with good quality.	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.
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 grown and harvested for milling and baking. The 2014 field samples have been milled, and various tests of milling and baking properties are ongoing. Milling and baking analysis of a bi-parental winter wheat mapping population has also been substantially completed	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 #:	**3019 5234**
Progress Report Year:	*_3___ 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 climate change, 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.

Fourty-eight advanced breeding lines along with 300 mapping population progeny were screened for Hessian fly resistance in 2014. Among elite breeding lines, 19 were resistant to Hessian fly, while 29 were susceptible. The HT080158LU/WA8076 doubled haploid mapping population was completed, and 300 progeny were produced. Esraa Alalwan, the PhD student working on this project, worked with Dr. Bosque-Perez at U of I to complete Hessian fly phenotyping from June-August 2014. Single gene Hessian fly resistance from WA8076 was determined in the DH population by 1:1 segregation. Genetic map construction is underway.

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. 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. Three 2014 spring wheat variety releases are Hessian fly resistant based on selection data from this project.

Outputs and Outcomes:

WGC project number:	5234
	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:	2012
Project year:	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	48 elite breeding lines were screened in 2014. 19 were resistant to Hessian fly. 300 progeny of a mapping population were also phenotyped.	Annually	Progress will be presented by M. Pumphrey, K. Garland Campbell 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 HF donors, and additional stocks were recently received for Hessian fly testing and future crossing	Annually	
Use association mapping to identify SNP-based DNA markers for routine selection of Hessian fly resistance	DNA markers and genetic information on PNW sources of Hessian fly resistance	A doubled haploid population was phenotyped and genotyped in 2014, which showed 1:1 segregation and will validate and tag one resistance gene detected by association mapping	Genetic map construction will be completed by Summer 2015	

Washington Grain Commission
Wheat and Barley Research Annual Progress Final Report

Project #: 4168 1353

Final Report Year: __4__ of __3__ (maximum of 3 year funding cycle)

Title: Stem Rust and Common Barberry Awareness Education

Cooperators: Diana Roberts (WSU Extension Spokane/Lincoln Counties), Tim Murray (WSU Plant Pathology), Xianming Chen (USDA-ARS Pullman), and Steve Van Vleet (WSU Extension Whitman County).

Executive summary: The project is complete. There is a greater teachable moment for this topic due to the stem rust outbreak in 2012. We got barberry listed as a Class C Noxious Weed in Washington. In November 2014, we published an Extension fact sheet; FS151E Control of Common Barberry to Reduce Stem Rust of Wheat and Barley, which is available free at https://pubs.wsu.edu. Without the alternate host, the disease triangle is broken and stem rust is rarely a problem. In a 2013 WSU Extension survey, 61% of 124 respondents had increased their understanding of stem rust and 30% had used our information in making on-farm management decisions.

Impact: Stem rust can easily cause 100% yield loss in spring wheat and barley. It is unlikely to cause widespread loss in Washington as it is rare that we have warm, moist summer weather that it requires. 2012 was the closest I have ever seen to summer rainfall patterns here. The primary threat due to stem rust is providing an area in eastern WA where the rust pathogen can undergo sexual reproduction on common barberry, the alternate host, and thus develop new, virulent races that could spread to the Midwest and cause major loss there.

Following an Extension talk on stem rust and barberry in Colville in December 2014, a grower took a copy of the new bulletin. A few days later he found a large barberry bush in his mother's yard, adjacent to the fields that have been infected with stem rust since 2007. The bush was not listed on the original data cards. According to the family, it had been transplanted from a neighboring home. It was likely very small when the eradication crews came through first in 1959. The grower will eradicate the bush in the spring. However, it is likely that there are more bushes in the local area and in eastern Washington. Having the new bulletin available will make it easier for landowners to identify and eradicate common barberry on their land.

WGC project number:	4168 1353			
WGC project title:	Stem Rust and Common Barberry Awareness Education			
Project PI(s):	Diana Roberts (WSU Extension Spokane/Lincoln Counties), Tim Murray (WSU Plant Pathology), Xianming Chen (USDA-ARS Pullman), and Steve Van Vleet (WSU Extension Whitman County).			
	Jul-11			
Project year:	3			
Objective	**Deliverable**	**Progress**	**Timeline**	**Communication**
1. Education of growers and field consultants	Flyers and posters describing stem rust and barberry.	Completed and published 2011		Poster published in Wheat Life, flyers available at workshops and tours
	Educational curricula (PowerPoint presentations) that we are developing right now that we will begin to use at grower workshops this winter (2011).	Completed and published 2011, updated annually by Diana Roberts and Tim Murray . We are also working with the WA State Weed Association on putting out educational materials. Extension fact sheet on identification and eradication of barberry published in November 2014		Presentations in 2012 reached 166 growers in Spokane, Lincoln, Yakima Counties (WA) and bonner County (ID). In 2013 reached 60 growers in Steven County, which is likely a center for barberry bush regeneration. In a2013 WSU Extension survey, 61% of 124 respondents had increased their understanding of stem rust and 30% had used our information in making on-farm management decisions. Following an Extension talk on stem rust and barberry in Colville in December 2014, a grower took the new bulletin and found a large barberry bush in his mother's yard, adjacent to the fields affected since 2007.
	A webinar for winter 2011/2012 that will reach a regional and national audience.		Completed February, 2013	
	Articles written annually for popular magazines, including Wheat Life.	Articles in Wheat Life 2011. Statewide newsrelease published August 2012 due to widespread incidence of stem rust with the wet summer conditions that year		Articles in Wheat Life 2011. Statewide newsrelease published August 2012 due to widespread incidence of stem rust with the wet summer conditions that year
	A web-based reporting system for stem rust infestations and barberry bush locations	Completed and made available in 2011 at www.PNWstemrust.wsu.edu A grower from Stevens County reported stem rust in 2013 - he has had regular occurences since 2007 so there is likely barberry in his area. We seearched for it in the fall of 2012 but were unable to locate bushes.		There was some use of this system in 2012 following the newsrelease about the stem rust outbreak in September 2012

2. Best management practices for common barberry eradication	Identify effective treatments to eradicate common barberry		An Extension fact sheet FS151E Control of Common Barberry to Reduce Stem Rust of Wheat and Barley was published November 2014 and is available free online at https://pubs.wsu.edu/	These data were included in presentations made since November 2012.
3. Develop a GIS database of the original barberry eradication records from ID, OR, WA, and MT.		This database is well under way - with funding from an alternate source	Funding is from an alternate source	Datapoints close to a stem rust infection site in Stevens County did not yield barberry bushes when examined in November 2012. Stem rust occurred in barley fields here again in 2013 and 2014. The bush likely responsible for infection was found in December 2014 and was not listed on the original data cards - it had been transplanted from a neighboring home and was small when the eradication crews came through.

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Project #: 4127 1298

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

Title: Integrated Pest Management (IPM) for the Wheat Midge

Cooperators: *Diana Roberts (WSU Extension Spokane/Lincoln Counties), Ed Bechinski (UI Entomology), Rory Eggers (Primeland)*

Executive summary: The wheat midge (also known as the orange wheat blossom midge - OWBM) is a known pest of spring grains (wheat and barley) in the Midwest and Canadian prairies. The midge has been troublesome in Boundary County, ID, for 20+ years. The last 5 years it has caused concern on the Rathdrum Prairie, ID, and Peone Prairie that lies NE of Spokane City.

In 2014 we found the wheat midge widespread in pheromone traps located in Spokane, Stevens, and Lincoln Counties. Hotspots were concentrated on Peone Prairie, Rathdrum Prairie, and to a lesser extent, in Stevens County. Pheromone traps contain a sex hormone specific to the species that draw in male insects from a wide area, so number of insects captured do not relate directly to field infestation at that site. Further monitoring (counting insects flying at dusk) is necessary to make definitive determination of the pest pressure while the crop is susceptible (heading out prior to full flowering).

Traps in Whitman and Columbia Counties did not capture any wheat midge in 2014. Little or no grain is being grown currently in Pend Oreille County, which would otherwise be an area of interest.

Soil samples from hotspot areas assayed after harvest have been sent to NDSU to determine if naturally occurring parasitoids are present in the midge

Impact: It is unknown whether the wheat midge will become a major pest in eastern Washington. This project is intended to be proactive in identifying hotspots, developing degree day models that enable growers to use seeding dates to avoid the pest, and quantifying whether insect biocontrols are present in this environment and able to manage the pest. Educating growers and field consultants how to identify and manage the midge is an important component of the project.

Due to confusion about funding cycles, we received only one year's funding ($14,000) for this project from the WGC. We hope to obtain continued funding under the new proposal to the WGC, Integrated Monitoring of Insect Pests in Cereal Crops with Dave Crowder.

WGC project number:	4127 1298			
	Integrated Pest Management (IPM) for the Wheat Midge			
Project Pis	Diana Roberts (WSU Extension)			
Project Cooperators	Ed Bechinski (UI Entomology), Rory Eggers (Primeland), farmers at Peone and Rathdrum Prairie			
Project initiation date:	6/1/2012			
Project year:	3			
Objective	**Deliverable**	**Progress**	**Timeline**	**Communication**
a. In Year One and Two, use pheromone traps to determine the range and severity of wheat midge infestations.	The areas of interest include, but are not limited to, Stevens, Pend Oreille, Spokane, Whitman, Lincoln, Asotin, Garfield, Columbia, and Walla Walla Counties.	In 2014, with the help of a technician hired to the project, again we assayed traps across most of the region of interest: Spokane - 11 sites (5 on the Peone Prairie), Lincoln - 2 sites, Stevens - 3 sites, Whitman - 3 sites Columbia - 1 site, and 4 on the Rathdrum Prairie of Idaho. No midge were found in Whitman or Columbia Counties. Midge populations were low, generally. However, some sites on the Peone Prairie had higher populations and growers treated some with insecticide. It should be noted that trap catches are not considered to be a direct measure of pest populations, but do indicate need for sampling within fields.	Due to confusion about the grant process, we did not get further funds for this project in 2014. We hope to receive funds in 2015 under the new project Integrated Monitoring of Insect Pests in Cereal Crops with Dave Crowder. In this case, we will continue monitoring studies in conjunction with other insects	
b. In subsequent years, if there are hotspots or areas of concern, utilize them to develop a degree-day model for wheat midge development in the state.		A degree day model is crucial for managing the midge, as indicated in the literature about this pest. In 2013, spring wheat at Peone Prairie missed infestation by not being in the early heading stage when the midge population was flying. With the aid of a degree day model, growers should be able to plan spring wheat plantings to avoid the pest.	We were unable to purchase an AWN weather station due to lack of funds. We had technical problems with the one we borrowed, and the project PI (Roberts) was dealing with head injury/concussion issues and not managing detailed things well, so we didn't get any usable weather data this year. Plan to try again in 2015	
c. At hotspots, determine economic thresholds for infestations.		The Peone and Rathrum Prairies remain the primary hotspots for wheat midge, although some sites in Stevens County had a fair number. Spring wheat is not grown much in Stevens County, so numbers might be higher if the traps were in wheat rather than barley fields	We will continue this objective under the Integrated Insect Monitoring Project	
d. At hotspots, determine whether the biocontrol wasp has moved in with the pest.		We contract with Dr. Jan Knodel at NDSU to assay soil samples for midge cocoons (overwintering stage) and biocontrol parasitoids. We sent samples to NDSU in 2013 - several collected from Peone Prairie and some from the Rathdrum Prairie in ID where the infestation warranted spraying (samples were from an unsprayed portion of the field). Cocoons were found in 5 of the 7 samples but numbers were in the low range (about 200/square meter where 1200 would be high risk). Note - pheromone traps draw insects in from across the whole field, so they are not indicative of populations at that point. Samples sent in 2014 have not yet been processed.	We will continue this objective under the Integrated Insect Monitoring Project	

e. Determine whether the biocontrol wasp occurs here already and if not, import it from North Dakota or Canada.		Samples sent in 2014 have not yet been processed	We will continue this objective under the Integrated Insect Monitoring Project	
f. Teach crop consultants and farmers how to use the traps, to survey infested fields, and to identify the midge correctly.		Based on their experience with the cereal leaf beetle, the farmers at Peone Prairie have been eager to cooperate on the project and reluctant to spray for the wheat midge because it would kill any benefical insects also. Hearing this from them was music to my ears! I have included their crop consultant, Rory Eggers from Primeland, as a collaborator on the project. Working closely with him in this capacity has improved cooperation all round - we have standardized the pheromone traps we use so that it is easier to make comparisons among sites.	I have alerted growers to this potential problem via several presentations in 2011, 2012, 2013, and 2014. Right now I'm focusing education to those farmers/crop consultants who are directly affected by the midge. Will expand outreach as needed as the project develops...	Presentations: Spokane County Crop Improvement Assoc 2010, 2011 & 2012 - 60 growers and consultants each year. WGC Review 2012 & 2013 - 35 participants. each year. Stevens County producers 2010, 2013,and 2014 - 90 participants. Whitman County 2011 - 55 growers & consultants. Lincoln County producers 2012 - 25 growers. **In a 2013 WSU Extension survey, 39% of 117 respondents said they had increased their knowledge of the wheat midge and 10% had used our information in making on-farm management decisions.**

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Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: 6451

Progress Report Year: __*3*__ *of* _*3*___ *Final Report*

Title: A Genetic Arsenal for Wheat Production under Drought

Project PIs: Camille Steber, Kimberly Garland Campbell, and Scot Hulbert
Cooperators: Michael Pumphrey, Arron Carter

Executive summary: This project identified genes associated with drought tolerance. The molecular markers associated with these QTLs can be used by the Washington wheat breeding programs to select for drought-tolerance-associated traits. Some of the lines generated are being considered for release, or will be used in the wheat breeding programs.

Objective 1. Characterize lines from the three RIL mapping populations Louise/Alpowa, Alpowa/Express, and Drysdale/Hollis for drought tolerance, map drought tolerance loci, and make breeding selections that create unique combinations of drought tolerance mechanisms. The goal was to improve yield under drought by developing populations from parents that use different mechanisms to yield well under drought. The resulting populations allowed selection of lines that yielded better than either parent under drought, and mapping of quantitative trait loci (QTLs) for drought tolerance traits. Molecular maps were developed based on SNPs and SSR markers. QTL analysis is completed in the Alpowa/Express and the Hollis x Drysdale population, and the Louise/Alpowa population will be finished by June 2015. Drought tolerance mechanisms and ability to yield well under drought (measured based on drought susceptibility index) was examined in Louise/Alpowa and Alpowa/Express in the 2011 and 2012 field seasons, and the Hollis/Drysdale population in the 2012 and 2013 field seasons. Selected lines that yielded well under drought were further analyzed in the field in 2013 and 2014. Selected Louise/Alpowa derived lines that yielded better than both parents were crossed to related lines carrying the Yr5 and Yr15 stripe rust resistance genes as a collaboration with M. Pumphrey. However, Louise/Alpowa lines carrying HTAP resistance will be placed into the Western Regional Trials and in the WSU Cereal Variety Trials for further evaluation for release. Although Drysdale is a Australian line, it performed very well in Washington and appears to be an excellent source of drought tolerance for this region. Selected lines from the Hollis x Drysdale will be developed in collaboration with M. Pumphrey, and have been included in the WSU Cereal Variety Trials.

Objective 2. Using Hollis and Louise as standard hard red spring and soft white spring backgrounds, develop lines that have new sources of drought tolerance introgressed into locally adapted germplasm. The previous project identified CIMMYT lines showing drought tolerance in eastern Washington. 516 lines from crosses between CIMMYT germplasm and Hollis or Louise were examined in Lind. Of these, 98 were selected for advanced testing in 2013 and 2014. A further 17 more advanced CIMMYT lines and varieties showing good performance at Lind were crossed to Hollis, and the F1's intermated to begin making a single Multiparent

Advanced Generation Inter-Cross (MAGIC) population for both QTL mapping and line selection. The lines have now been intercrossed three times and 500 of the resulting plants have been self-fertilized to begin establishing lines. This will provide an excellent resource for future breeding for drought tolerance. Two very promising lines were recovered from the second backcross of Dharwar Dry to Louise. These lines yielded better than Louise under drought stress at Lind Farm in 2014.

Objective 3. Generate and use genomic selection indices based on the available populations to increase the speed of drought tolerance breeding.
This project has identified molecular markers linked to water use efficiency, canopy temperature, and yield under drought that can be used to improve selection for drought tolerance within breeding programs. Surprisingly, higher water use efficiency did not show a strong correlation to yield under drought. However, lines with high water use efficiency tend to be among the best yielding under drought. This suggests that there is not a simple relationship because yield and water-use efficiency. Future work in collaboration with Dr. Asaph Cousins, an expert in photosynthesis, will examine what physiological properties allow Louise to benefit from high water use efficiency. A QTL for delayed flag leaf senescence on chromosome 4A linked to marker IWA4319 with a LOD of 6.18 explained 35% of the variation for yield under drought. This emphasizes the importance of maintaining photosynthetic capacity under stress. A QTL for cooler canopy under drought stress on chromosome 3B linked to marker IWA4311 (LOD 6.02) explained 15% of the variation for yield under drought. In general, cooler canopy under drought stress was associated with higher yield. Previous work showed that cooler canopies are associated with deeper and healthier root systems (Lopes et al., 2010). This suggests that root architecture is very important to performance under drought stress in the eastern Washington environment. This will be further investigated in the next project led by Dr. Karen Sanguinet, an expert in root physiology who was recently hired in the Washington State University, Department of Crop and Soil Science.

Impact: Improved drought tolerance in selected lines has the potential to improve yield and cropping systems on the dry side of Washington by reducing production risk and the number of fallow seasons.

WGC project number: 6451
WGC project title: A Genetic Arsenal for Wheat Production under Drought
Project PI(s): Camille M.. Steber, Kimberly Garland-Campbell, Scot Hulbert
Project initiation date: 7/1/2012
Project year: 3 of 3 (2015)

Objective	Deliverable	Progress	Timeline	Communication
1. Characterize lines from two RIL mapping populations for drought tolerance, map drought tolerance loci, and make breeding selections that create unique combinations of drought tolerance mechanisms.	A. SSR and SNP analysis was performed on two RIL populations, and by SNP analysis on a third. B. Molecular markers linked to QTL for drought tolerance mechanisms including canopy temperature, water use efficiency, and delayed flag leaf senescence were identified. C. Cooler canopy showed the strongest correlation to yield under drought, suggesting that deeper root systems are very important. D. New germplasm available for testing in Western Regional Nurseries by June 2015.	1. Drought tolerance traits segregating in the Louise x Alpowa, Alpowa x Express, and Hollis x Drysdale RIL populations have been characterized. 2. QTL analysis has been used to map drought tolerance genes in two mapping populations, and a third will be completed by June of 2015. 3. A linkage map for use in QTL analysis has been generated for the Louise/Alpowa population. 4. Promising lines have been shared with the spring wheat breeding program, entered into the Western Regional Nursery, and entered into the Cereal Variety Trial.	Tasks completed: 1) Analysis of selected lines from each population for drought tolerance in the field; 2. Analysis of stripe rust resistance of the selected lines in the field to determine which drought tolerant lines have sufficient stripe rust resistance to be entered into regional trials; 3. Completion of data analysis and QTL mapping for drought tolerance traits.	Results were communicated at the Wheat Research Review, and at the Lind and Spillman Field Days.
2. Using Hollis and Louise as standard hard red spring and soft white spring backgrounds, develop lines that have new sources of drought tolerance introgressed into locally adapted germplasm.	A. New genetic sources of drought tolerance introgressed into locally adapted cultivars Louise and Alpowa. These pre-breeding lines have been made available to wheat breeding programs at WSU	1. Crosses of Australian and CIMMYT lines to Louise and Hollis have been completed. 2. Selections have been made from crosses to Hollis. 3. Prebreeding lines derived from Hollis/Drysdale have been selected for increased water use efficiency in a Hollis background.	Selection for improved drought tolerance in the locally adapted backgrounds of Louise and Hollis were made in the 2014 and the 2015 field seasons.	Results were communicated at the Wheat Research Review, and at the Lind and Spillman Field Days.
3. Generate and use genomic selection indices based on the available populations to increase the speed of drought tolerance breeding.	Markers for drought tolerance loci from Alpowa, Louise, and Drysdale that can be used to move loci within the spring and winter breeding programs by June 2015.	1. Molecular markers were identified linked to: a. high water use efficiency on chromosomes 2B and 3B; b. delayed flag leaf yellowing on chromosome 4A; and c. cooler canopy temperature on chromosome 2B . 2. Intercrosses between selected Louise/Alpowa lines to sources of stripe rust resistance genes Yr5 and Yr 15 to select germplasm with both increased drought tolerance and stripe rust resistance.	Populations derived from crosses between drought tolerant Louise/Alpowa RILs and Alpowa and Louise-like lines with Yr5 and Yr15 are under development. Molecular markers linked to drought tolerance loci will be used to follow gene deployment.	

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Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: 7599

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

Title: Developing Washington Wheat with Stable Hagberg Falling Numbers

Cooperators: Stephen Guy, Craig Morris, Kimberly Garland Campbell

Executive summary: This project was initiated because Washington farmers experienced serious losses due to low Falling Numbers in 2011 and in 2013. The overall goal was to breed for stable Falling Numbers (FN) in Washington wheat. To achieve this goal, we first needed to assess whether the problem was due to Late Maturity Alpha-Amylase (LMA), susceptibility to low FN in response to cold shock during grain maturation, or to preharvest sprouting (PHS), low FN that occurs when mature grain gets rained on before harvest. Much of the problems in 2011 and 2013 were a result of preharvest sprouting. Using additional WGC funding in 2013, we turned the sprouting problem of 2013 to our advantage by performing FN testing of the WSU cereal variety trials. This allowed us to create an online database of FN by cultivar and location that can provide farmers with a good tool to find cultivars with good yield potential in their region that also have less PHS susceptibility (see website: http://steberlab.org/project7599.php). In the course of this project, we discovered that LMA-susceptibility is an emerging problem in Washington, Idaho, and Oregon wheat breeding programs.

Objective 1. Characterize wheat varieties grown at multiple locations as part of the Cereal Variety Trials in 2011, 2012, 2013, and 2014 using the Falling Number test.
FN has been tested in 2011, 2012, and 2013. FN testing of 2013 winter wheat from the Cereal Variety Trials grown in Spillman Farm is now complete. Bruneau, Bruehl, Xerpha, and Selbu had low FN, whereas Ovation, Puma, and Cara had higher FN.

Objective 2 and 3. Characterize spring and winter wheat varieties for degree of LMA susceptibility using methods for simulating LMA-inducing cold shock in greenhouse growth chambers. Determine if LMA susceptibility correlates with previously published molecular markers linked to LMA in Australian wheat cultivars.
Greenhouse LMA testing examined alpha-amylase levels in lines used the the soft white spring wheats grown in the Cereal Variety Trials by comparing lines grown without cold shock (22°C Day/16°C Night) and with a cold shock (18°C Day/7.5°C Night) treatment at 25 days after pollen shedding. LMA susceptible lines should show higher alpha-amylase levels (correlated with low FN) with cold treatment than without cold treatment. Alturas was the only named soft spring cultivar show to show a statistically significant increase in alpha-amylase with cold-treatment. Lines that appeared to be LMA susceptible included: Alturas, WA8124, ARS503174, and IDO854. WA8124 and Alturas also showed low FN in 2011. This very preliminary result suggests that selection against LMA susceptibility in breeding material is needed, but that the problem is not yet wide-spread in released spring cultivars. Molecular marker analysis will be performed once greenhouse testing of winter wheat is completed.

Objective 4. Determine if low Hagberg falling numbers in the field are correlated to with high alpha-amylase levels in greenhouse LMA testing or to PHS susceptibility.
Preharvest sprouting susceptibility was examined using the spike-wetting test followed by scoring for visible sprouting. Based on this assay, some sprouting resistant cultivars had higher FN (Ovation, Masami) and some sprouting susceptible cultivars had very low FN (Bruneau, Xerpha, Selbu). But overall, there was not a strong correlation (r = -0.22; p-value = 0.09) between sprouting tolerance in the spike-wetting test and FN of the winter variety trials grown at Spillman Farm in 2013. This lack of correlation may result from the fact that while greenhouse spike-wetting tests take maturation date into account, field FN data does not. Or it suggests that a better testing method is needed to predict susceptibility of wheat cultivars to low FN/high alpha-amylase in response to rain.

Impact: Wheat in all market classes is dramatically discounted if testing shows that it has low falling numbers (below 300). Moreover, a consistent problem with low FN could damage the reputation of Washington wheat in foreign markets. Selection against The discovery that LMA susceptbility has made its way in Washington cultivars is bad news in the sense that we have to deal with breeding against this problem, but it is good news in that it appears to be a problem mainly in WSU and USDA breeding lines. This means that we have the opportunity to correct the problem before it negatively impacts our market and reputation. Selection of wheat varieties with consistently higher falling numbers. is the most practical and straightforward strategy of controlling this problem.

WGC project number: 7599
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: 07/01/12
Project year: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Characterize wheat varieties grown at multiple locations as part of the Cereal Variety Trials in 2011, 2012, and 2013 using the Falling Number test and examination for signs of preharvest sprouting in order to determine which varieties are susceptible to LMA or have significantly lower falling numbers.	Knowledge about the susceptibility of spring and winter wheat varieties to low FN both in years when there was not a serious problem (2012) and in years when there was a problem with low FN (2011, 2013, 2014)	The Falling Numbers of the Spring and Winter Variety Trials were analyzed at selected locations in 2011 and 2012 to determine which lines tended to have lower falling numbers. With supplementary funding, the project was able to analyze FN for all available locations in 2013, and 2014 is in progress. All Falling Number data plus a tool for comparing FN to yeild have been entered into a database that is available on the website: steberlab.org/project7599.php	Year 1. FN testing of breeding lines and variety trials from select locations in 2011 and 2012. Year 2. FN testing of breeding lines and all locations available from the 2013 Cereal Variety Trail. Year 3. Single repetition data has been completed for the soft white winter and spring variety trials at multiple locations. Remaining variety trial and beeding samples will be analyzed by June 2014.	Results were communicated through talks at the Wheat Research Review, the Western Wheat Quality Council, and at two conferences, through annual Wheat Life articles, abstracts submitted to the Lind and Spillman Field Days, and through the project website: steberlab.org/project7599.php.
2. Characterize spring and winter wheat varieties for degree of LMA susceptibility using methods for simulating LMA-inducing cold shock in greenhouse growth chambers. The techniques will be developed in 2012 and used for wide-scale evaluation in 2013 to 2014.	Knowledge about the susceptibility of spring and winter wheat varieties to low FN resulting from alpha-amylase expression in response to cold shock during late grain maturation. This LMA is genetically different from preharvest sprouting, and does not require a rain event after maturation to see damage.	Greenhouse testing for LMA has been performed for entries in the 2013 Spring and Winter Cereal Variety Trial entries.	Year 1. Developed LMA Greenhouse testing method using known resistant and susceptible lines. Year 2. LMA testing of spring wheat. Year 3. LMA testing of winter wheat.	Results were communicated through talks at the Wheat Research Review, the Western Wheat Quality Council, and at two conferences, through annual Wheat Life articles, abstracts submitted to the Lind and Spillman Field Days.
3. Determine LMA susceptibility in Washington cultivars is associated with previously published molecular markers for LMA on chromosomes 3B and 7B.	If LMA susceptiblity in Washington wheat is associated with the known molecular markers for this problem, then this will provide breeders with a tool to select against LMA	Genomic DNA has been prepared from lines identified as LMA susceptible and resistant, and markers will be run by June 2015.	This objective was dependent on completion of Objective 2. Marker analysis will be completed in Year 3.	Results will be communicated at the Wheat Research Reviews. Information will be communicated to farmers through annual Wheat Life articles, and as abstracts submitted to the Lind and Spillman Field Days.
4. Determine if low Hagberg falling numbers in the field are correlated to with high alpha-amylase levels in greenhouse LMA testing or to PHS susceptibility.	Knowledge about preharvest sprouting susceptbility based on the spike wetting tests. Information about with LMA or preharvest sprouting susceptiblity is associated with the low FN problem.	Preharvest sprouting based on visible sprout in the spike wetting test did not strongly correlate with low FN. However, it was concluded that most of the problems in 2011 and 2013 were due to rain-induced preharvest sprouting. This suggests that we need a better method to determine which cultivars tend to induce alpha-amylase in response to rain events. LMA susceptibility was associated with low FN in the field in Mayview 2011, and in Mayview and Walla Walla in 2013.	Analysis of the association between LMA and low FN in Wahsington will be performed upon completion of the greenhouse LMA testing.	Results were communicated through talks at the Wheat Research Review, the Western Wheat Quality Council, and at two conferences, through annual Wheat Life articles, abstracts submitted to the Lind and Spillman Field Days.

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

Project: 3389

Progress Report Year: *__2__ 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. Evaluation of the Jagger population revealed that it was not suitable for the screen for altered vernalization and photoperiod sensitivity. A new Norstar population will be generated this screen.

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. 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. The JD population was advanced for generation of a new club wheat TILLING population. Additional JD lines will be generated in year 3.

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, and this population will be generated in year 3.

Impact: This project provides 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 allowed WSU researchers to propose the use of existing mutant populations in grant proposals with aims involving gene cloning and wheat improvement.

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: 2 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 that can be screened for altered stripe rust resistance and heat tolerance (Year 1). Initial screening showed that Jagger did not have a strong enough vernalization requirement for use in forward mutant screens for altered vernalization and photoperiod sensitivity. Eltan is better, but it was decided that a larger mutant population with a higher density of mutations would be needed. Finally, three labs requested a Norstar mutant population because of its excellent freezing tolerance. The Norstar TILLING population was added to the objectives for year 3.	Year 1. The Louise population was advanced, and initial analysis of Jagger population performed. Year 2. Mutagenesis of Eltan for use in making 1,000 additional Eltan TILLING lines. Year 3. Mutagenesis of Norstar and construction of a TILLING population.	Results will be reported at the Wheat Research Review, at field day presentations, and Wheat Life Articles.
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 and 2. The JD TILLING population construction. Year 2. Creation of 1,000 new Eltan TILLING lines. Year 3. Creation of a Norstar TILLING population.	Results will be reported at the Wheat Research Review, at field day presentations, and Wheat Life Articles.
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	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 will be reported at the Wheat Research Review, at field day presentations, and Wheat Life Articles.

Washington Grain Commission Annual Project Report FY 2014

Project #:*3061-5548*

Progress Report Year: 3 of 3

Title: Establishing Plant Pest Diagnostic Services in Eastern Washington

Cooperators: Karen F. Ward and Hanu R. Pappu, co-PI's; Diagnostic Clinic Advisory Committee: Tim Murray, Lindsey duToit, and Dennis Johnson, WSU Dept. of Plant Pathology; Randy Baldree, WSU Extension; and Raina Spence, Washington State Potato Commission.

Executive summary:

The Diagnostician processed approximately 200 disease samples each year. Approximately thirty-five percent of the physical samples were wheat, barley and pulses. Additionally weed samples from small grain rotations were forwarded to the WSU Crops and Soils weeds consultant.

Diagnoses on small grains included barley yellow dwarf, soil-borne wheat mosaic and wheat streak mosaic viruses, pink and grey snow mold, take-all, sharp eyespot and strawbreaker foot rot, Pythium root rot and head scab. There was not much dryland root rot, but cold injury was common in the spring. Work continues on a disease found the past several years that may be only pink snow mold but may be associated with another pathogen as well. The symptoms are similar to dryland root rot (*Fusarium* spp.) and sharp eyespot (*Rhizoctonia cerealis*).

ELISA testing was offered by the Clinic for seven small grain viruses in years two and three of the proposal. Testing was done at the discretion of the diagnostician once samples are examined, if sample symptoms warranted it, to reduce turn-around time and cost to the client.

Sample fee invoices were roughly $2000 per year. Efforts to increase sample fee income included developing DNA assays for some high incidence diseases, like potato ring rot, or emerging possibilities like pollen-borne diseases.

With the goal of increasing visibility and utilization of the Clinic, the diagnostician made presentations to industry groups (a high of 12 in 2013), designed and displayed Clinic promotional posters and offered Clinic promotional brochures at six industry meetings. An undergraduate intern was hired for the summer of 2014 with funding from CAHNRS to assist in the Clinic and thereby learn diagnostic skills.

Because of the small numbers of diagnostic requests, only about 35% of them from small grains, we were disappointed with the impact the diagnostic Clinic was having on the industry. The Clinic was therefore closed in September 2014. No funds for the 2014 funding period were spent. We are currently developing a new model for funding diagnostic services at WSU for the Palouse area. In the meantime, Tim Murray is handling diagnostic services for the growing season this year.

Impact:

Through the Plant Pest Diagnostic Clinic, growers and agricultural industry people have access to objective assessments of the nature of problems found on crops. The Clinic offers a "second-opinion" service which augments industry and other diagnostic resources. The most important potential impact is early detection of pest epidemics, which greatly improves the probability of disease control and containment. Prompt and accurate diagnoses may also inform pesticide and other disease and pest control decisions, either eliminating unnecessary and costly control measures, or promoting timely and cost-effective treatment of threatening disease outbreaks.

WGC project no. 3061-5548 (0545)
WGC project title: Establishing Plant Pest Diagnostic Services in Eastern Washington
Project PI(s): Karen Ward and Hanu Pappu
Initiation date: July 1, 2012
Project year: three of three

Objective	Deliverable	Progress	Timeline	Communication
Encourage growers and industry professionals to utilize diagnostic clinic services.	Brochure and other promotional items with information about the Clinic for distribution to potential clients. Talks on diagnostics and the Clinic before groups of growers, ag industry professionals. Contact individuals working for various agricultural chemical and consulting companies to promote Clinic services.	A brochure for the Pullman clinic was created, printed and distributed. Contacts made with individuals from agricultural consulting and crop managment companies, who agreed to distribute Clinic information to their co-workers statewide. The Clinic website is online and makes sample submission instructions and forms available to clients. Contact and shipping information is also available, as are links to other Clinics and helpful resources.	promotional phase ended. Clinic was closed in September 2014	Spoke and/or distributed brochures at multiple industry meetings each year; sent brochures to industry representatives for distribution. Examples include Columbia Basin Crop Consultants Association Short Course and Oilseed/Direct Seed conference. Sent brochures for distribution to several company representatives.
	Write article for Wheat Life; promote Clinic through wheat industry Green Sheet.	Contacted Scott Yates and Kara Rowe. Wrote an article for Wheat Life. Arranged to have Clinic promotional reminders in grain industry Green Sheet.	Completed	Article about Clinic progress in Wheat Life in spring 2014; reminders to growers about Clinic services in Green Sheet.
Offer serological and molecular testing to identify plant pathogens.	Provide local testing for small grain viruses and other pathogens.	The Clinic provided ELISA testing for seven small grain viruses, as well as other viruses as the need arises.	Clinic was closed in September 2014	

Increase Clinic support from other sources including establishment of pathogen-specific testing of large lots of a commodity if the industry perceives a need for	Garner support from other commodity commissions, agricultural industry organizations, public agencies and other groups, and by establishing an endowment for the Clinic. Provide testing for plant pathogens in large lots of specific commodities	With Dr. Scot Hulbert and Dr. Tim Murray, wrote a successful grant proposal for an undergraduate intern for summer 2014 and received support. The objective of increasing clinic support for testing large lots samples, failed for the most part. The clinic had some success in increasing numbers of bacterial ring rot samples of potato.	Clinic was closed in September 2014	Offered Clinic services for bid at Silent Auctions at Tilth Producers' Conference 2013 and at Washington Association of Wine Grape Growers in 2014.
Provide Washington farmers, ag industry professionals and home gardeners with a reliable, accurate and valuable diagnostic service.	Diagnosis via traditional and molecular testing methods.	In 2013, we received 146 physical samples and 47 digital samples, a modest increase over 2012. Samples numbers are not increasing to the extent that we had hoped. The Clinic is thus not having the impact we had hoped, and was closed in September 2014.	Clinic was closed in September 2014	A diagnostic report is provided to every client along with management recommendations; at least one informal interim conversation occurs between the client and the diagnostician. Following the diagnostic report, clients are invoiced.