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Washington State University Wheat and Barley Research Progress Reports

WASHINGTON GRAIN COMMISSION

2017-2018 Fiscal Year

2017-18 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: 2 of 3

Title: **Weed Management in Wheat**

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

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 ~40 events over the first year 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: 2 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 2016 WSU Weed Control Report was published in January of 2017 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/
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		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 in preparation for submission in 2018. 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

		A laboratory study was conducted to understand surfactant effects on absorption and translocation of metsulfuron in smooth scouringrush. Metsulfuron applied with NIS had greater absorption than metsulfuron applied with a basal bark oil, which disagreed with greenhouse efficacy work suggesting the opposite. Very little applied metsulfuron was absorbed, and surfactant appears to be critical for management of smooth scouringrush.	The experiment is complete and a publicaiton is in preparation.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles
		Two years of a field study were completed in 2017 near Lacrosse addressing 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 and 2017 field work is complete, a publication has been submitted to Weed Technology.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles
		A study addressing buckwheat control in irrigated wheat was completed in 2017 at a field site near Pasco.	The 2016 and 2017 field work is complete, a publication is in preparation.	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 and 2017 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.	New studies based on the results from 2016 and 2017 will be developed and put out in 2018.	
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 was completed in 2017, and publications and extension bulletins are in preparation.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles

		Common garden and greenhouse experiments using the downy brome PNW core collection were performed from 2015-2017 to indentify differences in downy brome seed dormancy. Four distict dormancy scenarios, or phenotypes, were identified for the PNW region. Differences in dormancy phenotypes were then used to explore the possibility that downy brome seed dormancy is regulated, at least in part, by the genes that control the synthesis and degredation of the dormancy promoting hormone abscisic acid (ABA). Quantitative PCR was used to measure relative gene expression of two ABA biosynthesis genes (NCED1 and NCED2) and two ABA catabolic genes (ABA8'OH-1 and ABA8'OH-2) in all identified dormancy phenotypes. Expression patterns were partially conserved with wheat, barley, and brachypodium gene orthologues suggesting some genetic overlap with related species. Expression patterns were also distinct for specific seed dormancy phenotypes. Competitive ELISA tests were also used to quantify changes in endogenous ABA levels associated with dormancy phenotypes form the PNW core collection. ABA levels were higher in more dormant downy brome embryos and lower with decreased dormancy. The differences being the length of time required for dormancy release. i.e. after-ripening. A subset of the PNW core collection is being sequenced to identify novel SNPs that might be associated with seed dormancy.	Work on seed dormancy continues and will be completed in 2018. We anticipate development of molecular markers to detect dormancy type by 2018.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles.
		Mayweed chamomile is a difficult to manage spring annual weed primarily found in the high rainfall zone. We have observed that mayweed has a very consistent developmental pattern, so we have collected sufficient data to create a growing degree day model. The degree day model will be incorporated into a decision support system and used to more accurately time herbicide applications.	Project completed in 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 2016.	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: _2_ *of* _3__

Title: Field Breeding Hard White and Red Winter Wheat

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

Executive summary: 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. This variety has replaced many of the Farnum acres and should be seen in large commercial production in 2018. Apart from this line, there are additional lines being testing in variety testing for release potential, under both low and high rainfall conditions. WA8268 is a hard red line adapted to the high rainfall zones of the state with excellent yield potential and disease resistance. In 2017 WA8268 was in the top significant group for yield with newly released cultivars LCS Jet and LCS Rocket. As such, we have begun seed increase of this line. 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. We have identified lines with aluminum tolerance and are testing them for release potential. 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 with herbicide resistance.

Impact: Sequoia replaced many of the Farnum acres in the state due to its excellent emergence capability and high yield potential under low rainfall and deep planting conditions. Emergence capabilities are a desired trait to reduce risk to planting failures under deep planting conditions when moisture is limited. WA8268 is one of the first WSU hard red lines targeted to high rainfall conditions and will provide growers with a high yielding line with good disease resistance adapted to PNW growing conditions. Current and future hard red and white lines will continue to lead to a sustainable production of hard wheat in the PNW.

WGC project number: 3193
WGC project title: Development of hard red winter wheat
Project PI(s): AH Carter
Project initiation date: July 1, 2013
Project year: 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
Develop hard red and white winter wheat cultivars	New cultivars released for production in WA	In 2015 we released Sequoia, and will be on large commercial production in 2018, replacing many of the Farnum acres. We have 3 low rainfall and 3 high rainfall hard red breeding lines in statewide testing for release consideration. WA8268 has been performing very well in high rainfall trials and WA8248 has shown excellent aluminum tolerance. We had over 3,000 plots and 15,000 rows of hard material under evaluation at various stages of the breeding process for 2017. Some hard white winter lines have been submitted for testing n Southern Idaho and have had very good performance under irrigated conditions. These continue to be evaluated for release potential. Focus has been on developing lines with herbicide tolerance as well.	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 15 locations in 2017. 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. Our snow mold locations gave a good rating of snow mold tolerance. 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.	In 2017 we communicated results of this project through the following venues: 8 peer-reviewed publications; 2 field day abstracts; 4 invited speaker presentations; 6 poster presentations; 5 popular press interviews; 4 grower meeting presentations; 2 wheat workshop presentations; 12 field day presentations; 2 seed dealer presentations; participation in the Tri-State Grain Growers Convention; and hosted 3 trade teams.
	Biotic and Abiotic stress resistance	Lines were screened for snow mold, stripe rust, eyespot foot rot, nematodes, 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 2018. Lines with inferior performance will be discarded from selection in 2018. We screened nearly 800 early generation lines for end-use quality 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	Trials were conducted in Lind, Walla Walla, and Pullman for herbicide resistance. The hard red material had a lower priority for development when we started compared to the soft white germplasm, but now since that material has matured more emphasis is on the hard red material. 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: *_3_ of _3__*

Title: Use of biotechnology for wheat improvement

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

Executive summary: In 2017 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, low PPO, Fusarium head blight, Hessian fly, and nematode resistance. Over 10,000 data points were collected on 200 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 and genotyping. Data is being used to validate end-use quality selection models. In the greenhouse, we made approximately 500 crosses consisting mainly of soft white and hard red germplasm. These are being advanced to the F1 generation, and then divided between our DH production and MAS protocol. We planted ~3,600 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 2019. 110 crosses have been submitted for DH production in 2018. We also have about 100 specialty crosses to introgress traits from non-PNW adapted material.

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 (Otto, Puma, Jasper, Sequoia) have benefited through this project by incorporation of disease and end-use quality genes. Released lines have gained popularity and are growing in demand due to the gene combinations they were selected for. The breeding program as a whole has become more efficient in the selection process, and more focus is placed on field evaluations since known genes are already confirmed to be present in the breeding lines. 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: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
Marker-assisted selection				Results are presented through annual progress reports, the research review, field tours, and grower meetings
	Foot rot resistant lines	In 2017, 105 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. Since more lines are being advanced with Pch1, fewer populations are segregating for the gene as we recycle lines back into the breeding program.	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	In 2017 we communicated results of this project through the following venues: 8 peer-reviewed publications; 2 field day abstracts; 4 invited speaker presentations; 6 poster presentations; 5 popular press interviews; 4 grower meeting presentations; 2 wheat workshop presentations; 12 field day presentations; 2 seed dealer presentations; participation in the Tri-State Grain Growers Convention; and hosted 3 trade teams.
	Stripe rust resistant lines	In 2017, 75 populations for stripe rust resistance (Yr5, Yr15, Yr17, Yr18, YrEltan) 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 2017, 11 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. These lines hav now been put back into the breeding cycle as parents. As such, many populations being advanced are fixed for the presence of these genes. Lines previously selected for GBSS genes (waxy) and the glutenin genes have also been advanced to yield testing. We also have DNA extraxted to test for low PPO and GBSS gene in the upcoming year.	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 2017, no segregating populations were screened for incorporation of Rht genes. Instead, all breeding lines in field trials were screened to identify which dwarfing gene they carry in order to aid in selection and crossing decisions. Previous populations were planted at Lind to be screened for emergence potential.	Each year new crosses are being made to incorporate 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 and Dr. Godoy, we have begun genomic prediction model building. Lines from the 2015-2017 breeding program have been genotyped as well as a large training panel. Models built were used to assist with selection in the 2017 crop year. End-use quality is the first trait we are developing models for and validating.	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. Validation of results is proceeding.	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 2017, 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 2017 we made approximately 500 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 2017 we submitted 110 crosses for DH production. We are advancing roughly 3,500 DH lines in the greenhouse to get enough seed to plant in yield plots in the fall of 2018. We planted about 3,600 DH lines in the field for 2018 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, 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 populations are either currently planted in the field for observations, undergoing marker screening, or undergoing phenotypic selection in the greenhouse.	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 2017. 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 2017. 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 2017. 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 2017. 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: *_3_ of _3__*

Title: Field Breeding Soft White Winter Wheat

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

Executive summary: A new 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 in the non-snow mold areas, with improved disease resistance, yield potential, and cold hardiness. In the 2017 VT trails, Jasper continues to be one of the top yielding lines across >12" precipitation zones. Puma was in high demand in the fall of 2016 and was planted on ~63,000 acres in 2017. Puma continues to perform well across production zones. Otto, a 2011 release from this program, continues to maintain demand. For the past three years it has been planted on ~220,000 acres. Nine advanced breeding lines were entered into WSU's Variety Testing (VT) Program, four in the low rainfall zones and five in the high. One line, WA8234 is on seed increase and will be proposed for release in the Spring of 2018. This line has excellent yield potential and disease resistance, acceptable quality, and high falling numbers. WA8275CL+ is another line which has performed very well in trials, and is on seed increase as well. Over 2,000 unreplicated yield-trial plots were evaluated at either Pullman or Lind and thousands of F4 head rows and DH rows were evaluated in Pullman, Lind, and Waterville. Over 2,500 DH lines were planted for 2018 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 very 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. These include Bruehl, Eltan, Masami, Xerpha, Otto, Puma, Jasper, Curiosity CL+, and MelaCL+. Measured impact is demonstrated with increasing acres of past cultivars, release of new cultivars (Pritchett) and upcoming lines WA8234 and WA8275CL+.

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

Objective	Deliverable	Progress	Timeline	Communication
Develop soft white winter wheat cultivars	New cultivars released for production in WA	We released Otto in 2011. Puma (WA8134) was released in 2012. 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 2017. Jasper continues to gain interest of growers and production increases. Released lines have high yield potential, excellent disease resistance, and market accepted end-use quality. We also co-released Pritchett in 2015 in collaboration with the USDA. This line is intended to replace Bruehl. We have 4 breeding lines in statewide testing for consideration under low rainfall production systems and 5 in statewide testing for consideration under high rainfall production. One of these lines is a two-gene imazamox resistant lines. We have over 15,000 plots and 30,000 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.	In 2017 we communicated results of this project through the following venues: 8 peer-reviewed publications; 2 field day abstracts; 4 invited speaker presentations; 6 poster presentations; 5 popular press interviews; 4 grower meeting presentations; 2 wheat workshop presentations; 12 field day presentations; 2 seed dealer presentations; participation in the Tri-State Grain Growers Convention; and hosted 3 trade teams.
	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 2018.	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 2018. 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 2017 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 germplasm which can be used for crossing and pyramiding QTL together.	Evaluation will be done in field locations in WA in 2018	

	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 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 2018 to confirm this.	Evaluation will be done in field locations in WA in 2018	
	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 and segregating populations will be screened for resistance.	Additional populations will be screened in 2018 after backcrossing	
	Nematodes	Nematode screening has been done in collaboration with Dr. Paulitz and Dr. Campbell. Advanced material was screened in 2017 for cereal cyst resistance, and data was 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.	Validated genomic prediction models should be available for selection in 2018.	

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Washington Grain Commission
Wheat and Barley Research Annual Progress Report

Project #: 5682

Progress Report Year: 2 of 3 (2017)

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 2017, studies were conducted according to the objectives of the project proposal and all objectives specified for the second year have been successfully completed. In addition to the major accomplishments and their impacts listed below, this project results in genetic resources and techniques for further studying the biology and genetics of the pathogens and mechanisms of interactions between the pathogen and plants.

Impact: 1) Stripe rust was accurately forecasted in 2017. Rust updates and advises were provided on time to growers based on the forecasts using prediction models and our field surveys, which effectively protected both winter wheat and spring wheat crops from potentially huge yield losses under the extremely severe stripe rust epidemic. 2) We identified 11 races of the barley stripe rust pathogen and 55 races (including 21 new) of wheat stripe rust in the US, of which 6 and 23 were detected in Washington, respectively. Seven of the new races were from Washington. The virulence information is used to guide breeding programs for using effective resistance genes in developing resistant varieties. 3) We re-sequenced seven wheat stripe rust isolates and used them together with previously sequenced stripe rust isolates to identify 923 stripe rust specific secreted protein genes and candidate virulence genes corresponding to six resistance genes. The secret protein genes can be used to study the pathogen populations and identify markers for more virulence genes. 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 2017, we collaborated with breeders in releasing, pre-releasing, or registered 11 wheat and 2 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 two studies and mapped 10 genes for stripe rust resistance in two wheat lines and identified molecular markers for all mapped genes. We officially named two stripe rust resistance genes, and published 8 papers on molecular mapping of stripe rust resistance genes. We also collaborated with other programs in mapping a large number of stripe rust resistance genes in various wheat germplasm collections through the genome-wide association approach. 6) We provided seeds of our developed wheat germplasm lines to several breeding programs in the US and other countries for developing stripe rust resistant varieties. Use of these lines by breeding programs will diversify resistance genes in commercial varieties. 7) We tested 23 fungicide treatments for control of stripe rust and provided the data to chemical companies for registering new fungicides. We tested 24 winter wheat and 24 spring wheat varieties for yield loss caused by stripe rust and yield increase by fungicide application. The data of the fungicides and varieties are used for guiding the integrated control of stripe rust. 8) In 2017, we published 27 journal articles, 9 meeting abstracts, one chapter in an extension book, and the first book (titled *Stripe Rust*) summarizing research and management of stripe rust over 100 years, which should serve as a valuable reference for future research and control of the disease.

Outputs and Outcomes:

Progress, Timelines, and Communication are presented in Outcome Reporting file (file name: Chen_WGC 2017 Annual Report Outcome Reporting.pdf)

Publications:

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

Wan, A. M., Muleta, K. T., Zegeye, H., Hundie, B., Pumphrey, M. O., and **Chen, X. M.** 2017. 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(1):73-80.

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Liu, W. Z., Macaferri, M., Rynearson, S., Letta, T., Zegeye, H., Tuberosa, R., **Chen, X. M.**, and Pumphrey, M. 2017. Novel sources of stripe rust resistance identified by genome-wide association mapping in Ethiopian durum wheat (*Triticum turgidum* ssp. *durum*). Frontiers in Plant Science 8:774.

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Xia, C. J., Wang, M. N., Cornejo, O. E., Jiwan, D. A., See, D. R., **Chen, X. M.** 2017. Secretome characterization and correlation analysis reveal putative pathogenicity mechanisms and identify candidate avirulence genes in the wheat stripe rust fungus *Puccinia striiformis* f. sp. *tritici*. Frontiers in Microbiology 8:2394.

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Presentations and Reports:

In 2017, Xianming Chen presented invited talks at the following national and international meetings:

> "Stripe Rust Research and Control in the US" at the North American Wheat Research Initiative Meeting in the CIMMYT-HQ, EL Batan, Mexico, February 14, 2017 (about 30 people)
>
> "Races and Virulence Genes of *Puccinia striiformis* from 1968 to 2016 in the US" at the North American Cereal Rust Workshop, St. Paul, Minnesota, March 29, 2017 (about 40 people).
>
> "Unequal Contributions of Parental Isolates in Somatic Recombination of the Stripe Rust Fungus" at the 19th International Conference of Fungal Genetics. Venice, Italy, June 21, 2017 (about 40 people)

“Pathogenicity of stripe rust and its prevention and control” at the Training Course on Breeding and Production Technologies of Staple Crops in Southeast Asia, Chengdu, Sichuan, China, August 17, 2017 (about 60 people)

“Stripe Rust Research and Control in the US” at the Jinjiang Forum, Chengdu Institute, Chinese Academy of Sciences, Chengdu, Sichuan, China, August 22, 2017 (about 40 people)

“Stripe Rust Research and Control in the US” in the Institute of Crop Science, Sichuan Academy of Agricultural Sciences, Chengdu, Sichuan, China, August 23, 2017 (about 30 people)

“Stripe Rust Research and Control in the US” in the Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing China, August 24, 2017 (about 60 people)

“Stripe Rust Research and Control in the US” in the Institute of Genetics and Cell Developmental Biology, Chinese Academy of Sciences, Shijiazhuang, Hebei, China, August 25, 2017 (about 40 people)

“Stripe Rust Research and Control in the US” in the Institute of Genetics and Developmental Cell Biology, Chinese Academy of Science, Shijiazhuang, Hebei, China, August 25, 2017 (about 50 people)

“Stripe Rust Research and Control in the US” at the Chinese National Wheat Disease Management Workshop, Baoding, Hebei, China, August 26, 2017 (about 200 people)

“Biology, genetics, functional genomics, evolution, and epidemics caused by the stripe rust pathogen” at the 2nd International Conference of Mycology and Mushroom. Chicago, IL, September 25, 2017 (about 100 people)

“Biology, genetics, functional genomics, evolution, and epidemics caused by the stripe rust pathogen” in the College of Plant Protection, Northwest A&F University, Yangling, Shaanxi, China, October 11, 2017 (About 200 people).

In 2017, Xianming Chen, students and/or associates presented posters or oral presentations at the following national and international meetings:

Poster entitled “Identification of effector candidates for avirulence genes in the wheat stripe rust fungus (*Puccinia striiformis* f. sp. *tritici*) by secretome analysis” at the 29th Fungal Genetics Symposium and presented, Pacific Grove, California, March 13-17, 2017 (about 900 people)

Poster entitled “Mapping genes for and developing wheat germplasm with resistance to stripe rust” at the 13th International Wheat Genetics Symposium in Tuln, Austria, April 23-28, 2017 (more than 500 people)

Oral presentation entitled "Secretome characterization and correlation analysis reveal putative pathogenicity mechanisms in the wheat stripe rust fungus *Puccinia striiformis* f. sp. *tritici*" at the American Phytopathological Society Pacific Division meeting, June 28-29, 2017 (student: Chongjing Xia)

Oral presentation entitled "Molecular mapping of stripe rust resistance QTL in Pacific Northwest winter wheat cultivar Madsen" at the American Phytopathological Society Pacific Division meeting, June 28-29, 2017 (student: Lu Liu)

Oral presentation entitled "Virulence and molecular characterization of *Puccinia striiformis* f. sp. *tritici* mutants generated using ethyl methanesulfonate" at the American Phytopathological Society Pacific Division meeting, June 28-29, 2017 (student: Yuxiang Li)

Poster entitled "Stripe rust epidemics of wheat and barley and races of *Puccinia striiformis* identified in the United States in 2016" at the American Phytopathology Society Annual Meeting in San Antonio, TX August 5-9, 2017 (about 1600 people)

Poster entitled "Molecular mapping and comparison of *YrTr1* with other genes on chromosome 1BS for resistance to wheat stripe rust" at the American Phytopathology Society Annual Meeting in San Antonio, TX August 5-9, 2017 (about 1600 people)

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

May 31-June 1, 2017. Western Wheat Workers and WEAR 97 meeting at Corvallis, OR (about 40 people)

June 15, 2017. Lind Field Day (about 100 people)

July 7, 2017. Farmington Field Day (about 30 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: 2 of 3 (2017)

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 2017 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 growers and researchers. Field surveys were conducted by our program and collaborators throughout the Pacific Northwest (PNW) and other regions throughout the country. In the eastern PNW, widespread infection occurred in the fall 2016 and the pathogen well survived the winter under the long snow cover, resulting in a early start of epidemic development in the spring 2017. The stripe rust favorable weather conditions in the spring and early summer made the disease an extremely severe epidemics (75% yield loss occurred on highly susceptible winter wheat varieties in our experimental fields). The timely applications of fungicides on susceptible and moderately susceptible wheat varieties prevented major yield loss. Barley stripe rust was much lower than wheat stripe rust, but relatively significant compared to the previous years. Leaf rust of wheat was normal in western but absent in eastern PNW; and leaf rust of barley in the western PNW was less than the previous years, but presented for the first time in the eastern PNW (just in three fields of barley planted in the fall of 2016 in the Walla Walla area along the Oregon border. Stem rust of wheat and barley was 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 2007, we collected and received 393 stripe rust samples throughout the country and 50% of the samples were from Washington. We have completed about 80% of the race ID work for the 2017 samples as scheduled by this time. So far we have detected 55 wheat stripe rust races (including 21 new races) and 5 barley stripe rust races, of which 23 wheat and 6 barley stripe rust races were detected 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 sequenced more isolates of the stripe rust pathogen, identified secreted protein (SP) genes as candidates for virulence genes, and developed more than 800 SP-SNP markers to study rust pathogen populations and identify virulence genes.	The race identification work for the 2017 stripe rust samples will be completed by late February, 2018, as scheduled. The race ID work for 2018 samples will start in March. Molecular work of the 2016 samples and DNA extraction of the 2017 samples will be completed by June, 2018.	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 2017, 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 2017, we collaborated with public breeding programs in releasing and registered 11 wheat and 2 barley varieties. 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 2017-18 winter wheat nurseries were planted in fields in September and October 2017. The 2018 spring crop nurseries will be planted in March-April, 2018. The greenhouse tests of the 2017 spring nurseries and the 2017-18 winter wheat nurseries have been conducting in the greenhouse during the winter, and will be completed by May, 2018	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 2017, We completed two studies and mapped 10 genes for stripe rust resistance in two wheat lines and identified molecular markers for all mapped genes. We officially named two stripe rust resistance genes (Yr78 and Yr79). We also collaborate with other laboratories in mapping of numerous stripe rust resistance loci in various wheat germplasm collections through genome-wide association study approach, and published 8 papers on molecular mapping of stripe rust resistance genes. We registered 29 new wheat germplasm lines with single new genes or combinations of genes for resistance to stripe rust to make them available for breeding programs and directly provided seeds to a few US breeding programs in 2017. In 2017, we phenotyped ten mapping populations for stripe rust responses and advanced progeny populations for 40 winter wheat crosses for mapping stripe rust resistance genes.	All experiments scheduled for 2017 were successfully completed. Mapping populations of winter wheat were planted in fields in October 2017 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 2018.	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 2017, we evaluated 23 fungicide treatments, plus a non-treated check on both winter wheat and spring wheat for control of stripe rust in experimental fields near Pullman, WA. Treatments with two applications were more effective than only one application in reducing rust and increasing yield. For winter wheat, all treatments significantly reduced rust severity and increased grain yield, and 10 of the treatment also increased test weight compared with the non-treated check. Yield increases ranged from 19 bushes (88%) to 54 bushes (242%). Similarly for spring wheat, all fungicide treatments significantly reduced rust severity and increased grain yield, and 10 treatments also increased test weight compared with the non-treated check. The yield increases of grain yield ranged from 11 bushes (26%) to 33 bushes (80%) depending upon fungicide treatments. In 2017, we tested 23 winter wheat and 23 spring wheat varieties commonly grown in the PNW, plus highly susceptible checks. For winter wheat, stripe rust caused 75% yield loss on the susceptible check and from 0 to 49% yield losses at an average of 16% on commercially grown varieties. Fungicide application increased yield by 0 to 96% at an average of 10% on commercially grown varieties. For spring wheat, stripe rust caused 48% yield loss on the susceptible check and from 0 to 22% yield losses at an average of 7% on commercial varieties. Fungicide application increased grain yields by 0 to 28% on commercial varieties at an average of 9%. 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 2017 were successfully completed. For the 2017-18 growing season, the winter wheat plots of the fungicide and variety yield loss studies were planted in October, 2017 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), 2018	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 used the artificial screening system in the greenhouse to evaluate:
Winter wheat breeding lines from the WSU and ARS breeding programs.
The Western Regional Winter wheat hard and soft nurseries
The Northern and Southern Regional Performance Nurseries
The Association Mapping Training Panel representing the WSU and ARS breeding programs
The WSU Spring Variety Trials
The WSU Winter Wheat Variety Trials are currently being evaluated.
The Winter Wheat Core Nursery

We now have a dataset of survival scores from 3135 winter wheat breeding lines, cultivars and germplasm.

We evaluated the large association mapping panels and regional nurseries for allelic and copy number variation at genes that are known to be associated with cold tolerance in wheat. Many of these alleles are segregating in our populations.

We conducted an association mapping project for cold tolerance using data available in our breeding programs. In addition to the known loci, we discovered new loci on the group 1 and group 6 chromosomes.

Impact

- The data from these cold tolerance trials can be used by growers to select winter wheat that is less sensitive to winter kill (data available on smallgrain.org)
- 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.

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	http://smallgrains.wsu.edu/
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	The Western Regional soft and hard winter wheat trials and the Northern and Southern Performance trials were evaluated.	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	Hard Spring Variety Trials evaluated.	Data avilable by Feb. of the year following the field trials, Feb. 2017-2019	http://smallgrains.wsu.edu/
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	Survival data was evaluated for the WSU Winter Wheat and the USDA Winter Wheat breeding programs.	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.	Lack of freezer space delayed progress. New freezers are being installed.	Populations selected each year, 2016-2019.	

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	The Winter Wheat association mapping panel and the Winter Wheat Core Nursery were evalauted.	Sept 2016-June 2019.	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:
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.	Lack of freezer space delayed progress. New freezers are being installed.	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: *2 of 3 (maximum of 3 year funding cycle)*
Title: CLUB WHEAT BREEDING

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

Executive summary: ARS Castella (ARS20060123-31C) developed by the USDA-ARS and WSU was released in 2017 an early maturing club wheat with good performance, excellent stripe rust resistance, aluminum tolerance and tolerance to low falling numbers. ARS Castella was entered into the WAVT dry trials only where yields were 109% and 115% of the trial averages in the 12-16, and <12 inch rainfall zones, respectfully.

Foundation seed of Pritchett, was produced. Pritchett is targeted to the traditional club wheat growing region in the dry precipitation zones. Yields of Pritchett in the WAVT dry trials were 102% and 107% of the trial averages in the 12-16, and <12 inch rainfall zones, respectfully.

We entered the following breeding lines into 2018 trials: ARSDH08X117-83C in the WAVT Dry, North Idaho, and Oregon Wheat Elite Yield Trial (OWEYT); ARSWA2J100065C in the WAVT Dry; ARSDH08X103-102C and ARS06132-45Cin the WAVT-Wet; ARSDH08X028-9C in the WA/OR coopeartive trials and OWEYT; ARSDH08X142-11L, ARSDH08X103-102C, DH08X028-9C, and ARS2J100065-C in the Western Regional Nurseries.

We genotyped all our the entries in all of our yield trials using the targeted amplicon sequencing (TAS) procedure in the USDA Western Small Grains Genotyping laboratory.We used KASP and SSR markers to select for resistance to low falling number, BYDV, eyespot, stripe rust, dough strength, cold tolerance and reduced height.

We evaluated several hundred doubled haploid lines and 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. 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 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. 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.

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: **2**

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 was increased as Foundation seed. ARS-Castella (ARS20060123-31C) was approved for preliminary seed increase of breeders seed.	Sept 2016-June 2019. Cutlivar releases are targeted as one every three years per rainfall zone.	Report of Progress: Washington Grains Commission Research Review, "Club Wheat Breeding", Pullman WA, Feb. 2017. Garland-Campbell, K, Carter, AH, Jones, SS, Chen, XM, DeMacon, P, Higginbotham, R, Engle, D, Guy, SO, Mundt, CC, Murray, TD, Morris, CF, See, D, 2017. Registration of "Pritchett" Soft White Winter Club Wheat. J. Plant Reg. 11. DOI: 10.3198/jpr2016.04.0018crc
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.	Two new lines, (ARSDH08X117-83C and ARSWA2J100065C) were entered into the dry trials.	Sept 2016-June 2019.	Plot and field day tours speaking to approximately 15-30 growers and industry representatives per tour during June, 2017: Connell, Harrington, Lamont, St. Andrews
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.	ARSDH08X105-102C and ARS06132-45C were entered into the 2018 Washington variety trials targeted to the > 15 inch rainfall zone. ARSDH08X028-9C was entered into the OR trials. ARSDH08X117-	Sept 2016-June 2019.	Plot and field day tours speaking to approximately 15-30 growers and industry representatives per tour during June, 2017: St Johns, and Walla Walla

4. Release a club wheat cultivar with early maturity targeted to SE Washington and NE Oregon.	Club wheat cultivars with early maturity (2-5d earlier than Pritchett) combined with excellent stripe rust resistance.	Head rows were planted in Pendleton in the fall of 2017 so that earlier maturing 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	Invited talk, 'Falling Numbers' Northwest Grain Growers Meeting, June 21, 2017. Walla Walla WA
5. Release germplasm with improved resistance tolow falling number	Club wheat breeding lines with stable falling numbers above 300 in all but extreme environments.	All elite lines in the breeding pogram were assayed for LMA using field testing and PHS using spike wetting tests. Lines that were susceptible were not advanced.	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 Reports and Final Reports

Project #:

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

Title: Assessment of soil acidity on soil-borne pathogens, weed spectrum, herbicide activity, yield, and crop quality on dryland wheat production.

Principal Investigators:
Christina Hagerty, Assistant Prof. of Cereal Pathology, OSU, CBARC, Pendleton, OR
Paul Carter, Associate Prof., Regional Extension Soil Specialist, WSU, Columbia County, WA

Cooperators:
Kurt Schroeder (U of I), *Tim Murray* (WSU), *Stephen Van Vleet* (WSU), *Judit Barroso* (OSU), *Stephen Machado* (OSU), *Don Wysocki* (OSU).

Executive summary: To initiate this long-term research effort, 24 x 50ft. plots were established in fall 2016 and treated with four ultrafine liquid calcium carbonate treatments (0, 600, 1200, and 2400 lbs/acre) with 4 replications. The plots were soil tested in April 2017 and successfully established different soil acidity levels ranghing from pH 4.9 to pH 6.4. Micro-nutrients were applied based on soil test results and included Zinc, Boron, and Copper. The plots were established in three distinct production zones in order to make the results of this research effort applicable to a wide audience of producers, provide a robust multi-location dataset, and understand how the effects of liming and soil acidity may differ regionally. The three locations include: CBARC Sherman Station in Sherman County, OR (11 in. annual rainfall), the CBARC Pendleton Station in Umatilla County, OR (16 in. annual rainfall), and in Whitman County, WAat the Palouse Conservation Field Station and in a farmer's field (18 in. annual rainfall). The project was initiated in 2017, most results are only initial findings and base-line establishment for continued research. In 2017, plots were established in spring wheat following fallow (Oregon locations) and re-cropping following chickpeas in Whitman County.

Impact: Soils below a threshold of pH 5.2 are considered poor management and below the critical level for optimum grain production. Most dryland wheat production soils of the PNW are at or below the pH 5.2 critical threshold. This study will help quantify the impact of soil acidity to local wheat production and will serve as a foundation to develop solutions to affordably address soil acidity in the dryland PNW.

The measureable impacts in the most recent funding cycle:

1. Preliminary results indicate that modest applications of agricultural lime are effective to buffer acidic soils in the dryland wheat production region.
2. This project is increasing the awareness about the issue of soil acidity in the PNW. In addition, the project has assured producers that the PNW wheat research community is addressing the soil acidity problem, and ultimately working on economical solutions to help manage soil acidity.

WGC project number:
WGC project title: Assessment of soil acidity on soil-borne pathogens, weed spectrum, herbicide activity, yield, and crop quality on dryland wheat production.
Project PI(s): Christina Hagerty and Paul Carter
Project initiation date: July 1, 2017
Project year (X of 3-yr cycle): This year 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
Quantify impact of soil acidity on soil-borne pathogens	Quantify pathogens in each soil pH treatment, statistically evaluate the relationship between pathogens and pH	Replicated plots ranging from pH 4.9 - pH 6.4 were sucessfully established in three different locations	Fall 2019	Extension programming to communicate results directly to grower clientele and peer reviewed publications to communicate results to the scientific audience
Quantify impact of soil acidity on weed spectrum	Quantify weed spectrum in each soil pH treatment, statistically evaluate the relationship between weeds and pH	Replicated plots ranging from pH 4.9 - pH 6.4 were sucessfully established in three different locations	Fall 2019	Extension programming to communicate results directly to grower clientele and peer reviewed publications to communicate results to the scientific audience
Quantify impact of soil acidity on herbicide activity	Quantify herbicide activity in each soil pH treatment, statistically evaluate the relationship between herbicide activity and pH	Replicated plots ranging from pH 4.9 - pH 6.4 were sucessfully established in three different locations	Fall 2019	Extension programming to communicate results directly to grower clientele and peer reviewed publications to communicate results to the scientific audience
Quantify impact of soil acidity on yield	Quantify yield in each soil pH treatment, statistically evaluate the relationship between yield and pH	Replicated plots ranging from pH 4.9 - pH 6.4 were sucessfully established in three different locations	Fall 2019	Extension programming to communicate results directly to grower clientele and peer reviewed publications to communicate results to the scientific audience
Quantify impact of soil acidity on crop quality	Quantify crop quality in each soil pH treatment, statistically evaluate the relationship between quality and pH	Replicated plots ranging from pH 4.9 - pH 6.4 were sucessfully established in three different locations	Fall 2019	Extension programming to communicate results directly to grower clientele and peer reviewed publications to communicate results to the scientific audience
Understand more about the total picture of the impact of soil acidity on the dryland wheat production system	Synthesize the parameters listed above to understand more about the total impact of soil acidity on the Columbia Basin dryland wheat production region.	Replicated plots ranging from pH 4.9 - pH 6.4 were sucessfully established in three different locations	Fall 2019	Extension programming to communicate results directly to grower clientele and peer reviewed publications to communicate results to the scientific audience

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Washington Grain Commission
Wheat and Barley Research Annual Progress Report

Project #: 4127-1605

Progress Report Year: *_2_ of _3__*

Title: Evaluation of Barley Varieties

Investigator: Ryan Higginbotham

Executive summary:
In 2017, the Cereal Variety Testing Program (VTP) conducted 12 spring barley variety trials across eastern Washington. The total number of individual barley plots evaluated was 864. 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 (9 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 buying 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 2017 are as follows:

1. Barley VTP field tours were attended by 234 farmers/clientele. At those tours, I presented a few details about each entry in the trial.
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 (23,815 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: 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Conduct barley variety trials in Eastern Washington	12 spring barley trials, 24 entries/trial	2017 trials complete (24 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.
		2018 trials in planning		
2. Public and private entries in trials	All widely grown, commercially available varieties included in trials.	2017 barley entries: 67% Public and 33% Private	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. Graduate students conducting fertility and nutritional studies on harvested barley grain.	Ongoing cooperation and collaboration that fit with timelines and other listed objectives.	VTP data used for variety release. Graduate students will publish research results.
4. Extension programming	Grower Meetings	5 grower mtgs in 2017;	Whenever I'm invited	Grower Meetings: 5 in 2017
	Field Tours (with county Extension)	9 in 2017; 9 planned for 2018	June - July	*Field Tours: 9 in 2017 (listed below)
	Email List serve	2017 results delivered	October - November	Email list serve: data sent to 200+ members
	Website	up to date with 2017 data	fall/winter	23,815 pageviews of the VTP section of the small grains website
	Annual Report	Published in December 2017	December	Annual Report: 2017 Technical Report 17-3
	WSCIA Seed Buyers Guides	2017 published, 2018 in preparation	January--February	2017 Seed Buyers Guide published January 2017
	Wheat Life	2016 barley results in Feb. 2017 issue	February	Wheat Life: 1 article planned for 2018
	Variety Selection Tool (http://smallgrains.wsu.edu)	Selection tool updated with 2017 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.
* 2017 TOUR SCHEDULE--BARLEY				
Location	**Date**	**Attendance**		
Mayview	30-Jun	20		
Dayton	29-Jun	31		
Almira	22-Jun	80		
Reardan	23-Jun	15		
Fairfield	21-Jun	21		
St. John	14-Jul	10		
Lamont	14-Jul	8		
Farmington	13-Jul	11		
Palouse	11-Jul	10		
		Total = 206		

Washington Grain Commission
Wheat and Barley Research Annual Progress Report

Project #: 4127-1604

Progress Report Year: *_2_ of _3__*

Title: Evaluation of Wheat Varieties

Investigator: Ryan Higginbotham

Executive summary:

In 2017, the Cereal Variety Testing Program (VTP) conducted 24 soft winter, 16 hard winter, 18 soft spring, and 18 hard spring wheat variety trials across eastern Washington. The total number of individual wheat plots evaluated was 8,172. 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 (20 tours in 2017), grower meetings (5 in 2017), 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 buying 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 2016, there were roughly 1.8 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 $7.2 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 2017 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 505 farmers/clientele. At those tours, I highlighted each entry in the trial and gave a few details, strengths/weaknesses about each entry.
3. The addition of winter wheat trials at Bickleton and Eureka, and the partnership with OSU on trials at Dayton, Walla Walla and Eureka.
4. The variety testing section of the small grains website (http://smallgrains.wsu.edu/variety/) was the most visited section of the site (23,815 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: 2 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) 2018 trials planted; 2017 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) 2018 trials planted; 2017 results finished		
	c) 18 soft spring wheat trials; 24 entries/trial	c) 2018 trials in planning; 2017 results finished		
	d) 18 hard spring wheat trials; 36 entries/trial	d) 2018 trials in planning; 2017 results finished		
		We are continuing the collaboration with OSU on trials at Dayton, Walla Walla and Eureka. To meet grower demands and better represent the production area, the >16" trial was planted at Dusty and Eureka, despite the fact that those locations receive less than 16" of precip. The "higher rainfall" entries are more common and relevant at those locations.		
2. Public and private entries in trials	All widely grown, commercially available varieties included in trials.	2018 winter trials: 58% Public and 42% Private. Every major breeding program in the PNW is actively participating in the VTP trials. 2018 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.
		2017 spring trials: 51% Public and 49% Private		
3. Trials and data available to other projects	Participation by other projects/programs	Cooperation with breeders, pathologists, quality lab, FGIS, seed dealers, WSCIA, Extension	Ongoing cooperation and collaboration that fit with timelines and other listed objectives	Quality results in G&E study and preferred variety pamphlet, falling number results presented by corresponding project, disease ratings presented in seed buyers guide and variety selection tool, VTP data used for variety release and PVP applications
4. Extension programming	Grower Meetings	5 grower mtgs in 2016;	Whenever I'm asked to speak	Grower Meetings: 5 in 2017;
	Field Tours (with county Extension)	20 planned for 2018	May 2017 - July 2017	*Field Tours: 20 in 2017 (listed below)
	Email List serve	2017 results delivered	July 2016 - Sept. 2016	Email list serve: data sent to 200+ members
	Website	up to date with 2017 data & 2018 maps	summer & fall	23,815 pageviews of the VTP section of small grains website
	Annual Report	Published in December 2017	December	Annual Report: 2017 Technical Report 17-3
	WSCIA Seed Buyers Guide	2017 guide published, 2018 in preparation	January--February	2017 Seed Buyers Guide published in Jan. 2017
	Wheat Life Articles	2 articles written in 2017	spring in Feb. winter in May	Wheat Life: 2 articles planned for 2018
	Variety Selection Tool (http://smallgrains.wsu.edu)	Selection tool updated with 2017 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.

2017 TOUR SCHEDULE--WHEAT

Location	Date	Attendance	Crops
Horse Heaven	6-Jun	29	Winter & Spring Wheat
Ritzville	7-Jun	23	Winter Wheat
Western Whitman Co. - Dusty	8-Jun	12	Winter Wheat
Connell	8-Jun	32	Winter Wheat
Harrington	14-Jun	28	Winter Wheat
St. Andrews	16-Jun	15	Winter Wheat
Mayview	20-Jun	20	Winter & Spring Wheat
Eureka	20-Jun	31	Winter Wheat
Walla Walla	21-Jun	90	Winter Wheat
Dayton	22-Jun	31	Winter & Spring Wheat
Anatone	22-Jun	8	Winter Wheat
Moses Lake	27-Jun	12	Winter & Spring Wheat
Almira	27-Jun	80	Winter & Spring Wheat

Reardan	28-Jun	15	Winter & Spring Wheat	
Fairfield	29-Jun	21	Winter & Spring Wheat	
St. John	6-Jul	10	Winter & Spring Wheat	
Lamont	6-Jul	8	Winter & Spring Wheat	
Farmington	7-Jul	11	Winter & Spring Wheat	
Palouse	7-Jul	10	Spring Wheat	
Bickleton	11-Jul	19	Winter & Spring Wheat	
		Total = 505		

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

Project #: 3061-5746

Progress Report Year: 3 of 3 **(Final)**

Title: Pre-breeding for Root Rot Resistance

Researchers: Scot Hulbert, Pat Okubara

Cooperators: Timothy Paulitz, Deven See, Karen Sanguinet

Executive summary:
Rhizoctonia solani and *R. oryzae*, are soilborne fungal pathogens of wheat and crops used in rotation with wheat that cause root rot, stunting and bare patch. *Rhizoctonia* root rot is one of the main disease causing green bridge problems in spring cereals in the PNW. **The aim of this project is to characterize resistance or tolerance to *Rhizoctonia* and other green bridge-promoted diseases identified from several synthetic wheat lines** and transfer the resistance to the cultivar Louise. The cultivar Louise was selected because it already has a good root system, and enhancing its resistance to *Rhizoctonia* would create a valuable germplasm asset for the breeding programs. The resistances are controlled by the additive effects of several genes in each of the sources of resistance, so backcrossing the resistance to adapted germplasm takes many more generations than backcrossing a single gene trait, like many of the rust resistance genes used in the breeding programs. After each cross to Louise, the progeny lines are advanced 3-4 generations under selection for resistance to try to collect and maintain all of the genes from the resistant parent. In addition, the sources of resistance were *synthetic* lines; artificially generated by combining the genomes of AB and D wheats (Table 1) to reconstruct the bread wheat genome. Thus, the original sources were all poorly adapted to the PNW and exhibited many of the wild characteristics of the AB and D genome parents, (e.g. difficult threshing, poor quality). We felt that at least three crosses to an adapted cultivar would be required to develop lines that could be evaluated for performance in field trials. We also used the same cultivar, Louise, as the recipient of all of the sources of resistance so that the resistances could be compared in the same genetic background. The original sources of resistance all had very different root systems making it impossible to tell which aspects of these root systems were associated with resistance. Once the resistances are transferred into the same genetic background, analysis and comparisons of the root systems is more informative.

***Characterization of advanced lines*:**
The project focused on five sources of resistance that are listed in Table 1. The backcross 2 (BC2) designation indicates the original cross to Louise was followed by two more crosses with multiple generations of selection in between. For two of the sources of resistance, Syn172 and CIMMYT 3104, we also advanced large BC1 derived populations of lines for mapping the resistance genes (below). 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. 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 are continuing to evaluate for multiple disease resistance.

Table 1. Advanced lines tested in 2016 from five different sources into the cultivar Louise

Resistance Source	# lines	Current Stage	Pedigree*
Synthetic Sny30	4	BC2-F5:8	**CROC_1**/AE.SQ. (210)
Synthetic Syn182	12	BC2-F5:8	**CROC_1**/AE.SQ. (518)
Synthetic Syn201	9	BC2-F5:8	**68112/WARD**//AE.SQ. (369)
Synthetic Syn172	10	BC2-F5:8	**SNIPE/YAV79//DACK/TEAL**/3/AE.SQ. (904)
CIMMYT 3104	8	BC2-F5:8	(**CROC1**/ AE.SQ. (224)//OPATA/3/PASTOR)

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

***Mapping genes for resistance*:**
We completed field resistance evaluation and genetic mapping 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. While multiple pathogens are present in our field assays (*Pythium*, etc.) the greenhouse assays are conducted with *Rhizoctonia* only, so results differ to some extent. However, the lines that perform best in the greenhouse assays generally performed best in the field assays. Furthermore, the genes contributing quantitatively to resistance (QTL) were generally the same ones controlling resistance both in the field and greenhouse assays. This verifies our hypothesis that resistance or tolerance to *Rhizoctonia* is a major component of the resistance to green bridge conditions in the field.

In collaboration with Deven See, we mapped genes controlling the resistance from the CIMMYT 3104 and Syn172 sources. The three genes with the strongest effects were mapped from both lines and found to map to different locations, **indicating the resistances in the two synthetic lines were mainly controlled by completely different genes**. The genes from CIMMYT 3104 were found on chromosomes 1BL, 2AS and 2DL which those from 172 QTL were on chromosomes 2AL, 7DS and 7DL (Mahoney et al. 2016, 2017). Unfortunately, all of the genes had relatively small effects and no single gene with large effects, like the *Pch1* gene for eyespot resistance, were identified.

Resistance genes with small effects are inefficient to select in breeding programs, especially if they conferred resistance to single diseases. Their use would be more efficient if some provided resistance to additional diseases, like Fusarium crown rot. We have found evidence that some genes do provide quantitative levels of resistance to both *Fusarium*, *Rhizoctonia* and even nematode pathogens. In cooperation with Drs. Campbell and Paulitz, we identified one QTL in the Iranian land race IWA8608077 that provided partial resistance to *Fusarium* root and crown rot and root lesion nematodes (*Pratylenchus thornei* and *P. neglectus*) as well as Rhizoctonia (Table 2; Thompson et al. 2017). Thus, determining which of the genes in our synthetic-derived lines have broad spectrum effects would indicate which combinations of genes would be most useful.

Table 2. A QTL on chromosome 5A from the Iranian land race IWA8608077 confers partial resistance to Pratylenchus species (nematodes) as well as Fusarium crown rot and Rhizoctonia root rot.

Resistance trait	Chrom-Position	Significance	% variation explained
Fusarium culmorum	**5A-2**	4.13	12.2
P. neglectus damage	**5A-2**	6.03	14.5
P. thornei damage	**5A-2**	5.00	17.1
Rhizoctonia solani	**5A-2**	3.67	11.5

Future work

Our work has demonstrated that high levels of resistance to multiple diseases are available in wheat germplasm (synthetic wheat lines and land races). This resistance can be bred into elite PNW wheat cultivars but it requires transfer of multiple genes. The next goal is to determine which of these resistances are effective against multiple root diseases including Fusarium crown rot to ultimately create multiple disease resistant lines with broad spectrum resistance controlled by the fewest genes possible. Our most advanced, BC2-derived, lines will be tested for resistance to Fusarium and Pratylenchus species. We will simultaneously advance all five source of resistance until one or two are determined to provide the broadest levels of disease control. Backcross four lines have been created for all five sources of resistance and BC4-F3 families will be screened in green bridge assays in spring 2018.

Publications:

Mahoney, A. K., Babiker, E. M., Paulitz T. C., See, D., Okubara, P.A., and Hulbert, S. H. (2016) Characterizing and mapping resistance in synthetic-derived wheat to Rhizoctonia root rot in a green bridge environment. Phytopathology 106(10):1170-1176. http://dx.doi.org/10.1094/PHYTO-02-16-0055-FI

Mahoney, A. K., Babiker, E. M., See, D.R., Paulitz, T.C., Okubara, P.A., Hulbert, S.H. (2017) Analysis and mapping of Rhizoctonia root rot resistance traits from the synthetic wheat (*Triticum aestivum* L) line SYN-172. Molecular Breeding, 37:130

Thompson, A.L., Mahoney, A.K., Smiley, R.W., Paulitz, T.C., Hulbert, S.H., and Garland-Campbell, K. (2017) Resistance to multiple soil-borne pathogens of the Pacific Northwest is co-located in a wheat recombinant inbred line population. G3:Genes/Genomes/Genetics 7:1109-1116.

Impact:

We have identified resistance to green bridge-associated diseases like Rhizoctonia root rot from five different synthetic wheat lines and crossed this resistance into spring wheat to obtain resistant lines that are approximately 85% Louise genetic background. 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 due to multiple genes with small effects. These wheats carry the first known characterized genetic resistance to *Rhizoctonia*. Given its multigenic nature, resistance is expected to be durable, but will not be simple to move between lines. We must therefore determine which of the five sources of resistance provides the broadest benefits in terms of disease control and finish characterizing and transferring these resistances into elite PNW lines.

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: 3 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 develop PNW spring wheat cultivars.	Multiple (four to 13) BC2 lines from each of the five sources of resistance were selected and amplified. Replicated plots were examined in three locations in 2016 and 2017.	Additional crosses have been made with elite spring wheat varieties for further breeding efforts. Selections among these crosses will be performed this year, but no additional funding will be requested this year.	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. Results will be presented to growers through field day abstracts, Cook Chair reviews & research reviews.
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 Syn172 parents are complete.	This objective has been completed.	An article was published in 2016 in the journal Phytopathology and a second one in Molecular Breeding in 2017. Results have also been presented at conferences and seminars.
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 the relationships between the different soures of resistance.	The BC2 lines have been examined. For the most part the resistances all look different. We next need to compare them for resistance to different diseases.	All resistances will be well characterized at the end of FY18.	in 2016-17, results were reported at a regional meeting of the American Phytopathological Society and in the WSU Dryland Field Day Abstracts. Another article will be published and the results will be presented to growers through field day abstracts, Cook Chair reviews & research reviews.

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

Project #: 4150-1224

Progress Report Year: 2 of 3

Title: Extension Education for Wheat and Barley Growers

Cooperators: Drew Lyon, 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 Wheat and Small Grains website (smallgrains.wsu.edu) was launched by the Extension Dryland Cropping Systems Team in early 2014. The website serves as a one-stop shop for all the information WSU Extension has on small grains production. In 2017, the website was transitioned to the new WSU spine, which required reformatting all of the pages. The new pages have larger text and are easier to read and navigate than the previous pages. This was a major undertaking that would not have been possible without our Communications Consultant, Blythe Howell. Some noteworthy new content for the Wheat and Small Grains website in 2017 included: 1) the Wheat Beat Podcast, 2) the Residue Production Calculator, 3) the Seeding Rate Converter, and 4) the Herbicide Mechanisms of Action (MOA) Tool for Pulse Crops. The cereal variety selection and testing pages were awarded a 2017 Certificate of Excellence for websites, blogs, and social media from the Extension Education Community of the American Society of Agronomy. The Extension Dryland Cropping Systems Team was awarded the 2017 CAHNRS Team Interdisciplinary Award. The Wheat Academy was held on the WSU Pullman Campus on December 12 and 13. Attendance was limited to 75 people. There were 42 industry participants and 33 farmers.

Impact: Measureable impacts for the past year include a 49% increase in sessions and a 38% increase in unique users visiting the Wheat and Small Grains website compared to the previous year. The site had 39,747 sessions with 25,534 unique users in 2017, which was up from 26,603 sessions and 58,492 unique users in 2016. The 2017 Wheat Academy filled in less than two weeks and meeting surveys were very positive for the event. Attendees included 43 industry and 32 farmer participants.

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. An article will be written annually for Wheat Life magazine on our Extension activities.	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 content in 2017 included the Wheat Beat Podcast, the Residue Production Calculator, the Seeding Rate Converter, and the Herbicide Mechanisms of Action (MOA) Tool for Pulse Crops.	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, including an annual article in Wheat Life magazine, 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. In 2017, the Wheat Academy filled in 2 weeks and included 42 industry participants and 33 farmers.	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 growers through 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: *3 of 3*

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

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

Executive summary: The 2017 harvest sample analysis is nearing completion; the project also covered the 2015 and 2016 harvests (3 years). As in previous years, all quality data were/will be analyzed using the *t*-Score statistic. The quality *t*-Scores for each soft white winter, club, soft white spring and club, hard red winter, hard red spring and hard white winter and spring 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"* each year with annual updates. Completion of the variety rankings in February represents the first significant accomplishment each year 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.

Deliverables: Over the three years of the project period, we processed 3,518 samples, broken down as follows: SWW 1,888, SWS 346, Club 239, Hard Winter 652, and Hard Spring 393.

Inserted at the end is the recent Preferred Variety pamphlet.

Outputs and Outcomes:

Following are recent advanced lines and released varieties that were supported with complete end-use quality analyses:

4J71366C	Pritchett	winter club
KXB-01	--	--
WA8118	Sprinter	HRS
WA8124	Ryan	SWS
WA8143	Curiosity CL+	SWW
WA8155	Mela CL+	SWW
WA8158	--	HWW
WA8162	Seahawk	SWS
WA8165	Chet	HRS
WA8166	Alum	HRS
WA8169	Jasper	SWW
WA8177	--	SWW
WA8180	Sequoia	HRW
WA8184	Earl	HWW
WA8187	Resilience CL+	SWW
WA8189	--	SWS
WA8189	Tekoa	SWS
WA8193	Melba	spring club
WA8212	--	SWW
WA8232	--	SWW
WA8235	--	SWW

2017 Quality Rankings

Varieties are listed by statistical quality rankings by class. When making a decision between varieties with similar agronomic characteristics and grain yield potential, choose the variety with the higher quality ranking. This will help to increase the overall quality and desirability of Pacific Northwest (PNW) wheat.

Most Desirable (MD)—These varieties generally have high test weights, appropriate protein content (kernel properties), and excellent milling and end-use properties.

Desirable (D)—The kernel, milling, and end-use qualities of these varieties range from good to very good. The quality attributes of these varieties are desirable in international trade.

Acceptable (A)—The kernel, milling, and end-use qualities of these varieties range from acceptable to good. Individual varieties may possess minor flaws. The quality attributes of these varieties are acceptable in international trade.

Least Desirable (LD)—These varieties have displayed low quality characteristics for this class of wheat. The intrinsic quality of PNW wheat will be improved if these varieties are not planted.

Unacceptable Except Customer-Specific Uses (UCS)—One or more critical flaws in quality are present in these varieities and will not make suitable products for this class of wheat. Production of these varieties should be targeted to specific end-uses and kept strictly segregated from general commercial channels.

These rankings are based on the results of the *Genotype and Environment Study (G&E)* quality testing conducted by the USDA Western Wheat Quality Laboratory, the Washington State Univeristy Wheat Quality Program, the University of Idaho Wheat Quality Laboratory, and the Oregon State University Cereal Quality Laboratory, including relevant breeding nurseries.

End-use quality determinations were based on results from grain, milling and product quality tests.

The quality scores presented here reflect a minimum of three years' data in the G&E study, using a reference variety for each class. The scores are reviewed yearly as new data becomes available, and are subject to change. Varieties not listed have not been tested or have less than three years of data. For complete results, please visit the website:

www.wsu.edu/~wwql/php/index.php

For agronomic information, please consult: 1) the Washington State Crop Improvement Association Certified Seed Buying Guide; 2) WSU Uniform Cereal Variety Testing Program (http://variety.wsu.edu); 3) North Idaho Extension Cereals Program (http://cals.uidaho.edu/cereals/nidaho); 4) Oregon Elite Yield Trials (http://cropandsoil.oregonstate.edu/wheat/state_performance_data.htm).

Washington Grain Commission
2702 West Sunset Blvd, Suite A
Spokane, WA 99224
(509) 456-2481
E-mail: syates@wagrains.org
Website: www.wagrains.org

Oregon Wheat Commission
1200 NW Naito Pkwy, #370
Portland, OR 97209-2879
(503) 467-2161
E-mail: tsimpson@oregonwheat.org
Website: www.owgl.org

Idaho Wheat Commission
821 West State St
Boise, ID 83702-5832
(208) 334-2353
E-mail: cathy.wilson@idahowheat.org
Website: www.idahowheat.org

USDA Western Wheat Quality Lab
Craig Morris, Lab Director
Doug Engle, Lab Manager
(509) 335-4062
E-mail: morrisc@wsu.edu
Website: www.wsu.edu/~wwql

Preferred Wheat Varieties *is provided courtesy of: The Washington Grain Commission, the Oregon Wheat Commission, and the Idaho Wheat Commission.*
The G and E Study *is financially supported by the WGC, OWC, and IWC.*

Washington
Oregon
North Idaho

Preferred Wheat Varieties 2017

Based on end-use quality

Soft White Winter

Bobtail	OSU	MD
Brundage96	UI	MD
BrundageCF	UI	MD
ARS-Amber	ARS	MD
Kaseberg	OSU	MD
Bruneau	UI	MD
Ladd	OSU	MD
Puma	WSU	MD
WSU UI Huffman	WSU UI	MD
WB-Junction	WB	MD
Jasper	WSU	MD
ARS-Selbu	ARS	D
Mary	OSU	D
ORCF101	OSU	D
Masami	WSU	D
LCS Drive	LCS	D
SY Ovation	SY	D
Skiles	OSU	D
UI Sparrow	UI	D
WB 523	WB	D
Legion	SY	D
Eltan	WSU	D
Norwest Duet	OSU/LCS	D
WB-528	WB	D
Otto	WSU	D
Stephens	OSU	D
SY Assure	SY	A
ORCF103	OSU	A
Madsen	ARS	A
LCS Artdeco	LCS	A
Mela CL+	WSU	A
Rosalyn	OSU	A
WB1604	WB	A
ORCF102	OSU	A
WB-1070CL	WB	A
Curiosity CL+	WSU	A
WB1529	WB	A
Goetze	OSU	A
WB-1066CL	WB	A
AP700CL	SY	A
WB 456	WB	LD
Xerpha	WSU	LD
Tubbs06	OSU	LD
SY107	SY	LD

Soft White Spring

UI Stone	UI	MD
Tekoa	WSU	MD
Diva	WSU	MD
WB6341	WB	MD
Louise	WSU	MD
Alturas	UI	MD
Ryan	WSU	MD
Seahawk	WSU	MD
Whit	WSU	MD
Babe	WSU	MD
Nick	WB	D
Cataldo	UI	D
WB-1035CL+	WB	UCS

Club

ARS-Crescent	ARS	MD
Cara	ARS	MD
Chukar	ARS	MD
ARS-Pritchet	ARS	D
ARS-Chrystal	ARS	D
Bruehl	WSU	D
Coda	ARS	D

Spring Club

Melba	WSU	MD
JD	WSU	MD

Hard White Winter[1]

UI Silver	UI	MD
Darwin	UI	MD
MDM	WSU	A
Palomino	SY	LD

Hard White Spring[1]

UI Platinum	UI	MD
WB-Hartline	WB	D
Dayn	WSU	D
LCS Star	LCS	A
BR7030	Arizona Plant Breeders	UCS

[1]Hard white wheats are scored for export quality requirements such as bread quality and potential noodle quality.

Hard Red Winter

WB-Arrowhead	WB	MD
Eddy	WB	MD
Sprinter	WSU	MD
UI SRG	UI	MD
Whetstone	SY	MD
Norwest 553	OSU	D
Buchanan	WSU	D
LCS Evina	LCS	D
Farnum	WSU	D
LCS Jet	LCS	A
Keldin	WB	A
Rimrock	WB	A
Esperia	Societa Produttori Sementi Spa	A
LCS Colonia	LCS	A
LCS Azimut	LCS	A
Residence	Cebeco	UCS
Estica	Cebeco	UCS
Symphony	Tanio Tech	UCS

Hard Red Spring

Hollis	WSU	MD
SY605 CL	SY	MD
Alum	WSU	MD
SY Steelhead	SY	MD
Glee	WSU	MD
Chet	WSU	MD
WB-Fuzion	WB	MD
LCS Luna	LCS	MD
Winchester	UI	D
LCS Iron	LCS	D
Bullseye	SY	D
Jefferson	UI	D
Kelse	WSU	D
Jedd	WB	A
WB 9879CLP	WB	A
Buck Pronto	LCS	A

Abbreviations

WSU	*Washington State University*
OSU	*Oregon State University*
UI	*University of Idaho*
ARS	*Agricultural Research Service*
SY	*Syngenta*
WB	*WestBred/Monsanto*
LCS	*Limagrain Cereal Seeds*

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

Project #: 4722

Progress Report Year: *3 of 3*

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

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

Executive summary: This WGC support provides for about 3 months of additional 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 2016-Crop were completed and 2017-Crop testing is well under way at the Western Wheat Quality Lab. This reporting period also covers the 2015 and 2016 harvests.

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.

Deliverables:

Following are recent advanced lines and released varieties that were supported with complete end-use quality analyses:

4J71366C	Pritchett	winter club
KXB-01	--	--
WA8118	Sprinter	HRS
WA8124	Ryan	SWS
WA8143	Curiosity CL+	SWW
WA8155	Mela CL+	SWW
WA8158	--	HWW
WA8162	Seahawk	SWS
WA8165	Chet	HRS
WA8166	Alum	HRS
WA8169	Jasper	SWW
WA8177	--	SWW
WA8180	Sequoia	HRW
WA8184	Earl	HWW
WA8187	Resilience CL+	SWW
WA8189	--	SWS
WA8189	Tekoa	SWS
WA8193	Melba	spring club
WA8212	--	SWW
WA8232	--	SWW
WA8235	--	SWW

Outputs and Outcomes:

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-18**			
Project year:	3			
Objective	**Deliverable**	**Progress**	**Timeline**	**Communication**
Complete spring wheat samples	Full mill & bake data delivered to breeder by early Feb.	will be reported; progress on last year's crop is 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,
Complete winter wheat samples	Full mill & bake data delivered to breeder by early June	will be reported; progress on last year's crop is 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,

Washington Grain Commission
Barley Research Final Report

Project #: 3019-3009

Title: Improving Barley Varieties for Feed, Food and Malt

Cooperators: Kevin Murphy, Janet Matanguihan, Max Wood, Deven See, Xianming Chen, Stephen Guy, Ryan Higginbotham

Executive summary:

Over the past three years (2015 to 2017), significant and substantial progress in breeding and varietal development has been achieved within each market class – feed, malting, and food – of barley. A total of five barley varieties have been released: Lyon and Muir in the conventional feed barley class, Survivor in the herbicide tolerant feed barley class, and Havener and Meg's Song in the hulless food barley class. Here I will briefly summarize their respective performance using multi-year, multi-location WSU Variety Testing data.

Muir was released in 2015 for the <16" rainfall zone. It is resistant to prevalent races of barley stripe rust, and ranks higher in yield than commonly grown barley varieties Lenetah, Champion, LCS Vespa, Lyon, LCS Genie, and CDC Copeland over a five-year span from 2013-2017 across the low rainfall zone locations. Muir has replaced Bob and Baronesse as the go-to variety in these locations.

Lyon was also released in 2015, with the high rainfall zone (>20") as its target environment. Across multiple locations over five years (2013-2017), Lyon is consistently (and statistically) among the highest yielding group of barley varieties in the high rainfall locations. Lyon has effectively replaced both Bob and Baronesse in these locations.

Survivor was released in 2017 and in that year was among the highest three yielding varieties topping the high rainfall precipitation zone (4 locations). It is also the only IMI-herbicide tolerant variety available to farmers. Over a three-year timespan (the most available), Survivor yielded equal to Lyon, Muir, Champion, LCS Genie, Lenetah, LCS Vespa, Claymore, LCS Odyssey and Oreana. In other words, Survivor stands with the best of the current barley varieties in terms of yield, and better than most for stripe rust resistance, in the high rainfall zone. We continue to test thousands of herbicide tolerant breeding lines each year to target both the malt and food market classes in addition to the feed barley market class.

Havener, the first hulless food barley released 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, has 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.

Released in 2015, Havener has higher yields and test weights across all eastern Washington rainfall zones than the hulless variety Meresse.

Meg's Song was released in 2017, with even higher β-glucan (~7.5%) than Meresse or Havener (~6.0%), and high yields across a broad spectrum of environments. Meg's Song has excellent tolerance to lodging in the field and has attracted the attention of seed dealers and end-users. It has a substantially different cooking and baking profile than Havener, giving them both a solid foothold on the emerging hulless food barley market.

Malt barley: We have made excellent progress on our malt barley program as well, with top experimental line 11WA-107.58 performing exceptionally well over two years (2016-2017) in the high rainfall zone. Other top malt lines that have only been in WSU Variety Testing for one year include 11WA-107.36 which topped the high rainfall zone locations in 2017 and 12WA-120.14 which yielded over 1000 #/acre more than CDC Copeland across two intermediate rainfall zone locations in 2017. ***Our highest programmatic priority at this point is to release a high-quality, high-yielding malt barley variety within the next two years.***

Impact:

Of the earliest varieties released in my program, Lyon and Havener are beginning to gain traction in the market. They were only recently made available to farmers, so although acreage of each is low, the reception they have received by growers and industry has been positive and should have an upward trend over the next funding period.

The two most pressing issues or constraints to barley production are the decreasing price of barley and the large acreage of Clearfield winter wheat grown in Washington. Price has decreased steadily from $5.53/bushel in 2012, to $4.12/bushel in 2013, $3.54/bushel in 2014, $3.31 in 2015, and $2.90 in 2016 (wagrains.org). Understandably, harvested acreage and total production of barley has decreased over this period. Though it is difficult for my program to have a positive impact on barley price, we are doing so in two meaningful ways. The first is the development of value-added food barley varieties for the emerging market that pays a premium on higher beta-glucan varieties. In addition to releasing two new varieties, Havener (2015) and Meg's Song (2017), with a 50 to 75% increase in beta-glucan content over currently grown hulled feed barley, these new varieties are significantly higher yielding than their hulless predecessors. Havener is already being exported to Asia, and I intend to keep this trend of increased yield coupled with high beta-glucan varieties going. The second way we are addressing price is through the targeting of malt barley varietal releases, and in particular, that of craft malt. Prices are higher for the malt barley market class and could make a positive difference in the economics of growing barley. We are within two years of releasing the first WSU malting barley in over three decades.

To address the impact of Clearfield winter wheat on spring barley production in Washington, in 2017 we released Survivor, a feed variety tolerant to residual herbicide in the soil. Survivor will be first available to growers in 2018, and it too should have a positive impact on barley production in Washington.

Outputs and Outcomes:

Objective	Deliverable	Progress	Timeline	Communication
Hulled, Feed Barley	Two new feed barley varieties, ***Lyon*** and ***Muir***, were released.	Excellent (with continued feed barley development expected to result in another release by 2020-2021).	2015	Talks and presentations at field days; distribution of informative variety rack cards; Wheat Life articles.
Herbicide Tolerant Barley	Our first herbicide tolerant barley variety, ***Survivor***, was released.	Excellent (with continued herbicide tolerant barley varieties across all market classes in development and expected for full release by 2020-2021).	2017	Talks and presentations at field days; distribution of informative variety rack cards; Wheat Life articles.
Hulless, Food Barley	Two new hulless, food barley varieties, ***Havener*** and ***Meg's Song***, with high (>6%) beta glucan, were released.	Excellent (with continued hulless food barley development in progress, particularly for waxy types not represented in Havener or Meg's Song).	2015 (Havener) 2017 (Meg's Song)	a) Talks and presentations at field days; Wheat Life articles; b) Distribution of informative variety rack cards.
Malt Barley	This program was revived from scratch, and we now have 5 to 6 entries in WSU Variety Testing with excellent potential for an upcoming malt barley release.	Utilizing molecular markers, doubled haploids, single seed descent, and off-site winter nurseries, we have fast-tracked the malt barley program and are now within two years of releasing the first WSU high-quality malt barley in three decades.	2020-2021	Talks and presentations at field days; 3 years of the annual Know Barley, Know Beer field day; distribution of informative variety rack cards; Wheat Life articles.

Progress Report

Project #: 3682

Progress Report Year: 2 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: Variety trials for eyespot and Cephalosporium stripe were not conducted in 2016-17. However, the trial was planted in 2017 for evaluation in 2018, and data from previous plots was used to update variety disease ratings in the Washington State Crop Improvement Association Seed Buyers Guide. A seed treatment trial conducted in 2016-17; this is the second year with no yield or disease control benefit, so this work will not be continued. A study was begun to map disease resistance genes to both of the eyespot fungi in Madsen. Although Madsen is one of the first eyespot resistant varieties in WA, its resistance to both eyespot pathogens has never been mapped to determine whether the same genes control resistance to both pathogens. In collaboration with colleagues, we are also mapping resistance to cereal cyst nematode (CCN). Spore-trapping for the eyespot fungi was conducted again at the Palouse Conservation Field Station and Spillman Farm to understand the seasonal dynamics of ascospore release, which may contribute to pathogen genetic variation; data are still being collected and analyzed. Field studies to determine the effect of variety mixtures on eyespot and Cephalosporium stripe were continued. Disease data were collected from both experiments, but the eyespot nursery was flooded by spring rains and yield was not determined.

Impact: Although variety trials for Cephalosporium stripe and eyespot were not conducted this year, data from previous years was used to provide ratings for some newly released varieties and to update others already listed in the WSCIA seed buyer's guide and the WSU Small Grains variety selection tool for use by growers in making variety selection decisions. Currently, the gene present in Madsen is the primary source of resistance in all other PNW eyespot-resistant varieties and understanding its genetic control will insure it remains effective. New genes are needed for eyespot resistance to improve effectiveness, further reduce losses to this disease and broaden the genetic base of resistance. Developing a better understanding of genetic variation in the eyespot and Cephalosporium stripe pathogens 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): 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. 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.	**2016:** 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. Unfortunately, yield data were not obtained from the eyespot plot due to spring flooding. Data are being analyzed now. **2017:** Data was collected from field plots planted in 2016 and is being analyzed. Field plots were planted again in fall 2017 for data collection in 2018.	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.
2. 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.	**2016:** 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. **2017:** A Madsen population was screened for resistance to one of the two eyespot pathogens to determine whether the same genes are involved in resistance to both pathogens. This population is also being screened for cereal cyst nematode resistance.	**2016:** This work will begin in fall 2016 or spring 2017, but not completed until the end of the project. **2017:** Screening of the Madsen population will continue during the first half of 2018, afterwhich we plan to compelte screening some wheat relatives through 2018 into 2019.	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.
3. Evaluate eyespot pathogen populations for resistance to new fungicide active ingredients.	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.	**2016:** 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. **2017:** No activity on this objective during 2017.	**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.

4. 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 .	**2016:** Molecular markers were developed for one of the eyespot fungi 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 release, which may contribute to pathogen genetic variation. Traps are sampled weekly and evaluated using microscopy and real-time PCR to determine when and relatively how many spores were released. **2017:** Aerial spore-traps were again deployed from September through May, with samples collected weekly. Samples from spring have been analyzed; data from fall collections are still being collected and summarized to determine when ascospores of the eyespot fungi are present. No progress was made on development of molecular markers for the eyespot fungi.	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.
	Prepare an article for Wheat Life during the three-year project summarizing results.	**2016:** No progress. **2017:** An article on eyespot and Cephalosporium stripe will be submitted in April 2018.	Submit an article in spring 2018.	
5. 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.	**2016:** 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. **2017:** Variety screening was not conducted in 2017, but field plots were planted and inoculated for both eyespot and Cephalosporium stripe rating in 2018. Data from previous trials was used to provide and update ratings for the WSCIA Seed Buyer's Guide and WSU Small Grains variety selection tool.	**2016:** Testing did not occur due to staff and funding limitations. **2017:** Disease testing plots for new varieties were planted in collaboration with the WSU Variety Testing progam in fall 2017 for rating in 2018.	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.

Progress Report

Project #: 3675

Progress Report Year: 2 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: Field plots were established 2016 at three locations in WA and one in Tetonia, ID to test advanced breeding lines and three new doubled-haploid populations for snow mold resistance and agronomic performance. Snow cover persisted for well over 100 days in WA and disease development was good enough to collect useful data on disease reaction. Field plots were planted again in 2017 for evaluation in spring 2018, depending on disease development. Wheat samples for fructan analysis were collected from field and growth chamber experiments. Methods for analysis of the sugars were revised and are being optimized with a goal to complete the analyses by the end of February and complete data analysis in 2018. Results of these studies will be used to improve growth chamber screening for resistance. Controlled environment testing won't replace field testing, but 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, validation of molecular markers for snow mold resistance in a Xerpha x Munstertaler population was completed and preparation of a manuscript is in progress. Results were presented at one scientific meeting.

The source of resistance in the three new double haploid populations is new to Washington and may result in more effective resistance to the snow mold diseases than exists now.

Successful completion of these objectives will provide growers with a greater selection of 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: 2 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.	**2016**: 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 was collected in the spring of 2017 for snow mold tolerance. **2017:** The populations were planted again in Waterville and Mansfield, as well as in Tetonia, ID for snow mold screening. Waiting for data collection in spring 2018.	Field testing will be conducted in 2017 and 2018. More years of testing may be needed depending on the level of snow mold in each year. One of the three populations will be genotyped in 2018 using GBS and the other two will be used for validation.	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.	**2016:** The winter wheat breeding program planted 246 advanced breeding lines for testing in the spring of 2017 under snow mold conditions. We were able to identify many breeding lines with excellent resistance to snow mold. Many of these have come up through the program with continual selection under snow mold conditions. The establishment of excellent lines with snow mold resistance indicates that selection under natural conditions is an appropriate method for development of new lines. We also evaluated a diversity panel of 480 soft white lines for further genetic understanding of snow mold resistance. **2017:** In the fall of 2017 we planted the diversity panel of 480 lines in both Waterville and Tetonia for evaluation. Our breeding lines were planted in two locations in Waterville. We planted ~300 breeding lines for evaluation. We also planted ~40 populations for early generation selection, and have started including Kim Campbell's club wheat (both early and late generation) in our planting designs to improve club wheat performance to snow mold.	Field plots will be established 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.	**2017:** No progress. A new schedule was developed for 2018 articles and snow mold was not included.	An article will be submitted in late 2018 near the end of the project.	

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.	**2016:** 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. **2017:** Samples were collected from field and greenhouse experiments. Work is in progress now to optimize methods for measuring the fructans. The goal is to have all analyses completed by the end of February 2018.	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 occurred in 2017 and analyses are in progress.	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.	**2016:** Waiting for results from fructan studies to identify critical environmental conditions to identify resistance. **2017:** Growth chamber experiments were conducted in 2017 to collect samples for carbohydrate analyses. These data will be used to develop growth chamber screening methods.	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.

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

(Begin 1 page limit)
Project #: 3061-7667
Progress Report Year: *2 of 3 (maximum of 3 year funding cycle)*

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

Executive summary:

- In 2017, we concentrated our survey around the infested fields in Colton and near Colfax, to locate additional "hot" locations for testing purposes. We identified an additional field with *H. filipjevi* that would be suitable, if monocropped to wheat or barley. We identified a field for *H. avenae* that was in wheat last year.
- We established greenhouse pot cultures of *H. avenae* and *H. filipjevi.* These cultures will be grown in the greenhouse to increase nematode populations and then used for screening
- In spring and summer 2017, we developed a high throughput greenhouse technique and screened 786 advanced lines from 4 WSU breeding programs for resistance to *H. filipjevi* and *H. avenae.* This was the largest number screened to date. This method assesses roots of young plants grown in cone-tainers containing soil collected from highly infested fields in fall and vernalized at 4 C prior to planting.
- From this screening, we identified resistance in 10 to 21% of the advanced winter wheat lines, but less than 2% of spring wheat lines. Named and advanced lines resistant to *filipjevi* in one or more trials include ARS Crescent and Selbu, Cara, Otto, Masami, Madsen, Foote, ORCF-102, Prichett, SY605CL and Steelhead; WA 8235, 8206, 8163, 8194; Svevo and Soft Svevo.
- Preliminary resistance to *H. avenae* was found in Norwest 553, Jasper, and WA 8227. Chara and WA 8235 showed resistance to both *H. filipjevi* and H. *avenae.* In addition, three HRW and 12 SWW showed resistance.
- We developed KASP markers for QTLs for resistance to *H. filipjevi* that were identified in a CIMMYT study and assayed the breeding lines that we evaluated above. We were not able to identify the same QTLs in our material, except in the durum Svevo and Soft Svevo. These sources of resistance may be specific to CIMMYT derived material.
  Impact:
- Using the high throughput greenhouse screening system, we can now screen material at an earlier stage and report results to breeders. We identified many good sources of resistance to cereal cyst nematode *H. filipjevi* and *avenae* in the adapted winter wheat and a few in spring wheat breeding lines and varieties. Planting these varieties will reduce the inoculum levels in infested fields.
- We collected all the data needed to identify markers associated with specific *Cre* genes, which should speed up selection and possibly identify new sources of resistance
- **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: 2017-2018

Objective	Deliverable	Progress	Timeline	Communication
Obj. 1. Screen adapted PNW and US varieties and advanced material in WA breeding programs for resistance to *Heterodera* in infested soil in the greenhousem, 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 fifth year of resistance testing, all in the greenhouse, using vernalized field soil infested with *H. filipjevi* and *avenae* against both winter and spring wheat. Screened 786 lines from the programs of Carter, Pumphrey, Campbell, and Morris, regional nurseries, and a Campbell mapping population (NEMAMAX). Identified 135 resistant lines. Named and advanced lines with resistance to *H. filipjevi* include ARS Crescent and Selbu; Cara, Otto, Masami, Madsen, Foote, ORCF-102 Prichett, SY605CL and Steelhead; WA 8235, 8206, 8163, 8194; Svevo and Soft Svevo. • Preliminary resistance to *H. avenae* was found in Norwest 553, Jasper, and WA 8227. Chara and WA 8235 showed resistance to both *H. filipjevi* and *H. avenae* . In addition, 3 HRW and 12 SWW showed resistance.	Will continue greenhouse testing next year using vernalized, infested soil in the greenhouse.	T. C. Paulitz, Y. Manning-Thompson, Nuan Wen, Dan Schlatter, James Borneman, and Kimberly Garland-Campbell. 2017. Research on Cereal Cyst Nematode in Eastern Washington. 6th International Cereal Nematode Symposium, Agadir, Morocco Sept. 11-15, 2017.
	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 2017. The soil has been vernalized and will be tested to look at hatchability and make sure the cultures do not have mixed species. The populations will aslo be increased with one more cycle in the greenhouse	
Objective 2. Use markers to identify the *Cre* genes in our lines, and use markers to incorporate this resistance into breeding programs	Usable markers that can be incorporated in the breeding programs.	Markers for QTLs showing resistance to *H. filipjevi* in CIMMYT lines were converted to KASP markers, and large set of our resistant material was run to see if we have any of these QTLs. Unfortunately, these markers were only found in resistant durum lines. This indicates that our material may have different background resistance that the CIMMYT lines, although we are using this germplasm in our program. SSR markers linked to *Cre1* , *Cre3* , *Cre5* , *Cre8* , *CreX* , and *CreY* genes are currently being tested. These markers may facilitate the understanding of the resistance background of our material.	Continue to develop and test markers for other identified *Cre* genes	
	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. In 2017, we concentrated our survey efforts to identify other fields with high levels of *filipjevi* and *avenae* that could be used for greenhouse testing. We identified a field near Colfax for *H . avenae,* and a field near Colton that may have to be increased for *H. filipjevi.*	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. 2017. "Root Disease Research at ARS Pullman-What's New?" Spokane Farm Forum, Ag Expo, Feb. 2, 2017. (presentation).
Obj. 4. Identify pathotypes of *H. filipjevi*	Knowledge of pathogen diversity in relation to other world populations, to aid in selecting resistance *Cre* genes	Differential lines were imported from Turkey and seed was increased in the greehouse. Initial screens were started in Fall, 2017.	Pathotype testing will continue in the greenhouse in 2018-2019.	

Washington Grain Commission

Wheat and Barley Research Annual Progress Reports and Final Reports

Project #:	**3019 3574**
Progress Report Year:	*_3___ of __3__ (maximum of 3 year funding cycle)*
Title:	**Evaluation of WSU wheat breeding lines for management of Hessian fly and development of DNA markers for resistance breeding**
Cooperators:	Mike Pumphrey, Nilsa A. Bosque-Pérez

Executive summary:
Hessian fly (HF) infestations continue to cause significant annual yield losses in spring wheat production areas of Washington and neighboring regions of Oregon and Idaho. Hessian fly is in many ways a silent problem. Moderate infestations are not visually striking, and their occurrence is somewhat variable over space and time. Factors such as weather patterns, crop rotation, variety selection, and tillage or conservation practices can impact HF pressure. Infestation may also be a significant barrier to increased conservation tillage practices in the Palouse. Advanced breeding lines, new sources of resistance genes *H13*, *H26*, and two unknown resistances source, along with mapping population progeny were screened for Hessian fly resistance in 2015-2017. Backcross populations were developed with four new sources of resistance, and progeny selfed to select homozygous resistant lines. 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. This project supported the now routine screening of all new entries in WSU Variety Testing Program spring wheat trials, as well as other germplasm such as soft durum wheat lines. In 2017, we completed a systematic screening of all available known sources of resistance to Hessian fly with multiple Hessian fly populations collected in the PNW. The effectiveness of *H5, H13, H15, H22*, *H25, H26, H32*, and *H34* to these PNW HF populations was documented, and this has guided our future germplasm development, breeding efforts, and DNA marker discovery and validation research. In other words, for the first time, we now know the full set of effective genes that we can use to protect against damage and are actively incorporating them.

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: attached

WGC project number: 3574 (renewal)
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: 2018
Project year: 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
Screen WSU Spring Wheat breeding populations and advanced breeding lines for resistance to Hessian fly in the laboratory	Information on resistance of elite breeding lines on an annual basis	Over 80 spring wheat lines, 12 winter wheat breeding populations, and new entries into the WSU Wheat Variety Testing Program were screened in 2017.	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. BC4 populations were self pollinated, selected for Hessian fly resistance, and Doubled-haploid progeny were developed from resistant plants. Also, JD and Melba were used to begin intrgession of four new resistance sources through backcrossing with phenotypic selection. In 2017, screening of 29 resistance sournces with two populations of HF from the PNW revealed eight resistance sources that 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: ___*1*_ *of* _*3*___ *(maximum of 3 year funding cycle)*

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

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

Executive summary:

WSU spring and winter wheat variety development programs heavily emphasize selection for superior end-use quality. 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. The majority of wheat from the PNW is exported to overseas markets. To maintain current markets, penetrate new markets, and recapture lost markets, PNW wheat must possess quality characteristics that make it superior 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. 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.

Impact:

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 variety releases that are widely adopted that also have very good to excellent end-use quality. One of our goals as public breeding programs in Washington State is to set a high-bar for end-use quality, and continue to raise that bar for long term market health. By releasing lines with superior agronomics, paired with most desirable end-use quality, we provide growers with options that put quality in the decision process, while not sacrificing yield or other agronomic and protection traits. Several of our newest varieties are preferentially sourced because of their superior end-use quality, and specific traits like gluten strength and breadmaking quality, low cadmium concentration, partial waxiness, and outstanding cookie and cracker quality. Landmark varieties like Louise and Xerpha, are being replaced by better end-use quality replacements with higher yields, better agronomics, and stable performance. This short, medium, and long-term impact is of paramount importance to the Washington grain industry.

Outputs and Outcomes: File attached

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

Objective	Deliverable	Progress	Timeline	Communication
Early to late generation quality testing of WSU experimental lines to aid variety development	New spring wheat and winter wheat varieties that are superior to existing varieties. This effort includes all market classes of spring and winter wheat and all precipitation regions in Washington state.	Over 1500 breeding samples were analyzed by numerous milling and baking quality tests each year in recent years. This is a substantial increase over previous years and has allowed enhanced selection of advanced breeding lines with good quality. Two new wheat varieties were released in part due to this project and data in 2017.	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.	A hard red spring wheat bi-parental popualtion was milled and baked to map breadmaking quality traits in 2017. Milling and baking analysis of a bi-parental winter wheat mapping population has also been completed. A new breadmaking quality marker, WBM, was tested and validated in 2017, and used to screen elite sspring wheat germplasm.	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: _2___ *of* __3__ *(maximum of 3 year funding cycle)*

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

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

Executive summary:

The WSU spring wheat breeding program's elite material and recently released varieties continue to be the top performers is statewide variety trials and for growers. Foundation and registered seed of Ryan, Seahawk, Tekoa, Diva, Louise, and Whit soft white spring wheats, Alum, Chet, Kelse, and Glee hard red spring wheats and JD and Melba spring club wheats was produced and sold in 2017, and they accounted for ~54% of all certified spring wheat production acres in Washington. Each variety has very good to excellent end-use quality, which is a primary goal of our program to help maintain and increase the value of Washington wheat. Our newest soft white spring wheat varieties, Ryan, Seahawk, Tekoa, and Melba, have broad adaptation, superior all-around disease, grain, and agronomic traits, most desirable end-use quality, and top yield performance. They have been rapidly adopted by seed dealers and growers as seed stocks are multiplied. Kelse and Glee have been the leading hard red spring wheat varieties in the state the past few years, while Chet has been widely adopted in lower rainfall areas and Alum is rapidly increasing in acreage. The consistency, broad adaptation, disease and pest resistances, sound grain traits, most desirable end-use quality, good falling numbers, and overall performance of these varieties reflects the outputs of comprehensive wheat breeding and genetics research effort supported primarily through funding from this project.

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 release 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. Our newer releases are poised to lead acreages planted in the future due to improved potential profitability for growers, and rapid industry adoption. 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: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
Develop biotic and abiotic stress tolerant, high-yielding, and high-quality hard red, soft white, club, and hard white spring wheat varieties for diverse Washington production environments.	New spring wheat wheat varieties that are superior to existing varieties. This effort includes all four market classes of spring wheat and all precipitation regions in Washington state.	Newly released varieties Seahawk, Alum, Chet, Tekoa, Melba, and Ryan continued to lead yield trials in their classes in 2017, and are rapidly increasing in seed availability. Each is expected to have a significant positive economic impact for PNW growers. We had very good test plots across regions in 2017. Good data quality is fundamental to making solid selections. Our 2-gene CF breeding efforts have fully matured, and outstanding variety candidates in each market class will enter statewide Variety Testing plots in 2018. Our attention to stable falling numbers over the past five years has resulted in selection of superior lines for this trait.	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 2017. A primary focus in 2017 was backcrossing Fusarium head blight resistance into hard red spring wheat germplasm. Extensive crossing blocks for irrigated hard red spring wheat germplasm development were also completed. Our collaborative efforts on soft durum spring wheat with Dr. Craig Morris have increased, and multi-location yield trials are now routine as we develop germplasm for breeding this potentially value-added market class.	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 2017 to help long term breeding efforts. Scientific products of our efforts through multiple projects in 2017 include 13 publications in high-quality international scientific journals. Information from these research efforts help guide specific germplasm development efforts focused on Hessian fly, stripe rust, genomic selection, high-throuput phenotyping, association mapping, marker-assisted selection, drought tolerance, heat tolerance, yield, test weight, gluten strenth, etc.	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: *___2_ 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 1800 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 2017.

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 'Seahawk', 'Diva', 'Louise', 'Whit', 'JD' and 'Babe' accounted for ~68% of the soft white spring wheat acres planted in the state in 2017*. WSU varieties 'Kelse' and 'Glee' were leading hard red spring wheat varieties in 2017. *In total, ~54% of the 2017 Washington spring wheat acres were planted to WSU spring wheat varieties based on certified seed sales, which would be higher on an acre percentage basis due to dominance of our varieties in rain-fed production areas with lower seeding rates*. Over the past three years, we have released Chet, Alum, Seahawk, Tekoa, Ryan, 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. ***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: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
Develop DNA markers and select breeding lines by marker-assisted selection with stripe rust resistance, Hessian fly resistance, and two-gene Clearfield™ herbicide tolerance as well as other traits when desirable.	Elite variety candidates will result, in part, due to these molecular selection activities. Many of these populations will be ideal for marker optimization, new genetic mapping studies, and potentially the basis of new competitively funded projects.	The Spring wheat breeding program discovered or optimized several DNA markers in 2017, a few of which were published in peer-reviewed scientific journals, and are now being used in our breeding efforts. The Clearfield breeding efforts are progressing nicely, with new 2 gene lines entering advanced yield trials each year. One Wheat Life article was written/contributed in 2017, as well as supporting two other articles. A new DNA marker for wheat quality was tested and validated for bredmaking quality in 2017. This WBM locus is present in some of our bread wheat germplasm, but interestingly is nearly fixed in most elite good quality club wheat germplasm. We believe this locus may be significantly contributing to sponge cake volume, and will conduct validation experiments in 2018. If this is proven, this would be a significant step forward in better defining our critical sponge cake quality traits from a genetic perspective, which is an area that has been lacking.	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 2017, we completed evaluation of ~1800 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 2018.	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 2017, ~1800 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 2018 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.	We have continued to successfully develop and advanced hundreds of crosses for selection in breeding populations. In 2017 we advanced dozens of special-purpose populations, representing nearly 10,000 distinct lines in the greenhouse. The primary focus in 2017 was Hessian fly resistance selection in club wheat, and introgresssion of new Hessian fly resistance genes,	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.	

Washington Grain Commission
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Format

(Begin 1 page limit)
Project #:3019-3564

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

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

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

Cooperators:

Executive summary:

- we found two potential QTLs for resistance to *F. culmorum,* in addition to the two found to *F. pseudograminearum* in a previous funding cycle.
-we have screened almost 500 lines from regional nurseries and variety testing for resistance to *F. culmorum,* and are identifying the most resistant and susceptible.
-we have further optimized our greenhouse testing protocol to maximize disease and reduce variability by using a cold vernalization period followed by a water stress treatment at the end.
-we assessed lines in five variety testing sites in the intermediate rainfall zone for two years, in areas with high levels of *F. culmorum*. However, results were confounded by eyespot
-We conducted inoculated field trials for three years in Lind and Pullman, and have identified the most susceptible and resistant
-we evaluated statistical designs and models to minimize spatial variation in the WA variety testing locations, and found a better model than the one presently used.

Impact:

The economic impact of this disease continues to be large and impacts all growing areas of Washington.

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

A list of the most susceptible and resistant varieties, better methods to screen in the greenhouse for future work.

(End 1 page limit)

Fusarium Grant 2015-2017

3019-3564

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

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

3 year summary and final report.

Over the last 3 years, our main objectives have been to identify new and existing sources of resistance that can be use in the WA breeding programs to create tolerant varieties. Finding resistance to Fusarium crown rot is a much more intractable problem than finding single-major genes to control diseases such as stripe rust or cereal cyst nematode. There are no major genes identified for resistance against this disease. A much longer and better funded effort in Australia over the last 30 years has identified some varieties with moderate tolerance. They also have identified the most susceptible varieties, which is another goal of our program. The Australians have been able to obtain better resistance by combining sources of partial resistance. The other difficulty is the large genotype X environment interaction with this disease, which makes field screening much more difficult. Thus, much of our effort has gone into perfecting a reliable greenhouse screening method, and we have recently made advances in getting higher disease levels by vernalizing and water stressing the plants and rating them at the boot stage rather than at the seedling stage. Unlike the previous 3 year cycle, we have also concentrated on *F. culmorum* rather than *F. pseudograminearium.* This species is also widespread in the PNW and gaps needed to be filled in.

Our main objectives have been

1) to find new sources of resistance with association mapping. This is a continuation of previously funded projects to find QTLs to *F. pseudograminearum.* The efforts of our PhD student Yvonne Thompson is to conduct a genome-wide association study (GWAS) to determine the genetic architecture of resistance to *F. culmorum* in a diverse global spring wheat collection. To achieve this objective, a modified greenhouse screening system* was developed that encourages higher disease pressure enhancing our capability in evaluating disease response. The germplasm used is part of the spring core nursery of the USDA National Small Grains Germplasm bank. A representative subset of 600 wheat accessions, from nearly 5,000, was obtained via phylogenetic analysis. This collection was screened three times in 2015-2016. Resulting average ratings of the three trials were highly skewed towards resistance suggesting that disease pressure was too low to separate resistant from susceptible wheat accessions. As a result, the screening system was reassessed and modified to produce the optimal environment for pathogen growth and infection. Using the modified greenhouse screening system, phenotypic data of one 2017 trial suggest differential responses reflecting genetic variability under disease pressure. Genotypic data for the germplasm set was acquired using the Illumina wheat 9K iSelect SNP chip which has also been assayed for several other field and disease related traits as part of the USDA-NIFA Triticeae CAP project. Thus, it can be an important resource where a number of resistant genes can be combined. GWAS was conducted using the software package GAPIT

R. Two statistically significant marker trait associations (MTA) were confirmed on chromosomes 3B and 2B, however more phenotypic repetitions are needed to increase experimental power. Results from repetitions 2-4 are currently underway and will be available for analysis in February 2018. KASP markers will be developed and verified from MTAs for use in assisted selection for introgression into wheat cultivars ultimately providing improved resistance to Fusarium crown rot.

*Modified Greenhouse Screening System

Five PNW *F. culmorum* isolates were used in the assays to include a wide range of pathogenic capabilities representative of isolate variability in the native population. A colonized grain method was used to produce inoculum. Inoculated trials were conducted in a Conviron growth room provided by the Washington State University Plant Growth Facilities. Growth room temperature was set at 10°C during the day and 5°C at night with a photoperiod of 14-hour days and 10-hour nights during the first week. Thereafter, the temperature was adjusted on a weekly basis to correlate with optimum fungal toxin production as follows.

Temperature adjustment by week for growth room		
Week	Day Temp in C	Night Temp in C
1	10	5
2	13	8
3	15	10
4	18	13
5	20	15
6	25	20
7	30	25
8	35	30

Method: A single seed from each accession was planted in a 4 cm diameter 20.5 cm long cone-tainers (Stuewe and Sons, Corvallis, OR, USA) arranged in racks and filled with Sungro professional growing mix (Sun Gro Horticulture Inc, Bellevue, WA, USA). One-week-old seedlings were inoculated with one gram of colonized millet. Plants were watered over the top for the first 2 weeks then sub-irrigated every other day with regular water during the week and nutrient water during the weekend. Plants were subjected to water stress two weeks prior to rating, to exacerbate disease symptoms, by watering at wilt only. Stem base crown tissues of eight-week-old plants were rated and recorded for disease severity on a 0-10 rating scale (0 meaning no infection and 10 meaning severely diseased).

The second object was **to screen variety collections and regional nurseries in the greenhouse.**

This includes both spring and winter material. Unlike the previous objective which looks for exotic sources of resistance, the purpose of this objective is to identify the level of resistance or tolerance in existing lines. Over the last 3 years over 407 lines have been rated in 8 greenhouse trials. These involve inoculation with a mixture of *F. culmorum* isolates and rating the crown rot on a 1-10 scale. However, in 2016, we optimized this test by giving the spring wheat a cold treatment the first two weeks at (4 C) to simulate conditions in the field and then to water stress the plants at the end. Water stress has been known for many years to be a predisposing factor to this disease, but is often difficult to do in the greenhouse. We attempted to mimic water stress by providing fertilizer and adequate water for plants to grow at their full potential. In the last two weeks of the trial, plants were watered only twice a week. This caused the plants to weaken and wilt, allowing the Fusarium to take advantage. Since 2016, we have further optimized the test to the aforementioned conditions (*Modified Greenhouse Screening System) which produces consistent and more severe Fusarium crown rot disease.

Dylan Larkin, the MSc student funded by this project, rated 106 soft white winter wheat lines using nine replicates grown under controlled conditions and inoculated with a mix of five *F. culmorum* isolates collected throughout Eastern Washington. Genotypes were evaluated for crown rot severity on a 1 through 8 scale, with 1 = no disease and 8 = most susceptible. The distribution of average disease symptoms ranged from 2.4 to 5.4. There were 22 genotypes significantly more resistant than the susceptible check 'Madsen', while nine of those were significantly more resistant than the partially-resistant check 'Bobtail'. The named varieties that were more resistant than Bobtail were Xerpha, SY Assure, Eltan, SY Dayton, and Northwest Tandem. Susceptible lines included Madsen, Legion, and AP700CL. 23 lines were significantly more tolerant to FCR compared to the susceptible check, 'Madsen' ($\alpha = 0.05$). Additional spring wheat testing is needed but more resistant lines include Otis, WA8163, and SY605CL.

3. The third objective was **to test varieties in the field, either in inoculated trials or under natural inoculum.**

Field experiments at the Reardan, Creston, Lamont, Ritzville, Mansfield, Harrington, and Connell variety testing locations in 2015 and 2016 containing the same 106 soft white wheat genotypes tested above were evaluated for symptoms of Fusarium crown rot. These areas were chosen because it is a hot area for *F. culmorum.* There were positive correlations among genotype ratings for response to Fusarium crown rot between Lamont and Ritzville, Reardan and Harrington, and Lamont and Harrington. Symptoms of crown rot were identified and rated in all environments. Field results were highly variable due to differing environmental conditions from 2015 to 2016 and presence of other soil-borne pathogens.

Correlations between field and greenhouse screening trials were weak, 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 or strawbreaker foot rot, caused by *Oculimacula* spp., which is widely distributed in the dryland wheat areas of the Pacific Northwest. The crown symptoms are similar, except that eyespot also causes characteristic 'eye-shaped' lesions on the stems. The two pathogens are widely distributed in all wheat production locations and the one causing the most disease is likely due to soil moisture availability with Fusarium favored in drier environments.

We also tested spring varieties under inoculated conditions in Lind in 2015 and 2016 and in Pullman in 2017. At Lind, we manipulated the disease pressure by irrigating the wheat to provide luxurious growth, and then cutting the water to provide water stress.

Louise and Otis have consistently shown the lowest scores for Fusarium crown rot in these inoculated trials. These results enable us to use adapted breeding lines as a base to incorporate new sources for better combined resistance.

The other breakthrough of the work of Dylan was to test new statistical models to control for spatial variation in the Washington State University Extension Cereal Variety Testing

Program, specifically linear mixed models with spatial covariance structures (SLMM). This was supported by the WGC and is an important spinoff of his Fusarium work. He evaluated yield data from 143 environments over 22 locations, seven years, and five precipitation zones using five different SLMM compared to the randomized complete block (RCB) and alpha-lattice designs (PBLR). Using Akaike Information Criterion and likelihood ration tests, he found that SLMM performed better in 86% of environments compared to RCB and PBLR designs. This information can be used for WSU and regional breeding programs in performing more efficient and effective analyses of their field data.

Deliverables

1. Resistance ratings of spring and winter varieties grown in WA
2. Identification of new QTLs for resistance to *F. culmorum*
3. Better greenhouse methodology for screening for Fusarium resistance in greenhouse
4. Better statistical design for variety testing trials

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. G3: Genes, Genomes, Genetics. 7:1109–1116

Theses

Larkin, D.L., 2017. Disease screening and statistical strategies for predicting variety performance in wheat. Masters Thesis. Dept. of Crop and Soil Sciences, WSU. Pullman WA.

Abstracts

Thompson, Y.A., Garland-Campbell, K.A., Paulitz, T.C., 2016. Differential Response of Wheat (*Triticum aestivum* L.) to *Fusarium culmorum*. Poster session presented at: Resilience emerging from scarcity and abundance. ASA, CSSA and SSSA International Annual Meetings, Phoenix, AZ. 6-9 Nov. Poster 332-906.

Thompson, Y.A., Garland-Campbell, K.A., Paulitz, T.C., 2017. Genome wide association study (GWAS) in spring wheat to identify QTLs for resistance to *Fusarium culmorum*. Poster session presented at: Diverse Crops-Diverse Challenges. National Association of Plant Breeders Annual Meeting, Davis, CA. 7-10 Aug. WED47.

Larkin, D.L, K.A. Garland Campbell, and T.C. Paulitz. 2016. Comparison of greenhouse and field rating systems for Fusarium crown rot in winter wheat. Poster session presented at: Resilience emerging from scarcity and abundance. ASA, CSSA and SSSA International Annual Meetings, Phoenix, AZ. 6-9 Nov. Poster 163-1417.

Larkin, D.L., K.A. Garland Campbell, and T.C. Paulitz. 2016. Comparison of greenhouse and field rating systems for Fusarium crown rot in winter wheat. Poster session presented at: Improving efficiency in breeding programs. NAPB Annual Meeting, Raleigh, NC. 15-18 Aug. Poster 29.

WGC project number:	**3019-3564**
WGC project title:	**Fusarium Crown Rot on Wheat: Prebreeding and Development of Tools for Genetic Disease Managemen**
Project PI(s):	**M. Pumphrey, K. Garland-Campbell, and T. Paulitz**
Project initiation date:	**7/1/2015**
Project year:	**Year 3 2016/2017**

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. We found two potential QTLs for resistance to *F. culmorum* , in addition to the two found to *F. pseudograminearum* in a previous funding cycle.	Verification of QTLs will continue in 2018-2019, see new proposal. In addition, we will be testing a new CIMMYT synthetic population in 2018-2019	See publication list
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.	We have screened almost 500 lines from regional nurseries and variety testing for resistance to *F . culmorum,* and are identifying the most resistant and susceptible. We have further optimized our greenhouse testing protocol to maximize disease and reduce variability by using a cold vernalization period followed by a water stress treatment at the end.	Greenhouse screening will continue with optimized methods in 2018-2019	See publication list
Objective 3. Expand field testing to two locations, and test variety and regional nurseries.	Ratings of varieties for Fusarium tolerance in the the WSCIA seed buyers guide and other publications.	We assessed lines in five variety testing sites in the intermediate rainfall zone for two years, in areas with high levels of *F. culmorum* . However, results were confounded by eyespot -We conducted inoculated field trials for three years in Lind and Pullman, and have identified the most susceptible and resistant -We evaluated statistical designs and models to minimize spatial variation in the WA variety testing locations, and found a better model than the one presently used.	All future field work will be with inoculated field plots in Lind and Pullman.	See publication list

Project #: 7768

Progress Report Year: *__3__ 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 has been completed for the greenhouse trials for two years using Hollis, Drysdale, Louise, AUS28451, Alpowa, and Dharwar Dry with clear differences between cultivars in rooting depth, volume and area. The field trials with Hollis, Drysdale, and the RILs showed considerable variation and there was no correlation between rooting traits and yield in the RILs, but differences were observed in the between Hollis and Drysdale. Currently, we are performing another greenhouse trial in larger bins with well-watered control vs. water-withheld challenges for the varieties Louise, Drysdale, Hollis, AUS20451, Onas, Alpowa, and Dharwar Dry. 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. Root scans were taken throughout the growing seasons in 2016 and 2017 in additions to soil coring after crop maturity. Preliminary findings showed that there were no statistically significant differences for rooting depth at maturity conferred by *Rht* alleles.

Impact: Combined drought and heat routinely experienced in the PNW can cause 20-50% losses in grain yields as experienced in recent years. 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. The ultimate goal of this research project is to improve root traits, architecture, and structure in current breeding populations of both spring and winter wheat cultivars to improve yield under drought stress. The root system has been touted as the next frontier in crop improvement. This work has helped provide preliminary data for federal grant applications, and data is being complied for peer-reviewed scientific publications as well as for articles in Wheat Life and data for field days to benefit PNW growers.

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: final year

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 rooting 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 Summers of 2015 and 2016. In addition, we performed two years of (2015-2016 and 2016-2017) greenhouse trials on Louise, Hollis, Drysdale, Alpowa, AUS28451, and Dharwar Dry.	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 . They were also presented at the Tri-societies meeting in Fall 2016. In addition, we attended the Lind and Spillman field days in 2015, 2016 and 2017. We will publish a short communication in a peer-reviewed journal regarding our spring wheat work, which is in preparation.
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 and then again in summer of 2016. Images were taken every two weeks. We found different growth trends in the field for Hollis and Drysdale, but the RIL data were inconsistent.	After analysis of RIL data from summer 2015 and summer 2016, there was no clear correlation between measured root traits and overall yield in the RILs.	We will communicate these findings at field days and in an extension publication.
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.	The BC1F6 lines are now ready for analysis and will begin in 2018. We were behind schedule in their analysis.	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. We also performed deep soil coring of the lines at maturity to capture final rooting depth.	Imaging and analysis of root growth of winter wheat (*wt, Rht1, Rht2,* and *Rht1 Rht2* occurred at Spillman Farm in 2016 and 2017. The same lines were 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). Preliminary analysis just of rooting depth showed no significant difference between standard and *Rht* lines. However, further analysis of other root traits are underway.	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 particuarly in drought or water-limiting conditions.				

The expected outcomes are:

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

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

Washington Grain Commission
Wheat and Barley Research Annual Progress Report

Project #: 5389

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

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

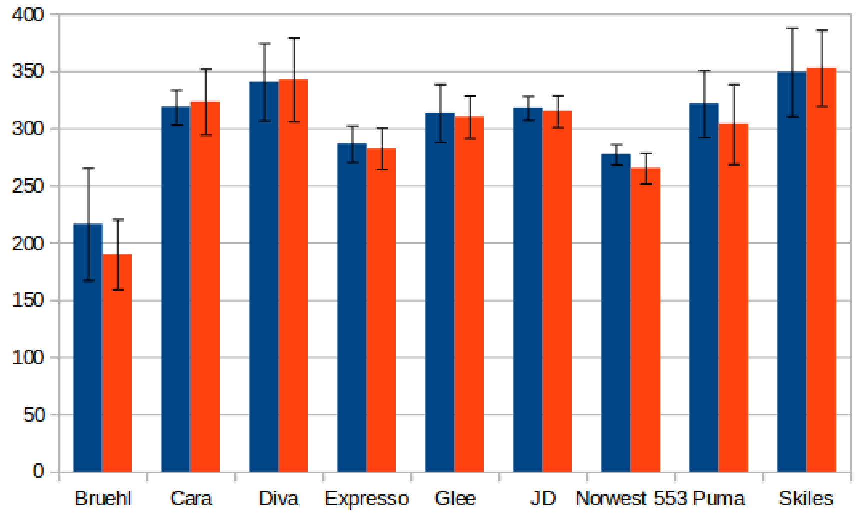
Project PIs: Camille M. Steber, Michael O. Pumphrey, Arron H. Carter
Cooperators: Kimberly Garland-Campbell, Ryan Higginbotham, Deven See, Craig Morris

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 project identified cultivars with sprouting and LMA problems through evaluation of the WSU cereal variety trials. Whereas preharvest sprouting due to rain was the major cause of low FN in 2013, LMA due to large temperature fluctuations during late grain filling was the major cause of low FN in 2016. Analysis of the 2016 crop revealed that there are problems with LMA susceptibility in all market classes, including both red and white wheat. The project developed LMA and PHS field screening systems, identified molecular markers linked to PHS tolerance genes in northwest winter wheat, and initiated mapping of LMA susceptibility genes.

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. FN was evaluated for the winter and spring wheat variety trial locations in 2015 and 2016. Over 4000 2016 variety trial datapoints were reported on (http://steberlab.org/project7599.php). This does not include wheat breeding lines and mapping lines evaluated for FN.
B. The effect of fungicide treatment on FN. Preliminary data from the 2016 field season suggests that fungicide treatment with Quilt does not cause a significant decrease in FN (Figure 1). Grain from plants grown in Pullman WA with and without Quilt fungicide treatment (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. Given that the standard deviation of the FN test can be 30 to 50 seconds, multiple repetitions are needed to see a significant upward trend. Previous work showed that FN increased significantly only at higher temperatures (Ji and Baik, 2016; Adams and Ross, personal communication). So storing grain over the winter may not appreciably increase FN. Careful consideration is needed before choosing to store grain over the winter months.

D. Near-infrared (NIR) spectrometry as an alternative to FN. NIR is used to measure protein levels in intact grains of wheat. A collaboration was arranged with Dr. Stephen Delwiche (USDA-ARS, Beltsville MD) to examine whether an NIR calibration could be developed as a nondestructive method to estimate FN at the elevator. This could allow grain with low FN to be segregated from high FN grain, thereby preventing the low FN grain from degrading the quality of all of the grain going into a bin. We sent 544 grain samples for NIR measurement that were selected to cover a wide range of falling numbers, and to represent multiple locations from the WSU Cereal Variety Trials. Unfortunately, while it was possible to develop a calibration for one location or set of samples, the calibrations did not fit samples from other locations. This was tested using both whole grain samples and milled samples in the NIR. This means that NIR cannot reliably be used to estimate NIR at the elevator.

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. LMA induction was used to detect LMA-susceptible breeding lines in 2015 and 2017. Because there was a natural LMA event in 2016, LMA susceptible breeding lines were identified using half-seed assays of field-harvested grain. 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 developed as a method to determine if low FN in the field was due to LMA or to preharvest 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, whereas LMA causes fairly similar levels at the embryo and brush ends of the grain (Mares et al., 2006). Grains were cut, and 10 embryo ends were ground and used in one assay, while 10 brush ends were used in the other. Using the Phadebas alpha-amylase assay method in 96-well format, we were able to characterize the cause of low FN in the eleven soft white winter 2016 Cereal Variety Trial locations. 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. Half-seed assays also revealed that most of the low FN of hard red winter trials in Ritzville were due to LMA.

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. Association mapping identified preharvest sprouting susceptibility/tolerance loci in white winter wheat. Mapping was performed using both spike-wetting tests and FN on the same mapping population of 469 lines representing seven northwest breeding programs (Table 1, collaboration with Dr. Z. Zhang). Spike-wetting tests did not detect any 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 tests in addition to spike-wetting tests. One of the strong FN loci identified in 2016, *QFN.wsu.7B.1* is closely linked to a location on wheat chromosome 7B previously mapped for LMA resistance in Australian wheat. This suggests that some of the low FN problem in 2016 may be due to a known LMA susceptibility locus/gene. Table 1 below shows some of the molecular markers significantly associated with resistance to preharvest sprouting based on the spike-wetting tests and with higher FN. QTL on chromosome 3A were located close to the clone sprouting resistance gene *TaMFT1* and on 4D were close to the resistance gene *TaMKK3*. Interestingly, a strong PHS resistance gene on chromosome 2D is close to the gene giving club-shaped kernels. This may be one reason that many club varieties like ARS Crescent, Cara, and Coda have higher FN.

B. Genome-Wide Association Mapping for LMA. Preliminary examination of spring 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 of 250 lines was subjected to LMA-induction in the greenhouse in 2016 and in the field in 2017. The winter QAM panel of 469 lines was subjected to field LMA induction. These samples are currently being evaluated using alpha-amylase enzyme assays. Results will be used to identify molecular markers associated with LMA resistance and susceptibility in northwest wheat varieties.

Table 1. Loci associated with Falling Numbers (FN) and preharvest sprouting (PHS).

QTL[a]	Marker	Chr[b]	cM[b]	-log10(*p*)	maf	Effect[c]	r^2
*QFN.wsu-4A**	IWB1884	4A	152	6.63	0.48	10.28	0.00
*QFN.wsu-5A.1**	IWB60191	5A	23	7.27	0.27	7.53	0.00
QFN.wsu-5A.2	IWB9800	5A	141	7.77	0.20	7.43	0.00
QFN.wsu-5D	IWB36060	5D	202	6.11	0.35	11.70	0.08
QFN.wsu-7A.1	IWB22966	7A	35	8.34	0.06	26.09	000
QFN.wsu-7A.2	IWA334	7A	126	12.36	0.41	7.99	0.01
QFN.wsu-7B.1	IWB39063	7B	162	7.91	0.48	10.88	0.01
QPHS.wsu-1A.1	IWB2320	1A	82	6.73	0.15	-0.04	0.00
QPHS.wsu-3A.2	IWB50719	3A	68	6.71	0.14	-0.29	0.04
QPHS.wsu-4A.1	IWA7535	4A	58	8.57	0.05	-0.07	0.03
*QPHS.wsu-4B.3**	IWB22055	4B	101	6.57	0.08	-0.37	0.00
QPHS.wsu-4A.2	IWB54609	4A	66	7.30	0.17	-0.35	0.01
QPHS.wsu-2D	**IWB7652**	**2D**	**52**	**12.69**	**0.37**	**-0.85**	**0.12**
QPHS.wsu-3A.1	IWB32631	3A	15	6.63	0.26	-0.31	0.02
QPHS.wsu-1D*	**IWB71680**	**1D**	**163**	**7.22**	**0.06**	**-0.03**	**0.10**
*QPHS.wsu-7B.2**	IWB7099	7B	133	8.63	0.00	-0.02	0.01
	IWB7099	7B	133	7.58	0.01	-0.02	0.00

[a] QTL in bold explained 10% (r^2 >0.1) or more of the phenotypic variation. QTL underlined were significant in 2 environments. Loci considered to be novel are indicated with ***.**

[b] Chromosome and position according to Wang et al. (2014). Positions are not reported if the location was identified on the GrainGenes database.

[c] The allelic effect is shown in FN seconds or sprouting score.

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 through Resistance to Preharvest Sprouting and LMA
Project PI(s): C. Steber, M. O. Pumphrey, A.H. Carter
Project initiation date: 07/01/15
Project year: year 3 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.** Performed FN testing of the 2016 WSU Cereal Vairety trail with the help of supplemental funding from project 5333. Examined the effect of fungicide treatment and storage on FN. **Year 3**. Examined the utility of NIR for as a nondestructive method to estimate FN, and were unable to generate a calibration that would work across all locations and years. Are in the process of examining FN for the 2017 Cereal Variety Trial locations that had low FN in susceptible cultivars.	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: a) the project website: steberlab.org/project7599.php, b) Wheat Life articles published in 2016 and 2017, c) Timely Topic articles on the Small Grains website in 2016 and 2017, d) an extension facts article published at pubs.wpdev.cahnrs.wsu.edu/pubs/fs242e , abstracts submitted to the Lind and Spillman Field Days, e) an extension review article published in Crops and Soils, f) talks at the Wheat Research Review in 2015 and 2016, g) 2015 and 2016 Wheat Academy presentations, h) a presentation to WSCIA in 2016, h) talks at 2016/17 growers meetings in Spokane, Connell, Colfax, 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. Developed a 96-well method for alpha-amylase enzyme assays using the Phadebas reagent. **Year 2.** Developed a 96-well method for alpha-amylase enzyme assays based on the Megazyme Ceralpha method. Developed half- seed assays to ascertain the contribution of LMA to the low FN problem of 2016. 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 3.** Performed field LMA testing of breeding lines. Continued to refine and develop standardized controls for the 96-well alpha-amylase enzyme assays.	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 3. Completed a genome-wide association mapping study for preharvest sprouting. Performed LMA field screening of the 469 line winter QAM assocation mapping panel and of the 250 line TCAP spring association mapping panels. Alpha-amylase enzye assays of these mapping populations are currently in process.	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: *3 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 released one software package and published two articles in this fiscal year. The software package is named as the name of our project: iPat (integrated Prediction and Association Tool). This is a user friendly software for breeders and genetic reseearchers to map genes and conduct molecular breeding. Its manuscript has been published reccently by bioinformatics leading journal, Bioinformatics. iPat has two major features. One is graphic user interface. Breeders can simplify use any computer pointing device to drag their datasets into the interface and then click on the graphical icons for analyses. With data analyzed by this software, we published a article on Plant Genome. The other feature is it is upgraded easily for internal engines. Currently, iPat's internal engines include GAPIT, FarmCPU and BLINK. FarmCPU is ten time faster than GAPIT and BLINK is ten time faster than FarmCPU. We applied a data size restriction to the public version of BLINK, but gave WSU/USDA-ARS breeders the advantage of assembling any size dataset from all available genotypic and phenotypic data. Our manuscript describing BLINK is currently under review for publication. We also publish an article on Wheat Life entitled "Genomics tools turnocharge classical breeding".*

Impact: *Our collabrative research positions WSU/USDA-ARS research team as one of the the world's leading institutions to conduct fundamental and applied research, publish academic articles, and update and release software packages. Our project's success not only benefit Washington, but will also benefit the entire world through the dissemination of knowledge. In short term, breeders can conduct most of data analyses without frustration on data formating and selecting different analytical functions. They have more oppertunities to find the casative genes controlling traits of interest. They 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.*

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: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
3) Integrate IPAT with Agrobase	iPat was released and the paper was published on Bioinformatics leading journal: Bioinformatics	Advanced data management system has been identified, HDF5 to manage big data collected from fields across multiple years and location, as well sequencing data from molecular labs. HDF5 was used by NASA for data management.	December 31, 2017: Develop source code on elementary functions; June 30, 2018: Complete system testing on real data from all the Co-Pis	1) One article was published on Wheat Life; 2) One presentation was given at WGC annual meeting; 3) Two presentation were given at national/international conference; and 4) Two papers were published on academic journal