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Washington State University
Wheat and Barley Research
Progress Reports

Washington Grain Commission

2016-2017 Fiscal Year

2016-17 WSU Wheat & Barley Research Progress Reports to the Washington Grain Commission

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

Project #: **3019-3379**

Progress Report Year: 1 of 3

Title: **Weed Management in Wheat**

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

Cooperators: A. Hauvermale, R. Zuger, D. Appel and H. Wetzel

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

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

- The project continues to generate data and local insights for Dow, Syngenta and BASF to assist these companies in labeling their new herbicide products for weed control in wheat. Our work is also critical in getting BASF to label higher use rates of in the PNW, contrary to what is labeled for the rest of the country. We have been working with bicylopyrone, a new broadleaf herbicide from Syngenta, as well as new broadleaf herbicides from Dow.
- A number of grower driven projects were started in the new cycle, including management of rush skeletonweed in wheat, troublesome weed management in fallow systems, management of rushes in wheat, and spring wheat preemergence herbicides for Italian ryegrass control.
- Combined, Drs. Burke and Lyon have presented the results of this research program at ~12 events over in the first months of this project. We host the WSU Weed Science Field Day, and typically participate in the Lind Field Day, the Wheat Academy, and Far West Agricultural Associates meeting, as well as numerous county meetings.

WGC project number: 3019-3379
WGC project title: Weed Management in Wheat
Project PI(s): Ian C. Burke and Drew J. Lyon
Project initiation date: July 1, 2016
Project year: 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
Evaluate herbicides	Efficacy and crop injury data to support use recommendations, new labels, and label changes to benefit WA small grain growers.	The 2015 WSU Weed Control Report was published in January of 2016 and distributed to the Washington Grain Commission, County Extension Educators in eastern Washington, and sponsoring chemical companies. The published studies will also be posted on the WSU Extension smallgrains website and discussed at winter Extension meetings. The 2016 report will be released before the WGC Research Review.	Annually, in time for winter meetings.	Annual weed control report; articles in Wheat Life, trade magazines and/or posted to WSU smallgrains website; field days; winter Extension meetings; decision support system tools. The Small Grains website now host an outlet for our efficacy results see https://herbicideefficacy.cahnrs.wsu.edu/
		The second year of a field study looking at smooth scouringrush control was completed near Rearden. Only one treatment, Glean + MCPA-ester, provided significantly improved control compared to the nontreated check, but only when applied in consecutive years. Greenhouse efficacy work has been initiated to determine the affects of MCPA and Glean on root and shoot growth and recovery.	The data from the first year of the scouringrush study will be combined with data from a simliar study initiated in 2015 in Oregon. The data from the two sites will be used in a student M.S. thesis and submitted for publication in 2017. The second year of the scouringrush study was completed in 2016.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles
		The first year of a field study was completed in 2016 near Lacrosse to look at the control of rush skeletonweed in wheat following CRP. Clopyralid and aminopyralid provided very good control of rush skeletonweed, particularly when applied in the fall.	The 2016 field work is complete, and new trials for harvest in 2017 are installed.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles
		The first year of a buckwheat control study was completed in 2016 at a field site near Pasco. The study will be repeated in 2017.	The field study will be repeated in 2017.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles
		Multiple field studies were conducted in association with agrichemical companies to investigate efficacy and crop tolerance to a range of grass and broadleaf weed control products. These studies allow us to evaluate new chemistries or new uses of old chemistries and also help us modify company labels to better suit our region.	Field studies were completed in the summer of 2016 and new winter wheat studies initiated in the fall of 2016.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles
		Multiple field studies were iniated in 2016 to identify alternatives to Roundup for fallow weed management in grain-fallow systems. Trials were targeted to identify 1) herbicides for troublesome weeds, 2) application through a weed-sensing sprayer, or 3) for rotation to pea or canola. Metribuzin was suprisingly effective for prickly lettuce control, and other products also had activity on Russian thistle.	Field studies are complete. New studies based on the results from 2016 will be developed and put out in 2017.	

Evaluate weed biology & ecology	Weed biology and ecology to aid in the design of effective and economic control strategies for troublesome weeds in WA small grain crops; decision support system database development.	A Russian-thistle common garden was grown in Pullman and Central Ferry in 2015. Accessions were sprayed with glyphosate and paraquat. No differential responses were observed to paraquat, but some variation in response to glyphosate was observed. A genetic analysis was completed in the fall of 2016. There appears to be just a single species of Salsola present in the PNW, and no real strong population structure.	Field studies are complete. A Ph.D. thesis based on this work will be completed in 2017.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles
		Results of previous common garden experiments identified differences in time to flowering of up to 19 d and time required for mature seed production of up to 21 d among accessions with little variation among siblings. From the common garden experiments cumulative growing degree days required for mature seed production for each accession was estimated using non-linear regression. Variation in vernalization requirements of related species have been attributed in part to variation of the vernalization gene VRN1. Quantifying the expression of a downy brome VRN1 orthologue may help explain the genetic controls regulating observed differences in vernalization. A series of greenhouse experiments were conducted to characterize the vernalization requirements of downy brome accessions demonstrating differences in development and flowering time, and to determine if differences in expression of VRN1 orthologues is associated with differences in flowering time. Semi-quantitative PCR was used measure VRN1 expression in eight downy brome accessions with different vernalization requirements. Expression of a VRN1 orthologue was only observed in treatments were flowering occurred, suggesting that the molecular controls regulating vernalization and flowering in downy brome are likely conserved with those in related species.	Work on seed dormancy continues and will be completed in 2017. We anticipate development of molecular markers to detect dormancy type by 2017.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles.
Evaluate cultural & mechanical management	Data to support recommendations for integrated weed management systems to control troublesome weeds in WA small grains.	Results from a two-year field study on windrow burning to control Italian ryegrass were published in Weed Technology in 2016.	Project completed in 2015.	Journal article and extension presentations. Data will be used to support future grant proposals on harvest weed seed control.

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

Project #: 3193

Progress Report Year: _1_ *of* _3__

Title: Field Breeding Hard White and Red Winter Wheat

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

Executive summary: One hard red winter wheat line was released in 2015. Sequoia (WA8180) is a standard height hard red winter wheat targeted to the <12” rainfall zones of Washington. This line has good end-use quality, average protein content, very good test weight, good stripe rust resistance, and good yield potential. What makes this line stand out from other lines is its ability to emerge from deep planting and dry soils. This line will be a benefit to growers in the low rainfall zones in moisture limiting conditions. Foundation seed has been produced and was sold in the fall of 2016. Apart from this line, there are additional lines being testing in variety testing for release potential, under both low and high rainfall conditions. After extensive selection of crosses targeted for the high rainfall zones of the state, the first material derived from DH is in statewide testing. This material comes through crossing to European material and is well adapted to Washington with high yield potential. We are very excited about these crosses. Continued emphasis has been placed on selecting breeding lines with superior quality and disease resistance. We also have a strong interest in developing hard lines with excellent emergence capabilities, and continually screen material to this end. Efforts have been initiated and are ongoing to develop hard cultivars with herbicide tolerance, snow mold resistance, and aluminum tolerance. After some renewed interest in hard white wheat, we had increased our efforts for crossing, but after further discussion with the Commission, have reduced this again due to a market shift. We maintain about 10% of the hard material as hard white and apply heavy selection pressure to ensure adapted material is advanced. Some of these hard white lines have been tested under irrigation in Southern Idaho and have performed very well. There is interest to release these lines for production under irrigation in Idaho. Our next main target is to develop hard red cultivars for the high rainfall areas of the state, as well as develop herbicide resistance in the hard red germplasm.

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. There was a slight increase in 2016 to 240,000 acres. Minimal increases are seen until new markets are developed or improved cultivars released. Input costs are constantly increasing, thereby lowering the return on crop production. Due to the extreme environmental conditions in this part of the state, average grain yield potentials are difficult to calculate. However, as an example, a modest increase in average grain yield of two bushel per acre of $5.00 wheat would mean nearly $2.2 million more per year for these growers and the state’s economy. Enhanced stress resistance such as aluminum tolerance, herbicide tolerance, and increased agronomic adaptability and emergence potential, along with improved nitrogen use efficiency would yield similar dollar benefits. This is being realized with current releases such as Sequoia, and upcoming experimental lines targeted to both the low and high rainfall zones.

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: 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
Develop hard red and white winter wheat cultivars	New cultivars released for production in WA	Sprinter was released in 2013 and was grown on about 13,000 acres in 2015. In 2014, Earl, a hard white winter wheat line was approved for release. In 2015 we released Sequoia, and Foundation seed was sold in 2016. We have 3 low rainfall and 3 high rainfall hard red breeding lines in statewide testing for release consideration. We had over 4,000 plots and 20,000 rows of hard material under evaluation at various stages of the breeding process for 2016. Some hard white winter lines have been submitted for testing n Southern Idaho and have had very good performance under irrigated conditions. These will be evaluated for release next summer.	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 18 locations in 2016. This includes emergence, winter survivability, heading date, test weight, plant height, and grain yield. Our Kahlotus and Ritzville trial gave a very good screen for emergence potential. All other locations had very good stand establishment and we are looking forward to a good year of screening the germplasm.	Evaluation is done annually at multiple locations across the state.	
	Biotic and Abiotic stress 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. Data should be back in early 2017. Lines with inferior performance will be discarded from selection in 2017. We screened nearly 800 early generation lines for end-use quality in 2016.	Each year, all head rows are evaluated for end-use quality and lines predicted to have superior quality advanced. Each yield trial is submitted for quality evaluations and those with high performance are advanced in the breeding process.	
	Herbicide resistance	Trials were conducted in Lind, Walla Walla, and Pullman for herbicide resistance. Crossing has been initiated to incorporate novel herbicide resistance into hard red lines.	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. Some lines have already been returned to the breeding program as parents for additional crosses.	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 #: 5195

Progress Report Year: *_2_ of _3__*

Title: Use of biotechnology for wheat improvement

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

Executive summary: In 201 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 8,500 data points were collected on 178 populations to confirm presence of desired genes based on marker profiling. These have been advanced to field testing to confirm presence of the selected genes. Markers were also used to screen all advanced breeding lines to identify presence of known genes. This information was used for selection and advancement purposes (in conjunction with field data) as well as for selecting lines which should be cross-hybridized to create future populations. The process of marker-assisted selection is an ongoing process, and at any given point we either have lines planted for analysis, in the laboratory undergoing marker profiling, or on increase in the greenhouse after selection to advance seed into field evaluations. Our genomic selection efforts are proceeding and we have completed our third year of phenotypic evaluations in the field. We are analyzing the GBS data from the 2015 and 2016 field entries, and are submitting our 2017 entries for GBS. Developed genomic selection models will be used for selection in 2017. We also screened 111 populations for 2-gene resistance in the laboratory, of which 41 made it to the field in for 2017 evaluations and the remaining will be for 2018 evaluation. 45 of these populations were also screened with markers for the traits listed above.

In the greenhouse, we made approximately 700 crosses consisting mainly of soft white and hard red germplasm. These are being advanced to the F2 generation. We planted ~2,200 DH plants in the field in 2017 for evaluation. The remaining DH lines are undergoing increase in the greenhouse and will have a similar number ready for yield evaluation in 2018. 90 crosses have been submitted for DH production in 2017. We also have about 100 specialty crosses to introgress traits such as nematode resistance, Hessian fly resistance, herbicide tolerance, FHB tolerance, low PPO, and novel stripe rust resistance genes.

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

WGC project number: 5195
WGC project title: Use of biotechnology for wheat improvement
Project PI(s): AH Carter
Project initiation date: July 1, 2012
Project year: 2 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 2016, 55 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 2016, 79 populations for stripe rust resistance (Yr5, Yr15, Yr17, Yr18, YrEltan, etc) were screened for and selected upon for upcoming field testing.	Each year new crosses are made to stripe rust resistant lines. These are subsequently developed, screened, and advanced to state-wide yield trials. At any given time, lines are in every stage of development	
	End-use quality lines	In 2016, 30 F2 populations were screened for the genes Gpc-B1. Lines which had previously been selected for Gpc-Bi and Bx7oe have been advanced to yield testing. Lines previously selected for GBSS genes (waxy) and the glutenin genes have also been advanced to yield testing.	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 2016, 14 populations were screened for incorporation of various Rht genes. Previous populations were planted at Lind to be screened for emergence potential.	Each year new crosses are being made to incorporate different Rht genes into the breeding program. We also verify presence of dwarfing genes in all material to assist with selection of lines with enhanced emergence potential.	

	Genomic selection	With the assistance of Dr. Zhang, we have begun genomic prediction model building. Lines from the 2015 and 2016 breeding program have been genotyped as well as a large training panel. The 2017 breeding program has been submitted for genotyping. Models built will be used to assist with selection in the 2017 crop year.	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 2016, the advanced germplasm was screened with DNA markers for about 20 traits of interest. This information was used to enhance selection of field tested material, as well as assist in parent cross-combinations to develop populations with desired traits of interest.	This is done annually	Results are presented through annual progress reports, with the outcomes of this research being realized in new cultivars
Greenhouse				Results are presented through annual progress reports, with the outcomes of this research being realized in new cultivars
	Hybridization and propagation	In 2016 we made approximately 700 crosses which were targeted for herbicide resistance, low rainfall and high rainfall production. These crosses were mainly in soft white backgrounds. Crosses were advanced to the F2 stage. We also made about 100 crosses for introgression of the below mentioned traits.	This is done annually, with the number of crosses/populations varying	
	Single-seed descent	No SSD populations were developed this year.		
	Doubled haploid	In 2016 we submitted 90 crosses for DH production. We are advancing roughly 4,000 DH lines in the greenhouse to get enough seed to plant in yield plots in the fall of 2017. We planted about 2,200 DH lines in the field for 2017 observations and yield testing at both Pullman and Lind.	This is done annually, with the number of crosses/populations varying	
	Trait Introgression	We made crosses to germplasm containing resistance/tolerance to snow mold, stem rust, stripe rust, end use quality, foot rot resistance, preharvest sprouting, Al tolerance, Ceph Stripe, SBWMV, vernalization duration, low PPO, Fusarium head blight, and certain herbicides (in coordination with Dr. Burke). The populations are being made and 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 2016 as rows at various locations and stages of development, depending on the trait of interest. Some will be screened in the greenhouse for traits of interest before being moved to field testing.	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 2016. 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 2016. 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 2016. 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. We continue to work on other populations to identify new genes for stripe rust resistance and develop markers for them. We also screen material in the greenhouse for resistance.	Screening and selection will be completed in 2016. Superior lines will be planted in the field and crossed back into the breeding program.	

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

Project #: 6195

Progress Report Year: *_2_ of _3__*

Title: Field Breeding Soft White Winter Wheat

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

Executive summary: A new club cultivar, developed in coordination and collaboration with the USDA breeding program, was approved for release in 2015 and will be named Pritchett. This is targeted to replace Bruehl, with improved disease resistance, yield potential, and cold hardiness. In the 2015 VT trails, Jasper was in the top five yielding lines in production zones with greater than 12" annual precipitation. In 2016, all foundation and registered seed was sold of this line. Puma was in high demand in the fall of 2016 and thousands of bushels were sold for commercial production with the expectation that acres will increase in 2017. Puma was in the top three yielding cultivars across the four production regions determined by the Variety Testing program, and was the number one yielding line in the 12-16" and 16-20" rainfall zones. Otto, a 2011 release from this program, continues to grow in demand. In 2016 it was estimated to be planted on 221,000 acres, and has been stable in production. Nine advanced breeding lines were entered into WSU's Variety Testing (VT) Program, five in the low rainfall zones and four in the high. Two lines, WA8234 and WA8232 were approved for prerelease and are on seed increase. Both lines have excellent yield potential and disease resistance, and had high falling numbers in 2015 and 2016.. Over 1,200 unreplicated yield-trial plots were evaluated at either Pullman or Lind and thousands of F4 head rows were evaluated in Pullman, Lind, and Waterville. Over 2,500 DH lines were planted for 2017 evaluation. High selection pressure is continually placed on disease resistance, emergence, flowering date, end-use quality, straw strength, etc. Multiple screening locations have been established to evaluate germplasm for: stripe rust resistance, foot rot resistance, snow mold resistance, good emergence, aluminum tolerance, soil borne wheat mosaic virus resistance, Cephalosporium tolerance, and nematode resistance. The program has also employed efforts to develop herbicide resistant cultivars and advanced lines have been entered into Variety Testing. Many lines have been performing every well and some are on breeders seed increase in preparation for variety release proposal. We continue to put a strong emphasis on soft white wheat in the program, and have begun to modify our breeding schemes to account for marker-assisted selection, genomic selection, and doubled-haploid production.

Impact: Traditionally, over 85% of the wheat crop in our state is winter wheat. Even very small reductions of required grower input and/or increases in productivity can mean millions of dollars to the growers, grain trade and allied industries. By providing genetic resistance to diseases and increasing agronomic adaptability, input costs will be reduced and grain yield increased. WSU soft white cultivars are grown on approximately 47% of the acres. This continues to increase each year. Measured impact is demonstrated with the releases of Otto, Puma, Jasper, and Pritchett, and upcoming lines WA8234 and WA8232.

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: 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
Develop soft white winter wheat cultivars	New cultivars released for production in WA	We released Otto in 2011. Puma (WA8134) was released in 2012. Jasper was released in 2014. Otto became the #1 grown cultivar in the state in 2015, replacing much of the Eltan acres. Puma was sold in high demand in the fall of 2016 and will be on large commercial production in 2017. Jasper was sold out of registered seed in 2016 and production and interest continues to increase. Released lines have high yield potential, excellent disease resistance, and very good end-use quality. We also co-released Pritchett in 2015 in collaboration with the USDA. This line is intended to replace Bruehl. We have 5 breeding lines in statewide testing for consideration under low rainfall production systems and 4 in statewide testing for consideration under high rainfall production. One of these lines is a two-gene imazamox resistant lines. We have over 12,000 plots and 20,000 rows of soft white material under evaluation at various stages of the breeding process.	Each year we evaluate germplasm at each stage of the breeding process. Each year lines are entered into statewide testing for final release consideration. A cultivar is released, on average, every two years.	Progress will be reported through field days, grower meetings, commission reports, annual progress reports, and peer-reviewed manuscripts
	Agronomic traits	We have 18 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. This year we continued head row selection at Lind due to the ability to screen for emergence and cold tolerance along with an extra location near Waterville to screen for snow mold.	Evaluation is done annually at multiple locations across the state.	
	Disease resistance	Disease resistance is recorded on our 18 breeding locations as disease is present, with certain locations being selected specifically for disease pressure (Waterville for snow mold, 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 2017.	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. One line has shown very good promise and is on increase for seed production in 2017. Novel traits are being incorporated into germplasm through collaboration with Dr. Ian Burke.	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 2016 we evaluated multiple populations in both early and preliminary yield trials. Material includes new genes identified from Eltan, Coda, and novel genes from GWAS analysis.	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. Field evaluations of these selections are done in collaboration with Dr. Campbell.	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 2017	

	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. Field screening has identified multiple lines that appear to have tolerance. Further screening will be done in 2017 to confirm this.	Evaluation will be done in field locations in WA in 2017	
	Hessian Fly	In collaboration with Dr. Nilsa Bosque-Perez we screened 12 F2 populations with new sources of resistance to Hessian Fly. Resistant plants were returned to the breeding program for further crossing.	Additional populations will be screened in 2017 after backcrossing	
	Nematodes	Nematode screening has been done in collaboration with Dr. Paulitz and Dr. Campbell. Advanced material was screened in 2016 for cereal cyst resistance, and data will be used to help selections in 2017.	Additional populations will be screened in 2017	
	End-use quality	Seed of bi-parental mapping populations have been submitted for quality analysis and an association mapping panel for end-use quality was grown for analysis in 2016. This data will be included in genomic selection prediction models.	Genomic prediction models should be available for selection in 2017.	

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Washington Grain Commission
Wheat and Barley Research Final Reports

Project #:	3673
Progress Report Year:	*_3_ of _3_*
Title:	Increasing Genetic Opportunities for Stripe Rust Resistance
Investigator/Cooperators:	**AH Carter, KG Campbell, M Pumphrey,** X. Chen, S. Hulbert, D. See

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

Impact: Throughout the project, we identified SNP and KASP markers which showed significant association with novel and known resistant genes. This totals an estimated 20 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. We have developed reliable KASP marker for *Yr5* which are easy to use for breeders. We have published five manuscripts on stripe rust resistance and have seven in preparation. It is a significant accomplishment to develop elite wheat cultivars with durable rust resistance in PNW wheat breeding programs. The impact of identifying new 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. This will not only be beneficial to WSU and USDA breeding programs, but to all breeding programs in the PNW interested in using these technologies. Wheat producers in Washington have access to wheat cultivars with better stripe rust resistance than they did three years ago. Progress is measured by the excellent stripe rust resistance that has been incorporated into recent releases such as Puma, Jasper, Sequoia, Melba, Seahawk, Alum, and Chet. These lines are gaining in popularity in part due to their rust resistance. Furthermore, progress is measured by other breeding groups requesting our germplasm and marker information so they can develop cultivars with stripe rust resistance.

Outputs:
Peer reviewed publications:

- Case AJ, Naruoka Y, Chen X, Garland-Campbell KA, Zemetra RS, Carter AH (2014) Mapping stripe rust resistance genes in a BrundageXCoda winter wheat population. PlosONE 9(3):e91758 doi: 10.1371/journal.pone.0091758.

- Naruoka Y, Garland-Campbell KA, and Carter AH (2015) Genome-wide association mapping for stripe rust (*Puccinia striiformis* F. sp. *tritici*) in US Pacific Northwest winter wheat (*Triticum aestivum* L.). Theoretical and Applied Genetics 128:1083-1101.

- Klarquist E, Chen XM, Carter AH (2016) Novel QTL for stripe rust (*Puccinia striiformis* f. sp. *tritici*) resistance on chromosomes 4A and 6B from soft white winter wheat (*Tricticum aestivum*). Agronomy 6:4.

- Naruoka, Y, K. Ando, P. Bulli, K.T. Muleta, S. Rynearson, and M.O. Pumphrey. 2016. Identificaiton and validation of SNP markers linked to the stripe rust reistance gene Yr5 in wheat. Crop Science 56:3055-3065.

- Weizhen Liu, Marco Maccaferri, Peter Bulli, Sheri Rynearson, Roberto Tuberosa, Xianming Chen, Michael Pumphrey. 2017. Genome-wide association mapping for seedling and field resistance to *Puccinia striiformis* f. sp. *tritici* in elite durum wheat. *Theoretical and Applied Genetics*. In press.

Submitted or in Preparation:

- Kebede T. Muleta, Matthew N. Rouse, Sheri Rynearson, Xianming Chen, Bedada G. Buta, Michael O. Pumphrey. Characterization of molecular diversity and genome-wide mapping of loci associated with resistance to stripe rust and stem rust in Ethiopian bread wheat accessions. Submitted to BMC Plant Biology.

- Kebede T. Muleta, Peter Bulli, Zhiwu Zhang, Xianming Chen, and Michael Pumphrey. Unlocking diversity in germplasm collection by genomic selection: a case study based on quantitative adult plant resistance to stripe rust (*Puccinia striiformis* f. sp. *tritici*) in spring wheat. Submitted to The Plant Genome.

- Weizhen Liu, Marco Maccaferri, Sheri Rynearson, Tesfaye Letta, Habtemariam Zegeye, Roberto Tuberosa, Xianming Chen, Michael Pumphrey. Novel sources of stripe rust resistance identified by genome-wide association mapping in Ethiopian durum wheat (*Triticum turgidum* ssp. *durum*). Frontiers in Plant Science. Submitted

- Kebede T. Muleta, Peter Bulli, Sheri Rynearson, Xianming Chen and Michael Pumphrey. Mapping of genomic loci associated with stripe rust (*Puccinia striiformis* f. sp. *tritici*) resistance in a collection of spring wheat accessions. Manuscript under preparation

- Kebede T. Muleta, Peter Bulli, Xianming Chen and Michael Pumphrey. Identifying quantitative trait loci for resistance to stripe rust (*Puccinia* f. sp. *striiformis*) in a global collection of winter wheat population. Manuscript under preparation.
- Weizhen Liu, Marco Maccaferri, Xianming Chen, Michael Pumphrey, Roberto Tuberosa. Genome-wide association mapping reveals a rich genetic architecture of stripe rust resistance loci in emmer wheat (*Triticum turgidum* ssp. *dicoccum*). Manuscript in preparation
- Weizhen Liu, James Kolmer, Sheri Rynearson, Michael Pumphrey. Identifying durable rust resistance to wheat via genome-wide association mapping in a hexaploid wheat population. Manuscript in preparation

Ongoing projects leveraged from this funding:

- Fine mapping all-stage resistance genes in cultivar 'Coda' on chromosome 1B.
- QTL mapping of stripe rust resistance loci in 'SWW10069' population.
- QTL mapping of durable stripe rust resistance genes in JD x Avocet population.
- Genome-wide association mapping for resistance to stripe rust in cultivated emmer wheat using wheat 9K SNP array.
- Genome-wide association mapping for resistance to stripe rust in PNW soft white winter wheat.
- Validation and development of KASP markers for loci identified by genome-wide association analyses for conferring seedling and adult plant resistance to stripe rust.
- Development of breeder-friendly molecular marker for stripe rust resistance gene *Yr53* and its transfer into elite background through backcrossing.

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: **3 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	WSU and USDA breeding programs are routinely using DNA markers to pyramid effective resistance into breeding material.	Populations have been developed, phenotyped, and genotyped. Breeding programs annually use markers to ensure effective resistance genes are present in germplasm.	Results have been communicated through grower field days, international conferences, and peer-reviewed manuscripts.
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	Two BC1F2 were advanced in greenhouse. Lines confirmed to have the Emmer resistance genes will be given to breeding programs for crossing.	Confirmation of lines will be completed in the Spring, and seed will be distributed to breeding programs.	Results have been communicated through field days, grower meetings, seminars, journal articles, annual progress reports, and the wheat research review, as well as through other venues as requested.
Develop 'near-perfect' markers for Yr5, Yr15, and YrCoda that can be used for marker-assisted selection.	DNA markers associated with genes resistant to currently known stripe rust races in Washington	Near perfect' markers for Yr5 have been developed. Mapping the Coda X Brundage population with additional SNP markers was carried out and verified YrCoda is novel. A population derived from a cross between JD (potentially carrying YrCoda and other resistance) and Avocet S was phenotyped in field and genotyping by sequencing has been completed. Populations developed for Yr15 showed complex segregation and markers did not seem to be associated with Yr15.	Yr5 markers have been developed and published. YrCoda markers are published, and work is ongoing to identify if this is one gene or two. Yr15 markers have been difficult to validate, and new research outside the scope of this project has been initiated to further investigate this gene.	Results have been communicated through field days, grower meetings, seminars, journal articles, annual progress reports, and the wheat research review, as well as through other venues as requested. 'Near perfect' markers for Yr5 have been published.

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Washington Grain Commission
Wheat and Barley Research Annual Progress Report

Project #: 5682

Progress Report Year: 1 of 3 (2016)

Title: Control of Rusts of Wheat and Barley

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

Executive summary: During 2016, studies were conducted according to the objectives of the project proposal and all objectives specified for the first year have been successfully completed. In addition to the major accomplishments and their impacts listed below, this project results in genetic resources and techniques for further studying the biology and genetics of the pathogens and mechanisms of interactions between the pathogen and plants.

Impact: 1) Stripe rust was accurately forecasted in 2016. Rust updates and advises were provided on time to growers based on the forecasts using prediction models and field surveys, which effectively protected both winter wheat and spring wheat crops from potentially huge yield losses, which ensured bumper harvest under the extremely severe stripe rust epidemic. 2) We identified 5 races of barley stripe rust and 34 races of wheat stripe rust in the US, of which 4 and 25 were detected in Washington, respectively. Four of the races from Washington were new. The virulence information is used to guide breeding programs for using effective resistance genes in developing resistant varieties. 3) We used molecular markers developed in our lab to study the stripe rust pathogen and determined the population changes in the past and present. 4) We evaluated more than 35,000 wheat and 3,000 barley entries for resistance to stripe rust. From the tests, we identified new sources of resistance and resistant breeding lines for breeding programs to release new varieties for growers to grow. In 2016, we collaborated with breeders in releasing, pre-releasing, or registered 7 wheat and 1 barley varieties. The germplasm evaluation data were also used to update the Seed Buyer's Guide for growers to choose resistant varieties to grow. 5) We completed studies for mapping 5 genes for stripe rust resistance in three wheat lines and identified molecular markers. We officially named one stripe rust resistance gene, and published 6 papers on molecular mapping of stripe rust resistance genes. 6) We developed 29 new wheat germplasm lines with single new genes or combinations of genes for resistance to stripe rust and registered them in the USDA National Small Grains Collection to make them available for breeding programs to use. 7) We provided seeds of our developed wheat germplasm lines to several breeding programs in the US and other countries for developing stripe rust resistant varieties. Use of these lines by breeding programs will diversify resistance genes in commercial varieties. 8) We tested 47 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. The data of the fungicides and varieties are used for guiding the integrated control of stripe rust. 8) We published 22 journal articles and 15 meeting abstracts in 2016.

Outputs and Outcomes:

Progress, Timelines, and Communication are presented in Outcome Reporting file (file name: Chen_WGC 2016 Annual Report Outcome Reporting.pdf)

Publications:

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

Klarquist, E. F., **Chen, X. M.**, Carter, A. H. 2016. Novel QTL for stripe rust resistance on chromosomes 4A and 6B in soft white winter wheat cultivars. Agronomy 6:4.

Chen, J., Wheeler, J., O'Brien, K., Zhao, W., Klassen, N., Zhang, J., Bowman, B., Jackson, Ch., Marshall, J. M., and **Chen, X. M.** 2016. Release of 'UI Platinum' hard white spring wheat. Journal of Plant Registrations 10:36-40.

Xia, C. J., Wang, M. N., Wan, A. M., Jiwan, D. A., See, D. R., **Chen, X. M.** 2016. Association analysis of SP-SNPs and avirulence genes in *Puccinia striiformis* f. sp. *tritici*, the wheat stripe rust pathogen. American Journal of Plant Sciences 7:126-137.

Tian, Y., Zhan, G. M., **Chen, X. M.**, Tungruentragoon, A., Lu, X., Zhao, J., Huang, L. L., and Kang, Z. S. 2016. Virulence and SSR marker segregation in a *Puccinia striiformis* f. sp. *tritici* population produced by selfing a Chinese isolate on *Berberis shensiana*. Phytopathology 106:185-191.

Zhan, G. M., Wang, F. P., **Chen, X. M.**, Wan, C. P., Han, Q. M., Huang, L. L., and Kang, Z. S. 2016. Virulence and molecular diversity of the *Puccinia striiformis* f. sp. *tritici* population in Xinjiang in relation to other regions of western China. Plant Disease 100:99-107.

Wang, Z. Y., Zhao, J., **Chen, X. M.**, Peng, Y. L., Ji, J. J., Zhao, S. L., Lu, Y. J., Huang, L. L., and Kang, Z. S. 2016. Virulence variations of *Puccinia striiformis* f. sp. *tritici* isolates collected from *Berberis* spp. in China. Plant Disease 100:131-138.

Chen, X. M., Evans, C. K., and Liu, Y. M. 2016. Control of stripe rust of winter wheat with various foliar fungicides, 2015. Plant Disease Management Reports 10:CF:022.

Chen, X. M., Evans, C. K., and Liu, Y. M. 2016. Responses of winter wheat cultivars to fungicide application for control of stripe rust in 2015. Plant Disease Management Reports 10:C023.

Cheng, P., **Chen, X. M.**, and See, D. 2016. Grass hosts harbor more diverse isolates of *Puccinia striiformis* than cereal crops. Phytopathology 106:362-371.

Li, K., Hegarty, J., Zhang, C. Z., Wan, A. M., Wu, J. J., Gina L Brown-Guedira, G. L., **Chen, X. M.**, Fu, D. L., and Dubcovsky, J. 2016. Fine mapping of barley locus *Rps6* conferring resistance to wheat stripe rust. Theoretical and Applied Genetics 129:845–859.

Xia, C. J., Wan, A. M., Wang, M. N., Jiwan, D. A., See, D. R., and **Chen, X. M.** 2016. Secreted protein gene derived-single nucleotide polymorphisms (SP-SNPs) reveal population diversity and differentiation of *Puccinia striiformis* f. sp. *tritici* in the United States. Fungal Biology 120:729-744.

Wan, A. M., **Chen, X. M.**, and Yuen, J. 2016. Races of *Puccinia striiformis* f. sp. *tritici* in the United States in 2011 and 2012 and comparison with races in 2010. Plant Disease 100:966-975.

Berg, J. E., Lamb, P. F., Miller, J. H., Wichman, D. M., Kephart, K. D., Stougaard, R. N., Pradhan, G. P., Nash, D. L., Grey, W. E., Gettel, D., Jin, Y., Kolmer, J. A., **Chen, X. M.**, Bai, G., Murray, T. D., and Bruckner, P. L. 2016. Registration of 'Northern' wheat. Journal of Plant Registrations 10:135-138.

Liu, M. Y., Lei, L., Powers, C., Liu, Z., Campbell, K. G., **Chen, X. M.**, Bowden, R. L. Carver, B. F., and Yan, L. L. 2016. *TaXa21-A1* on chromosome 5AL is associated with resistance to multiple pests in wheat. Theoretical and Applied Genetics 129:345–355.

Bulli, P., Zhang, J. L., Chao, S. M., **Chen, X. M.**, and Pumphrey, M. 2016. Genetic architecture of resistance to stripe rust in a global winter wheat germplasm collection. G3: Genes, Genomes and Genetics 6:2237-2253.

Zhao, J., Wang, M. N., **Chen, X. M.**, and Kang, Z. S. 2016. Role of alternate hosts in epidemiology and pathogen variation of cereal rusts. Annual Review of Phytopathology 54:207-228

Xiang, C., Feng, J. Y., Wang, M. N., **Chen, X. M.**, See, D. R., Wan, A. M., and Wang, T. 2016. Molecular mapping of *Yr76* for resistance to stripe rust in winter club wheat cultivar Tyee. Phytopathology 106:1186-1193.

Klos, K. E., Gordon, T., Bregitzer, P., Hayes, P., **Chen, X. M.**, del Blanco, I. A., Fisk, S., and Bonman, J. M. 2016. Barley stripe rust resistance QTL: Development and validation of SNP markers for resistance to *Puccinia striiformis* f. sp. *hordei*. Phytopathology 106:1344-1351.

Wang, J. J., Tao, F., An, F., Zou, Y. P., Tian, W., **Chen, X. M.**, Xu, X. M., and Hu, X. P. 2016. Wheat transcription factor TaWRKY70 is positively involved in wheat high-temperature seedling-plant resistance to *Puccinia striiformis* f. sp. *tritici*. Molecular Plant Pathology 17 DOI: 10.1111/mpp.12425

Akin, B., **Chen, X. M.**, Morgunov, A., Zencirci, N., Wan, A. M. 2016. High-temperature adult-plant (HTAP) stripe rust (*Puccinia striiformis* f. sp. *tritici*) resistance in facultative winter wheat. Crop & Pasture Science 67:1064-1074.

Wan, A. M., Muleta, K. T., Zegeye, H., Hundie, B., Pumphrey, M. O., and **Chen, X. M.** 2016. Virulence characterization of wheat stripe rust fungus *Puccinia striiformis* f. sp. *tritici* in

Ethiopia and evaluation of Ethiopian wheat germplasm for resistance to races of the pathogen from Ethiopia and the United States. Plant Disease 101:73-80.

Wu, J. H., Wang, Q. L., **Chen, X. M.**, Wang, M. J., Mu, J. M., Lv, X. N., Huang, L. L., Han, D. J., and Kang, Z. S. 2016. Stripe rust resistance in wheat breeding lines developed for central Shaanxi, an overwintering region for *Puccinia striiformis* f. sp. *tritici* in China. Canadian Journal of Plant Pathology 38:317-324.

Popular Press Articles:

January 11, 2016. First Forecast of Stripe Rust for 2016 and 2015 Fungicide and Variety Yield Loss Tests. Xianming Chen, E-mail sent to growers and the cereal group.

January 17, 2016. Pacific Northwest stripe rust outlook 'moderate'. Matthew Weaver, *Capital Press*, http://www.capitalpress.com/Profit/20160117/pacific-northwest-stripe-rust-outlook-moderate

February, 2016. Initial forecast predicts little stripe rust. Xianming Chen. *Wheat Life*, February 2016, page 14.

February 10, 2016. Stripe rust forecast is good news for wheat growers by Tim Murray. *On Solid Ground*. CAHNRS, WSU. http://cahnrs.wsu.edu/blog/2016/02/stripe-rust-forecast-is-good-news-for-wheat-growers/?utm_campaign=auto-draft&utm_source=on-solid-ground-february-2016-2016-10&utm_medium=email&utm_content=link-19.

March 4, 2016. Stripe Rust Forecast and Update, March 4, 2016. Xianming Chen, E-mail sent to growers and cereal group.

March 31, 2016. Stripe Rust Update, March 31, 2016. Xianming Chen, E-mail sent to growers and cereal group.

April 13, 2016. Stripe Rust Update, April 13 2016. Xianming Chen, E-mail sent to growers and cereal group.

April 14, 2016. Expert predicts severe stripe rust across PNW. Matthew Weaver, *Capital Press*. http://www.capitalpress.com/Profit/20160414/expert-predicts-severe-stripe-rust-across-pnw

April 30, 2016. Experts anticipate stripe rust epidemic. Josh Babcock, *Daily News*, http://dnews.com/local/experts-anticipate-stripe-rust-epidemic/article_420a5da4-9c32-5072-9cdc-a9274e2bc8ff.html

May, 2016. Stripe rust developing early in warm, wet spring weather. Xianming Chen, *Wheat Life*, May, 2016, pages 12-14.

May 5, 2016. Stripe Rust Update, May 5, 2016. Xianming Chen, E-mail sent to growers and cereal group.

May 26, 2016. Stripe Rust Update, May 26, 2016. Xianming Chen, E-mail sent to growers and cereal group.

June 3, 2016, All systems are go for grain crops, Region appears to have mostly avoided threats of late frost, stripe rust epidemic. Kathy Hedberg, *The Lewiston Tribune*.

June 2016, Stripe rust found throughout Pacific Northwest wheat fields. Xianming Chen, *Wheat Life*, June 2016, pages 12-14.

June 17, 2016, Stripe rust Update, June 17, 2016. Xianming Chen, E-mail sent to growers and cereal groups.

July, 2016. Stripe rust developing on spring wheat, barley crops. Xianming Chen, *Wheat Life*, July, 2016, pages 14-16.

July 25, 2016. Stripe rust pressure 'severe' in Northwest wheat, expert says. Matthew Weaver. *Capital Press*.

September 29, 2016. Estimates of yield losses caused by stripe rust and increase by fungicide application on PNW wheat varieties. Xianming Chen, E-mail sent to growers and cereal group.

November 9, 2016. Widespread Stripe Rust Infection on Winter Wheat in Washington. Xianming Chen, E-mail sent to growers and cereal group.

All 2016 nursery data were sent to growers, cereal group, and/or collaborators.

Presentations and Reports:

Xianming Chen presented an invited talk "Wheat Stripe Rust Integrated Control Based on Forecasting, Monitoring, and Resistance" at American Phytopathological Society Rust Symposium, 8-9 March, 2016, Pensacola, Florida. (About 100 people)

Xianming Chen presented the following posters at American Phytopathological Society Rust Symposium, 8-9 March, 2016, Pensacola, Florida (About 100 people)

1) "Wheat stripe rust integrated control based on forecasting, monitoring, and resistance"
2) "Virulence changes of *Puccinia striiformis* f. sp. *tritici* in 1968-2015 in the US"

Xianming Chen and graduate students, visiting students, and postdoctoral associates presented the following talks or posters at the American Phytopathological Society Pacific Division Meetings at La Conner, WA, June 29-30, 2016 (About 200 people):

1) "Characterization of somatic recombinant isolates of *Puccinia striiformis*, the stripe rust pathogen"

2) “Molecular mapping of stripe rust resistance genes in spring wheat line W18”
3) “Variation of telial formation in the *Puccinia striiformis* f. sp. *tritici* population”
4) “Towards construction of genetic linkages for mapping virulence genes in *Puccinia striiformis* f. sp. *tritici*, the wheat stripe rust pathogen”
5) “Pyramiding stripe rust resistance genes on wheat chromosomes 2B, 4B, and 7B”
6) “Expression profiling of pathogenesis-related protein genes in wheat resistance to the stripe rust pathogen (*Puccinia striiformis* f. sp. *tritici*)”
7) “Virulence characterization of *Puccinia striiformis* f. sp. *tritici* in the US for the past 48 years using the *Yr* single-gene differentials”
8) “Developing a wheat germplasm with linked genes *Yr64* and *Yr65* for resistance to stripe rust”
9) “Development of *Puccinia striiformis* f. sp. *tritici* mutants for avirulence characterization”
10) “Seedling reactions of Mexican wheat varieties and advanced lines to four races of *Puccinia striiformis* f. sp. *tritici*, the stripe rust pathogen”.

Xianming Chen presented the following posters at the American Phytopathological Society Annual Meeting, July 31-August 3, 2016, Tampa, Florida (over 2000 people):

1) “Stripe rust epidemics of wheat and barley and races of *Puccinia striiformis* identified in the United States in 2015”
2) “Molecular mapping of effective stripe rust resistance genes in wheat germplasm PI 182126”

Xianming Chen presented an invited talk “Recent Progress of Stripe Rust Research in the United States”. November 24, 2016 Northwest A&F University, Yangling, China (about 200 people)

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

- 6/16/2016: Lind Field Day (about 100 people)
- 7/13/2016: Farmington Field Day (about 25 people)
- 7/14/2016: St John Field Day (about 25 people)
- 7/14/2016: Lamont Field Day (about 16 people)

WGC project number: 5682

WGC project title: Control of Rusts of Wheat and Barley

Project PI(s): Xianming Chen

Project initiation date: 7/1/2016

Project year: 1 of 3 (2016)

Objective	Deliverable	Progress	Timeline	Communication
1. Conduct disease forecast and field survey for guiding disease management	**1) Stripe rust predictions.** Accurate prediction before the rust season will allow growers to prepare for appropriate control measures including choosing resistant varieties to plant and possible fungicide application. **2) Field disease monitoring updates and recommendations.** Disease updates and recommendations will allow growers to implement appropriate control.	All planned studies for the project in 2016 have been completed on time. There is no any delay, failure, or problem in studies to this objectives. Forecasts of wheat stripe rust epidemic were made in January based on the November and December weather conditions and in March based on the the entire winter weather conditions using our prediction models. Further forecasts were made throughout the season based on rust survey data and past and forecasted weather conditions. These forecasts and rust updates were reported to wheat researchers and growers. Field surveys were conducted by our program and collaborators throughout the Pacific Northwest (PNW) and the country. Stripe rust started earlier than normal in eastern PNW but normal as always in western PNW. The early started stripe rust created high disease pressure and the stripe rust favorable weather conditions throughout the growth season made the disease an extremely severe epidemics. The timely applications of fungicides on susceptible and moderately susceptible wheat varieties prevented major yield loss and ensured bumper harvest. Barley stripe rust was relatively significant compared to the recent year, but still not severe enough to be a major concern. Leaf rust of wheat was normal in western but absent in eastern PNW; and leaf rust of barley was normal in western but absent in eastern PNW. Stem rust of wheat and barley was basically absent in the PNW in 2016.	All studies and services were completed on time.	The rust forecasts and survey data were communicated to growers and other researchers through e-mails, telephones, 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. Identify races and characterize populations of the wheat and barley stripe rust pathogens for providing useful pathogen information to breeding programs for developing resistant varieties and to growers for managing diseases.	**1) New races. 2) Distribution, frequency, and changes of all races. 3) New tools such as molecular markers and population structures.** The information will be used by breeding programs to choose effective resistance genes for developing new varieties with adequate and durable resistance. We will use the information to select a set of races for screening wheat and barley germplasm and breeding lines. The information is also used for disease management based on races in different regions.	In 2006, we collected and received 444 stripe rust samples throughout the country and 39 of them from Washington. We have completed about 90% of the race ID work for the 2016 samples as scheduled by this time. So far we have detected 34 wheat stripe rust races and 5 barley stripe rust races, of which 25 and 4 were detected respectively in Washington. The distribution and frequency of each race and virulence factor in the US have been determined. Predominant races have been identified. The race and virulence information is used to guide breeding programs for using effective resistance genes in developing resistant varieties and selected predominant races with different virulence patterns are used in screening breeding lines for stripe rust resistance. We used molecular markers developed in our lab to study the stripe rust pathogen and determined the population changes in the past and present, and use molecular markers to tag virulence genes in the pathogen. We completed molecular characterization of historical stripe rust populations from 1968 to 2009 and also for the collections in the recent years up to 2013.	The race identification work for the 2016 stripe rust samples will be completed by late February, 2017, as scheduled. The race ID work for 2017 samples will start in March. Molecular work of the 2014-2015 samples and DNA extraction of the 2016 samples will be completed by June, 2017.	The rust race data were communicated to growers and researchers through e-mails, website, project reports, meeting presentations and publications in scientific journals (for detailed information, see the lists in the main report file).

3. Screening wheat and barley germplasm for supporting breeding programs to develop rust resistant varieties	**1) Stripe rust reaction data of wheat and barley germplasm and breeding lines. 2) Reactions to other diseases when occur. 3) Resistant germplasm for use in breeding programs. 4) New varieties for growers to grow.** The stripe rust data will allow breeding programs to get rid of susceptible lines or select lines for further improvement, and more importantly for releasing new varieties for with stripe rust resistance combined with other desirable traits fro grower to grow.	In 2016, we evaluated more than 35,000 wheat and 3,000 barley entries for resistance to stripe rust. The entries included germplasm, breeding lines, rust monitoring nurseries, and genetic populations from various breeding and extension programs. All nurseries were planted and evaluated at both Pullman and Mt. Vernon locations under natural stripe rust infection. Some of the nurseries were also tested in Walla Walla and Lind, WA . Germplasm and breeding lines in the variety trial and regional nurseries also were tested in the greenhouse with selected races of stripe rust for further characterization of resistance. Disease data of regional nurseries were provided to all breeding and extension programs, while data of individual breeders' nurseries were provided to the individual breeders. Through these tests, susceptible breeding lines can be eliminated, which should prevent risk of releasing susceptible cultivars and assisted breeding programs to release new cultivars of high yield and quality, good adaptation, and effective disease resistance. In 2016, we collaborated with public breeding programs in releasing and registered 7 wheat varieties and 1 barley variety. Varieties developed by private breeding programs were also resulted from our germplasm screening program.	All germplasm tests were completed and the data were provided to collaborators on time. The 2016-17 winter wheat nurseries were planted in fields in September and October 2016. The 2017 spring crop nurseries will be planted in March-April, 2017. The greenhouse tests of the 2016 spring nurseries and the 2016-17 winter wheat nurseries have been conducting in the greenhouse during the winter, and will be completed by May, 2017	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.
4. Identify and map new stripe rust resistance genes and develop new germplasm for use in breeding programs to diversify resistance genes in new varieties	**1) New stripe rust resistant sources. 2) New resistance genes with their genetic information. 3) Molecular markers for resistance genes. 4) New germplasm with improved traits.** The genetic resources and techniques will be used by breeding programs for developing varieties with diverse genes for stripe rust resistance, which will make the stripe rust control more effective, efficient, and sustainable.	Through the germplasm screening, we have established a collection of wheat germplasm with stripe rust resistance, which are valuable sources of stripe rust resistance for further characterization of resistance, identified new effective resistance genes, and for development of wheat varieties with effective resistance. Through our intensive testing, varieties with durable resistance to stripe rust have been developed. In 2016, we completed studies for mapping five stripe rust resistance genes in three wheat crosses, and identified molecular markers for these genes. We officially named one stripe rust resistance gene. We also collaborate with other laboratories in mapping of numerous stripe rust resistance loci in various wheat germplasm collection through genome-wide association study approach, and published 6 papers on molecular mapping of stripe rust resistance genes. We developed 29 new wheat germplasm lines with single new genes or combinations of genes for resistance to stripe rust and registered them in the USDA National Small Grains Collection to make them available for breeding programs to use. In 2016, we phenotyped eight mapping populations for stripe rust responses and advanced progeny populations for 30 winter wheat crosses for mapping stripe rust resistance genes.	All experiments scheduled for 2016 were successfully completed. Mapping populations of winter wheat were planted in fields in October 2016 and those of spring wheat will be planted in April, 2017 for stripe rust phenotype data. Populations with adequate phenotype data are genotyped with molecular markers for mapping resistance genes. Progenies of new crosses will be advanced in fields in 2017.	New genes and molecular markers were published in scientific journals (see the publication and presentation lists in the report main file)

5. Improve the integrated control strategies by screening new chemicals and determining potential yield losses and fungicide responses of individual varieties	**1) Data of fungicide efficacy, dosage, and timing of application for control stripe rust. 2) Potential new fungicides. 3) Stripe rust yield loss and fungicide increase data for major commercial varieties.** The information is used for developing more effective integrated control program based on individual varieties for growers to use to control stripe rust.	In 2016, we evaluated 23 fungicide treatments on winter wheat and 47 fungicide treatments on spring wheat for control of stripe rust in experimental fields near Pullman, WA. Treatments with two applications were more effective than only one application in reducing rust and increasing yield. For winter wheat, most treatments significantly increased gain yield compared with the non-treated check, and the significant increases ranged from 19 bushes (164%) to 91 bushes (797%). For spring wheat, most fungicide treatments significantly increased yield compared with the non-treated check. The significant increases of grain yield ranged from 8 bushes (65%) to 56 bushes (449%) depending upon fungicide treatments. In 2016, we tested 23 winter wheat and 15 spring wheat varieties commonly grown in the PNW, plus highly susceptible checks. For winter wheat, stripe rust caused 71% yield loss on the susceptible check and from 0 to 32% yield losses at an average of 8% on commercially grown varieties. Fungicide application increased yield by 0 to 47% at an average of 10% on commercially grown varieties. For spring wheat, stripe rust caused 54% yield loss on the susceptible check and from 0 to 43% yield losses at an average of 20% on commercial varieties. Fungicide application increased grain yields by 0 to 74% on commercial varieties at an average of 29%. These results will be used by chemical companies to register new fungicides and used by growers for selecting resistant varieties to grow and use suitable fungicide application for control stripe rust on varieties without an adequate level of resistance	For this objective, all tests scheduled for 2016 were successfully completed. For the 2016-17 growing season, the winter wheat plots of the fungicide and variety studies were planted in October, 2016 and the spring plots will be planted in April, 2017. The tests will be completed in August (for winter wheat) and September (for spring wheat), 2017	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 #: 30109-6600

Progress report year: 1 of 3

Title: Evaluation And Selection For Cold Tolerance In Wheat

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

Executive summary:

We were unable to complete all of the proposed objectives due to the funding cut of approximately 45%. We prioritized screening the Extension variety trials and new advanced breeding lines.

We used the artificial screening system in the greenhouse to evaluate the Washington Extension Soft and Hard Winter Wheat Trials, and the Western Regional Soft and Hard winter wheat nurseries.

- In the Washington State Hard Winter Wheat Nursery, the Norstar check was the most cold tolerant followed by Esperia, WA8229, WA8197, WB-Rimrock, WA8207, the Eltan check, WA8246, Keldin, Bauermeister, the Otto check, SY Clearstone CL2, OR2110679, Whetstone, WB40590, WA8247, WB-Arrowhead, and Farnum.
- In the Washington State Soft Winter Wheat Nursery, the most cold tolerant soft winter wheat was Norstar followed by ORCF103, WB-Junction, Curiosity CL+, Eltan, IDN07-28017B, ARS-Crescent, Masami, Bruehl, WA8251, Otto, and ARS06135-9C.
- In the Western Regional Soft Winter Wheat Nursery, Norstar was followed by ARS06135-9C, LWW14-70445, ARS06-132-45C, OR2121086, ORLD21130092, and ARS20060194-0-10L.
- In the Western Regional Hard Winter Wheat Nursery, the Otto check was the most tolerant, line followed by Kharkof, Eltan, Norstar, and ARS09200-0-T3.

We rated 430 breeding lines from regional winter wheat breeding programs for survival. All three breeding programs had lines that were more and less winter tolerant so this data provides useful information for selection.

We scored survival in a doubled haploid population derived from Cara/Xerpha and survival ranged from 10% to 99% in this population. This data will be added to agronomic data collected from multiple field locations from 2014-2016 to identify loci for adaptation and for winter survival that can be used by local breeding programs to developed improved and adapted cultivars.

We scored survival in a large Winter Wheat Core Nursery representing a global collection of winter wheat cultivars. The association mapping that we will conduct in this population will identify new sources of cold tolerance, of growth, and development that will be used to continue to improve survival.

We discovered that freezing tolerance follows a diurnal pattern. In plants grown under 12 hours light/12 hours dark at a constant 3 degrees C (37 degrees F), cold tolerance was significantly greater at the midpoints of the light, and of the dark periods, compared to the end of either light or dark period. This new knowledge will help us to schedule our freezing test runs to achieve the maximum freezing tolerance. It also has implications in the genetic control of freezing tolerance, which seems to involve the day length sensing system in plants.

Impact

- The data from these cold tolerance trials was published in the seed buyers guide so that farmers can select winter wheat that is less sensitive to winter kill.
- Our results from screening the regional nurseries, and screening breeding lines has been used by winter wheat breeders to select for resistance to winter injury.
- Varieties released from the WSU winter wheat breeding program have consistently excellent cold tolerance and this tolerance has been maintained because of testing using the procedures developed by this project.
- Because of the high correlation between our artificial screening trial and winter survival in the field, we are able to incorporate better cold tolerance into our early generation breeding lines.
- Most breeding programs have both winter tolerant and less tolerant breeding lines. The identification of molecular markers associated with freezing tolerance complements our screening system and increases our current screening capacity from about 1000 varieties and breeding lines to several thousand progeny from segregating populations per year. **D. Communication:**

Refereed papers

Kruse, E, Carle, S, Wen, N, Murray, TD, Skinner, DZ, Garland-Campbell, KA, and Carter, A.H, 2017 Genomic Regions Associated with Tolerance to Freezing Stress and Snow Mold in Winter Wheat." In press.

Skinner, D.Z., Bellinger, B.S. 2016. Freezing tolerance of winter wheat as influenced by extended growth at low temperature and exposure to freeze-thaw cycles. Canadian Journal of Plant Science. doi: 10.1139/CJPS-2016-0154.

Skinner, D. Z. 2017. Advances in cold-resistant wheat varieties. Chapter 7 In: Achieving sustainable production of wheat. Vol. 1. P. Langridge, ed. ISBN-13: 9781786760166..

Abstracts

Popular Press

Web

Presentations

WGC project number: **3019-6600**
WGC project title: **Evaluation And Selection For Cold Tolerance In Wheat**
Project PI(s): **Kimberly Garland-Campbell and Arron Carter**
Project initiation date: **7/1/16**
Project year: **2 of 3**

Objective	Deliverable	Progress	Timeline	Communication
1. Evaluate Washington winter wheat variety trials.	Survival data for all lines in winter wheat variety trials.	In 2016 survival data was collected for the soft and hard winter wheat variety trials.	Data available by Feb. of the year following the field trials, Feb. 2017-2019	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review. Refereed publications.
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.	Survival data for lines in US regional nurseries	In 2016, survival data was collected for the soft and hard western regional nurseries	Data available by April of the year following the field trials, April 2017-2019.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review. Refereed publications.
3. Evaluate cold tolerance of spring wheat variety trials.	Survival data for lines in spring wheat variety trials	We did not collect survival data for spring wheat variety trials due to funding cut.	Data avilable by Feb. of the year following the field trials, Feb. 2017-2019	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review. Refereed publications.
4. Evaluate cold tolerance of advanced breeding lines contributed by A. Carter, K. Gill, M. Pumphrey, R. Zemetra and others in the PNW as well as those in the ARS breeding program.	Survival data for advanced breeding lines submitted by regional breeders	In 2016, survival data was provided on advanced breeding lines in the WSU Winter Wheat program(208 lines); the USDA Club wheat breeding program(102 lines), and to B. Zemetra (120 lines)	Data available by June of the year that entries are submitted, June 2017-2019.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review.

5. Evaluate cold tolerance of F_3-F_5 (early generation) wheat populations that are segregating for cold tolerance and select resistant progeny.	Populations that have been selected for tolerance to deep freezing.	This was not accomplished due to funding cuts.	Populations selected each year, 2016-2019.	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.	New information about the Fr1, Fr2, and other loci controlling cold tolerance and spring growth in wheat	In 2016, survival data was recorded in a 130 member DH mapping population of Cara/Xerpha. We completed recording survival data for the Winter Wheat Core Nursery.	Sept 2016-June 2019.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review. Refereed publications.
7. Determine how cold tolerance interacts with resistance to soil borne disease, specifically snow mold, eyespot, and Fusarium crown rot resistance.	Survival data for wheat populations segregating for resistance to soil borne disease. Selected populations with resistance to cold and to individual diseases.	This was not accomplished due to funding cuts.	Trials with specific diseases conducted, one disease per year, 2016-2019.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review. Refereed publications.

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

PROJECT No.: 30109-6601
Progress report year: *1 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: The new club wheat cultivar, Pritchett, jointly developed by the USDA-ARS and WSU winter wheat breeding programs, was released in 2015, because of its superior agronomic productivity in the targeted region, and superior end use quality combined with resistance to multiple diseases and abiotic stress. Breeder seed of this cultivar was produced in Moses Lake in 2016.

The USDA-ARS Wheat breeding program managed field testing locations at Central Ferry, Lind, Harrington, Pullman, and Farmington WA and at Pendleton OR and Genesee ID. We also evaluated breeding lines at Walla Walla, St. Andrews, Mansfield, Ritzville, and Kahlotus, WA and Corvallis OR in collaboration with the WSU Winter Breeding program, the WSU Cereal Variety Testing Program, OSU-CBARC, the OSU Wheat Breeding program, the University of Idaho and Syngenta. The overall goal of this project has been to remove the agronomic constraints that make club wheat less attractive to growers than soft white wheat.

We focused club wheat development on two major goals: 1) Development of competitive club wheat cultivars for the < 15 inch rainfall zone with excellent resistance to snow mold, eyespot, stripe rust, sprouting and good emergence and winter hardiness and 2) Development of competitive early maturing club wheat for the > 15 inch rainfall zone with excellent resistance to eyespot, cephalosporium stripe, stripe rust, aluminum toxicity and good straw strength, and excellent test weight.

The club wheat ARS Crescent is a complement to Pritchett in the higher rainfall regions. In the 2016 WSU Cereal Variety Trials, ARS Crescent was the second highest released cultivar in the >20 in. precipitation region. ARS Crescent yielded 107%, 97%, 103% and 99% of the trial averages in the >20, 16-20, 12-16, and <12 inch rainfall zones, respected. ARS Crescent maintained acceptable falling numbers in almost all environments in 2016 and has achieved stable high performance across rainfall zones over multiple years. New club wheat breeding lines have been highly competitive with soft white wheat cultivars in multiple rainfall zones during the past three harvest seasons. The breeding line ARS20060123-31C, is being purified in head rows for possible release in 2018 targeted as an early maturing club wheat with good performance, stripe rust resistance, aluminum tolerance and tolerance to low falling numbers.

For the 2017 WA State Extension trials for the dry rainfall zones, we entered two lines: ARS20060123-31C (was in the 2015-16 trials) is derived from a cross between NY89066-7131/B980696//CHUKAR; a tall, early maturing, awnless club that has been very resistant to stripe rust in USDAARS trials;

ARSDH08028-111C, is a new entry for 2017 derived from a cross between Cara/Xerpha, an awned club that has performed well, where Xerpha is adapted but with better adult plant resistance to stripe rust and excellent milling quality.

For the 2017 WA State Extension trials for the high rainfall zones, we entered two lines: ARSDH08028-44C is an awnless club and new entry for 2017 derived from the Cara/Xerpha cross with excellent stripe rust resistance and moderately early maturity that has performed well in early maturing and higher rainfall regions.

ARS20040150-2C is also a new entry for 2017 derived from a cross between Chukar/Cayuga/2*Chukar. Cayuga is a source of preharvest sprouting resistance from NY. This entry was selected to have that resistance. We still need further testing to confirm but the line has performed well on the Palouse with good stripe rust resistance and maturity similar to Chukar.

These club breeding lines are all products of crossing with soft wheat from the Eastern US as additional sources of resistance to rusts, Hessian Fly and BYDV. We have added an additional head row purification and selection step to the breeding program in order to provide Washington Foundation Seed with quality Breeder seed in a timely manner.

We have greatly expanded our use of genotyping and are in the process of genotyping all our the entries in all of our yield trials using the genotyping by sequencing (GBS) procedure in the USDA Western Small Grains Genotyping laboratory. We are implementing genomic selection for end use quality and cold tolerance. Marker assisted selection using KASP and SSR markers was used to select for resistance to Preharvest sprouting, BYDV, eyespot, stripe rust and for dough strength.

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

Impact

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

D. Communication

Presentations:

a. Report of Progress: Washington Grains Commission Research Review, "Club Wheat Breeding", Pullman WA, Feb. 2016.
b. Plot and field day tours speaking to approximately 15-30 growers and industry representatives per tour during June, 2015: Reardan WA.
c. Invited by Planning Committee, Edgar Mcfadden Symposium to speak on, "Learning from the Daleks and the Silurians to Control Stripe Rust in the Great Plains" at Joint Edgar McFadden Symposium-Hard Winter Wheat Workers Workshop, April 19, 2016. San Antonio TX

Refereed manuscripts with applications to this project.

1. **Garland-Campbell, K**., Carter, A.H., Jones, S.S., Chen, X.M., DeMacon, P., Higginbotham, R., Engle, D., Guy, S.O., Mundt, C.C., Murray, T.D., Morris, C.F., See, D., 2017. Registration of "Pritchett" Soft White Winter Club Wheat. In press
2. *Gizaw, S.A*., **Garland-Campbell, K.**, Carter, A.H., 2016. Evaluation of agronomic traits and spectral reflectance in Pacific Northwest winter wheat under rain-fed and irrigated conditions. Field Crops Res. http://dx.doi.org/10.1016/j.fcr.2016.06.018
3. *Gizaw, S.A*., **Garland-Campbell, K.**, Carter, A.H. 2016. Use of spectral reflectance for indirect selection of yield potential and stability in Pacific Northwest winter wheat. Field Crops Res. Available online 21 July 2016. http://www.sciencedirect.com/science/article/pii/S0378429016302088
4. **Garland-Campbell, K.,** 2016. Errors in Statistical Decision Making. Chapter 2, In Glaz, B and K. M. Yeater, (eds). Applied Statistics in Agricultural, Biological and Environmental Sciences. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. Madison, WI. Peer reviewed, invited chapter, IN PRESS

Popular Press:

WGC project number: 3019-6601
WGC project title: Club wheat breeding
Project PI(s): Kimberly Garland-Campbell and Arron Carter
Project initiation date: 7/1/16
Project year: 1

Objective	Deliverable	Progress	Timeline	Communication
1. Develop agronomically competitive club wheat cultivars targeted to the diversity of rainfall and production zones of the PNW. These cultivars will possess the excellent end use quality characteristic of club wheat. They will also possess excellent resistance to stripe rust. Specific other characteristics will be targeted to individual rainfall regions.	Club cultivar releases	The club wheat cultivar Pritchett is on increases as Foundation seed. The breeding line ARS20060123-31C is being purified in head rows for possible release in 2018.	Sept 2016-June 2019. Cutlivar releases are targeted as one every three years per rainfall zone.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review.
2. Develop club breeding lines for the <15 inch rainfall zone with improved resistance to snow mold and fusarium crown rot , improved emergence and winter survival	Germplasm identified with resistance, used to introgress new resistance genes into existing club wheat germplasm. Better combination of traits in club wheat targeted to the <15 in. rainfall zone	ARS20060123-31C and ARSDH08028-111C were entered into the 2017 Washington variety trials targeted to the < 15 inch rainfall zone.	Sept 2016-June 2019.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review.
3. Develop club breeding lines for the > 15 inch rainfall zone with improved resistance to eyespot, cephalosporium stripe, aluminum toxicity, and cereal cyst nematodes.	Germplasm identified with resistance, used to introgress new resistance genes into existing club wheat germplasm. Better combination of traits in club wheat targeted to the >15 in. rainfall zone	ARSDH08028-44C and ARS20040150-2C were entered into the 2017 Washington variety trials targeted to the > 15 inch rainfall zone	Sept 2016-June 2019.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review.

4. Release a club wheat cultivar with early maturity targeted to SE Washington and NE Oregon.	Club wheat cultivar with early maturity (2-5d earlier than Pritchett) combined with excellent stripe rust resistance.	Head rows were planted in Pendleton in the fall of 2016 so that early generation selections can be made in that environment.	Sept 2016-June 2019. Our next club wheat release after Pritchett will be targeted to this growing environment	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review.
5. Release germplasm with improved resistance to preharvest sprouting	Club wheat Breeding lines with stable falling numbers above 300 in all but extreme environments.	ARS Crescent has improved resistance to low falling numbe. ARS20040150-2C was selected for improved resistance to preharvest sprouting.	Sept 2016-June 2019.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review.
6. Identify an early generation method to assess cake baking quality	Early generation prediction equation for cake baking quality, the key trait for club wheat.	Association mapping and genomic selection for improved baking quality is underway.	Sept 2016-June 2019.	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 Report

Project #: 4127-1605

Progress Report Year: *_1_ of _3__*

Title: Evaluation of Barley Varieties

Investigator: Ryan Higginbotham

Executive summary:
In 2016, the Cereal Variety Testing Program (VTP) conducted 12 spring barley variety trials across Eastern Washington. The total number of individual barley plots evaluated was 1,080. Entries in the trials included submissions from every major barley breeding program in the Pacific Northwest. Variety performance information is delivered to barley growers and other clientele through field tours (10 tours in 2016), grower meetings, the variety testing website, emails with preliminary results after harvest (over 200 recipients), the variety selection tool (located at smallgrains.wsu.edu), *Wheat Life*, seed buyers guide, annual technical report, direct contact with clientele, and reports to the Washington Grain Commission. The variety trials are used by WSU breeders for variety release decisions, by pathologists to rate disease reactions, and for county Extension programming.

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

Some of the most direct and measurable impacts that this project had in 2016 are as follows:

1. Barley VTP field tours were attended by 261 farmers/clientele. At those tours, I highlighted each entry in the trial and presented a few details about each entry.
2. As soon as harvest results were available, they were distributed via email to a listserv with 208 members and posted to the project website.
3. The variety testing section of the small grains website (http://smallgrains.wsu.edu/variety/) was the most visited section of the site (7,053 page views).

WGC project number: 4127-1605
WGC project title: Evaluation of Barley Varieties
Project PI(s): Ryan Higginbotham
Project initiation date: July 1, 2016
Project year: 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Conduct barley variety trials in Eastern Washington	12 spring barley trials, 30 entries/trial	2016 trials complete (30 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.	Results from variety trials are communicated via Extension programming and are detailed under Objective #4.
		2017 trials in planning		
		The Palouse location was new in 2016		
2. Public and private entries in trials	All widely grown, commercially available varieties included in trials.	2016 barley trial: 60% WSU, 30% Private, 10% Other Public	Entries by Feb. 15	Solicit entries February 1. Maintain positive relationship with breeding programs to ensure future participation.
3. Trials and data available to other projects	Participation by other projects/programs	Data is used by breeders for variety release and promotional materials. To this point, the grain itself is not used in any further testing outside the VTP. New avenues for collaboration need to be explored.	Ongoing cooperation and collaboration that fit with timelines and other listed objectives	VTP data used for variety release
4. Extension programming	Grower Meetings	3 grower mtgs in 2016;	Whenever I'm invited	Grower Meetings: 3 in 2016; accepting invites for 2017
	Field Tours (with county Extension)	10 in 2016; 10 planned for 2017	June 2017 - July 2017	*Field Tours: 10 in 2016 (listed below)
	Email List serve	2016 results delivered	Oct. 2016 - Nov. 2016	Email list serve: data sent to 200+ members
	Website	up to date with 2016 data	fall/winter	7,053 pageviews of the VTP section of the small grains website
	Annual Report	Published in December 2016	December	Annual Report: 2016 Technical Report 16-3
	WSCIA Seed Buyers Guides	2016 published, 2017 in preparation	January--February	2016 Seed Buyers Guide published January 2016
	Wheat Life	2015 barley results in Feb. 2016 issue	February	Wheat Life: 1 article planned for 2017
	Variety Selection Tool (http://smallgrains.wsu.edu)	Selection tool updated with 2016 results. Initiating tool to track website traffic/users.	Post harvest/as data is processed	The variety selection tool has been highlighted/promoted at grower meetings and field tours.

<u>* 2016 TOUR SCHEDULE--BARLEY SITES</u>

Location	Date	Attendance
Fairfield	21-Jun	21
Almira	22-Jun	85
Reardan	23-Jun	20
Walla Walla	28-Jun	14
Dayton	29-Jun	33
Mayview	30-Jun	30
Palouse	11-Jul	14
Farmington	13-Jul	18
St. John	14-Jul	12
Lamont	14-Jul	14
		Total = 261

Washington Grain Commission
Wheat and Barley Research Annual Progress Report

Project #: 4127-1604

Progress Report Year: *_1_ of _3__*

Title: Evaluation of Wheat Varieties

Investigator: Ryan Higginbotham

Executive summary:
In 2016, the Cereal Variety Testing Program (VTP) conducted 22 soft winter, 13 hard winter, 18 soft spring, and 18 hard spring wheat variety trials across Eastern Washington. The total number of individual wheat plots evaluated was 7,362. Entries in the trials included submissions from 12 different breeding programs/cooperators. Variety performance information is delivered to wheat growers and other clientele through field tours (18 tours in 2016), grower meetings (3 in 2016), the variety testing website, emails with preliminary results after harvest (over 200 recipients), the variety selection tool (located at smallgrains.wsu.edu), *Wheat Life* articles, seed buyers guides, annual technical report, direct contact with clientele, and reports to the Washington Grain Commission. Grain from variety trials is used to generate information on end use quality, disease reactions, market class grading, and falling numbers.

Impact:
The economic value (impact) of the WSU VTP is measured by providing information to growers and seed industry personnel that leads to variety selections that maximize profitability and minimize risk. Choosing an appropriate wheat variety to plant is one of the easiest ways that a grower can increase production and decrease costs (through decreased inputs). In 2015, there were 1.9 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 1.9 million bushels of grain. Using an average market price of $4.00/bushel, this would result in a gross increase of $7.6 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 offer for their patrons.

Some of the most direct and measurable impacts that this project had in 2016 are as follows:

1. The inclusion of every major wheat breeding program in the VTP trials. This provided growers and industry with a head-to-head comparison of the most widely grown varieties.
2. VTP field tours were attended by 463 farmers/clientele. At those tours, I highlighted each entry in the trial and gave a few details, strengths/weaknesses about each entry.
3. As soon as harvest results were available, they were distributed via email to a listserv with 208 member and posted to the project website.
4. The variety testing section of the small grains website (http://smallgrains.wsu.edu/variety/) was the most visited section of the site (7,053 page views).

WGC project number: 4127-1604
WGC project title: Evaluation of Wheat Varieties
Project PI(s): Ryan Higginbotham
Project initiation date: July 1, 2016
Project year: 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Conduct wheat variety trials in Eastern Washington	a) 24 soft winter wheat trials; 48-54 entries/trial	a) 2017 trials planted; 2016 results finished	Trials are planted in the spring or fall, data results are available to growers shortly after harvest. Field tours throughout the summer.	Results from variety trials are communicated via Extension programming and are detailed under Objective #4.
	b) 16 hard winter wheat trials; 18 entries/trial	b) 2017 trials planted; 2016 results finished		
	c) 18 soft spring wheat trials; 24 entries/trial	c) 2017 trials in planning; 2016 results finished		
	d) 18 hard spring wheat trials; 36 entries/trial	d) 2017 trials in planning; 2016 results finished		
		An additional irrigated site (Pasco), and high rainfall spring site (Palouse) were added in 2016. In the Fall of 2016, a winter trial was planted at Bickleton, the HRW trial was added to Anatone, and a new winter location (Eureka) was added in cooperation with OSU.		
2. Public and private entries in trials	All widely grown, commercially available varieties included in trials.	2017 winter trials: 27% WSU, 44% Private, 29% Other Public: Every major breeding program in the PNW is actively participating in the VTP trials. 2017 winter entries can be viewed on the variety testing website	Winter entries by Aug. 15th and spring entries by Feb. 15th	Solicit winter entries August 1 and spring entries February 1. Maintain positive relationship with breeding programs to ensure future participation.
		2016 spring wheat trials: 45% WSU, 49% Private, 6% Other Public		
3. Trials and data available to other projects	Participation by other projects/programs	Cooperation with breeders, pathologists, quality lab, FGIS, seed dealers, WSCIA, Extension	Ongoing cooperation and collaboration that fit with timelines and other listed objectives	Quality results in G&E study and preferred variety pamphlet, falling number results presented by corresponding project, disease ratings presented in seed buyers guide and variety selection tool, VTP data used for variety release and PVP applications
4. Extension programming	Grower Meetings	4 grower mtgs in 2016;	Whenever I'm asked to speak	Grower Meetings: 3 in 2016; accepting invites for 2017
	Field Tours (with county Extension)	20 planned for 2017	May 2017 - July 2017	*Field Tours: 18 in 2016 (listed below)
	Email List serve	2016 results delivered	July 2016 - Sept. 2016	Email list serve: data sent to 200+ members
	Website	up to date with 2016 data & 2017 maps	summer & fall	7,053 pageviews of the VTP section of small grains website
	Annual Report	Published in December 2015	December	Annual Report: 2016 Technical Report 16-3
	WSCIA Seed Buyers Guide	2016 guide published, 2017 in preparation	January--February	2016 Seed Buyers Guide published in Jan. 2016
	Wheat Life Articles	2 articles written in 2016	spring in Feb. winter in May	Wheat Life: 2 articles planned for 2017
	Variety Selection Tool (http://smallgrains.wsu.edu)	Selection tool updated with 2016 results. Initiating tool to track website traffic/users.	Post harvest/as data is processed	The variety selection tool has been highlighted/promoted at grower meetings, field tours.

*** 2016 TOUR SCHEDULE--WHEAT**

Location	Date	Attendance	Crops
Horse Heaven	7-Jun	39	Winter & Spring Wheat
Ritzville	8-Jun	40	Winter Wheat
Western Whitman Co. - Dusty	9-Jun	14	Winter Wheat
Connell	9-Jun	21	Winter Wheat
Harrington	15-Jun	30	Winter Wheat
St. Andrews	17-Jun	24	Winter Wheat
Fairfield	21-Jun	21	Winter & Spring Wheat
Almira	22-Jun	85	Winter & Spring Wheat
Reardan	23-Jun	20	Winter & Spring Wheat
Walla Walla	28-Jun	14	Winter & Spring Wheat
Dayton	29-Jun	33	Winter & Spring Wheat

Mayview	30-Jun	30	Winter & Spring Wheat
Anatone	30-Jun	12	Winter Wheat
Palouse	11-Jul	14	Spring Wheat
Bickleton	12-Jul	22	Spring Wheat
Farmington	13-Jul	18	Winter & Spring Wheat
St. John	14-Jul	12	Winter & Spring Wheat
Lamont	14-Jul	14	Winter & Spring Wheat
		Total = 463	

Washington Grain Commission, Wheat and Barley Research Proposal

Project # Continuing Proposal

Title: Precision N Management in Wheat

Researchers: David Huggins, David Brown, Wayne Thompson, Kate Painter

Cooperator: Aaron Esser

Date initiated: July 1, 2015

This is year _3_ of _3_ (maximum 3 years) of the funding cycle.

Justification: Science-based decision aids for the application of precision N management technologies in wheat are lacking including criteria for determining N management zones, precision N application rates and site-specific assessment of wheat performance (crop and economic evaluation).

A. Problem: Despite the availability of powerful precision agricultural technologies such as Global Positioning Systems (GPS), Geographic Information Systems (GIS), yield monitors, satellite remote sensing and variable rate applicators (VRT), there are currently no science-based, site-specific recommendations and limited grower practice of precision N management for dryland wheat in the inland Pacific Northwest (PNW) (Figure 1). During the past year, we interviewed dryland wheat growers (northeastern Oregon, eastern Washington and northern Idaho) practicing precision N management to assess how decisions are currently made with respect to developing a prescription N application map and practicing VRT. These interviews revealed major scientific weaknesses in identifying and evaluating economically suitable N management zones and associated N prescriptions. For example: too many management zones were often established based on intuition; often there was inadequate assessment of both spatial and temporal variability in wheat performance and other spatial data (too few years and/or no clear method of using/integrating yield monitor and/or other data); and little to no evaluation of N prescription performance as compared to "business as usual" was practiced. Clearly, a major barrier to adoption of precision technologies for N management has been the lack of data integration into a science-based, grower-oriented decision support system that includes monitoring, N application and evaluation practices and that optimizes the economic and environmental performance of N fertilizer use. In addition, precision N management strategies for other regions of the country have often been developed for in-crop N adjustments that are reactions to in-season weather conditions (Mamo et al., 2003). These N management strategies are not particularly applicable to crops in Mediterranean-like climates that rely on stored soil water as found in the dryland PNW.

In the case of site-specific N management, successful implementation in the PNW has proven challenging as virtually every factor used for WSU N fertilizer recommendations (e.g. crop yield goals, unit N requirement, soil test N and organic matter levels) has substantial spatial and temporal field variability (Pan et al., 1997). In the PNW, field variation in wheat grain yield and protein is well documented (Bhatti et al., 1991; Fiez et al., 1994; Yang et al., 1998; Huggins et al., 2010). Large within-field variation in wheat performance arises from landscape and soil attributes that produce variations in available water, organic matter and rooting depth (Busacca and Montgomery, 1992; Huggins and Pan, 2003; Ibrahim and Huggins, 2011). Collectively, these studies show that the strong influence of topographic and soil factors on grain yield, protein and N use efficiency (NUE) could facilitate their prediction and management through the use of precision farming technologies. A major unknown is whether or not the spatial and temporal variability in crop performance and N-related processes can be sufficiently characterized and predicted to enable N management decisions to be tailored to site-specific requirements. Assessing this unknown requires long-term databases that consist of detailed site-specific crop performance and soil data such as the 15-years that are available from studies at the WSU Cook Agronomy Farm.

Poor NUE represents not only a financial loss to the producer, but a serious environmental threat from increased N_2O emissions, as well as eutrophication and degradation of surface and ground waters via leached NO_3^-. Current strategies for managing N fertilizer in wheat-based dryland farming systems of the PNW were developed on a regional scale for the uniform, whole-field application of N under intensive tillage systems (Leggett, 1959). The inadequacy of current N fertilizer recommendations was first documented at the WSU Cook Agronomy Farm (CAF) near Pullman, WA, where uniform N applications have resulted in large within-field variations in wheat performance (yield and protein), N uptake efficiencies (12 to 48%) and N losses of up to 100% of applied fertilizer N (Huggins et al., 2010). Some consequences of the current approach to N management in dryland wheat production are: (1) insurance applications of N fertilizer designed to reduce the risk of N deficiencies over time and space; (2) sub-optimal N use efficiencies due to N supplies that are over or under crop requirements; (3) unbalanced cropping system N budgets with undesired N leaching and gaseous losses; and (4) lack of direct measures to evaluate N management strategies with respect to NUE and N losses (Huggins and Pan, 2003).

B. Impact: Increases in N fertilizer use efficiency will save producers money as well as improve water and air quality. If N management prescriptions can be tailored to site- and time-specific conditions, NUE could be improve by up to 50% (Huggins et al., 2010). Even a 20% savings in N fertilizer use where N applications, for example, are100 lbs/ac, can translate into 20-30 lbs ($12-18/ac at $0.60/lb N) less applied N/acre. Of course, this economic benefit would be offset by costs of precision farming technology and associated management requirements. Nevertheless, increases in NUE have the potential to have economic and environmental benefits for all classes of wheat grown in the PNW.

The expected outcomes of the project are: (1) on-farm demonstration and testing of precision management technologies and practices with a realistic prognosis for grower adoption; (2) grower-oriented precision N management decision-aid tools that result in greater performance of cereal crops, increased NUE and reduced N losses as compared to uniform N management; and

(3) outreach/extension materials and technical specifications for growers to achieve sound precision N management strategies.

C. Goal: Develop science-based decision aids for the application of precision N management strategies in wheat. Goal accomplished through the integration of crop (e.g. yield monitoring), soil (e.g. apparent electrical conductivity), remote sensed (e.g. Rapid-Eye imagery) and economic data using field-scale studies at the WSU Wilke Farm, WSU Cook Agronomy Farm and on-farm locations**.**

Process

Objectives will build onto on-going studies at the WSU Wilke Farm and Cook Agronomy Farm that have been funded by USDA over the last 2-3 years by the Site-Specific Climate Friendly Farming project and the Regional Approaches to Climate Change (REACCH) project. In addition, new farms with a history of practicing precision N management have been identified and will be used to aid development and testing of decision tools. The USDA Long-term Agroecosystem Research (LTAR) program will also support these research efforts.

A. Objectives:

Objective 1. Assess spatial variation in wheat performance and related causal factors to enhance precision N decisions. Measure field-scale, site-specific wheat performance and related variables (e.g. yield, protein, economic return, N status, N use efficiency, soil organic matter and inorganic N, soil water availability) required for precision N management decisions at the WSU Wilke, Cook Agronomy Farms as well as from on-farm trials.

Objective 2. Develop science-based criteria for establishing within-field management zones including site-specific evaluation of wheat performance (yield, protein, NUE, economics).

B. Procedures:

Objective 1. At the Wilke farm, precision N management studies were initiated in 2012 and comparisons consist of geo-referenced field strips with two treatments (uniform versus precision N management) with four replications per field. Grid points are established within the strips to hand harvest grain and analyze yield and protein. Soil sampling is targeted to assess treatment differences in N use and loss and romote sensing (Rapid-eye imagery) is being used to help assess spatial differences in treatments. A combine mounted yield monitor is also used to assess crop performance in the two treatments. Differences in crop performance and NUE will be analyzed to provide economic and environmental data for Objective 2. Results from these studies will be used to identify where gains in water, N efficiency or improvements in crop performance can be realized, thereby directing establishment and evaluation of management zones for precision N technology. In 2012-2013, two 26-ac fields at the Wilke Farm were used for a precision N studies and these will now be continued for winter wheat. Grain yield monitor (2 year) and apparent electrical conductivity (Geonics EM-38) data were used to establish three N management zones with low, medium and high yield goals (Figure 2). Variable rate N was applied during seeding of hard white spring wheat. Overall field averages for the two N application strategies were very similar (Figure 3). The N balance index (N removed in harvested grain divided by N fertilizer applied) was greater for VRT (0.99) as compared to the Uniform (0.82) treatment. Preliminary economic analyses show that the VRT strategy was more economical on 3 of 4 “high” zones and 2 of 3 “low” zones. Other data still under assessment include field soil water and inorganic N from comparative point samples as well as satellite imagery. These data will be used to further assess N and water use efficiency as well as the effectiveness of defining the three VRT zones. We repeated a similar experiment on this field as well as another field at the Wilke Farm in 2013 and the proposed project will continue these studies with winter wheat for years (2014-15).

At the CAF, a similar field-scale study will consist of strips with two N management treatments: (1) uniform application of N fertilizer based on WSU guidelines; and (2) site-specific N management based on the spatial patterns of yield, terrain and soil variables. Control points with 0 applied N will be strategically placed at geo-referenced topographic positions. Treatments will be established for winter wheat. Crop and soil sampling will be at historically established geo-referenced locations and components of N use efficiency will be assessed using methods described by Huggins and Pan, (2003). Site-specific N management will be compared to current WSU guidelines for N management in field-scale experiments. Consequently, we will test the null hypothesis of precision N management: given the large temporal and spatial variation in within-field crop yield and N-related processes, the optimal risk aversion strategy is uniform N management.

On-farm research will be coordinated with Wayne Thompson, WSU Cropping Systems Agronomist. Here, a field trial was established in fall, 2014, that consists of across-field strips of applied N. Five rates of N were used and data analyses will provide information on yield response curves to applied N across the field.

Objective 2. Precision N management zone development will key on economic, yield, N and water use efficiency criteria at all locations from data collected under Objective 1. Enterprise budgets will be developed comparing uniform and precision N management to assess the costs of the technology, differences in N fertilizer inputs and crop performance and to determine various economic risks and strategies associated with the adoption of the technology. At the WSU Cook Agronomy Farm, yield and economic data collected from 369 geo-referenced points (2 m^2) in a nonaligned, randomized, 100x100 ft grid over 92 acres of the CAF from 1999-2013 will be analyzed to assess similarities in year-to-year spatial structure using variography (Rossi et al., 1992). Preliminary analyses have shown promising year-to-year consistency in the spatial variation of relative yields of wheat and other crops in certain portions of the field. In addition, precision N farming strategies currently being used at on-farm locations will be assessed using farmer owned equipment and technology including evaluation of the effectiveness of the precision N treatment using “business as usual” N strips.

Decision-aid products will be developed for: (1) using yield monitor and relevant terrain and soil data to establish realistic crop performance goals; (2) targeting soil sampling in precision farming systems to assess soil N availability; (3) determining site-specific N management zones and prescriptions; and (4) assessing economic and environmental trade-offs for precision N management.

C. Cooperation and Coordination: Dr. Dave Huggins will provide overall research and outreach coordination and expertise on precision N management as well as WSU Cook Agronomy Farm collaboration. Dr. David Brown will provide expertise in spatial statistical analyses, remote sensing and decision support products. Mr. Wayne Thompson will provide expertise on precision agricultural technology, decision support products, southeast WA precision farming collaborators, as well as outreach activities and products. Dr. Kate Painter will provide agricultural economic expertise and assessment of precision N management. Aaron Esser will aid with WSU Wilke Farm collaboration as well as outreach activities and products.

D. Review: We will promote awareness of precision agriculture principles (e.g., assessing spatial and temporal yield variability and principles of precision management) and report research progress at the Wheat Research Review, regional scientific and stakeholder conferences and workshops, articles in *Wheat Life*, field days (Cook, PCFS), grower meetings (organized by county extension agents and ag companies) and by phone or by email as requested. Results will also be published in scientific journals and presented at scientific congresses.

E. Location(s): WSU Wilke Farm; WSU Cook Agronomy Farm; Other WA farms including Columbia Co. Farms to be identified.

Budget

1. Amount allocated by the Commission in fiscal year (FY) 2016: $ 900.00

2. Amount requested for FY 2017 (July 1, 2016-June 30, 2017):

Category	FY 2015	FY 2016	FY 2017	Total
Salaries[1]	788	788	788	2,364
Wages				
Employee Benefits	212	212	212	636
Goods and Services[1]				
Travel				
Equipment				
Total	1,000	1,000	1,000	3,000

[1] Salary for support of Associate in Research.

Figures

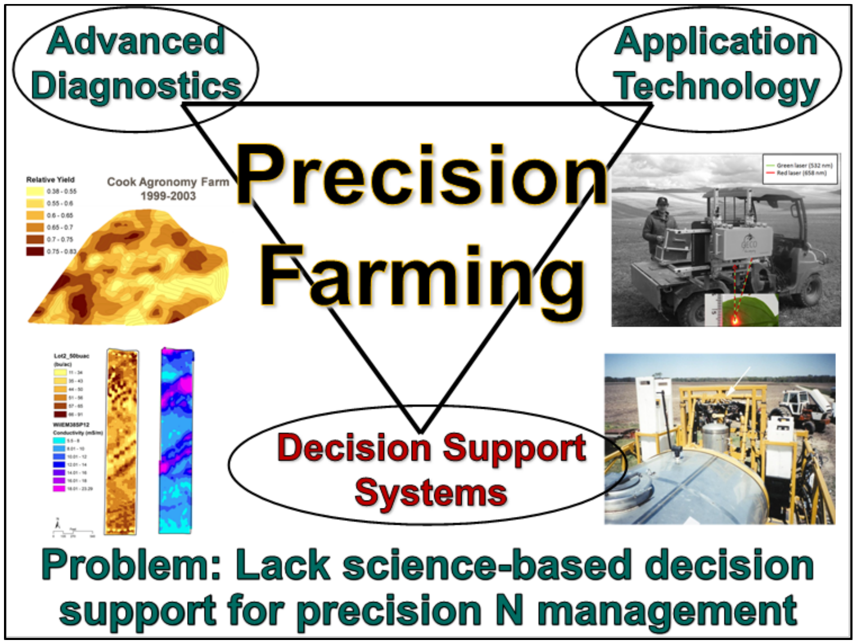

Figure 1. Successful application of precision farming requires that advanced field diagnostics and precision application technologies are coupled with science-based decision support systems at within-field scales.

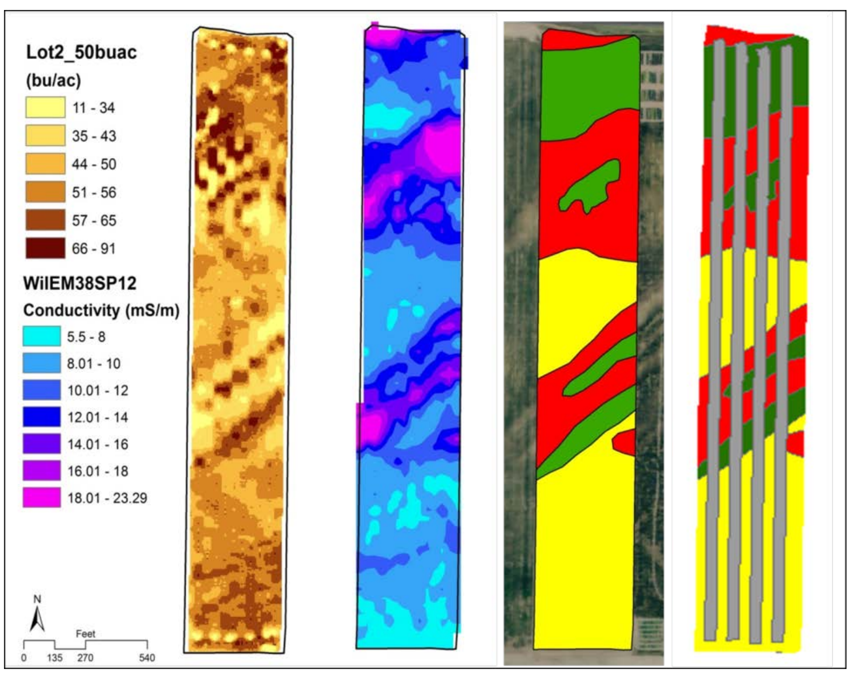

Figure 2. Grain yield monitor and apparent electrical conductivity data used to create N management zones (right) with high (green), medium (yellow) and low (red) yield goals at the WSU Wilke Farm. Control strips with uniform applications of N depicted in gray.

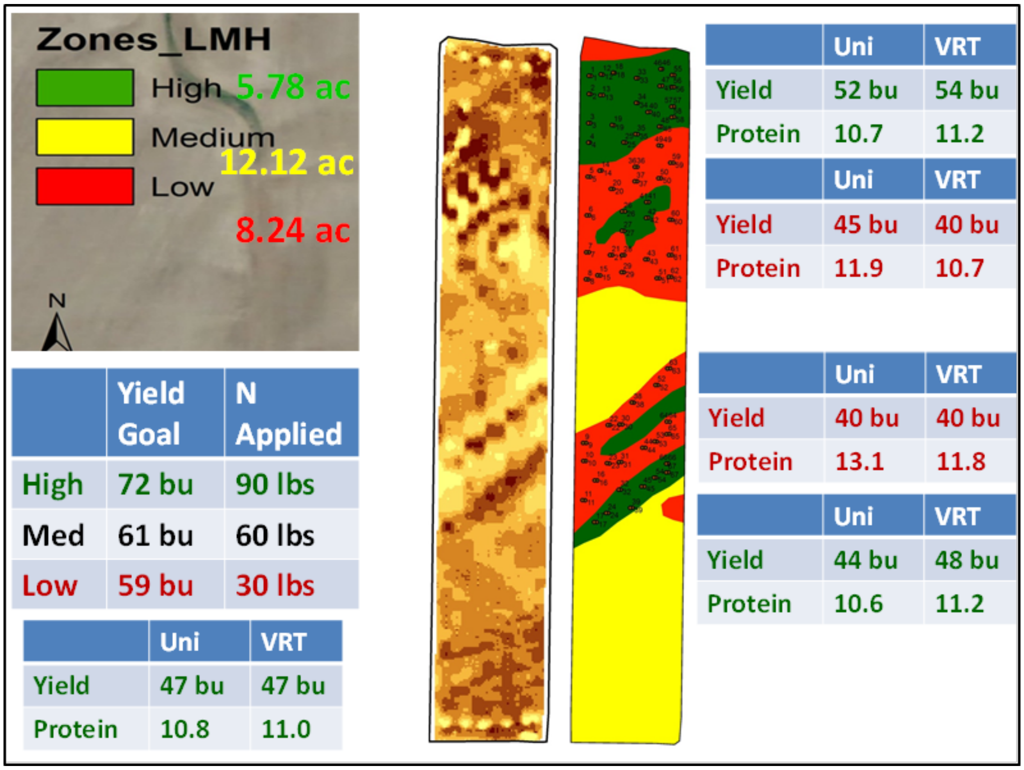

Figure 3. Yield goals, applied N and resultant yield and grain protein concentration at the WSU Wilke Farm study. Actual yield and protein for field zones on far right with a comparison between uniform (Uni) and variable rate (VRT) N application.

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F. Outcomes:

Evaluation of Variable Rate Nitrogen Application in Dryland Winter Wheat

Sub-field N management zones were created for three field sites in the inland Pacific Northwest Palouse region using yield and electrical conductivity (ECa) data, a method that reflected current grower practices. Significant differences in N use efficiency, N uptake efficiency, and N utilization efficiency ranged from 0% to increases of over 30%, 17%, and 25%, respectively. Spatial variability in grain protein response to N, and increases of 1% were observed as N fertilizer increased. Grain yield response to N fertilizer was small and significant differences were only observed between points that received starter fertilizer only and points receiving applied rates of 9 lbs/ac. Varying N rates at these sites was most effective in areas of the field that were defined as low yielding zones. Here decreasing N fertilizer application decreased potential N losses and money spent without taking yield penalties. Increasing N rates in zones defined as high yielding did not improve yield and decreased N use efficiency, thereby increasing the potential for N losses and decreasing financial profits.

Management Zone Delineation Based on N Use Efficiency Performance: a Decision-Support and Evaluation System for Precision N Applications

Grain yield, protein, and other performance criteria were measured and calculated at grouped points receiving variable rates of N fertilizer. Performance classification criteria were created that reflected crop performance goals regarding maximum yield and N uptake efficiency. Groups were classified based on 4 performance criteria to identify areas of the field that performed similarly. Different N rates were then analyzed for N management zones created using clustering and performance classification criteria. Results of the clustering analysis and performance zone classification only captured significant differences between zones at one of the two sites. At the site where differences between zones were significant, grain protein ranged from 8.2% to 11.6% and N use efficiency increased by 81% to 118% from highest N rate to the lowest across all zones. Performance class zones captured similar responses to N rates across all performance classes. The development of management zones based on performance criteria provides basis for the creation of management zones and the evaluation of N fertilizer decisions made within those management zones. The advantages to this method are in the management interpretation of performance classes as well as detailed evaluation of VR decisions increasing crop performance with regards to yield and protein as well as NUE and NUE component measurements.

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: Timothy Murray, David Crowder, Randy Fortenbery, Haiying Tao, Ryan Higginbotham, Aaron Esser, Stephen Van Vleet, Diana Roberts, Paul Carter, Dale Whaley, and Karen Sowers

Executive summary: The Extension Dryland Cropping Systems Team focused their efforts in three areas in 2016. These were: 1) the Wheat and Small Grains Website (smallgrains.wsu.edu), 2) the Crop Diagnostic Clinic, and 3) the Wheat Academy. In addition to these three focus areas, the Team responded to the crisis of Low Falling Numbers in the 2016 wheat crop with Timely Topics and a new Grain Quality Resources section on the Wheat and Small Grains website. Some noteworthy new content for the Wheat and Small Grains website in 2016 included three new dynamic decision tools: 1) Winter Wheat Herbicide Efficacy Tables, 2) Herbicide Mechanisms of Action (MOA) Tool, and 3) AMS Sprayer Mix Calculator. Additionally, three new videos on soil acidification were produced and put up on the Soil Acidification in the Inland Pacific Northwest page along with new publications on using a pH meter for in-field soil pH sampling, how acid soils interact with root diseases, and a three-part publication on agricultural lime and liming. The video series received the 2016 Outstanding Extension Educational Materials Audiovisual Award from the Extension Education Community of the American Society of Agronomy. Approximately 63 people attended the Crop Diagnostic Clinic. Forty-two percent of the participants were growers and the rest crop consultants. The Wheat Academy was held on the WSU Pullman Campus on December 13 and 14. Attendance was limited to 75 people.

Impact: Measureable impacts for the past year include a greater than 2x increase in sessions and unique users visiting the Wheat and Small Grains website compared to the previous year. For the six months of June through November, the site had 18,729 sessions with 11,542 unique users, this was up from 8,179 sessions and 4,951 unique users for the same period in 2015. In addition to three new decision tools, three new videos, and six new peer-reviewed Extension publications, the team also responded to the low falling numbers situation by providing growers with four Timely Topics on the subject and adding a new section on Grain Quality Resources to the website. On August 10, the Timely Topic titled "Washington Association of Wheat Growers Falling Number Update" was posted and received 441 pageviews in the first day. Through November, the four Timely Topics on Low Falling Numbers had received nearly 2,500 pageviews. The 2016 Wheat Academy filled in just eight days and meeting surveys were very positive for the event. Attendees included a nice balance of 38 industry and 37 farmer participants. The Crop Diagnostic Clinic was also held in 2016 and received positive feedback from attendees.

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, 2016
Project year: 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
Add new resources to the Wheat and Small Grains website	Publications, decision support tools and calculators, videos, quizzes, topic forums, etc. Specific deliverables identified include dynamic weed control tables, an ammonium sulfate spray tank calculator, a soil lime application calculator, and three videos on soil acidification as well as several new publications on this topic.	New content in 2016 included three dynamic decision tools: 1) Winter Wheat Herbicide Efficacy Tables, 2) Herbicide Mechanisms of Action (MOA) Tool, and 3) AMS Sprayer Mix Calculator. Three new videos on soil acidification were produced along with new publications on using a pH meter for in-field soil pH sampling, how acid soils interact with root diseases, and a three-part publication on agricultural lime and liming.	New resources will be added every year for the duration of this grant. The specific deliverables identified will be completed in 2016.	The development of new resources will be shared with growers through Timely Topic posts on the Wheat and Small Grains website, news releases, and at education events held throughout the year.
Develop and launch subscription listserv	Subscription listserv	The subscription listserv went live on September 30, 2016. As of January 3, 2017 there were 957 subscribers to the listserv.	The subscription listserv will be available by the end of 2016.	The subscription listserv will be announced to growers through Timely Topic posts on the Wheat and Small Grains website, news releases, and at education events held throughout the year.
Improve the Wheat Academy	A highly relevant and popular program will continue to improve and a means of serving more people without losing program quality will be sought.	Registration for the 2016 Wheat Academy was completed within eight days of opening registration, with 38 industry participants and 37 farmers. This was an increase of 12 farmers from 2015. The registration fee for farmers was reduced to $75 from $100 in 2015 and the price for industry participants was increased to $125.	This will be an ongoing process throughout the duration of the grant.	information on the Wheat Academy will be shared with growers through the Wheat and Small Grains website, through news releases, and other educational events. We will also attempt to make more of the information delivered at the Academy available to people through the website.
Respond to issues of concern as they arise	In-depth educational programs, publications, and decision support tools as called for by the particular issue.	Low falling numbers were a widespread problem in 2016. Growers had many questions on the topic. The Extension Dryland Cropping Systems Team worked with camille Steber, USDA-ARS, the Wsu wheat breeders, WAWG, and the WSDA to provide information on this topic. Four Timely Topics were written and posted to the Wheat and Small Grains website. Through November, these four Timely Topics received nearly 2,500 pageviews. Additionally, a Grain Quality resources page was added to the Wheat and Small Grains website.	This will be an ongoing process throughout the duration of the grant.	Educational resources and programming developed to address issues of concern will be shared with grower sthrough the Wheat and Small Grains website, news releases, and education events held throughout the year.

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

Project #: 4721

Progress Report Year: *2 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 2016 harvest sample analysis is complete. 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 variety rankings 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 Excel template provided 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-16
Project year:	2

Objective	**Deliverable**	**Progress**	**Timeline**	**Communication**
Complete milling & baking analyses	Data set complete	Winter and spring wheat datasets are complete	all tests are complete	internal
Analyzed data set for t-Scores	Grain, Milling, Baking and Overall t-Scores calculated	final data set is being processed	complete in January	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 at the PNW Wheat Quality Council	Meeting with PNW cereal chemists from USDA, WSU, U of I and OSU at the PNW Wheat Quality Council; then communicate results to WGC

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Project #: 4722

Progress Report Year: *2 of 3*

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

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

Executive summary: This WGC support provides for about 3 months of technician time. The additional work is devoted to evaluating breeder samples for quality from 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 wheat 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 2015-Crop were completed and 2016-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) Water, 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-16
Project year: 2

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

Washington Grain Commission: Barley Research Project Report

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

Executive Summary: Significant progress has been achieved within each market class – feed, malting, and food – of barley. Havener, the first hulless food barley release by the WSU Barley Breeding Program which addresses a need for higher yielding hulless varieties with an elevated β-glucan (a heart-healthy soluble dietary fiber) content, continued to perform well. Developed specifically for human consumption, Havener contains 50 to 75% higher β-glucan than common Washington-grown varieties Lyon, Muir, Champion, Bob and Baronesse. Havener has higher yields and test weights across all eastern Washington rainfall zones than the hulless variety Meresse. In addition to Havener, we identified a hulless breeding line, X05013-T1, with even higher β-glucan (~7.5%) than Meresse or Havener (~6.0%), and high yields across a broad spectrum of environments. It is our intention to put this up for full release in February 2017 at the WSU Cereal Release Committee meeting.

Our continued field trials of the imidazolinone (IMI) ***herbicide tolerant feed barley*** germplasm also are coming to fruition. Of the five advanced IMI-tolerant spring barley lines in the Bob background we to the WSU Variety Testing Program in 2015, we selected one, 07M-203, to submit for full release in February 2017. This line is similar in grain yield to Bob, but with added benefit of herbicide tolerance. This has been a major goal of our breeding program over the past several years, and our work here is beginning to pay off. Our continued breeding efforts for an IMI-tolerant spring barley include the development of hundreds of advanced feed, food and malt lines through extensive crossing and utilization of double haploid technology when appropriate to speed the breeding process. Our backcrossed and top-crossed lines continue to show promise and will be the focus of our breeding program to expedite the release of an additional IMI-tolerant barley variety in the near future.

Finally, low protein, high-yielding breeding lines that showed excellent potential for future release of ***malting barley*** lines were identified. Several high yielding breeding lines had low protein (6.3 to 9.5%) and significantly higher yields than both Champion and Baronesse and favorable malting quality traits. Several of these were included in the WSU Variety Testing program, marking the first time in many years where a malting line included in variety testing. They performed well, and are in their third to fourth year of malting quality evaluations. They will also be tested by larger scale micro-maltsters as well as by craft breweries and distilleries in 2017. Our goal is to release the first malting variety in three decades within the next two years. With our industry partnerships and research collaborations, this goal is certainly achievable.

Impact: As relatively newly released varieties, Havener, Muir and Lyon have yet to impact the market. Havener however, due to its enhanced β-glucan contend and increased yield for a hulless barley, farmers and distributors has attracted interest from farmers and industry. Seed of Havener should be available to growers in 2018. Though not a big market class, the hulless food types are sparking interest and have the potential to meet niche markets in the U.S. and abroad. Prices for food barley are often approximately $70/ton higher than feed barley and $20/ton higher than malting barley. Lyon is just starting to be grown on limited acreage, and along with Muir, is attracting attention from growers at field days and meetings, and both varieties are anticipated to make a positive impact on the market in the near future.

Additionally, at present, considerable winter wheat acreage is devoted to the planting of IMI-resistant varieties, which severely hinders spring barley production due to residual herbicide damage and associated plant back restrictions. Our herbicide resistant breeding lines with the potential for varietal release in the near future would have a significant positive impact on barley acreage and production.

Outputs and Outcomes:

Objective	Deliverable	Progress	Timeline	Communication
Objective 1. Continue to develop and release high yielding, spring, two-row feed barley varieties with improved disease resistance, high protein and test weight, and excellent agronomic characteristics.	Development of disease resistant and high yielding feed barley varieties designed to improve upon Lyon and Muir continues to progress.	Muir and Lyon continue to perform well. Lyon topped the 5-location Intermediate Precipitation Zone for yield in 2015 and Muir continues to perform well in low rainfall locations and sets the standard for stripe rust resistance. Experimental lines in our breeding program show potential improvements over these two varieties in terms of yield, test weight and/or protein content, and show excellent promise for future release.	2018 or 2019 for future release or pre-release of a new 2-row, hulled feed variety. 2017 proposed release of a new herbicide tolerant feed variety (see objective 2).	Talks and presentations at multiple field days; WSCIA annual meeting; Cascadia Grains annual conference; distribution of informative variety rack cards.
Objective 2. Continue to expedite the continued	Release one IMI-resistant barley variety during the 20167 winter	2016 pre-release approved in February 2016.Two acres of	2017 anticipated release of the first WSU barley variety with	Talks and presentations at multiple field days.

development and release of barley varieties across feed, malt and food market classes that are highly tolerant to the imidazolinone (IMI) herbicides used in winter wheat production.	Variety Release Proposal Committee Meeting.	our proposed February 2017 release were grown in Othello by Crop Improvement in 2016.	herbicide tolerance	
Objective 3. Capitalize on the leveraged funding from the American Malting Barley Association (AMBA) for malting barley research by focusing on the development of varieties that set new standards for malting quality.	a) Development of malting quality genetics; b)Potential release of a malting barley cultivar	We are finalizing our genome wide association mapping project with malting quality traits. This will be beneficial for the identification and use of markers to select for malting quality traits for both all-malt and adjunct malt market classes.	2017 for GWAS results 2019 for malting barley cultivar release	Talks and presentations at multiple field days, including the inaugural 'Know Barley Know Beer' field and brewery day with farmers, brewers, breeders and maltsters.
Objective 4. Evaluate, select and develop high-yielding, hulless, heart-healthy food barley varieties with elevated levels of beta glucan, protein, test weight, minerals and antioxidants.	2015 release of a hulless food barley, Havener, with significantly higher beta glucan, protein and test weight compared to hulled feed varieties and higher yields and test weight than other hulless varieties.	The food barley market class is in its infancy and very small compared to the malt and feed market classes. We will continue to test over 600 lines each year for beta glucan and are currently conducting a genome wide association study for beta glucan content.	2017 for potential new hulless food barley with high b-glucan release.	Talks and presentations at multiple field days, development of a rack card for Havener. Wheat life article.

Progress Report

Project #: 3675

Progress Report Year: 1 of 3

Title: Enhancing Resistance to Snow Mold Diseases in Winter Wheat

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

Executive summary: In fall 2015, field plots were established at three locations in WA and another near Tetonia, ID to test advanced breeding lines for snow mold resistance and agronomic performance. Development of three new doubled-haploid populations was completed using a new source of resistance, PI 173438, and PNW-adapted lines to expand the diversity of resistance genes. These populations were planted in field plots in fall 2016. Advanced winter wheat breeding lines were also planted at these locations for evaluation in spring 2017. Wheat samples for fructan analysis were collected from field and growth chamber experiments, and methods for the analysis were developed. Analysis of the samples is in progress and data analysis will begin in the first half of 2017. Results of these studies will be used to improve growth chamber screening for resistance. Although we don't expect controlled environment testing to replace field testing, it will allow us to make progress on genetic studies throughout the year and eliminate very susceptible lines from field testing.

Impact: During this funding cycle, data analysis and submission of a manuscript on new QTL and molecular markers associated with snow mold resistance and cold hardiness in the Finch x Eltan population was completed.

Development of three genetic populations with a new source of snow mold resistance PNW-adapted lines. These have potential for introduction of a new source of snow mold resistance in the PNW.

Successful completion of these objectives will provide growers with a greater selection of adapted, high-yielding snow mold-resistant varieties and the development cycle for future varieties will be shorter compared to the conventional methods now used. Results generated in this project are communicated to farmers and field consultants at field days, other meetings, and publications such as Wheat Life. Results are communicated to other scientists directly and through publication in appropriate journals.

WGC project number: 3675
WGC project title: Enhancing Resistance to Snow Mold Diseases in Winter Wheat
Project PI(s): T.D. Murray, A. Carter, D. Skinner, K. Garland-Campbell, J. Marshall
Project initiation date: July 1, 2016
Project year: 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Field test new doubled-haploid populations to identify resistant lines for breeding program, identify new genes and associated molecular markers.	Data on snow mold resistance of genetic populations that will be used to identify new genes and make selections for the breeding program.	Three doubled haploid populations were created in three different backgrounds all using PI173438 as the parent. There are two soft white parents and one hard red parent adapted to the PNW. Populations were planted in Waterville and Mansfield, as well as in Tetonia, ID for snow mold screening. Plots had good stand establishment in the fall, and data will be collected in the spring for snow mold tolerance.	Field testing will be conducted in the spring of 2017 and the spring of 2018. More years of testing may be needed depending on the level of snow mold in each year. The three populations will also need to be genotyped, but because of new developments in genotyping we are waiting to see if new platforms will be developed before genotyping.	Results of this work will be presented at field days, variety plot tours, other grower and industry talks, and on the WSU Wheat and Small Grains website.
2. Field test advanced breeding lines and new varieties to determine their reaction to snow mold diseases.	Provide data on snow mold resistance of advanced selections and new varieties. Expand variety ratings in the seed buyer's guide.	The winter wheat breeding program planted 246 advanced breeding lines for testing in the spring of 2017 under snow mold conditions.	Field plots will be establised in fall 2016 and rated in the spring of 2017 for reaction to snow mold. This will continue each year of the project.	Results of this work was presented at field days, variety plot tours, other grower and industry talks, and on the WSU Wheat and Small Grains website. Data will be used to provide ratings in the seed buyer's guide.
	Prepare an article for Wheat Life during the three-year project summarizing results to date.		An article will be submitted in February 2018.	
3. Measure fructan concentrations in winter wheat crowns of breeding populations and identify genes involved in its production to determine their association with snow mold resistance.	Methods and data that can be used to screen breeding populations efficiently and determine whether fructan accumulation can be used to indirectly select for resistance to snow mold diseases.	Samples were collected in 2016 from both field and growth chamber experiments. Sample preparation has been completed, and are now being run to determine fructan concentrations in the different lines. Data should be ready for analysis in early 2017. These lines have also been screened for cold tolerance and snow mold tolerance in order to correlate results. Two populations are being screened. One looking at different levels of cold and snow mold tolerance between lines, and the other is a set of isolines varying for the VRN alleles.	Multiple years of data will be needed to reach conclusions, so this work will be conducted each year of the project. Growth chamber plants were harvested in 2016 and will continue into 2017. Field collections are ongoing through 2017.	Results of this work will be presented at field days, variety plot tours, and other grower and industry talks. When completed, results will be published in Wheat Life, scientific journals, and the WSU Wheat and Small Grains website.

4. Establish protocols for screening large numbers of breeding lines for snow mold resistance under controlled environment conditions.	A method of screening for snow mold resistance in growth chambers.	Waiting for results from fructan studies to identify critical environmental conditions to idenify resistance.	Growth chamber experiments to measure fructan accumulation will begin in 2016 and continue each year of the project.	Results of this work will be presented at field days, and other grower and industry talks. When completed, results will be published in Wheat Life, scientific journals, and the WSU Wheat and Small Grains website.

Progress Report

Project #: 3682

Progress Report Year: 1 of 3

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

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

Executive summary: Resistance of 44 winter wheat varieties and advanced breeding lines to eyespot and Cephalosporium stripe was determined under field conditions. Summaries of this data were provided to breeders who contributed entries and made available through the WSU Wheat and Small Grains Extension website (smallgrains.wsu.edu). The data from these plots are used to provide disease ratings in the Washington State Crop Improvement Association Seed Buyers Guide. A field plot was established near Ritzville, WA in spring 2016, but later abandoned due to inadequate eyespot disease and too much dryland foot rot to provide meaningful results. A seed treatment trial was planted in fall 2015, disease evaluated and yield determined in summer 2016. Spore-traps were established at the Palouse Conservation Field Station and Spillman Farm to understand the seasonal dynamics of ascospore release, which may contribute to pathogen genetic variation. Field studies were begun to determine the impact of variety mixtures on impact of eyespot and Cephalosporium stripe in winter wheat production.

Impact: Forty four advanced winter wheat selections and new varieties were evaluated for their resistance to eyespot and Cephalosporium stripe. These data were shared with breeders and used to assign ratings in the WSCIA seed buyer's guide for use by growers in making variety selection decisions. Currently, the gene present in Madsen is the primary source of resistance in all other eyespot-resistant varieties. New genes are needed for eyespot resistance to improve effectiveness, further reduce losses to this disease and broaden the genetic base of resistance available to breeders. Developing a better understanding of genetic variation in the eyespot and Cephalosporium stripe pathogens is a long-term goal that will help insure resistance genes remain stable and effective.

WGC project number: 3682
WGC project title: Control of Eyespot and Cephalosporium Stripe in Winter Wheat
Project PI(s): T. Murray, A. Carter, K. Garland-Campbell
Project initiation date: July 1, 2016
Project year (X of 3-yr cycle): 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Evaluate advanced breeding lines and new varieties for resistance to eyespot and Cephalosporium in field plots	Provide unbiased data on the resistance reactions of advanced selections and new varieties to eyespot and Cephalosporium stripe.	Forty-four breeding lines and advanced selections were established in field plots and inoculated in fall 2015. Disease evaluation was conducted on both plots in June 2016. Yield data were not taken due to extensive lodging in both plots that was not related to disease resistance and would have led to misleading results.	This is the last year of variety testing in this funding cycle.	Results from these plots will be presented at field days, variety plot tours and other talks to grower and industry groups, and availble online at the Extension Small Grains Team website.
	Prepare an article for Wheat Life during the three-year project summarizing results.	No progress in 2016.	Submit an article in 2017 or 2018.	
2. Evaluate currently registered and potential new fungicides for eyespot control and yield loss in field plots	Provide data that will help growers and field consultants make decisions about whether and which fungicide to use in controlling eyespot by testing fungicides registered for eyespot control in multiple locations in eastern WA.	A field plot was established near Ritzville, WA in spring 2016, but later abandoned due to inadequate eyespot disease and too much dryland foot rot to provide meaningful results. A seed treatment trial was planted in fall 2015, disease evaluated and yield determined in summer 2016.	This is the last year of fungicide testing in this funding cycle unless the agchem industry provides support.	Results from these plots will be presented at field days, variety plot tours and other talks to grower and industry groups, and availble online at the Extension Small Grains Team website.
3. Evaluate eyespot pathogen populations for resistance to new fungicides	Develop data on sensitivity of the eyespot fungi to new fungicides, especially the active ingredients in Priaxor.	Preliminary in vitro tests were conducted, but methods need to be refined further before general screening of isolates can begin.	This work will begin in fall 2016 or spring 2017, but not complete until the end of the project.	Results of this research will be presented at field days, variety plot tours and other talks to grower and industry groups, and availble online at the Extension Small Grains Team website. Results also will be published in appropriate scientific journals.
4. Screen wild wheat relatives for potential new sources of resistance genes	Identify potential new eyespot resistance genes for use by breeders to improve effectiveness of resistant varieties.	No activity in 2016. Inoculum is being produced now to screen a Madsen population being mapped for cereal cyst nematode resistance to determine the relationship between these genes. Repeat tests of some wild species is anticipated during 2017 to confirm previous results and identify potential donors for genetic studies.	This work will begin in fall 2016 or spring 2017, but not completed until the end of the project.	Results of this research will be shared with breeders, presented at field days, variety plot tours and other talks to grower and industry groups. Results also will be published in appropriate scientific journals.
5. Determine impact of pathogen genetic variation on disease epidemiology, especially the eyespot pathogens, to insure resistance genes remain effective	Develop molecular and microbiological data describing genetic variation in the eyespot and Cephalosporium stripe pathogens and its potential effect on disease control using resistant varieties .	Molecular markers were developed for one of the eyespot fungal species during 2015. Marker development for the other eyespot fungus and *Cephalosporium gramineum* are in progress, but limited progress was made in the second half of 2016 due to personnel turnover. Spore-traps were established at the Palouse Conservation Field Station and Spillman Farm to understand the seasonal dynamics of ascospore	This is a long-term objective and work will be completed each year of the project.	Results of this research will be shared with breeders, presented at field days, variety plot tours and other talks to grower and industry groups. Results also will be published in appropriate scientific journals.

Evaluate mixtures of resistant/tolerant and susceptible varieties in field plots for their impact on eyespot and Cephalosporium stripe.	The potential effectiveness of variety mixtures in controlling eyespot and Cephalosporium stripe will be determined. This is particularly important for Cephalosporium stripe where varieties with highly effective resistance are not available.	Field plots were established in Fall 2015 on the Plant Pathology Farm (eyespot) and Palouse Conservation Field Station (Cephalosporium stripe) to determine the effect of mixtures on each disease. Each plot contains two reistant/tolerant and two susceptible varieties planted separately and in all possible combinations. Plots were inoculated in November and disease severity and yield determined in summer 2016. Data are being analyzed now.	Multiple years of data are needed to reach conclusions, so this work continue each year of the project.	Results from these plots will be presented at field days, variety plot tours and other talks to grower and industry groups, and availble online at the Extension Small Grains Team website.

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Project #: 3061-5746

Progress Report Year: 2 of 3

Title: Pre-breeding for Root Rot Resistance

Researchers: Scot Hulbert, Pat Okubara

Cooperators: Timothy Paulitz, Deven See, Karen Sanguinet

Executive summary:

The aim of this project is to characterize resistance or tolerance to *Rhizoctonia* and other green bridge-promoted diseases identified from five synthetic wheat lines and transfer the resistance to the cultivar Louise. We have now developed several backcross two (BC2) lines for each of the five sources. In the past year all of the BC2 lines were amplified and tested in a field trial in a Pullman site with disease pressure from a green bridge environment. All but two of the 43 lines yielded better than Louise in this trial. Preliminary yield trials were also conducted at the Wilke and Lind farms, but seed was limited. The trials allowed us to discard most of the lines that carried poor traits, like late maturity and poor test weight, from the resistance donor parents. We now have a set of 15 lines, three from each resistance source that we will thoroughly evaluate in 2017. In year 2 of the project, we also completed field resistance evaluation of two large populations of BC1-F5 derived lines from the CIMMYT 3104 and Syn172 sources. The resistance of these lines has also been evaluated in greenhouse assays, but the evaluation of the second population is not yet completed. In collaboration with Deven See, several hundred genetic markers were scored on the CIMMYT 3104 x Louise population using genotype by sequencing (GBS) in the past year. The marker data was then used to create a genetic map on which to integrate the resistance data. Genomic locations (QTL) on three chromosome arms were identified in which resistance from the CIMMYT 3104 parent mapped. GBS mapping of the Synthetic 172 x Louise population has been initiated will be completed in 2017/2018. We are testing for root growth traits that can be used to predict root rot resistance, with the hope that future breeding efforts will not have to rely on the green bridge assay.

Impact:

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

WGC project number: 5746
WGC project title: Pre-breeding for Root Rot Resistance
Project PI(s): Scot Hulbert & Pat Okubara
Project initiation date: July 1, 2015
Project year: Report for year 2 of 3

Original Objectives	Deliverable	Progress	Timeline	Communication
1) Advance resistance in our five top synthetic wheat lines and test BC2 derived lines from each of the five sources of resistance in multi-location yield trials to determine which resistances provide the best benefits in different types of field environments.	A set of novel Rhizoctonia/ green bridge associated disease resistant lines that can be used to develope PNW spring wheat cultivars.	Multiple (four to 13) BC2 lines from each of the five sources of resistance were selected and amplified this year. Replicated plots were examined in two locations in 2016.	final tests on performance of the advanced lines will be conducted in 2017/2018 at multiple field sites, greenhouse and lab tests.	Progress will be reported at the wheat research review and the Cook Chair review. A germplasm release article will be written in 2018 and the lines will be released to breeders.
2) Map the resistance genes to identify linked DNA markers.	Chromosomal locations and markers for the genes controlling resistance to assist future breeding efforts.	Mapping genes from the CIMMYT 3104 parent is completed and the Syn172 parent in progress.	Genes for resistance from both parents will be complete in 2018.	An article was published in 2016 in the journal Phytopathology and a second will be submitted in 2017. Results were presented at an international wheat conference in 2016.
3) Develop rapid greenhouse assays for Rhizoctonia resistance to reduce time from 14-21 days to 7-10 days, and with less resources.	A more rapid and economical means of selecting and advancing *Rhizoctonia* resistant plants.	This objective has been completed.	This objective has been completed.	A manuscript by Okubara et al. has been published in Plant Disease.
4) Characterize and compare root morphology traits correlated to resistance in advanced lines from each of the five sources of resistance.	Information on whether the synthetic wheats carry true resistance or tolerance, and how similar or unique root morphology traits are in two mosted advanced of the five sources of resistance in the Louise background.	Rigorous and reproducible assays for monitoring root growth variables were developed, and BC2 derived lines have been developed.	Deliverables will be produced at the end of FY18.	In FY16, results were reported at a regional meeting of the American Phytopathological Society and in the WSU Dryland Field Day Abstracts.

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(Begin 1 page limit)
Project #: 3061-7667
Progress Report Year: *1 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

Executive summary:

- In 2016, we surveyed 50 locations in Walla Walla, Garfield, Columbia and western Whitman counties. Cysts were identified to species level with DNA techniques developed in previous. *H. filipjevi* was only found in southern Whitman County, and *H. avenae* in eastern Whitman County. No cysts were found in other locations.
- In Spring 2016, we used a high throughput greenhouse technique to screen 216 advanced lines from 4 breeding programs at WSU for resistance to *H. filipjevi*. This method uses soil collected from highly infested fields in spring. In the past 6 years, screening has been done in an infested field in Colton, which limits the number of varieties that could be screened, and was mainly used for screening the regional nurseries. For the first time, we also initiated screening for *H. avenae* in the greenhouse.
- We also developed a method for collecting soil in the fall, vernalizing in the cold room at 4 C, and starting screening in Feb. We found that cysts remained viable and hatched for at least a year, and were successful in getting infection in Aug. 2016 from soil collected in Oct. 2015. This will allow us to do additional screening in the winter and summer.
- From this screening, ARS Crescent and ARS Selbu continue to show resistance to *H. filipjevi* and 8 advanced breeding lines with resistance were identified from the Campbell program. From the Carter program, 2 soft white and 2 hard red breeding lines were identified with resistance, in addition to Jasper, Azumut and WA 8206. From the Morris soft durum program, Svevo, Soft Strongfield and two selections of Soft Alzada were resistant. No resistant lines were identified in 2016 from the Spring Wheat Program of Pumphrey.
- Because of lower inoculum densities of *H. avenae*, resistance assessments were not as conclusive as with *H. filipjevi*, but a number of potentially resistant lines were identified in all programs.

Impact:

- Because of the higher throughput of the greenhouse screening system, we can now screen material at an earlier stage so breeders can use this information in deciding what crosses to advance. We have identified many good sources of resistance in the winter material, less with the spring material.We have also identified released winter and spring wheat varieties with resistance to cereal cyst nematode *H. filipjevi*. These varieties may be available to growers in the next 1-2 years, allowing them to reduce the inoculum levels in their fields.
- **What measurable impact(s) has your project had in the most recent funding cycle? Because of the greenhouse techniques that we developed, breeders can now screen more material and are incorporating *Heterodera* resistance into their selections.**

WGC project number: 3061-7667
WGC project title:Management of nematode diseases with genetic resistance
Project PI(s): S. Hulbert, T. Paulitz, K. Campbell
Project initiation date:7/1/2016
Project year:2016-2017

Objective	Deliverable	Progress	Timeline	Communication
Obj. 1 and 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	Completed a fourth year of resistance testing in a field site in Colton, infested with *H. filipjevi.* Screened over 100 lines from the Regional Spring Wheat Nursery. Evaluated lines based on number of white females on the root. Each line was paired with the susceptible "Alpowa" in each 4-row head row. Unfortunately, the field test was not successful because of low levels of infection. We hypothesize that we planted too late, because of the very warm spring conditions, the nematodes had already hatched out. This is the same time we have planted in past years, and we know there was good inoculum in the soil, because soil collected in early April gave good results in the greenhouse.	Have completed field testing of adapted varieties against *H. filipjevi* . This field will be cropped in bluegrass next year, so field testing will not be possible. We will put all our effort into greenhouse screening in the future	Manning-Thompson, Y,Thompson, A., Smiley,R., Paulitz,T., Garland-Campbell, K., 2016. Cereal Cyst Nematode Screening in Locally Adapted Spring Wheat (*Triticum aestivum* L.) Germplasm of the Pacific Northwest, 2015. Plant Dis Manag. Rep. 10:N003
	Germplasm rated for resistance to CCN	We developed a method for collecting soil in the fall, vernalizing in the cold room for 4 C, so we can start screening in Feb. We found that cysts remained viable and hatched for at least a year, and were successful in getting infection in Aug. 2016 from soil collected in Oct. 2015. This will allow us to do additional screening in the winter and summer months. Using this method, the following crosses were identified with resistance to *H. filipjevi:* HRSWQ033-0-0-0-1, SWW10111-DH-32, SWW10111-DH-54-s, SWW12120-DH-1-2, SWW12160-DH-1-10, and SWW12336-DH-1-4	Testing in field will be discontinued in 2017, but greenhouse testing will be used to test crosses and populations made with CCN resistant parents and locally adapted varieties.	
	High throughput greenhouse screening of both advanced and early crossing material from double haploid program.	216 advanced lines from 4 breeding programs at WSU for resistance to *H. filipjevi* in spring 2016. ARS Crescent and ARS Selbu continue to show resistance to *H. filipjevi* and 8 advanced soft elite advanced lines with resistance were identified from the Campbell program (DH08X028-106-0,DH08X028-111-0,DH08X028-193-0,DH08X028-26-0,X010730-6L, X20060123-0-31C, and X20060126-0-35C). From the Carter program, 2 soft white (SWW10106-DH-1-s and SWW10111-DH-54-s) and 2 hard red (HRW11132-1-DH-14-4 and HRSW0026-0-0-2) lines were identified with resistance, in addition to Jasper, Azumut and WA 8206. From the Morris soft durum program, Svevo, Soft Strongfield and two selections of Soft Alzada were resistant. No resistant lines were identified from the Spring Wheat Program of Pumphrey.	Continue greenhouse testing of varieties in Winter and Spring, 2017. Goal is to test all WSU winter and spring varieties that are in variety testing trials.	
	Greenhouse pot cultures of *H. filipjevi* and *H. avenae*	Ideally, instead of relying on naturally infested soil collected in the field, we should produce inoculum in the greenhouse. Because the nematode can only reproduce on living plants, this involves infecting plants in large pots, harvesting the soil after two months, and vernalizing it to induce the nematodes to hatch.	We were successful in creating pot cultures from infested field soil in summer, 2016. The soil has been vernalized and will be tested to look at hatchability and make sure the cultures do not have mixed species.	
Obj. 3. Conduct surveys for CCN	Maps of CCN around **all** of Eastern and Central Washington	From 2013-2015, we surveyed 210 fields in eastern Washton and the Palouse. In 2016, we surveyed 50 locations in Walla Walla, Garfield, Columbia and western Whitman counties. Cysts were identified to species level with DNA techniques developed in previous. *H. filipjevi* was only found in southern Whitman County, and *H. avenae* in eastern Whitman county. No cysts were found in other locations.	The species-specific survey for the Palouse has been completed. However, other areas of eastern Washington and possibly northern Idaho should be surveyed. In addition, we should use methods that have the ability to pick up mixed populations of the two species.	Paulitz, T. C. 2016. "Root Disease Research at ARS Pullman-What's New?" Spokane Farm Forum, Ag Expo, Feb. 3, 2016. (presentation).
Obj. 4. 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.	Germplasm with resistance/tolerance to root lesion nematode.	Backcross populations with AUS28451 as a resistance source are being selected. A mapping population has been created, and seed was increased in the field this year.	Lines will be tested in the field at Spillman in 2017.	Thompson, AL, Mahoney, AK, Smiley, RW, Paulitz, TC, Hulbert, S, Garland-Campbell, K, 2017, Resistance to multiple soil-borne pathogens of the Pacific Northwest is co-located in a wheat recombinant inbred line population. Submitted to G3.

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

Project #: 3019-3564
Progress Report Year: _2___ 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, Chris Mundt, OSU; Grant Poole, Syngenta.

Executive summary:

- We screened the 2015 and 2016 WA winter soft winter wheat variety trials adapted 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. 23 lines were significantly more 23 genotypes were significantly more tolerance to FCR compared to the susceptible check, 'Madsen' ($\alpha = 0.05$). No genotypes were significantly less tolerant to FCR than 'Madsen' ($\alpha = 0.05$).
- The nine genotypes with the best tolerance were Xerpha, 04PN096-2, IDN01-10704A, ARS20060126-35C, Eltan, 09PN062#18, LOR-334, KWS-034, LWW14-71195.
- We rated naturally inoculated field screening trials at Reardan, Creston, Lamont, Ritzville, Mansfield, Harrington, and Connell.
- There were positive correlations among genotype FCR ratings between Lamont and Ritzville, Reardan and Harrington, and Lamont and Harrington. These locations are close to each other in distance near the Channeled Scablands of Eastern Washington, and are all in rainfall zones of less than 406 mm yr^{-1}
- Correlations between field and greenhouse screening trials were weak, likely because the field trials had mixed populations of soil borne disease. This is likely due to the presence of other pathogens, variation in soil type, FCR disease severity and climatic factors. The pathogen most likely to cause a discrepancy in field screening is Eyespot, caused by *Ocumacula* spp., which is widely distributed in the dryland wheat areas of the Pacific Northwest. The root symptoms are similar, except that eyespot also causes characteristic 'eye-shaped' lesions on the stems
- We repeated these trials in the greenhouse and collected stems from additional locations to rate the incidence of eyespot to determine where mixed infections were prevalent.
- The spring wheat mini-core collection, developed from the Spring wheat germplasm of the National Small Grains collection was rated in the greenhouse for resistance to FCR. Association mapping for FCR resistance will be conducted in 2017 to identify new sources of resistance.
- A population segregating for resistance to lesion nematodes also has resistance to Fusarium and a QTL for resistance to multiple soil borne diseases was identified on chromosome 5A, derived from the wild wheat breeding line.

Impact:

- New sources of resistance have been identified. We are combining sources of resistance in winter wheat
- Development of resistant varieties will reduce losses from Fusarium crown rot and improve the economic and environmental sustainability for Washington growers
- The main goal is to provide genetic resistance to common soil borne diseases present in the Intermountain wheat growing area.
- Mixed infections of FCR and Eyespot means that breeding efforts must be dedicated to both pathogens. Our additional goal is to separate genetic resistance to FCR from genetic resistance to Eyespot so that we can better select for resistance to both pathogens.

Communication

Refereed papers

Thompson, AL, Mahoney, AK, Smiley, RW, Paulitz, TC, Hulbert, S, Garland-Campbell, K, 2017. Resistance to multiple soil-borne pathogens of the Pacific Northwest is co-located in a wheat recombinant inbred line population. In press..

Abstracts

Thompson, Y.A., Garland-Campbell, K.A., Paulitz, T.C., 2016. Differential Response of Wheat (Triticum aestivum L.) to Fusarium culmorum. Crop Science Soc. of America Annual Meeting, Phoenix AZ, Nov. 2016.

Larkin, D., Paulitz, T.C., and Garland-Campbell, K.A., 2016. Comparison of Greenhouse and Field Rating Systems for Fusarium Crown Rot in Winter Wheat (*Triticum aestivum* L.). Crop Science Soc. of America Annual Meeting, Phoenix AZ, Nov. 2016.

Larkin, D., Paulitz, T.C., and Garland-Campbell. K.A., 2016. Comparison of Greenhouse and Field Rating Systems for Fusarium Crown Rot in Winter Wheat (*Triticum aestivum* L.). National Assoc. of Plant Breeders. Aug. 2016. Raleigh NC.

Popular Press

Web

Presentations

WGC project number:	**3019-3564**
WGC project title:	**Fusarium Crown Rot on Wheat: Prebreeding and Development of Tools for Genetic Disease Management**
Project PI(s):	**M. Pumphrey, K. Garland-Campbell, and T. Paulitz**
Project initiation date:	**7/1/2015**
Project year:	**Year 3**
What measurable impact will your project have in the next three years?	**A list of the most tolerant and susceptible varieties in current use.**

Objective	Deliverable	Progress	Timeline	Communication
Objective 1. Perform association mapping on spring and winter core collections to identify further sources of resistance.	Resistant sources that can be used for variety development.	A mini-core collection was developed for the spring core collection. Phenotyping and screening of mapping population in the greenhouse has been completed.	Greenhouse screening (phenotyping) completed. Association mapping still needs to be done.	Articles in Wheat Life, grower presentations, abstracts, conference proceedings, refereed scientific articles
Objective 2. Screen all variety and regional nurseries for resistance in greenhouse screening.	Ratings of varieties for Fusarium tolerance in the the WSCIA seed buyers guide and other publications.	WSU winter variety trials are being screened in the Wheat Plant Growth Facility. We completed screening the complete winter wheat soft variety collection in both 2015 and 2016.	Ongoing, every year. Completion of that year's greenhouse trials by August.	Articles in Wheat Life, grower presentations, abstracts, conference proceedings, refereed scientific articles
Objective 3. Expand field testing to two locations, and test variety and regional nurseries. Evaluate new seed treatments, since there is little information on how seed treatments may protect against this disease.	Ratings of varieties for Fusarium tolerance in the the WSCIA seed buyers guide and other publications. Evaluation of seed treatment chemicals for efficacy against Fusarium crown rot.	Because of the widespread incidence of Fusarium crown rot in field locations in 2015, we sampled from WSU winter variety trials at Reardan, Creston, Ritzville, Harrington, Lamont and St. Andrews. We also planted an inoculated winter wheat trial at Mansfield and and inoculated spring wheat trial at Lind. These are currently being rated. Initial results from these trials have identified SY107, ORCF103, and WA8227 with more susceptibility to Fusarium crown rot and Coda, IDN-06-18102A, WA 8202, WB-1070CL, and ARS010679-1C with more resistance to Fusarium crown rot than other lines. We will compare these results to the greenhouse assays to determine how predictive the greenhouse assays are of field results. In 2016, stems were collected from seven variety testing locations in Washington, and are currently being evaluated.	Nursery evaluation will be ongoing with data analysis completed by Jan. of each year following the field trial.	Articles in Wheat Life, grower presentations, abstracts, conference proceedings, refereed scientific articles

Washington Grain Commission

Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: **3019 3574**

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

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

Cooperators: Mike Pumphrey, Nilsa A. Bosque-Pérez

Executive summary:
Hessian fly (HF) infestations continue to cause significant annual yield losses in spring wheat production areas of Washington and neighboring regions of Oregon and Idaho. Hessian fly is in many ways a silent problem. Moderate infestations are not visually striking, and their occurrence is somewhat variable over space and time. Nonetheless, significant reductions in grain yield and grain quality are observed across spring wheat production areas. Factors such as weather patterns, crop rotation, variety selection, and tillage or conservation practices can impact HF pressure. Infestation may also be a significant barrier to increased conservation tillage practices in the Palouse. Advanced breeding lines, new sources of resistance genes H13, H26, and two unknown resistances source, along with mapping population progeny were screened for Hessian fly resistance in 2016. Backcross populations were developed with four new sources of resistance, and progeny selfed to select homozygous resistant lines this winter. The HT080158LU/WA8076 doubled haploid mapping population was used to map a newly discovered Hessian fly resistance gene on chromosome 6A. Winter wheat populations were screened for the first time in many years, to introgress HF resistance into winter wheat.

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

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

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

Objective	Deliverable	Progress	Timeline	Communication
Screen WSU Spring Wheat breeding populations and advanced breeding lines for resistance to Hessian fly in the laboratory	Information on resistance of elite breeding lines on an annual basis	Over 60 spring wheat lines, 12 winter wheat breeding populations, and new entries into the WSU Wheat Variety Testing Program were screened in 2016.	Annually	Progress will be presented by M. Pumphrey and N. Bosque-Pérez at field days, plot tours, at Wheat Research Reviews for individual states. Presentations will be made to the Washington Wheat Commission and WAWG conferences upon invitation. Progress will be reported in Wheat Life magazine and data will be recorded with nursery data.
Continue to incorporate "new" Hessian fly resistance genes into breeding lines	Improved germplasm with useful sources of Hessian fly resistance	Several backcrosses have been made to known (H13, H26) and unknown resistance gene donors, using susceptible elite line "Dayn" as the initial recipient parent. BC3 populations were self pollinated, selected for Hessian fly resistance, and Doubled-haploid progeny were developed from resistant plants. A new resistance gene on chromosome 6A was mapped in an elite doubled haploid population, and DNA marker validation is underway. With these new Hessian fly resistance sources in elite genetic backgrounds, we can now use them more effectively in breeding efforts.	Annually	

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

Project #: 3667

Progress Report Year: ___3_ *of _3___ (maximum of 3 year funding cycle)*

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

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

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

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

Outputs and Outcomes: File attached

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

Objective	Deliverable	Progress	Timeline	Communication
Early to late generation quality testing of WSU experimental lines to aid variety development	New spring wheat and winter wheat varieties that are superior to existing varieties. This effort includes all market classes of spring and winter wheat and all precipitation regions in Washington state.	Over 1500 breeding samples were analyzed by numerous milling and baking quality tests each year from 2014-2016. This is a substantial increase over previous years and has allowed enhanced selection of advanced breeding lines with good quality. Three new wheat varieties were released using this project and data.	The economic return for this work will manifest itself each breeding cycle with superior quality varieties and germplasm.	Progress will be summarized and discussed at numerous field days (>10 per year), grower meetings (~10 per year), the annual Research Review, through WSCIA meetings, Wheat Life, Variety Release Meetings, and direct communication with the WGC every year. Graduate graduate student Kendre Jernigan won the Crop Science Society of America research poster award competion in 2015 summarizing this work.
Support genetic analysis of end-use quality to identify desirable alleles and to predict end-use quality through new genotyping methods	Improved germplasm selection procedures which translate to more efficient, cost-effective, and consistent genetic gain for end-use quality.	Over 400 winter wheat lines that have been genotyped with 90K SNPs were evaluated for milling and baking. Milling and baking analysis of a bi-parental winter wheat mapping population has also been substantially completed. Eleven loci for nine different quality traits were identified in the soft white winter wheat panel and a manuscript is being submitted. This data may also be used to help predict quality before conducting any quality tests. This would be a huge advantage in variety development	The reward for this work will compound each year and will fully be realized for many years to come as these lines continue to be crossed into existing breeding lines. We expect this effort to result in routine selection of outstanding quality wheat.	

Washington Grain Commission

Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: **3019 3676**

Progress Report Year: *_1___ 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 and registered seed of Seahawk (WA8162) soft white, Alum (WA8166) hard red, Chet (WA8165) low rainfall hard red, Tekoa (WA8189) and Melba (WA8193) spring club was produced and sold in 2016. Each variety has very good yield potential, a high level of stripe rust resistance, good-to-excellent end-use quality, and better straw strength compared to existing varieties. Melba club is intended to replace JD in >16" rainfall areas, with significantly shorter height and lower protein. Ryan (WA8214) soft white spring wheat was released in 2016, and we expect broad adoption due to early maturity, shorter height, and top yield performance. Ryan has aluminum tolerance, Hessian fly resistance, excellent rust resistance, and below average protein. Two-gene Clearfield variety candidates performed well in WSU variety testing trials, and we expect a release in the next one-two years.

Impact:
The WSU spring wheat breeding program is in a unique position to focus on grower opportunities and challenges, large and small. We identify and develop traits, technology, germplasm, and released varieties to meet the needs of the majority of Washington producers, whether the needs are localized or widespread. Our latest releases package excellent yields with superior quality and key yield protection traits. Glee hard red spring wheat was again a top performer in >12" through >20" precipitation areas, and was the leading hard red spring by acres in 2016. Diva, Louise, Whit, Babe and JD were collectively planted on the majority of soft spring wheat acres. Our newer releases should command these acres in the future due to improved potential profitability for growers. These varieties were also top performers in 2016 spring wheat variety testing trials. Public wheat breeding programs at WSU and across the country payback consistently on research dollars invested. It is commonly referenced that public wheat breeding programs consistently return > ~60% on investment. With >50% of the spring wheat acres in Washington planted to WSU varieties, growers continue to realize a substantial return on research dollars invested in this program.

Outputs and Outcomes: File attached

WGC project number: 3019 3676
WGC project title: Improving Spring Wheat Varieties for the Pacific Northwest
Project PI(s): Mike Pumphrey
Project initiation date: 2017
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.	Seahawk (WA8162) SWS, Alum (WA8166) HRS, and Chet (WA8165) HRS, Tekoa (WA8189) SWS, and Melba (WA8193) spring club continued to lead yield trials in their classes in 2016, and with greater seed availability, will have a significant positive economic impact for PNW growers. WA8214 SWS (released in 2016 as Ryan) was again a top performer in 2016 Variety Trials. We had excellent test plots across regions in 2016. Good data quality is fundamental to making solid selections.	Recurring annually	WSU Field days, Private company field days, Workshops/meetings/presentations attended/given by Pumphrey: Western Wheat Workers, WSCIA Annual Meeting, WSCIA Board, WA Grain Commission. Annual Wheat Life contributions as requested
Improve PNW spring wheat germplasm to strengthen long-term variety development efforts/genetic gain.	Enhanced germplasm. Consistent genetic gain for many desirable traits.	Multiple stripe rust, aluminum tolerance, Hessian fly, and quality traits were selected in backcross populations for long-term parent building in 2016. Continued development of a two-gene CF germplasm base is starting to really show in the perfromnce of 2 gene lines now entering yield trials. With or without herbicide application, we are seeing lines that beat our elite check cultivars in yield trials. We have specifically focused on irrigated hard red spring wheat germplasm development, and lines from those efforts are now entering yield trials. We have expanded irrigated testing in the program starting in 2016.	The payback for this work will fully be realized for many years to come as these lines continue to be crossed into existing breeding lines. We expect this effort to result in introgression of desirable variation for yield, disease resistance, and other agronomic characters.	

Objective	Deliverable	Progress	Timeline	Communication
Discover/improve/implement scientific techniques and information to enhance current selection methods.	We will continue to leverage the efficiency of the Spring Wheat Breeding Program to enhance traits and research of direct relevance to Washington producers. Current examples that will continue are development of DNA markers for useful sources of Hessian fly and stripe rust resistance, drought and heat tolerance loci, identification of superior germplasm through association mapping, screening for tolerance to aluminum, development of facultative wheat, screening for drought and heat tolerance, development and screening of mutant populations (TILLING) and the development of high-throughput field phenomics selection methods.	Several specific trials and locations were again evaluated in 2016 to help long term breeding efforts. Scientific products of our efforts through multiple projects in 2016 include: 1) Liu, W.. Genome-wide association mapping for seedling and field resistance to Puccinia striiformis f. sp. tritici in elite durum wheat. Theoretical and Applied Genetics, in press. 2) Rawat, N...2016. Wheat Fhb1 encodes a chimeric lectin with agglutinin domains and a pore-forming toxin-like domain conferring resistance to Fusarium head blight. Nature Genetics.doi:10.1038/ng.3706. 3) Turner, M.K..2016. Association mapping of leaf rust resistance loci in a spring wheat core collection. Theor Appl Genet. doi:10.1007/s00122-016-2815-y. 4) Bulli, P....2016. Genetic Architecture of Resistance to Stripe Rust in a Global Winter Wheat Germplasm Collection. G3: Genes|Genomes|Genetics. 6:2237-2253. 5) Wan, A...2016. Virulence Characterization of Wheat Stripe Rust Fungus Puccinia striiformis f. sp. tritici in Ethiopia and Evaluation of Ethiopian Wheat Germplasm for Resistance to Races of the Pathogen from Ethiopia and the United States. Plant Disease. http://dx.doi.org/10.1094/PDIS-03-16-0371-RE 6) Naruoka, Y... 2016. Identification and validation of SNP markers linked to the stripe rust resistance gene Yr5 in wheat. Crop Science. 56:3055-3065. 7). Nasseer, A. M...2016. Impact of a Quantitative Trait Locus for Tiller Number on Plasticity of Agronomic Traits in Spring Wheat. Crop Science. 56:595-602.	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.	

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

Project #: **3677**

Progress Report Year: *___1_ of _3___ (maximum of 3 year funding cycle)*

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

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

Executive summary:

This project is an integral component of the Spring Wheat Breeding program. The objective of this project is to support/enable the most effective and efficient selection procedures for development of superior Washington spring wheat varieties. In addition to routine early-generation grain quality selection carried out through this project, we apply DNA marker technology to elite breeding materials, and are conducting several research projects of direct relevance to our breeding efforts. This project also supports our two-gene Clearfield breeding effort, and expanded irrigated hard red spring wheat efforts, which have progressed nicely. Approximately 2600 early generation lines were evaluated for end-use quality with ~900 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 2016.

Impact:

This project is critical to the spring wheat breeding program and works seamlessly with project 3676. Program efficiency is significantly increased, by evaluating early generation lines for quality and eliminating those with poor quality characteristics before further field testing. This allows for increased testing of superior material in the field program and protects resources from being used to further test lines that are inferior in terms of quality, lack of adequate pest resistance, and numerous other DNA-marker selectable traits. The release of a top performing 2-gene Clearfield spring wheat varieties will be of substantial economic benefit to growers in Washington State by protecting yields where Imazamox or Imazethapyr has been heavily used. Spring wheat varieties with complex stripe rust resistance, Hessian fly resistance, superior end-use quality, and broad adaptation are critical for Washington wheat producers by adding millions of dollars of annual return. *WSU varieties 'Diva', 'Louise', 'Whit', 'JD' and 'Babe' accounted for ~72% of the soft white spring wheat acres planted in the state in 2015*. WSU varieties 'Kelse' and 'Glee' were leading hard red spring wheat varieties in 2015. *In total, >57% of the 2015 Washington spring wheat acres were planted to WSU spring wheat varieties*. Over the past three years, we have released Chet, Alum, Seahawk, Tekoa and Melba. Each variety is high quality, top yielding, pest and disease resistant, and have been accepted and adopted by seed dealers and farmers with increasing acres each year. Our newest soft white spring wheat, Ryan, was released in 2016, is a very exciting release that we anticipate broad adoption.

Outputs and Outcomes: File attached

WGC project number: 3019 3677
WGC project title:Greenhouse and laboratory efforts for spring wheat variety development
Project PI(s): Mike Pumphrey
Project initiation date: 2017
Project year: 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
Develop DNA markers and select breeding lines by marker-assisted selection with stripe rust resistance, Hessian fly resistance, and two-gene Clearfield™ herbicide tolerance as well as other traits when desirable.	Elite variety candidates will result, in part, due to these molecular selection activities. Many of these populations will be ideal for marker optimization, new genetic mapping studies, and potentially the basis of new competitively funded projects.	The Spring wheat breeding program discovered or optimized several DNA markers in 2016, a few of wwhich were published in peer-reviewed scientific journals, and are now being used in our breeding efforts. A new hessian fly resistance gene was genetically mapped, and Clearfield breeding efforts are progressing nicely, with new 2 gene lines entering advanced yield trials each year. Two Wheat Life articles were written/contributed in 2016.	Activities recur annually The two-gene Clearfield™ breeding effort is in full swing, and we anticipate a release in the proposal period. Activities are cyclical and occur annually throughout the normal breeding cycles.	Pumphrey will attended/present at numerous WSU field days, workshops/meetings, PNW wheat Quality Council, WSCIA Annual Meeting (presentation), WSCIA Board Meetings, WA Grain Commission meetings, industry tours.
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. Current analyses include: NIR-protein, NIR-hardness, SKCS-hardness, SDS micro-sedimentation, PPO, and micro-milling.	By Nov 2016, we completed evaluation of ~2500 headrow selections for several end-use quality traits. Over half of selections without superior quality related values were discarded, ensuring very high quality lines are advanced. These have been advanced to a greenhouse generation advance and will be evaluated as F5:6 lines in 2017.	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. In 2015, ~2600 head-row selections were subjected to specific laboratory-based grain quality assays based on market class, and ~900 were retained for single seed descent and 2016 F5:F6 nursery evaluation	

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.	2016 was our busiest year yet, due to expanded greenhouse space and facilities. The addition of the new wheat greenhouse facility expanded our capacity and we were not as limited by plant growth space. Operations have been more timely and efficient, by not waiting on space as long, and planting.	Greenhouse multiplication and crossing is completed annually, including two large crossing blocks and thousands of early generation lines tested for stripe rust and herbicide tolerance.	

Project #: 7768

Progress Report Year: *__2__ of __3__ (maximum of 3 year funding cycle)*

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

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

Executive summary: Dryland farms in eastern Washington routinely experience yield losses due to drought stress. Improving wheat root structure can help to resist such stresses by increasing access to water. The combined issues of drought, no-till practices and the changing pathogen load affect all market classes of wheat and barley. Traditional breeding for wheat and barley has mainly focused on the health of the aboveground parts of the plant. As a result, many modern varieties have small and/or shallow root systems compared to landraces. The primary goal of this research project is to identify root architectures in current breeding populations of both spring and winter wheat cultivars associated with better yield under drought stress. We assessed the root structures of Hollis, Drysdale, Louise, and AUS28451, as well as the 10 best and worst yielding lines from Hollis/Drysdale population in the summers of 2015 and 2016 at the Lind Dryland Research Station. Quantification of the root traits is underway, but preliminary analysis shows differences between cultivars in rooting depth, volume and area. Winter wheat genotypes (*wt, Rht1, Rht2, Rht1 Rht2*) in the Brevor and Golden backgrounds were sown at Spillman Farm in October 2015 and November 2016. Scans were taken after planting and insertion of imaging tubes. All winter and spring cultivars are being measured in pots in the wheat greenhouse; repetition 1 was completed in Spring 2016 and repetition 2 is underway. Once all root traits have been quantified, selected genotypes, cultivars, and RIL and backcross populations will be planted at both Spillman and Lind in 2017 and 2018.

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

WGC project number: 7768
WGC project title: A Genetic Arsenal for Drought Tolerance, Getting to the Root of the Problem
Project PI(s): K. Sanguinet, C. Steber, K. Campbell, T. Paulitz **Collaborator: S. Hulbert, A. Carter**
Project initiation date:7/1/2015
Project year: 2017-2018, year 3

Objective	Deliverable	Progress	Timeline	Communication
1. Characterize the root systems of the five RIL parental lines: Louise, AUS28451, Dharwar Dry, Hollis and Drysdale using a digital in situ root imaging system to measure root traits such as root hair length and density root mass and root depth.	Methods and analysis of two key traits for drought stress: root architecture and lignin content in Louise, AUS28451, Dharwar Dry, Hollis and Drysdale (2017).	We ave successfully imaged Louise, AUS28451, Hollis, and Drysdale in the field in Summer 2015. Serial scans every 3 days for Louise, AUS28451, Drysdale, Hollis, Dharwar Dry, and Alpowa are underway in the wheat greenhouse in the winter 2015-2016. Quantificaiton of root architectural traits are underway using RootSnap! software.	The first round of field trials and quantification of root architecture was completed by the end of 2015. Lignin content measurements will be performed in the greenhouse in winter 2015-16 of the parental lines.	Our findings will be reported in the July 2016 issue of Wheat Life and at the CSA meeting in Fall 2016. In addition, we attended the Lind and Spillman field days in 2015, 2016 and will again in 2017. We will publish a short communication in a peer-reviewed journal regarding our spring wheat work, which will be submitted for review late spring/early summer 2017.
2. Examine the Hollis/Drysdale RIL population to determine if yield under drought and canopy temperature correlate with a specific root trait or traits.	Determine the link between canopy temperature, root architecture traits and yield (end of 2017).	With the aid of Dr. Hulbert, the 10 highest and lowest yielding RIL populations from Hollis/Drysdale RIL populations were sown at Lind in summer 2015. Images were taken every two weeks. We found that the 3 ft. long imaging tubes were too short and need to continue subsequent imaging in the field with 6 ft. long tubes. Nonetheless, informative data were obtained and differences in architecture and rooting depth were obsercved between Hollis and Drysdale. These analyses will be repeated in Summer 2016 at Lind and Spillman.	Field trials will be initiated in both dry and irrigated conditions in summer of 2015 of the parents and will be analyzed again in summer 2016 comparing 10 of the best yielding versus worst yielding RILs. Time and data permitting. This will be repeated again in summer 2017.	Our findings will be reported in Wheat Life and prepared for publication in a scentific journal.
3. Examine backcross lines in the Louise background with specific root traits from AUS28451 including higher root lignin, root depth, root branching, root biomass, and root hair density to improve yield under drought and to select breeding lines with vigorous roots. Also backcross lines of Dharwar Dry to Louise will be analyzed for improved drought resistance and root architecture traits.	Development of breeding lines with increased lignin and root vigor which are predicted to show enhanced drought tolerance (2018-2020).	We have begun analyzing the parental lines. With help from Dr. Garland-Campbell's group, backcrossing to Louise is advancing and we will be evaluating the Louise/AUS28451 advanced BC lines beginning in 2017.	Analysis and selection of backcross lines will commence in summer of 2015. The backcross lines will be further backcrossed to the Louise parent and will undergo several rounds of selection. The timeline for the selection of breeding lines will take 3-5 years.	Our findings will be communicated at field days at Lind and Spillman farms. In addition, we will again prepare a publication for Wheat Life.
4*. Examine root architectural traits in wild type, *Rht1, Rht2* and *Rht1 Rht2* dwarf winter wheat lines in the Brevor and Golden backgrounds.	Development tools and imaging to assess the importance of root growth and the *Rht* alleles on winter wheat cultivars (2017-2018).	With the help of Dr. Carter, *wt, Rht1, Rht2*, and *Rht1 Rht2* lines in the Brevor and Golden backgrounds were sown in October 2015 and November 2016 at Spillman Farm. Imaging tubes were places after sowing. Seeds were be bulked for more expansive testing in Fall 2016-Summer 2017.	Imaging and analysis of root growth of winter wheat (*wt, Rht1, Rht2,* and *Rht1 Rht2* will occur at Spillman Farm Winter 2015 until Summer 2016. A repetion of imaging will occur in the field in Fall 2016 to Summer 2017 to confirm and extend findings in the field. The same lines will be sown in vernalization chambers in the wheat greenhouse followed by growth in the WSU wheat greenhouse (performed Winter 2015-2016 and repeated Winter 2016-2017).	Our findings will be communicated at field days at Lind and Spillman farms, on the small grains website and in a publication for Wheat Life, and will be submitted for publication in a peer-reviewed journal.
Expected impacts over the next 3 years: Previous data has shown that root and shoot traits are not correlated. The proposed research uses *in situ* root imaging techniques to add another metric for selection of breeding lines and determination of the supposed link between deeper rooting, canopy temperature and yield by addressing which root traits (depth, branching, thickness, angle, root hairs, lignin content) most influence yield. Once precise traits and their impact on yield are determined, this provides another tool in the breeding tool box for selection of plant traits that correlate with increased yield particularly in drought or water-limiting conditions.				

The expected outcomes are:

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

*-new objective and outcome for years 2-3.

Washington Grain Commission
Wheat and Barley Research Annual Progress Report

Project #: 5389

Progress Report Year: *_2__ of _3__ (maximum of 3 year funding cycle)*

Title: Developing Washington Wheat with Stable Falling Numbers (FN) through Resistance to Preharvest Sprouting and LMA.

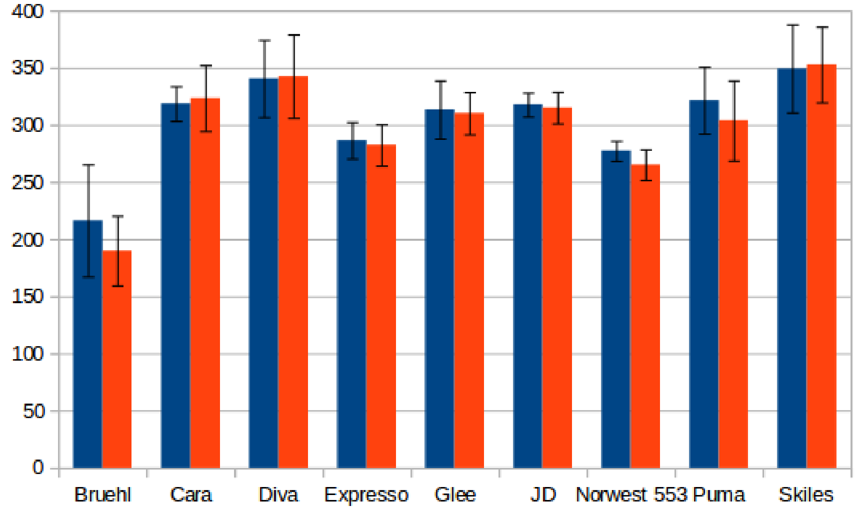
Project PIs: Camille M. Steber, Michael O. Pumphrey, Arron H. Carter
Cooperators: Kimberly Garland Campbell, Ryan Higginbotham, Deven See, Craig Morris

Executive summary: The goal of this project is to breed for stable Falling Numbers (FN) in Washington wheat through selection for genetic resistance to preharvest sprouting and late maturity alpha-amylase (LMA). The previous project identified existing cultivars with sprouting and LMA problems through evaluation of the WSU cereal variety trials. In order to help growers and breeders to make informed decisions, data was made available through a website showing FN relative to yield data from 2013, 2014, 2015, and 2016 (http://steberlab.org/project7599.php). The current project will enable breeders to select for resistance to LMA and PHS by developing and using phenotypic screens and molecular markers.

Objective 1. Screen spring and winter wheat cultivars, breeding, and mapping lines for preharvest sprouting tolerance using the spike wetting test and the Falling Number test.
Please note that many of the Objective 1 accomplishments were funded in part by 5389 and in part by the nonrenewable supplemental project 5333.

A. Characterization of FN. Because FN and spike-wetting tests were not well correlated in 2015, a decision was made to emphasize FN. Locations showing low FN were identified for the winter and spring wheat variety trial locations in 2015, and FN was determined for complete trials at these locations. We are in the process of analyzing FN of the 2016 WSU variety trials (over 2000 data points reported on http://steberlab.org/project7599.php), wheat breeding lines, and mapping lines for association mapping.
B. The effect of fungicide treatment on FN. Preliminary data from the 2016 field season suggests that fungicide treatment with Qulit does not cause a significant decrease in FN (Figure 1). Grain from plants grown in Pullman WA with and without Quilt fungicide treat (14 oz, applied twice and early and late jointing) were obtained from Dr. X. Chen. Based on ANOVA analysis, fungicide treatment did not have a statistically significant effect on FN in five winter wheat cultivars and in four spring wheat cultivars. The chart below shows average FN (n=4, error bars show standard deviation) for the untreated control (blue bar) and the fungicide treated (red bar) samples. This experiment was performed using varieties with stripe rust resistance. Previous publications suggested that fungicide treatment may increase the likelihood of lower FN due to LMA in stripe-rust-susceptible cultivars because dead plants don't respond to temperature shock.

Figure 1. FN with (red) and without fungicide (blue) treatment.



C. The effect of storage on FN. The FN of winter wheat breeding lines was measured in July and again in December following storage at room temperature. On average over 19 varieties, there was an increase of 38 seconds in FN over 5 months. All but one cultivar showed an increase in FN. That one line showed a 2 second decrease.

Objective 2. Improve screening for LMA susceptibility to prevent release of susceptible spring and winter varieties.

A. Cut-spike LMA testing. Greenhouse LMA testing is slow and requires considerable growth chamber space for cold treatment of whole wheat plants. LMA experiments were performed with a more efficient "cut spike" protocol for field-grown wheat. Screening detected LMA-susceptible winter breeding lines. Field cut spike experiments detected known LMA susceptible lines, but appeared to over-predict the number of LMA susceptible lines. Field cut spike assays will enable us to perform the large scale screening needed for association mapping, but will need to be confirmed by other methods.
B. 96-well alpha-amylase tests. In the greenhouse LMA test, alpha-amylase activity is detected using the Phadebas assay. In 2016, this assay was adapted into a 96 well format which greatly improves the speed of LMA testing. This also allowed us to perform faster half-seed assays to determine if low FN in the field trials were due to sprouting or to LMA.
C. Half seed assays. Half-seed alpha-amylase assays were used to determine if low FN in the field is due to LMA or sprouting. When grain is sprouted, the alpha-amylase levels are much higher at the germ/embryo end of the grain than at the brush end. Using the 96-well method, we were able to characterize the cause of low FN in the Pullman and in the Anatone 2016 Cereal Variety Trials. Surprisingly, it appears that most of the low FN was due to LMA rather than to sprouting at these two locations. For example, only 4 of 16 low-FN varieties from Anatone appeared to be sprouted based on half seed assays.

Objective 3. Identify molecular markers linked to sprouting and LMA resistance and susceptibility genes by association mapping.

A. Genome-Wide Association Mapping for Preharvest Sprouting. Preliminary association mapping identified molecular markers linked to preharvest sprouting susceptibility/tolerance in winter wheat. Mapping was performed using both spike wetting tests and FN on the same mapping population. Spike wetting tests did not detect many of the sprouting tolerance loci detected by FN. This suggests that if we want to breed for stable FN we will need to continue running FN assays instead of relying on the less labor-intensive spike-wetting tests. The table below shows molecular markers significantly associated with resistance to preharvest sprouting based on the spike-wetting test, and with higher FN. A single locus on chromosome 6A accounting for 12% of the variation was associated BOTH with higher FN and with sprouting tolerance based on the spike wetting test.

Trait	Marker	Chrom	Position cM	Nominal p-value	MAF	Allelic effect	Environment
Spike Wetting Test	64868	1B	431.21	3.20E-07	0.15	-0.31	CF 2014
	41233	2A	158.02	1.53E-06	0.40	-0.11	Pul 2015
	7652	2D	140.14	2.10E-09	0.37	-0.42	CF 2014
	75777	3A	355.57	2.45E-08	0.07	-0.40	CF 2014
	48693	3B	250.27	1.73E-07	0.47	-0.21	CF 2014
	22512	6A	190.32	8.39E-06	0.34	0.12	Pul 2015
Falling Number	81042	1B	240.55	1.10E-08	0.17	6.93	Pul 2015
	65377	2B	308.30	7.24	0.01	-46.82	Pul 2013
	47123	5D	514.36	6.28	0.37	11.28	Pul 2013
	46863	6A	190.39	6.71	0.42	-12.24	Pul 2013
	75568	7A	372.48	12.62	0.41	-10.26	CF 2014
	75568	7A	372.48	12.31	0.41	-7.64	Pul 2015

B. Genome-Wide Association Mapping for LMA. Preliminary examination of variety trial lines did not find a significant association of LMA resistance with known SSR molecular markers on chromosomes 3B and 7B. Based on this it is important to perform association mapping using not SSR markers, but SNP markers. The spring TCAP population was subjected to LMA-induction in the field in 2016. We are currently performed greenhouse LMA experiments with the same TCAP population. Results should be available at the end of year 3.

Impact: Wheat in all market classes is dramatically discounted for low falling numbers (below 300s). Moreover, a consistent problem with low FN could damage the reputation of Washington wheat in foreign markets. Screening for low FN, LMA, and sprout-susceptibility will the selection of new varieties with more stable FN. Posting of FN data on the pacific northwest FN website makes this data available to farmers and to breeders.

WGC project number: 5389
WGC project title: Developing Washington Wheat with Stable Hagberg Falling Numbers
Project PI(s): C. Steber, M. O. Pumphrey, A.H. Carter
Project initiation date: 07/01/15
Project year: year 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Screen spring and winter wheat cultivars, breeding, and mapping lines for preharvest sprouting tolerance using the spike wetting test and the Falling Number test.	Knowledge about the susceptibility of spring and winter wheat cultivars and breeding lines to preharvest sprouting based on the spike-wetting test and on to FN (2015, 2016, 2017). Selection of breeding lines with higher resistance to preharvest sprouting compared to current varieties.	**Year 1**. Completed FN testing for the 2014 variety trials (see steberlog.org/project 7599). Conducted spike wetting tests of winter wheat breeding lines from the 2015 field season. Identified locations with low FN problems in 2015 by FN testing of known susceptible spring and winter wheat lines. Generated 571 FN datapoints for locations with low FN problems. **Year 2.** Performing FN testing of the entire WSU Cereal Vairety trail with the help of supplemental funding from project 5333. We have generated 2340 datapoints since August. We have also examined the effect of fungicide treatment and storage on FN.	Year 1, 2, and 3. Spike-wetting tests and FN testing of breeding lines, association mapping lines, and affected variety trial locations.	Results were communicated through the project website: steberlab.org/project7599.php, a Wheat Life article published in 2016, Timely Topic articles on the Small Grains website, an extension facts article published at pubs.wpdev.cahnrs.wsu.edu/pubs/fs242e , abstracts submitted to the Lind and Spillman Field Days, talks at the Wheat Research Review in 2015 and 2016, 2015 and 2016 Wheat Academy presentations, a presentation to WSCIA in 2016, talks at 2016/17 growers meetings in Spokane, Connell, and Fairfield WA, and in Pendleton OR.
2. Improve screening for LMA susceptibility to prevent release of susceptible spring and winter varieties.	Knowledge about the susceptibility of spring and winter wheat varieties and breeding lines to LMA. Breeding of LMA resistant wheat.	**Year 1**. Compared the field cut-spike LMA testing with greenhouse LMA tests. The field cut spike assay detects known LMA susceptible lines, but may score mistake soem LMA resistant lines for susceptible lines. **Year 2.** Performed LMA screening of winter and spring wheat breeding lines in the field. Based on FN and LMA testing data, winter LMA suspects include, Jasper, SY-Ovation, Bruehl, WA8202, 4J071246-1C, and Rosalyn. Spring wheat LMA suspects include Alturus, ARS504174, WB6341, IDO851, IDO854, Nick, UI-Stone, and WA8124.	Year 1. Perform LMA testing using both the established greenhouse and new field-based technique. Determine if the field technique gives the similar results to greenhouse. Year 2 and 3. LMA testing of breeding lines and spring association panel.	same
3. Identify molecular markers linked to preharvest sprouting resistance and susceptibility genes by association mapping	Molecular markers for use in early selection for increased preharvest sprouting tolerance.	**Year 1**. Molecular markers linked to preharvest sprouting tolerance were identified based on Falling Number and spike wetting test data. The genes/loci identified by Falling Number were not identical to those identified by spike wetting test. This suggests that we need to continue to emphasize FN data when making selections in the breeding programs. **Year 2.** Identified a locus on chromosome 6A linked to preharvest sprouting as measured both by FN testing and spike-wetting tests. Performing LMA testing of the spring wheat association mapping panel to identify LMA-susceptibility genes.	Year 1. Perform association mapping to identify loci linked with PHS tolerance. Year 2 and 3. Perform field LMA tests in preparation for association mapping. Year 3 perform LMA association mapping.	same

Project #: 126593

Progress Report Year: *2 of 3 years (maximum of 3 year funding cycle)*

Title: Intelligent Prediction and Association Tool to Facilitate Wheat Breeding

PI: *Dr. Zhiwu Zhang*

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

Executive summary: *We had two major accomplishments each corresponding a publication in this year. One was that we developed a golden standard to evaluate accuracy of genomic selection without bias. The results were published in 2016 by Briefings of Bioinformatics. The other was that we developed a software for breeders, iPat (integrated Prediction and Association Tool). iPat has a friendly Graphic User Interface (GUI). The GUI allows breeders to perform data analyses without any programming requirements. The software was written in Java to adapt any third-party software packages in R, including our newly developed packages of FarmCPU and GAPIT for genome-wide association studies and genomic selection. GAPIT serves as one of the iPat engines with two new statistical methods implemented. The new version of GAPIT was also published in 2016 by academic journal, Plant Genome.*

Impact: *Implementation of our research findings creates the opportunity to efficiently develop varieties with high yield, high quality, and resistance to biotic and abiotic stress. In short term, breeders have more confidence to eliminate lines with low genetic potentials to reduce the cost of field trials. In long term, breeders have more chances to retain the genetic lines with desirable genes, and recombine them to create superior varieties. In our previous funding cycle, we established pipeline to conduct genomic selection and evaluate prediction accuracy by cross validation. In recent funding cycle, we developed the golden standard for cross validation that allow the evaluation of prediction accuracy without bias. In recent funding cycle, we also developed software with friendly graphic user interface that allow breeders to conduct data analyses without any programming requirements. With this computing tool, breeders are able to access data and variety of statistical models and visualized analytical results and make decisions for molecular breeding.*

WGC project number: 126593

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

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

Project initiation date: 1-Jul-15

Project year: 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
2) Enhance statistical software usability with a user-friendly graphic interface	IPAT with graphic user interface for wheat breeders	a) We developed a golden standard to evaluate accuracy of genomic selection without bias. b) We developed the new version of GAPIT that implemented two new statistical methods for genomic selection with improved accuracy of prediction. Real data have been analyzed the improvements have been demonstrated through cross validation. c) We developed a new software, iPat, that was written in JAVA with friendly graphic user interface for breeders without any programming requirements.	We have met the timeline of June 30, 2016 to Complete GAPIT package that can be used by researchers for wheat breeding. We developed two new statistical methods for genomic section and integrated them into our existing software (GAPIT). We have also met the timeline of December 31, 2016 for the development of source code on elementary functions in iPat, an integrated Prediction and Association Tool with friendly Graphic User Interface (GUI) for breeders.	a) We published two articles on academic journals. One is Briefings in Bioinformatics and the other is Plant Genome; b) We have one article on Wheat Life to introduce the lead PI; c) We instructed one course and three workshops for training next generation breeders.