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Washington State University Wheat and Barley Research Progress Reports

WASHINGTON GRAIN COMMISSION

2019-2020 Fiscal Year

2019-20 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 #: 3019-3009

Progress Report Year: 2 of 3

Title: Improving Barley Varieties for Feed, Food and Malt

Researcher: Robert Brueggeman

Cooperators: Deven See, Xianming Chen

Executive summary:
In the previous reporting period the WSU barley program continued advancing feed, food and malting populations and lines in the field at Spillman Farm. Approximately 1000 plots were harvested and processing to collect data for selection and advancement of elite material. In the 2019-2020 greenhouse the spring malting crossing blocks was planted with selected high quality malting parental lines and high yielding adapted PNW germplasm selected with increased malt quality. Winter malting and feed barley lines were also selected and planted to begin crossing for the WSU winter barley program that we are initiating in 2020. We are also continuing to evaluate and advance IMI-tolerance in multiple classes of selected elite barley lines. To better utilize molecular marker selection current parental lines and breeding material from the WSU breeding program are being evaluated by genotyping with malt quality molecular markers. In collaboration with Dr. Deven See we are utilizing our PCR targeted Genotype-By-Sequencing (PCR-GBS) platform developed for Ion Torrent next generation sequencing technology to screen 40 WSU two-rowed parental lines to analyze a panel selected from markers associated with low grain protein, increasing malt extract, and reduced wort ß-glucan. A training population and random lines will be screened from selected 2016 WSU lines with malting data to test prediction accuracy utilizing the marker panel for future genomic selection. A virulent population of *Puccinia graminis* f. sp *tritici* was also collected from three Washington barley fields. Nearly 100 hundred single spore *P. graminis* f. sp. *tritici* isolates were generated and inoculated onto a barley differential set containing the only two effective barley stem rust resistance genes, *Rpg1* and *rpg4/Rpg5.* We identified multiple isolates that are highly virulent on both *Rpg1* and *rpg4/Rpg5.* This type of virulence has never been reported as the combination of these two genes has historically shown resistance to all known isolates worldwide. In order to identify new sources of resistance effective against the new virulent isolates the world barley core collection (BCC) is being screened with the virulent isolates. We conducted phenotypic evaluation and have genotypic data for the BCC lines which will be utilize to identify novel resistance genes as well as utilized for association mapping of identified resistances. If identified these novel stem rust resistances will be introgressed into WSU breeding lines.

Impact:
We are further optimizing and streamlining our selection processes including high throughput genotyping and phenotyping procedures to optimize the return on funding invested. As we move the breeding program forward these investments will have measurable impact on the ability to make more precise selections from intensive hybridization and screening of larger numbers of recombinant individuals. Our major focus will be on fixing malt quality in the program while increasing agronomic traits such water use efficiency, disease resistance and ultimately yield.

Outputs and Outcomes:

Objective	Deliverable	Progress	Timeline	Communication
1	Release of a malting barley cultivar suited to brewing and/or distilling	Several of the advanced malting barley breeding lines have performed well in malting end use quality tests and agronomically in Variety Testing. A second WSU malting line should be released in the coming year	2021-2022	Talks and presentations at field days; distribution of informative variety rack cards; Wheat Life articles
2	Release of a second IMI-tolerant barley variety with high yield and excellent disease resistance to complement Survivor. This could also be in the food or malt market class	We have thousands of known IMI-tolerant barley lines in our breeding pipeline. These have and will continue to undergo greenhouse and field trials as well as multi-location yield trials to identify the superior breeding lines available.	2022	Talks and presentations at field days; distribution of informative variety rack cards; Wheat Life articles
3	Hulless, waxy food barley variety release to support non-waxy high beta glucan varieties Havener and Meg's Song	Our hulless, high Beta-glucan breeding lines are performing well in the advanced breeder trials and will be included in variety testing trials	2021-2022	Talks and presentations at field days; distribution of informative variety rack cards; Wheat Life articles
4	One new two-row feed spring barley variety released with superior yield disease resistance, protein and agronomic characteristics	Two two-row spring varieties were released in 2013. The elite breeding lines are showing excellent promise to exceed these and other existing varieties.	2021-2022	Talks and presentations at field days; distribution of informative variety rack cards; Wheat Life articles

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

Project #: **3019-3155**

Progress Report Year: 1 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 are summarized in the WSU Weed Control Report, which is 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, Russian-thistle, and mayweed chamomile.

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 (wsu.smallgrains.edu). 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 various agrichemical companies to assist them in labeling their new herbicide products for weed control in wheat. We have been working with bicylopyrone, a new broadleaf herbicide from Syngenta, as well as new herbicides from Corteva, Bayer, FMC, and an old herbicide from Albaugh.
- A number of grower driven projects were continued in the new cycle, including management of rush skeletonweed and other troublesome weeds in fallow, management of scouringrushes in wheat, spring wheat preemergence herbicides for Italian ryegrass control, and management of brome species with preemergence herbicides.
- Combined, Drs. Burke and Lyon have presented the results of this research program at ~15 events over the first six months of this project. We host the WSU Weed Science Field Day, and typically participate in the Lind Field Day, the Wheat Academy, and Far West Agricultural Associates meeting, as well as numerous county meetings and retailer training meetings.

WGC project number: 3019-3155
WGC project title: Weed Management in Wheat
Project PI(s): Ian C. Burke and Drew J. Lyon
Project initiation date: July 1, 2019
Project year: 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
Evaluate herbicides	Efficacy and crop injury data to support use recommendations, new labels, and label changes to benefit WA small grain growers.	The WSU Weed Control Report was published annually and distributed to the Washington Grain Commission, County Extension Educators in eastern Washington, and sponsoring chemical companies. The published studies are posted on the WSU Extension smallgrains website and discussed at winter Extension meetings.	Annually, in time for winter meetings.	Annual weed control report; articles in Wheat Life, trade magazines and/or posted to WSU smallgrains website; field days; winter Extension meetings; decision support system tools. The Small Grains website now host an outlet for our efficacy results see https://herbicideefficacy.cahnrs.wsu.edu/
		In a multi-year field study looking at smooth scouringrush control near Rearden, only one treatment, Glean + MCPA-ester, provided significantly improved control compared to the nontreated check. A 5-year field study was initiated in 2017 near Omak to look at how frequently Finesse and Amber herbicides must be used to maintain control of smooth scouringrush in winter wheat-fallow production systems. Greenhouse efficacy workconducted to determine the affects of MCPA and Glean on root and shoot growth and recovery.	The data from the Rearden study was combined with data from a simliar study initiated in Oregon and submitted to Weed Technology for publication. The manuscript is being revised after review. The Omak study will not be completed until 2022.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles
		Field studies were continued in 2019 near Lacrosse and Hay 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.	Ongoing, with anticipated completion in 2022.	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 will be conducted every year during this project.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles
		A WEED-It sensor sprayer system was acquired in the spring of 2018 using Camp Endowment funds, and multiple experiments were initiated to evaluate efficacy of various fallow herbicides using the sensor system.	Additional trials were installed in the spring of 2019. New trials will be designed based on the trial experiments to evaluate the sensor sprayer when used season long in fallow as well as in crop.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles
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.	Common garden and greenhouse experiments using the downy brome PNW core collection have started to identify variation in flowering time. Flowering time genes strongly coordinate with vernalization genes to regulate when flowering occurs in downy brome. In previous work, vernalization regulated if flowering occured, but it was evident that, when place in different environments, flowering time was plastic.	Work has started on flowering time and should be completed by 2022.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles.

		We have identified a new and potentially troublesome pest in the inland Pacific Northwest. Discovered while conducting field trials near Asotin and Ewan, sterile brome does not appear to respond to postemergence herbicides. The weed has a very similar appearance to downy brome except while flowering, and thus is usually identified as downy brome.	We are preparing an identification guide for *Bromus* species and will produce an extension bulletin in spring 2020.	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.	As part of our work to understand seed dormancy in downy brome, we have discovered that gibberillic acid can be used to stimulate germination in the field. Current work has focused on identification of the duration of the effect as well as on additional weed species that may respond to such an input. Recent greenhouse work indicates that soil temperature may play a role in the effect we have observed.	Field studies will be conducted every year during this project.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles.

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

Project #: **3019-3380**

Progress Report Year: 3 of 3

Title: **Herbicide Resistance and Susceptibility in Wheat and Weeds**

Researcher(s): Ian C. Burke

Cooperators: Arron Carter

Executive summary: Herbicide resistance in wheat can be a valuable trait, while herbicide resistance in weeds can and often does increase production costs. The lack of new herbicides, let alone herbicide modes of action, means that producers will slowly but surely lose the ability to manage weeds with currently deployed herbicides. The project has two foci – to identify multiple novel traits that confer herbicide resistance or susceptibility in wheat, and to develop a high throughput herbicide resistance testing program for weeds. The TCAP core collection has been screened for resistance to 5 herbicides, including clethodim and indaziflam. Although this approach has yielded several potential traits, other options are being explored to increase trait discovery rates. The barley mutant *fxp1* that has sensitivity to fenoxaprop (the herbicide Puma) has been well characterized, and the same genes are present in wheat. Although work as stalled to develop wheat lines with the same sensitivity as the barley mutant, the gene is of considerable utility in barley.

The herbicide resistance testing program continues to mature – to date 8 novel types of herbicide resistance have been identified that were previously unknown, including Russian thistle and downy brome resistant to glyphosate. Forms for communicating with growers have been developed. The biggest hurdle to timely test results is seed dormancy, as well as seed germinability. Genetic tests have also been developed for herbicide resistance multiple weed species, but are judged to be too expensive for use in the laboratory testing program. The testing program now routinely receives ~25 samples per year, of which a subset are new types of herbicide resistance not known in the world.

Impact: New herbicide products for the wheat market are now rare – any new herbicide systems are going to depend in part on regional efforts to identify tolerance and resistance in wheat as much as discovery programs at major companies. That tolerance and resistance could be tailored to market class, and could allow growers to manage not just weeds, but also volunteer crop plants. As intellectual property, such a trait will help provide continued income to the university, especially if licensed for use by other entities. Our goal is to establish WSU as a leader in development of useful herbicide-related wheat traits. This project has generated 5 new herbicide traits for use in wheat, any one of which will have major impact when developed into a useful product.

Furthermore, herbicide resistance in weeds is likely to only increase, as we are continuing to use the same active ingredients year after year. It is imperative we find new herbicides to protect our wheat crop to allow greater rotational flexibility, volunteer management, and weed resistance management. It is also imperative that we develop a rapid technology-based herbicide resistance testing program for Washington.

WGC project number:3019-3380
WGC project title: Herbicide Resistance and Susceptibility in Weeds and Wheat
Project PI(s): Ian C. Burke
Project initiation date: July 1, 2017
Project year (3 of 3-yr cycle): 3

Objective	Deliverable	Progress	Timeline	Communication
Develop a high-throughput herbicide resistance testing program for weeds in wheat	Rapid reliable program to test weeds for herbicide resistance.	Two methods have been initiated: Genetic testing, and herbicide efficacy (spraying). **Herbicide efficacy:** 193 biotypes have been received, given an identification number, entered into a spreadsheet, and have (or will) undergone an initial screening for possible plant tolerances/resistance to screened herbicides. After satisfactory data is collected from an initial screening, the biotypes are than given a dose response of up to 128X the recommended rate. A report of procedure and results are than written up and delivered to the submitters. Methods for screening have been developed so all biotype undergo the same testing in a timely manner. We have also created methods to help deal with downy brome dormancy. The primary weeds tested are currently downy brome, wild oats, Italian ryegrass, common windgrass, and some broadleaf weeds. We recieve approximatley 15 - 30 new biotypes each year. **Genetic testing:** DNA primers and procedures were successfully tested to allow DNA delivered to the submitters. We have developed the ability to test Italian ryegrass for ACCase resistance substitutions Ile1781, Trp2027, and Ile2041. Methods for ALS resistance substitutions at Ala122, Pro197, Ala205, Asp376, Trp574, Ser653, and Gly654 were also tested successfully in multiple species, including Italian ryegrass, shepards-purse, prickly lettuce and downy brome. Procedures for additional resistance substitutions are being developed.	Continue refining methods. Research has emphasized important herbicide resistance cases, including glyphosate resistant Russian thistle, downy brome, and kochia, as well as Beyond resistant jointed goatgrass and clopyralid resistant mayweed chamomile. Rapid tests have been devised for older well know resistance cases, but are relatively more expensive compared to spraying.	Journal articles; articles in Wheat Life, trade magazines and/or posted to WSU smallgrains website; winter Extension meetings.

Identify multiple novel traits that confer herbicide resistance to herbicides or herbicide modes of action not currently used in wheat.	Resistance or susceptibility to herbicides in wheat.	**Herbicide resistance:** Screening methodology has been developed and implemented. Approximately 1400 winter wheat core collection lines were screened with metolachlor and indaziflam. Approximately 2500 spring wheat core collection lines were screened for mesotrione, metribuzin, clethodim, glyphosate and fomesafen. A few potentially resistant lines have been identified for clethodim, indaziflam, and aminocyclopyrachlor. This information was provided to the winter wheat breeding program. Crosses and mapping populations are being made. A growth chamber based soil assay has been developed for evaluation of response to the residual effects of indaziflam. Field trials are in place to determine field response of weeds and winter wheat to indaziflam alone and in mixture with pyroxsulam across the summer fallow season. Sequencing of candidate loci contributing to clethodim resistance is also underway and QTL mapping of the clethodim and indaziflam resistance traits is ongoing.	We intend to continually apply as many approaches as possible to identify new traits. New traits could be discovered any time.	Annual Washington Grain Commission Review, and as appropriate for discovery status, other outlets including journal articles; articles in Wheat Life, trade magazines and/or posted to WSU smallgrains website; winter Extension meetings; Weed Science Society annual scientific meetings.

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

Project #: 3193

Progress Report Year: _1_ *of* _3__

Title: Field Breeding Hard White and Red Winter Wheat

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

Executive summary: One hard red winter wheat line was released in 2019. Scorpio (WA8268) is a semi-dwarf, high yielding cultivar targets to the intermediate and high rainfall zones of the state, including regions of Northern Oregon and Idaho. This line has excellent stripe rust resistance and is tolerant to low pH soils where there are high amounts of free aluminum. The end-use quality of the line meets export and domestic standards, and is being considered by Shepherd's Grain for approval in their system. Scorpio is competitive with other hard red cultivars on the market for yield potential, and has the increased benefit of improved disease resistance. In 2019 we tested multiple other hard red winter lines. Another line which is being considered for release is WA8289, and awnless cultivar which has shown very high yield potential in the PNW. This line is targeted to the intermediate and high rainfall production areas. WA8310 is a hard red winter wheat cultivar targeted to the lower rainfall production areas. This line is a semi-dwarf line, but still shows excellent emergence from deep planting and in dry soils. WA8310 has high yield potential and also maintains a higher grain protein content than other lines at a similar yield potential. In addition to these two lines, we have also submitted to the variety testing program a hard red winter wheat line with 2-gene resistance to imazamox. This line is targeted to the low and intermediate rainfall zones of the state, and is targeted to replace acres of SY Clearstone CL2. We continue to make crosses in the market class and develop them through DH methods. Continued emphasis has been placed on selecting breeding lines with superior quality and disease resistance. We also have a strong interest in developing hard lines with excellent emergence capabilities, and continually screen material to this end. Efforts have been initiated and are ongoing to develop hard cultivars with herbicide tolerance, snow mold resistance, and aluminum tolerance. After some renewed interest in hard white wheat, we had increased our efforts for crossing, but after further discussion with the Commission, have reduced this again due to a market shift. We maintain about 10% of the hard material as hard white and apply heavy selection pressure to ensure adapted material is advanced. Some of these hard white lines have been tested under irrigation in Southern Idaho and have performed very well. There is interest to release these lines for production under irrigation in Idaho. Our next main target is to develop hard red cultivars 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. Scorpio is a recent WSU hard red cultivar 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: 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
Develop hard red and white winter wheat cultivars	New cultivars released for production in WA	In 2018 we released Scorpio, and will be on large commercial production in 2020. This line is intended to replace many of the current hard red cultivars to do high yield potential, and excellent disease resistance. Mainly, this line has excellent stripe rust resistance and tolerance to low pH soils. Additionally, there has been interest from Montana on a breeding line WA8248AL, which also had very good tolerance to low pH soils and is agronomically adapted to production in Montana. We had over 2,800 plots and 12,000 rows of hard material under evaluation at various stages of the breeding process for 2019. 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 2019. 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 2019 we communicated results of this project through the following venues: 6 peer-reviewed publications; 2 field day abstracts; 3 invited speaker presentations; 5 poster presentations; 3 popular press interviews; 2 grower meeting presentations; 1 wheat workshop presentations; 10 field day presentations; 3 seed dealer presentations; participation in the Tri-State Grain Growers Convention; and hosted 4 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 2020. Lines with inferior performance will be discarded from selection in 2019. We screened nearly 1,000 early generation lines for end-use quality in 2019.	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	We have entered one hard red line into variety testing with 2-gene resistance to imazamox
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.	
	SBWMV	Crosses are initiated and being evaluated for resistance to SBWMV, mainly first through marker analysis and then under field trials in Walla Walla.	Crosses made through the project #5195 will be evaluated under field conditions upon MAS.	
	Stripe rust genes	Multiple different stripe rust resistance genes have been introgressed into our 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.	
	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.	
	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.	

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

Project #: 5195

Progress Report Year: *_2_ of _3__*

Title: Use of biotechnology for wheat improvement

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

Executive summary: In 2019 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 15,000 data points were collected on 230 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 fourth 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 550 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 ~2,600 DH plants in the field in 2020 for evaluation. The remaining DH lines are undergoing increase in the greenhouse and will have a similar number ready for yield evaluation in 2021. Our screening process has been slightly altered to allow for marker selection after some field selection is completed.

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, Devote, Stingray CL+, Scorpio, Purl) 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: 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
Marker-assisted selection				Results are presented through annual progress reports, the research review, field tours, and grower meetings
	Foot rot resistant lines	In 2019, 115 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 2019 we communicated results of this project through the following venues: 9 peer-reviewed publications; 1 field day abstracts; 3 invited speaker presentations; 8 poster presentations; 4 popular press interviews; 2 grower meeting presentations; 1 wheat workshop presentations; 10 field day presentations; 3 seed dealer presentations; participation in the Tri-State Grain Growers Convention; and hosted 4 trade teams.
	Stripe rust resistant lines	In 2019, 100 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 2019, populations were selected for combinations of the GBSS genes (waxy) and the glutenin genes. We also had a high school student intern with us and select lines null for all three PPO genes. Field testing also evaluated previously identified waxy wheat families for advancement in the program.	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 2019, all breeding lines in field trials were screened to identify which dwarfing gene they carry in order to aid in selection and crossing decisions. Selection is then made on which genes are present rather than incorporating new genes as they already exist in our breeding program. All lines are field tested 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. Lozada, we have begun genomic prediction model building. Lines from the 2015-2019 breeding program have been genotyped as well as a large training panel. Models built were used to assist with selection in the 2019 crop year. End-use quality models are being explored, as well as models for agronomic traits and spectral reflectance traits.	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 2019, the advanced germplasm was screened with DNA markers for about 22 markers 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 2019 we made approximately 550 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 60 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 2019 we submitted all crosses for DH production. We are advancing roughly 2,600 DH lines in the greenhouse to get enough seed to plant in field trials in the fall of 2019.	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.	Screening and selection will be completed in 2020. 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 2020. 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 2020. Superior lines will be planted in the field and crossed back into the breeding program.	
	Stripe rust	Previously, 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. because selection with markers is difficult for these QTL, we have begun looking at genomic selection as an improved method to introgress these QTL. We continue to work on other populations to identify new genes for stripe rust resistance and develop markers for them.	Screening and selection will be completed in 2020. Superior lines will be planted in the field and crossed back into the breeding program.	

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

Project #: 6195

Progress Report Year: *_2_ of _3__*

Title: Field Breeding Soft White Winter Wheat

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

Executive summary: A new club cultivar, developed in coordination and collaboration with the USDA breeding program, was approved for release and was named ARS-Castella. This line has excellent stripe rust resistance and tolerance to low pH soils, and is targeted to replace many of the club wheat acres grown in the state. Stingray CL+ was released. It is the highest yielding 2-gene Clearfield line in the WSU and OSU trials when averaged over three years. Seed will be available commercially in 2020. Devote was another soft white line recently released and is targeted to the low rainfall zones of the state. This line has very good yield potential, and resistance/tolerance to stripe rust, eyespot foot rot, cold temperatures, snow mold, and Fusarium crown rot. WSU lines continue to be very competitive in the market and are well-liked by growers. Many lines were in variety testing trials in 2019, and showed excellent performance. Two of them, WA8305 CL+ and WA8306 CL+ were the highest yielding lines of the 2-gene Clearfield lines, and many times were the highest yielding lines in the trials. We are started seed increases of these two lines. Many other lines are looking promising and breeder seed has been started on them. Over 2,200 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 2,000 DH lines were planted for 2020 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. 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 40% of the acres. These include Bruehl, Eltan, Masami, Xerpha, Otto, Puma, Jasper, Purl, Curiosity CL+, Mela CL+, and Resilience CL+. Measured impact is demonstrated with increasing acres of past cultivars, release of new cultivars (Pritchett, ARS-Castella, Stingray CL+, Devote) and upcoming lines WA8290, WA8308, WA8305 CL+, and WA8306 CL+.

WGC project number: 6195
WGC project title: Field Breeding Soft White Winter Wheat
Project PI(s): AH Carter
Project initiation date: July 1, 2012
Project year: 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
Develop soft white winter wheat cultivars	New cultivars released for production in WA	We released the soft white lines Otto, Jasper, Puma, Purl, Stingray CL+, and Devote. Collaborative releases include Curiosity CL+, Mela CL+, Resilience CL+, Pritchett, and ARS-Castella. All lines are being commercially produced or are in seed increase for commercial production. We have multiple breeding lines in statewide testing for consideration of release, many of which had excellent performance in 2019. We have over 15,000 plots and 20,000 rows of soft white material under evaluation at various stages of the breeding process.	Each year we evaluate germplasm at each stage of the breeding process. Each year lines are entered into statewide testing for final release consideration. A cultivar is released, on average, every two years.	Progress will be reported through field days, grower meetings, commission reports, annual progress reports, and peer-reviewed manuscripts
	Agronomic traits	We have 17 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 moved all DH production to initial 4-row selections due to the ability to screen for important traits such as emergence and stripe rust, along with our snow mold screening in Waterville.	Evaluation is done annually at multiple locations across the state.	In 2019 we communicated results of this project through the following venues: 9 peer-reviewed publications; 2 field day abstracts; 3 invited speaker presentations; 8 poster presentations; 4 popular press interviews; 2 grower meeting presentations; 1 wheat workshop presentations; 10 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 17 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/DH 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 2019.	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. We have multiple Clearfield lines, advanced lines in testing for the CoAXium system, and 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.	
	Stripe rust genes	We constantly have material coming out of the MAS program for stripe rust. In 2019 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.	
	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.	
	Cephalosporium	No markers are currently being used for this introgression. All selection is being done under field conditions. We recenlty made many crosses to resistant material and are now field screening them for selection of resistant material.	Evaluation will be done in field locations in WA in 2020	
	Aluminum tolerance	Field screening of breeding lines for aluminum tolerance is being conducted under field conditions. We recently made many crosses with material that was aluminum tolerant. Screeing of this material will be completed in 2020.	Evaluation will be done in field locations in WA in 2020	
	Hessian Fly	In collaboration with Dr. Nilsa Bosque-Perez and Arash Rashed 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 populationsare cuttnly being screened again for resistance. Selected lines will be advanced ot field screening in 2020.	Additional populations will be screened in 2020 after backcrossing	

	Nematodes	Nematode screening has been done in collaboration with Dr. Paulitz and Dr. Campbell. Additional advanced material will be screened in 2020.	Additional populations will be screened in 2020	
	End-use quality	Lines are continually screened for end-use quality. We sbumitted an additional 10 lines for statewide testing to begin generating quality scores prior to release decisions.	Validated genomic prediction models will be available for selection in 2020.	

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Washington Grain Commission
Wheat and Barley Research Annual Progress Report

Project #: 3144

Progress Report Year: 1 of 3 (2019)

Title: Improving Control of Rusts of Wheat and Barley

Cooperators: K. Garland Campbell, A. Carter, M. Pumphrey, & D. See

Executive summary: During 2019, studies were conducted according to the objectives of the project proposal, and all objectives specified for the first year have been successfully completed. In addition to the major accomplishments and their impacts listed below, this project results in genetic resources and techniques for further studying the biology and genetics of the pathogens, rust resistance, and mechanisms of interactions between the pathogens and plants.

Impact: 1) Stripe rust was accurately forecasted in 2019. Rust updates and advises were provided on time to growers based on the forecasts using prediction models and field surveys, which protected both winter wheat and spring wheat crops from stripe rust damage and reduced unnecessary use of fungicides. 2) We identified 25 (including 1 new) races of the wheat stripe rust pathogen and 8 (including 1 new) races of the barley stripe rust pathogen in the US, of which 23 and 7 were detected in Washington, respectively. The virulence information is used to guide breeding programs for using effective resistance genes in developing resistant varieties. 3) We identified stripe rust mutants with relatively low sensitivity to DMI fungicides using molecular markers of the chemical-targeting gene and determined the frequencies of the mutants in the pathogen population. The results support fungicides containing two or more chemicals with different modes of action or rotation of chemicals. 4) We identified candidate virulence genes by whole-genome sequencing a mutant population of the stripe rust pathogen. The candidate virulence genes will be used to develop virulence-specific markers for monitoring virulence changes in the pathogen population. 5) We evaluated more than 35,000 wheat, barley, and triticale entries for resistance to stripe rust. From the tests, we identified new sources of resistance and resistant breeding lines for breeding programs to release new varieties for growers to grow. In 2019, we collaborated with breeders in releasing, pre-releasing, or registered 15 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. 6) We mapped 6 genes for all-stage and high-temperature adult-plant resistance to stripe rust in wheat landrace PI 181410. We completed two genome-wide association studies and mapped more than 30 genes for stripe rust resistance in each panel of 616 spring wheat and 857 winter wheat varieties and breeding lines in the US. These genes and their markers will be useful in breeding stripe rust resistant wheat varieties. 7) We tested 33 fungicide treatments for control of stripe rust on winter and spring wheat and provided the data to chemical companies for registering new fungicides. 8) We tested 24 winter wheat and 24 spring wheat varieties for yield loss caused by stripe rust and yield increase by fungicide application. The data of the fungicides and varieties are used for guiding the integrated control of stripe rust. 9) In 2019, we published 26 journal articles and 5 meeting abstracts.

Outputs and Outcomes:

WGC project number: 3144				
WGC project title: Improving Control of Rusts of Wheat and Barley				
Project PI(s): Xianming Chen				
Project initiation date: 7/1/2019				
Project year: 1 of 3 (2019)				
Objective	**Deliverable**	**Progress**	**Timeline**	**Communication**
1. Improve the understanding of rust disease epidemiology and the pathogen populations.	**1) New races. 2) Information on distribution, frequency, and changes of all races, and possible fungicide tolerant strains. 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.	All planned studies for the project in 2019 have been completed on time. There is no any delay, failure, or problem in studies to this objective. The race identification for the 2018 collection was completed and summarized. The data and summary were sent to growers, collaborators and related scientists in May, 2019. In the 2019 crop season, we collected and received 336 stripe rust samples throughout the country and 65% of the samples were from Washington. We have completed about 95% of the race ID work for the 2019 samples as scheduled by this time. So far we have detected 25 wheat stripe rust races (including 1 new races) and 8 barley stripe rust races (including 1 new races), of which 23 wheat and 7 barley stripe rust races have been detected in Washington. The distribution and frequency of each race and virulence factor in WA and the whole country have been determined. Predominant races have been identified. The race and virulence information is used to guide breeding programs for using effective resistance genes in developing resistant varieties and selected predominant races with different virulence patterns are used in screening breeding lines for stripe rust resistance. We have used molecular markers developed in our lab to study the stripe rust pathogen and determined the population changes in the past and present. We sequenced more isolates of the stripe rust pathogen and developed more markers to study rust pathogen populations and identify candidate virulence genes. We have used a molecular marker developed from the DMI fungicide target gene to test the historical and recent stripe rust collections in the US and detected isolates with homozygous and heterozygouse mutant isolates in the stripe rust populations. The fungicide target gene mutants exist in the State of Washington, although in low frequencies. Through whole-genome sequencing, we completed a molecular study and determined the effects of mutation on genome structure and on changing avirulence to virulence and identified effector genes associated to avirulence/virulence phenotypes.	The race identification work for the 2018 stripe rust samples was completed. The race ID work for 2019 samples was done about 95% of the entire work. Molecular work for both the population genetic study and the fungicide tolerance mutant study have been completed. DNA extraction of the 2018 samples have been completed and of the 2019 samples are underway.	The rust race data were communicated to growers and researchers through e-mails, websites, project reports, meeting presentations and publications in scientific journals (for detailed information, see the lists in the main report file).

2. Improve rust resistance in wheat and barley varieties.	**1) Stripe rust reaction data of wheat and barley germplasm and breeding lines. 2) Reactions to other diseases when occur. 3) New resistance genes with their genetic information and molecular markers. 4) New germplasm with improved traits. 5) New varieties for production.** 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.	In 2019, we evaluated more than 35,000 wheat, barley and triticale entries for resistance to stripe rust. The entries included germplasm, breeding lines, rust monitoring nurseries, and genetic populations from various breeding and extension programs. All nurseries were planted and evaluated at both Pullman and Mt. Vernon locations under natural stripe rust infection. Some of the nurseries were also tested in Walla Walla and Lind, WA. Germplasm and breeding lines in the variety trial and regional nurseries also were tested in the greenhouse with selected races of stripe rust for further characterization of resistance. Disease data of regional nurseries were provided to all breeding and extension programs, while data of individual breeders' nurseries were provided to the individual breeders. Through these tests, susceptible breeding lines can be eliminated, which should prevent risk of releasing susceptible cultivars and assisted breeding programs to release new cultivars of high yield and quality, good adaptation, and effective disease resistance. In 2019, we collaborated with public breeding programs in releasing and registered 15 wheat varieties and 2 barley varieties. Varieties developed by private breeding programs were also resulted from our germplasm screening program. Through our 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 2019, we completed the study and mapped six genes for all-stage and high-temperature adult-plant resistance to stripe rust in wheat landrace PI 181410. We completed a whole-genome associate studies (GWAS) and mapped 37 loci on 15 chromosomes in a panel of 616 US spring wheat cultivars and breeding lines and identified 34 loci also on 15 chromosomes together with 15 previously reported genes identified with specific markers in a panel of 857 US winter wheat cultivars and breeding lines. We determined the frequencies and distributions of stripe rust resistance genes used in various regions in the US with the PNW had the highest number of genes. We selected new wheat germplasm lines with single new genes or combinations of genes for resistance to stripe rust to make them available for breeding programs and directly provided seeds to some US breeding programs. In 2019, we phenotyped 40 mapping populations for stripe rust responses to map stripe rust resistance genes, completed the bulk segregation tests of the resistance and susceptible bulks of the populations with molecular markers and identified 233 potentially different loci for stripe rust resistance in the 40 populations.	All 2019 germplasm tests were completed and the data were provided to collaborators on time. The 2019-20 winter wheat nurseries were planted in fields in September and October 2019. The 2019 spring crop nurseries will be planted in March-April, 2019. The greenhouse tests of the 2019 spring nurseries and the 2019-20 winter wheat nurseries have been conducting in the greenhouse during the winter, and will be completed by May, 2019. All experiments of the molecular mapping studies cheduled for 2019 were completed. Mapping populations of winter wheat were planted in fields in October 2019 and those of spring wheat will be planted in April, 2020 for stripe rust phenotype data. Populations with adequate phenotype data are genotyped with molecular markers for mapping resistance genes.	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, websites, Seed Buyer's Guide, variety release documents. Test data of individual breeding programs were sent to the individual breeders. New genes and molecular markers were reported in scientific meetings and published in scientific journals (see the publication and presentation lists in the report main file).

3. Improve the integrated management of rust diseases.	**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. 4) Stripe rust forecasts and updates. 5) Guidance for rust management.** The information is used for developing more effective integrated control program based on individual varieties. Disease updates and recommendations will allow growers to implement appropriate control.	In 2019, we evaluated 31 fungicide treatments on winter wheat and 33 fungicide treatments on spring wheat, plus a non-treated check, for control of stripe rust in experimental fields near Pullman, WA. On winter wheat study, 28 treatments significantly reduced rust severity and increased grain yield; 23 treatments had higher test weight than the non-treated check, including all treatments with applications at Feekes 10; and 15 treatments produced yield higher than the non-treated check. All treatments of either only a Feekes 10 application or both Feekes 6 and Feekes 10 applications had significantly higher yield compared with the non-treated check. The significant yield responses ranged from 9.3 bu/A (11.1%) to 48.5 bu/A (57.9%). On spring wheat, all 33 fungicide treatments significantly reduced stripe rust severity; 18 treatments had significantly greater test weight than the non-treated check; and 32 treatments had significantly higher yield than the non-treated check. The significant yield responses ranged from 9.4 bu/A (20.7%) to 34.3 bu/A (75.4%). In 2019, 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 35.8% yield loss on the susceptible check and from 0 to 18.6% (average of 5.5%) on commercially grown varieties. Fungicide application increased yield by 0 to 22.9% (average of 6.2%) on commercially grown varieties. For spring wheat, stripe rust caused 32.7% yield loss on the susceptible check and from 0 to 12.7% (average 2.3%) yield losses on commercial varieties. Fungicide application increased grain yields by 0 to 13.8% (average 2.5%) on commercial varieties. These results can be used by chemical companies to register new fungicides and used by growers for selecting resistant varieties to grow and use suitable fungicide application for control stripe rust on varieties without an adequate level of resistance. Forecasts of wheat stripe rust epidemic were made in January 2019 based on the November and December weather conditions and in March 2019 based on the entire winter weather conditions using our prediction models. Further forecasts were made throughout the crop 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 PNW and other regions throughout the country. In the central and eastern PNW, the time of first observations of stripe rust were slightly later than normal and stripe rust pressure was generally low in commercial fields with necessary fungicide application only in few in fields in central Washington. In our experimental fields near Pullman articially inoculated, stripe rust developed to adequate levels for reliable germplasm screening. Barley stripe rust was low. Leaf rust of wheat was low in western and absent in eastern PNW; leaf rust of barley in the western PNW was less than the previous years, and absent in the eastern PNW. Stem rust appeared as hotspots in some experimental fields around Pullman in 2019. In November 2019, significant stripe rust was observed in several early-planted winter wheat fields in Lincohn and Douglas counties.	For this objective, all tests scheduled for 2019 were successfully completed. For the 2019-20 growing season, the winter wheat plots of the fungicide and variety yield loss studies were planted in October 2019, and the spring plots will be planted in April, 2019. The tests will be completed in August (for winter wheat) and September (for spring wheat), 2020.	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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Liu, W. Z., Kolmer, J., Rynearson, S., **Chen, X. M.**, Gao, L., Anderson, J., Turner, M., and Pumphrey, M. 2019. Identifying loci conferring resistance to leaf and stripe rusts in a spring wheat population (*Triticum eastivum* L.) via genome-wide association mapping. Phytopathology 109(11):1932-1940.

Bruckner, P. L., Berg, J. E., Lamb, P. F., Carr, P., Wichman, D. M., Miller, J. H., Meccage, E., Miller, Z., Chen, C., Kephart, K. D., Eberly, J. O., Pradhan, G. P., Nash, D. L., Holen, D. L., Cook, J. P., Gale, S., Jin, Y., and **Chen, X. M.** 2019. Registration of 'Ray' hard red winter forage wheat. Journal of Plant Registrations 13(3):392-395.

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Popular Press Articles:

January 8, 2019. First Stripe Rust Forecast and 2018 Fungicide and Variety Yield Loss Tests. E-mail sent to cereal group. http://smallgrains.wsu.edu/2019-first-stripe-rust-forecast-and-2018-fungicide-and-variety-yield-loss-tests/

March 22, 2019. Stripe Rust Forecast and Update, March 22, 2019, E-mail sent to cereal group. http://smallgrains.wsu.edu/stripe-rust-forecast-and-update-march-22-2019/

April, 2019. The rise and fall of stripe rust epidemics. Integrated management is key to savings. *Wheat Life*, April, 2019.

April 18, 2019. Stripe rust update April 18, 2019, E-mail sent to cereal group. http://smallgrains.wsu.edu/stripe-rust-update-april-18-2019/

May 2, 2019. Stripe rust update May 2 2019, E-mail sent to cereal group. https://striperust.wsu.edu/2019/05/06/stripe-rust-update-may-2-2019/

May 9, 2019. Stripe Rust Update May 9, 2019, E-mail sent to cereal group. https://striperust.wsu.edu/2019/05/10/stripe-rust-update-may-9-2019/

May 29, 2019. Stripe Rust Update May 29, 2019, E-mail sent to cereal group. https://striperust.wsu.edu/2019/06/03/stripe-rust-update-may-29-2019/

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July 12, 2019. Rust Update July 12, 2019. E-mail sent to cereal group. https://striperust.wsu.edu/2019/07/15/stripe-rust-update-july-12-2019/

November 20, 2019. Stripe Rust Observed in Wheat Fields in Lincoln and Douglas Counties, Washington E-mail sent to cereal group. https://striperust.wsu.edu/2019/11/27/stripe-rust-update-november-20-2019/

Presentations and Reports:

In 2019, Xianming Chen presented invited talks at the following national and international meetings:

"Stripe rust update and North American race characterization", NCERA 184 Annual Meeting, Pensacola Beach, Monday, March 4, 2019 (about 30 people)

"Whole-genome Sequencing of a Sexual Population of the Wheat Stripe Rust Pathogen Identified Candidates for Avirulence Genes". Rust Workshop at 30th Fungal Genetics Conference, Pacific Grove, California, March 12, 2019 (about 40 people)

"Stripe rust virulence in the United States in 2018". North American Cereal Workshop, Morden, Manitoba, March 26, 2019 (about 40 people)

"Whole-genome Sequencing of a Sexual Population of the Wheat Stripe Rust Pathogen Identified Candidates for Avirulence Genes". North American Cereal Workshop, Morden, Manitoba, March 27, 2019 (about 40 people)

"Wheat Germplasm Exploration, Characterization, Development, and Utilization for Achieving Sustainable Control of Stripe Rust", Triticeae Research Institute, Sichuan Agricultural University, Chengdu, Sichuan, China, May 18, 2019 (about 100 people)

"Wheat Germplasm Exploration, Characterization, Development, and Utilization for Achieving Sustainable Control of Stripe Rust", College of Plant Protection, Northwest A&F University, Yangling, Shaanxi, China, May 22, 2019 (about 100 people)

"Discovery, development, and deployment of plant resistance for green protection of crops", 2019 Yangling International Agri-Science Forum, October 23, 2019, Yangling, Shaanxi, China (about 300 people)

In 2019, Xianming Chen, students, and/or associates presented posters or oral presentations at the following national and international meetings:

Posters and student's oral presentation

Poster entitled "Whole-genome Sequencing of a Sexual Population of the Wheat Stripe Rust Pathogen Identified Candidates for Avirulence Genes" at the 30th Fungal Genetic Conference, Pacific Grove, California, March 12-17, 2019 (about 500 people)

Poster entitled "Whole-genome mapping of QTL conferring all-stage and high-temperature adult-plant resistance to stripe rust in spring wheat landrace PI 181410" At the 1st International Wheat Congress, July 22 - 26, 2019, Saskatoon, SK, Canada (about 900 people).

Poster entitled "Stripe rust epidemics of wheat and barley and races of *Puccinia striiformis* identified in the United States in 2018" at the American Phytopathological Society 2019 Annual Meeting (Plant Health), Cleveland, Ohio, USA, August 3-7, 2019 (about 1,500 people)

Student oral presentation entitled "Whole-genome sequencing of a *Puccinia striiformis* f. sp. *tritici* mutant population identifies avirulence gene candidates" at the American Phytopathological Society 2019 Annual Meeting (Plant Health), Cleveland, Ohio, USA, August 3-7, 2019 (about 100 people)

Reports:

Report of race summaries of the 2018 stripe rust collection in the US. May 2019, https://striperust.wsu.edu/races/data/

Stripe data of various wheat and barley germplasm nurseries tested in 2019, https://striperust.wsu.edu/nursery-data/2019-nursery-data/

Chen, X. M., Evans, K. C., Wang, M. N., Sprott, J., Liu, L., Liu, Y. M., Liu, Y., Xia, C. J., and Li, Y. X. 2019. Cereal rust management and research in 2018. Pages 36-37 in: 2019 Dryland Field Day Abstracts, Highlights of Research Progress, University of Idaho, Oregon State University, and Washington State University.

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

PROJECT #: 30109-3156

Progress report year: 1 of 3

Title: Club wheat Breeding

Researcher(s): **Kimberly Garland Campbell, Arron Carter**
Cooperator: **Mike Pumphrey**

Executive summary:

Pritchett was widely available to farmers as a replacement for Bruehl except in severe snow mold regions. Pritchett club wheat was jointly released in 2016 by USDA-ARS and WSU with improved grain yield, test weight, end use quality, and emergence over Bruehl, and stripe rust resistance, cephalosporium stripe resistance, equal to Bruehl, which it is intended to replace. Castella was increased as foundation seed. It was released jointly by USDA-ARS and WSU in 2017, with improved grain yield, test weight, end use quality and stripe rust resistance over current club cultivars is targeted for the intermediate rainfall area. New entries with better resistance to snow-mold, including one IMI-club, were entered in the WA variety trials in the dry zone. New entries with earlier maturity, excellent standability, excellent club wheat quality and resistance to stripe rust were entered into the WA variety trials in the high rainfall zone. With our collaborators, we evaluated nurseries at 12 locations in Washington, Idaho and Oregon. Evaluation of our elite breeding lines for resistance to low falling number is underway. We discovered that Castella is the only current winter wheat cultivar with resistance to Hessian fly. Pritchett was rated as resistant to soil borne mosaic virus. We evaluated over 2700 breeding lines from around the U.S. for resistance to stripe rust. Because of our work with stripe rust introgression, we have made crosses to several good sources of Hessian fly and wheat virus resistance. We are now increasing in these populations in the greenhouse. We generated 235 doubled haploids. We also evaluated mini-bulk breeding and speed breeding techniques in the greenhouse and discovered that we can save about 20 days off of normal winter wheat generations using these techniques which allows us to advance material through the greenhouse faster and serves as a cost effective alternative to doubled haploids. We advanced 14 populations using this method and plan to increase these efforts in 2020.

Impact

We develop club wheat cultivars with agronomic characteristics that are competitive with soft white wheat cultivars. The integration of genomic selection, speed breeding, doubled haploid breeding, and new methods of analyzing data enables us to continue to be efficient with grower dollars and produce club wheat cultivars that are competitive as well as additional soft wheat germplasm with specific useful traits for other breeders. Better resistance to low falling number will stabilize markets and reduce grower risk. Growers will maximize choice in marketing strategy. New marketing strategies for increased use of club wheat would also be useful although those are outside the scope of this project.

WGC project number: **3019-3156**
WGC project title: **Club wheat breeding**
Project PI(s): **Kimberly Garland-Campbell and Arron Carter**
Project initiation date: **7/1/19**
Project year: **1 of 3**

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 (see below).	Club cultivar releases	ARSDH08X117-83C was entered into 2019 variety trials but was dropped upon recommendation from the Japanese Flour Millers Assn. Quality Evaluation team. This collaboration was initiated in 2019 and is strengthening our evaluations to meet current market demand. ARS09X492-6C was also entered into the 2019 Variety testing trials and was competitive enough to be re-entered into the 2020 trials.	June 2019-June 2022. Cutlivar releases are targeted as one every three years per rainfall zone.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review. K. Garland-Campbell attended Field plot tours and Field days in Pendleton OR and Fairfield, Harrington, Lind, Mayview, Reardan, St. Andrews and St John WA in 2019.
A. Develop club breeding lines and cultivars for the <15 inch rainfall zone with improved resistance to snow mold and fusarium crown rot, improved emergence and winter survival.	Club cultivar releases and breedling lines entered into Western Regional and state extension trials.	Pritchett was planted on 10,000 acres in 2019. ARS Castella was increased as Foundation seed. New entries into the dry trials are ARSX12015-68CBW (X010746-5C/BRUNEAU) and WA 8317 (Sww13657-b-4-1-1T-3). WA 8317 is an Imi-club.	Sept 2016-June 2019.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review.
B. Develop club breeding lines and cultivars for the >15 inch rainfall zone with improved resistance to eyespot, cephalosporium stripe, aluminum toxicity, and cereal cyst nematodes.	Club cultivar releases and breedling lines entered into Western Regional and state extension trials.	New entries into the high rainfall WA Variety trials in 2020 include ARS09X492-6CBW (ARSC96059-2/IL01-11934//ARSC96059-2-0-6) and ARSX12016-45CBW (X010746-5C/Bitterroot).	Sept 2016-June 2019.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review.
C. Release a club breeding lines and cultivars with early spring green up, targeted to SE Washington.	Club cultivar releases and breedling lines entered into Western Regional and state extension trials.	Both ARS09X492-6CBW and ARS12016-45CBW are earlier than current clubs.	Sept 2016-June 2019. Our next club wheat release after Pritchett will be targeted to this growing environment	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review.
Objective 2. Release germplasm and cultivars with the excellent end use quality characteristic of club wheat and with resistance to preharvest sprouting and late maturity alpha amylase (LMA)	Club wheat Breeding lines with stable falling numbers above 300 in all but extreme environments.	We have been collaborating with C. Steber to evaluate breeding lines and develop molecular markers to aid selection for resistance to low falling numbers.	Sept 2016-June 2019.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review. Presentation at the 2020 Falling Numbers Wokshop Jan 28-29, 2020.

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

PROJECT #: 30109-3157

Progress report year: 1 of 3

Title: Evaluation and Selection for Cold Tolerance in Wheat

Cooperators: K. Garland Campbell, K. Sanguinet, A.H. Carter

Executive summary:

We used the artificial screening system in the greenhouse to evaluate the Washington Extension Soft and Hard Winter Wheat Trials. We have screened these extension trials every year since 2001. The survival results for the top varieties grown according to the Washington Grain Commission Variety Survey are below.

In 2019 we rated 936 breeding lines from public regional winter wheat breeding programs for survival. All breeding programs had lines that varied in winter tolerance. Breeders have used this information for selection of new experimental lines.

We are analyzing the data from two mapping experiments. The first is a large genome wide association study of soft wheat from the WSU winter wheat and ARS winter wheat programs. The second is a doubled haploid population of Cara/Xerpha. These two populations will give us the information about markers associated with freeze tolerance in our adapted wheat populations.

Impact

- The data from these cold tolerance trials was published in the seed buyers guide so that farmers can select winter wheat that is less sensitive to winter kill.
- Our results from screening the regional nurseries, and screening breeding lines has been used by winter wheat breeders to select for resistance to winter injury.
- Varieties released from the WSU winter wheat breeding program have consistently excellent cold tolerance and this tolerance has been maintained because of testing using the procedures developed by this project.
- Because of the high correlation between our artificial screening trial and winter survival in the field, we are able to incorporate better cold tolerance into our early generation breeding lines.
- We have identified molecular markers that are being used by breeders to select for winter survival.

Freeze Survival of Top Acreage Winter Wheat Varieties Based on 2019 Washington Wheat Variety Survey

		Percent Survival	95% LCL*	95% UCL*
	Soft White Wheat			
1	UI Magic CL+	10%	0	27
2	Otto	55%	41	69
3	Curiosity CL+	80%	63	97
4	Norwest Duet	52%	35	70
5	Norwest Tandem	56%	35	77
6	Mela Cl+	68%	51	86
7	LCS Art Deco	23%	5	40
8	M-Press	33%	12	54
9	Puma	40%	23	58
10	Sy Ovation	14%	0	32
11	Wb 1604	41%	24	59
12	Resilience CL+	47%	29	64
13	LCS Drive	14%	0	35
14	ORCF 102	23%	5	40
15	Jasper	28%	10	45
16	SY Assure	22%	1	43
17	SY Dayton	16%	0	33
18	SY Raptor	5%	0	34
19	Eltan	73%	62	84
20	UI Castle CL+	11%	0	28
21	Madsen	26%	9	43
22	Bobtail	26%	8	43
23	WB 1783	55%	34	76

		Percent Survival	95% LCL	95% UCL
	Club Wheat			
1	ARS Crescent	63%	46	81
2	Bruehl	53%	35	70
3	Pritchett	54%	37	72
	Hard Winter Wheat			
1	LCS Jet	34%	17	52
2	Keldin	63%	45	81
3	SY Clearstone CL2	66%	48	83
4	WB 4303	85%	64	107
5	LCS Fusion AX	Not tested		
6	SY Touchstone	47%	26	69
	Checks			
	Norstar	87%	76	98
	Stephens	31%	20	42

* LCL and UCL are the lower and upper confidence limits for the percent survival.

Data provided by K. Garland-Campbell and E. Klarquist based on artificial freezing tests conducted at the WSU wheat plant growth facility 2016-2019. Funding from the Washington Grains Commission, project 6600. Additional data for cultivars and breeding lines included in the 2019 WSU variety testing nurseries but not on this list provided by request: kim.garland-campbell@usda.gov

WGC project number: **3019-3157**
WGC project title: **Evaluation And Selection For Cold Tolerance In Wheat**
Project PI(s): **Kimberly Garland-Campbell, Karen Sanguinet and Arron Carter.**
Project initiation date: **7/1/19**
Project year: **Year 1**

Objective	Deliverable	Progress	Timeline	Communication
1. Evaluate Washington winter wheat variety trials and the hard spring wheat trials.	Ratings for freezing tolerance for commonly grown and new winter wheat cultivars and hard sprign cultivars and breeding lines.	2019 Washington winter wheat trials were evaluated in the artificial freezing trials.	June 2019 - June 2022.	Presentation at grower meetings, Wheat commission meetings, field days, plot tours, Wheat Life and Research Review. Published on WSU small grains Web-site
2. Evaluate cold tolerance of new breeding lines in US regional nurseries in order to identify germplasm to use in crossing for better winter survival.	Ratings for freezing tolerance for advanced wheat germplasm from the US that can be used as new sources of cold tolerance for the PNW.	New breeeding lines from the WSU winter wheat breeding project and the USDA-ARS winter wheat breeding project for 2019 were evaluated. These data were used for selection.	June 2019 - June 2022.	Presentation at grower meetings, Wheat commission meetings, Wheat Life and Research Review. Email results to regional nursery cooperators and publish on regional nursery web sites.
3. Evaluate cold tolerance of advanced breeding lines contributed by regional winter wheat breeding programs, including the WSU and USDA-ARS wheat breeding programs.	Ratings for breeding lines contributed by regional wheat breeders that will facilitate their selection decisions.	The Western Regional Soft Winter wheat and the Western Regional Hard Winter Wheat trials were evaluated. Data were sent to cooperators.	June 2019 - June 2022.	Peer reviewed publications. Direct comunication with wheat breeders.
4. Evaluate cold tolerance of F3-F5 (early generation) wheat populations that are segregating for cold tolerance and select resistant progeny.	Selections made for cold tolerance in early populations.	The methods were worked out to conduct these trials and the first set of lines has undergone freezing.	June 2019 - June 2022.	Direct communication with wheat breeders.
5. Identify genes controlling cold hardiness in winter wheat.	New molecular markers and genomic selection indices for cold tolerance in PNW winter wheat and Hard red spring wheat.	RNA seq was conducted on Norstar wheat expressing different levels of cold tolerance due to epigeetic gene action. These data are being analyzed.	June 2019 - June 2022.	Direct communication with wheat breeders. Peer reviewed publications.

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

Project #:

Progress Report Year: __3__ 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 spring 2017, 2018, and 2019. Soil test results indicate the lime applications successfully established different soil acidity levels ranghing from pH 4.85 to pH 6.65. 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).

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.

The major themes we see at this point in time are:

1. At all four locations, the lime application in fall 2016 created a pH gradient at the soil surface (0-3in). The gradient at Pendleton (pH 4.87 – 5.93) may be most compelling.
2. At all four locations, the lime application in 2016 has yet to impact soil pH below 3in.
3. At all four locations, there was no yield response to the lime application in harvest 2019. However, we expect to observe a yield response in time, as the lime treatment moves down further into the soil profile.

Harvest 2020 will be our last harvest of these plots under support from Washington Grain Commission and the Oregon Wheat Commission. We will continue to seek other funding opportunities for the plots, and plan to continue to monitor the plots at a basic level to understand changes and impact of liming over time. Oregon plots will "rest" unplanted for the 2020-2021 seasons, but will remain "intact" for future studies. No determination has been made for the plots in Washington at this time, although the farmer plot will continue to be farmed and we could possibly return at a later date to evaluate soil changes and possible future plot harvest of the farmer seeded crop.

Around this time next year, we will be compiling 2016-2020 data from all four locations and writing a summary manuscript(s). In addition, Dr. Paulitz, Dr. Yin, and Dr. Schlatter are collaborating on a soil microbiome study to investigate soil bacterial and fungal community ecology as a function of pH – the microbiome work is supported by funding from USDA-ARS.

There are four figures attached for each of the four locations to graphically illustrate our main findings. Results are preliminary.

We sincerely thank the WGC and OWC for funding to further understand the impact of soil acidity on our production system. This work continues to generate tremendous interest and support from the producer clientele of OR and WA wheat.

Outputs and Outcomes:

See attached Excel template

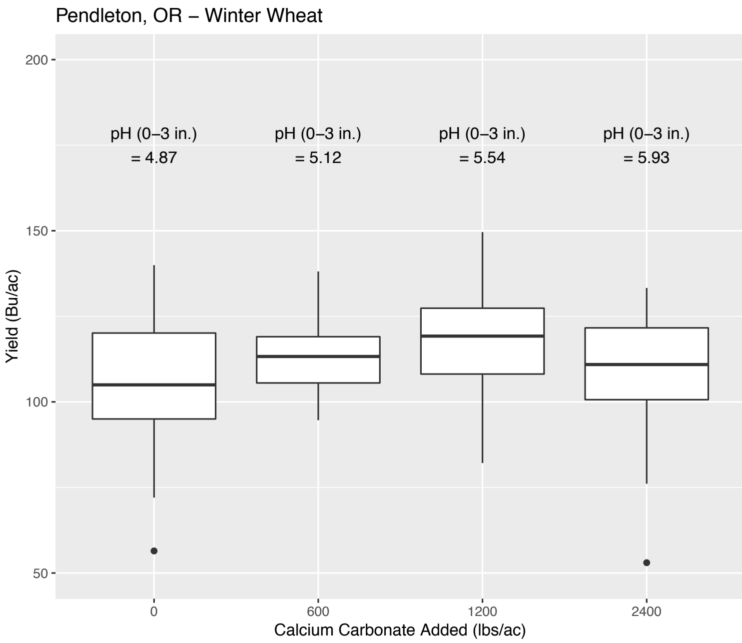
Use the Excel template provided to report on the following. Ideally, you simply update your spreadsheet from previous reports. The objectives and deliverables identified in the spreadsheet should be consistent with the original objectives and deliverables described in the project proposal.

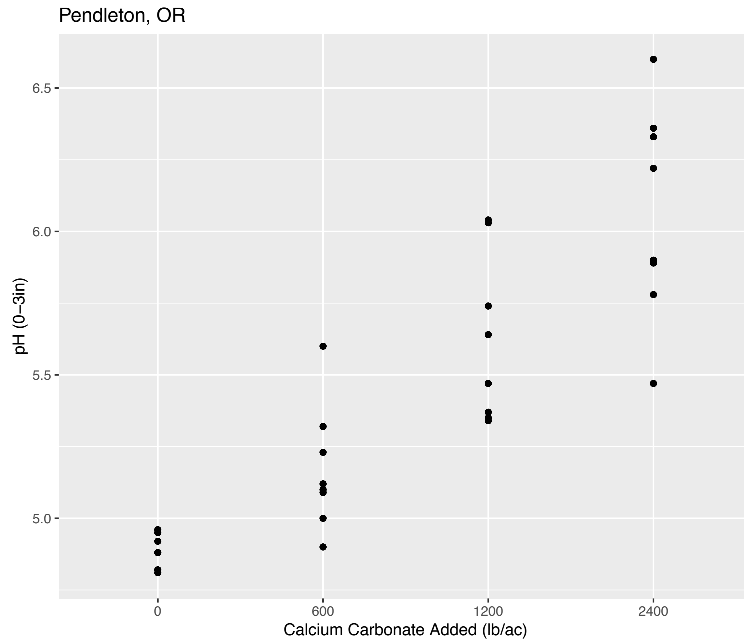
A. Progress:	For each objective and deliverable, describe the current status/progress towards completing the stated objective? If there have been delays or problems with progress, please keep the WGC informed through the current proposal, annual progress report and quarterly reports. Delays or failures are an expected part of research; however, the WGC would like to know when they occur.
C. Timeline:	State when the deliverable will be or was produced.
D. Communication:	State the method of communicating results to growers. (A listing of refereed publications, presentations, articles and field day/tour participation should be included in the report block).

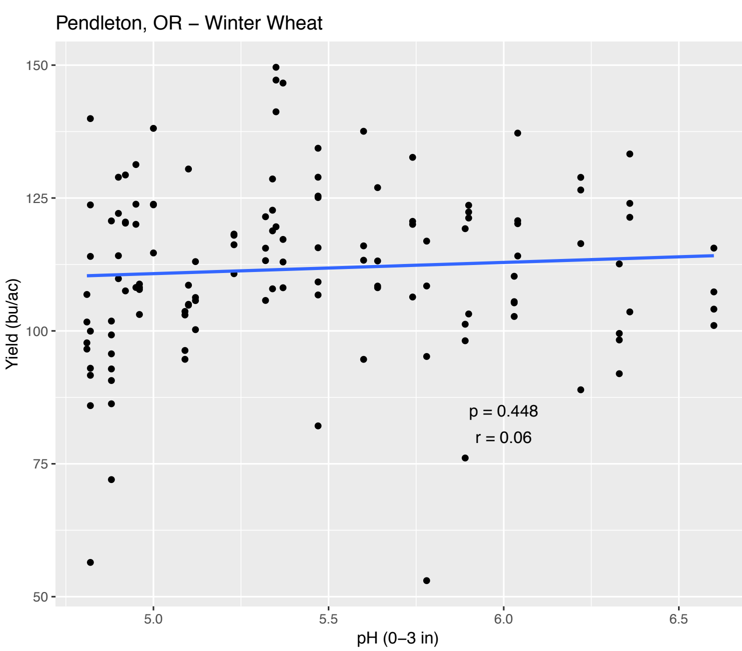
WGC project number:
WGC project title: Assessment of soil acidity on soil-borne pathogens, weed spectrum, herbicide activity, yield, and crop quality on dryland wheat production.
Project PI(s): Christina Hagerty and Paul Carter
Project initiation date: July 1, 2017
Project year (X of 3-yr cycle): This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

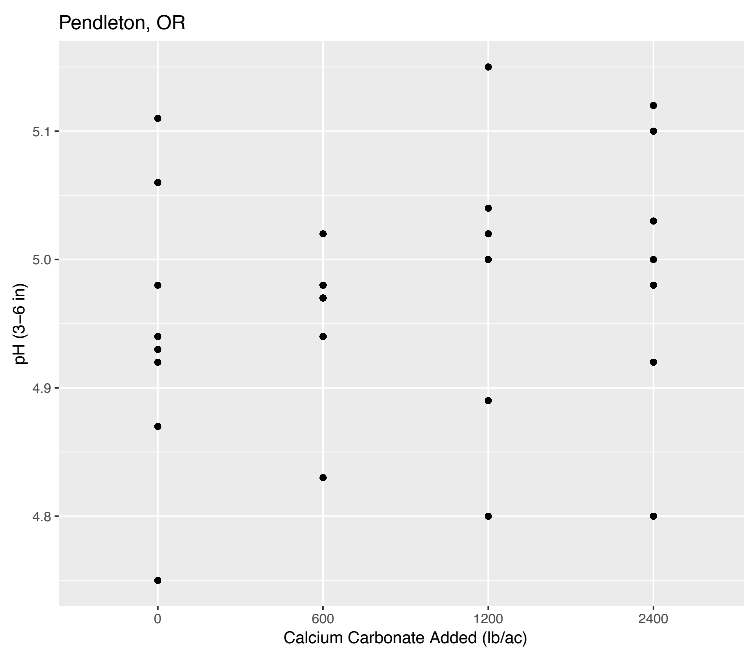
Objective	Deliverable	Progress	Timeline	Communication
Quantify impact of soil acidity on soil-borne pathogens	Quantify disease in each soil pH treatment, statistically evaluate the relationship between pathogens and pH	Disease quantification has occoured in Spring 2018, and Spring 2019, and will occour in Spring 2020.	Fall 2020 synthesize and compile results	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	Weed spectrum quantification has occoured in Spring 2018, and Spring 2019, and will occour in Spring 2020.	Fall 2020 synthesize and compile results	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	Weed spectrum quantification has occoured in Spring 2018, and Spring 2019, and will occour in Spring 2020.	Fall 2020 synthesize and compile results	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	Yield quantification has occoured in Spring 2018, and Spring 2019, and will occour in Spring 2020.	Fall 2020 synthesize and compile results	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	Grain quality samples will be submitted after harvest 2020.	Fall 2020 synthesize and compile results	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.	Data compilation is ongoing.	Fall 2020 synthesize and compile results	Extension programming to communicate results directly to grower clientele and peer reviewed publications to communicate results to the scientific audience

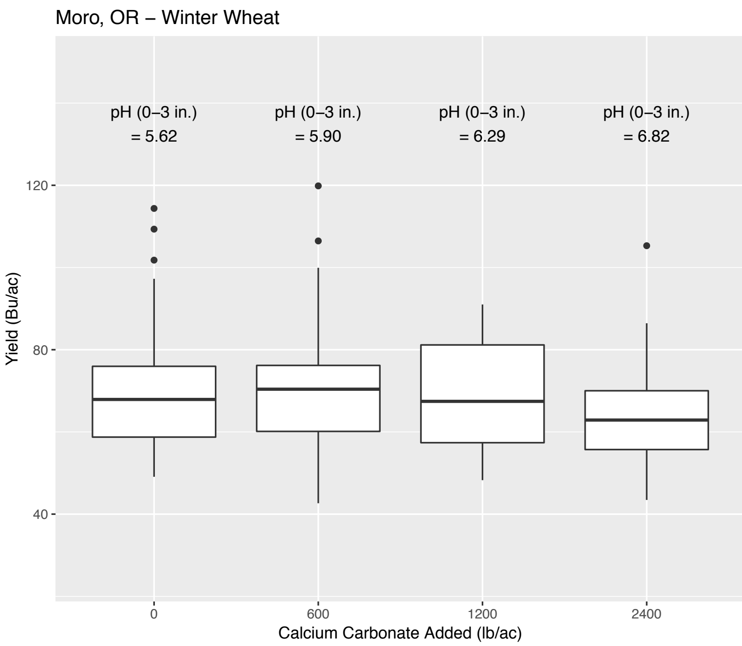
Do not use a font size less than 10 point. Let the template break over pages if necessary. The formatting will be retained when saved as a pdf file.

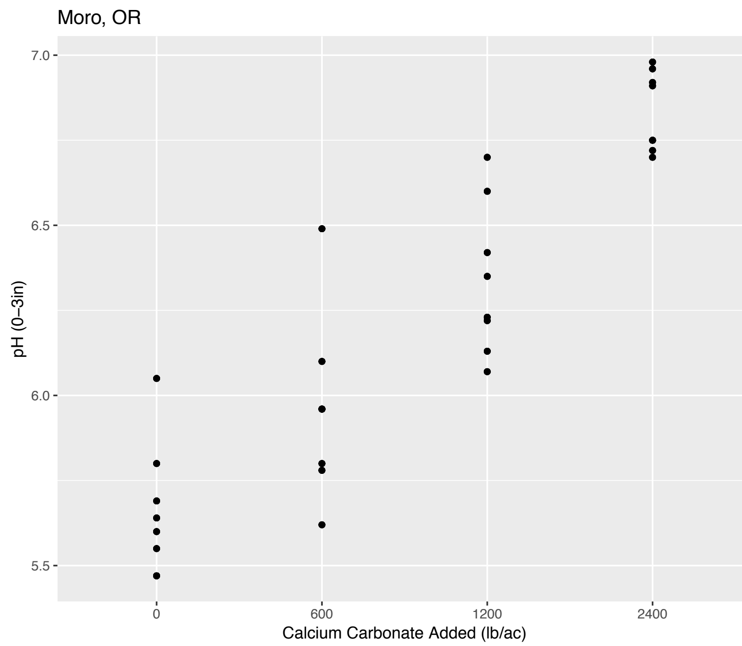

Pendleton, OR – Winter Wheat
pH (0–3 in.) = 4.87
pH (0–3 in.) = 5.12
pH (0–3 in.) = 5.54
pH (0–3 in.) = 5.93
Yield (Bu/ac)
Calcium Carbonate Added (lbs/ac)

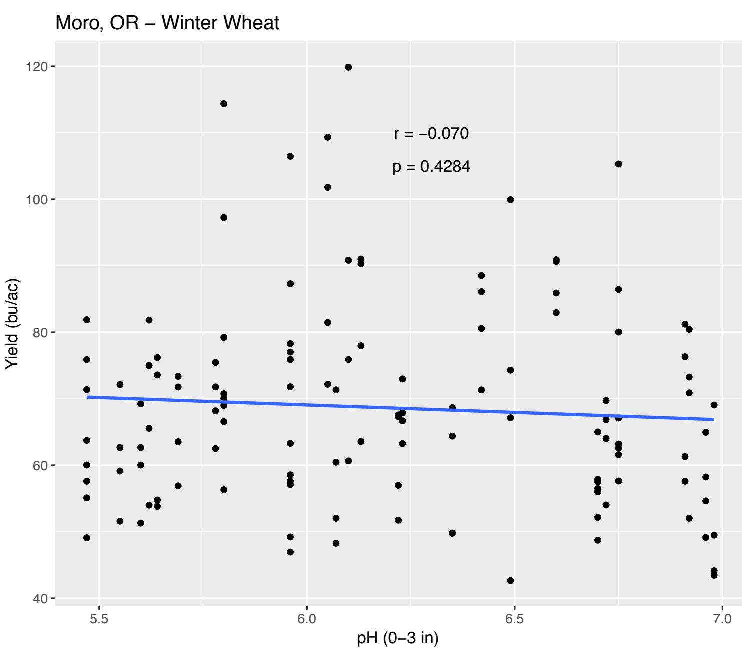

Pendleton, OR
pH (0–3in)
Calcium Carbonate Added (lb/ac)

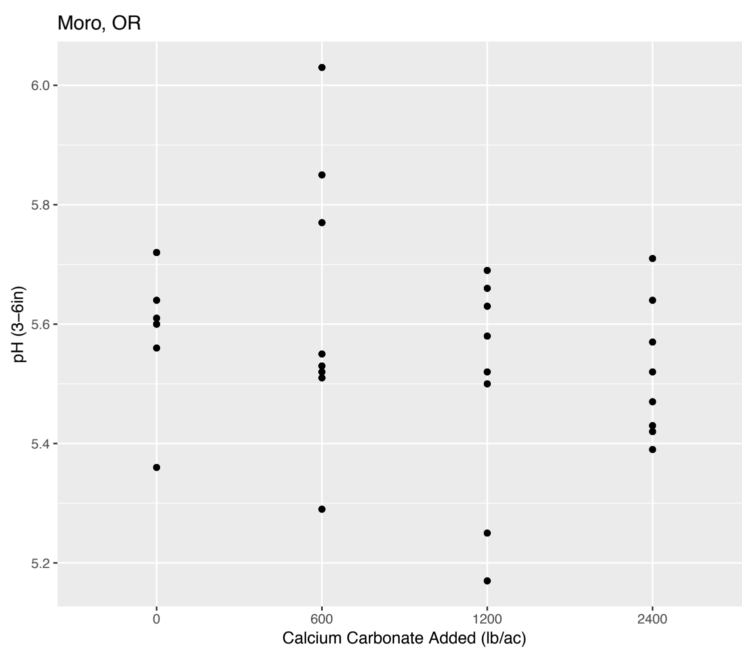

Pendleton, OR – Winter Wheat
p = 0.448
r = 0.06
Yield (bu/ac)
pH (0–3 in)

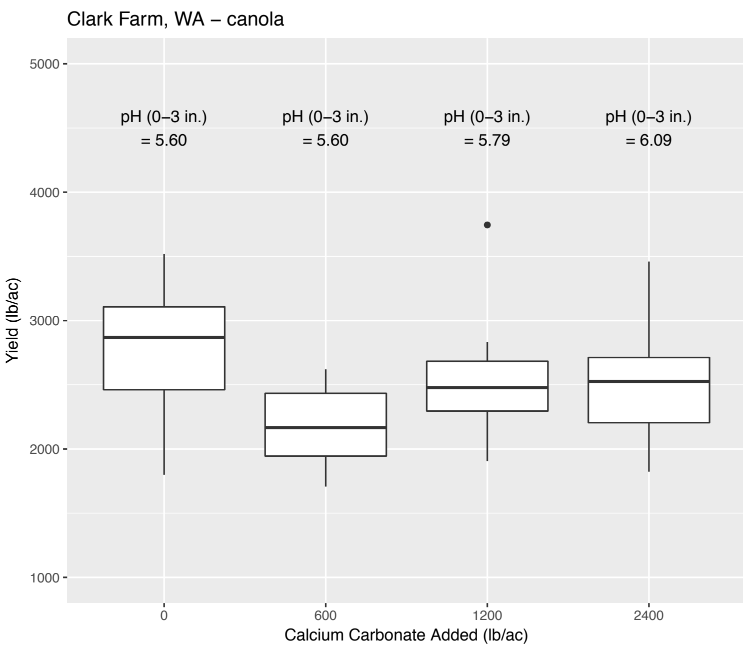

Pendleton, OR
pH (3–6 in)
Calcium Carbonate Added (lb/ac)

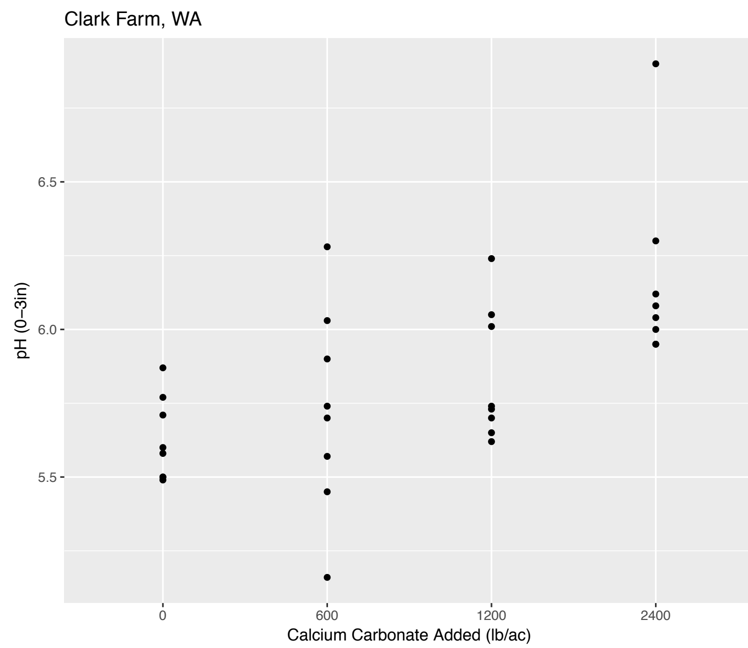

Moro, OR – Winter Wheat
pH (0–3 in.) = 5.62
pH (0–3 in.) = 5.90
pH (0–3 in.) = 6.29
pH (0–3 in.) = 6.82
Yield (Bu/ac)
Calcium Carbonate Added (lb/ac)

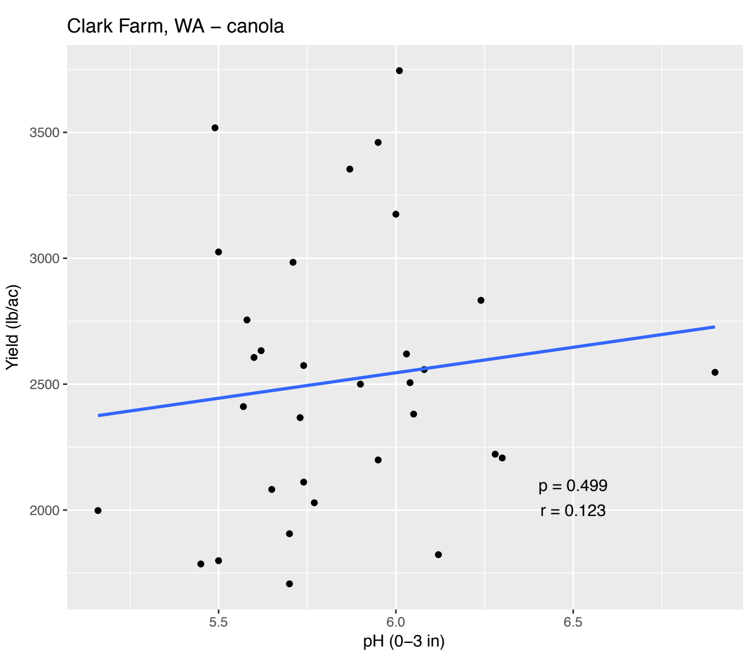

Moro, OR
pH (0–3in)
Calcium Carbonate Added (lb/ac)

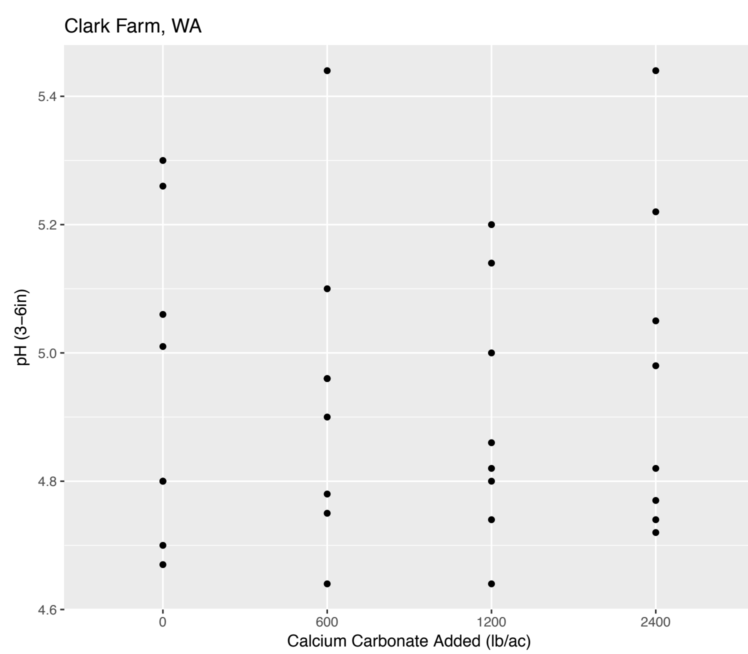

Moro, OR – Winter Wheat
r = –0.070
p = 0.4284
Yield (bu/ac)
pH (0–3 in)

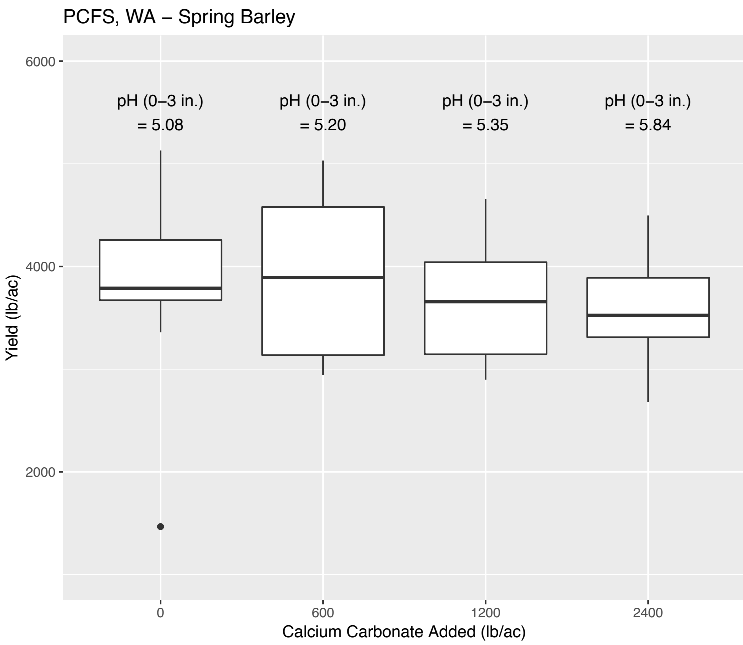

Moro, OR
pH (3–6in)
Calcium Carbonate Added (lb/ac)

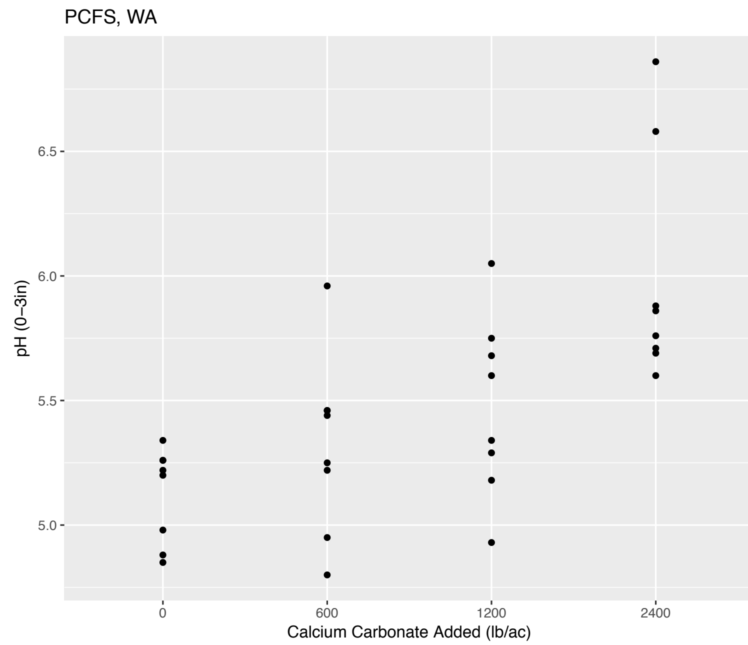

Clark Farm, WA – canola
pH (0–3 in.) = 5.60
pH (0–3 in.) = 5.60
pH (0–3 in.) = 5.79
pH (0–3 in.) = 6.09
Yield (lb/ac)
5000
4000
3000
2000
1000
0
600
1200
2400
Calcium Carbonate Added (lb/ac)

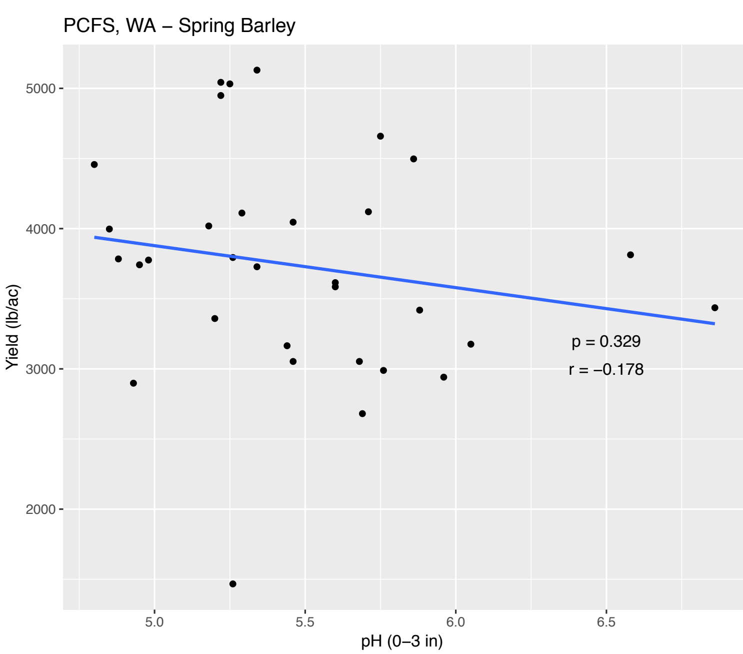

Clark Farm, WA
pH (0–3in)
6.5
6.0
5.5
0
600
1200
2400
Calcium Carbonate Added (lb/ac)

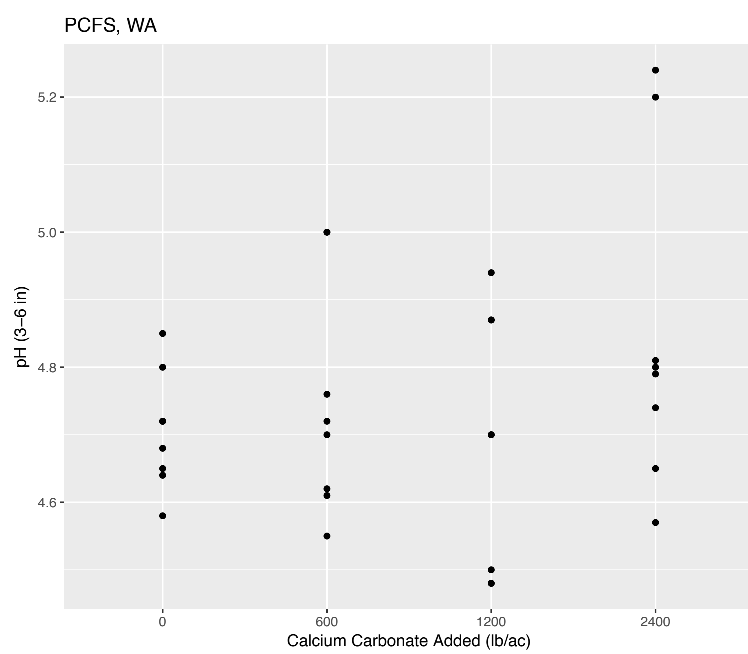

Clark Farm, WA – canola
Yield (lb/ac)
3500
3000
2500
2000
p = 0.499
r = 0.123
5.5
6.0
6.5
pH (0–3 in)


Clark Farm, WA
pH (3–6in)
5.4
5.2
5.0
4.8
4.6
0
600
1200
2400
Calcium Carbonate Added (lb/ac)


PCFS, WA – Spring Barley
pH (0–3 in.) = 5.08
pH (0–3 in.) = 5.20
pH (0–3 in.) = 5.35
pH (0–3 in.) = 5.84
Yield (lb/ac)
6000
4000
2000
0
600
1200
2400
Calcium Carbonate Added (lb/ac)


PCFS, WA
pH (0–3in)
6.5
6.0
5.5
5.0
0
600
1200
2400
Calcium Carbonate Added (lb/ac)


PCFS, WA – Spring Barley
Yield (lb/ac)
5000
4000
3000
2000
p = 0.329
r = –0.178
5.0
5.5
6.0
6.5
pH (0–3 in)


PCFS, WA
pH (3–6 in)
5.2
5.0
4.8
4.6
0
600
1200
2400
Calcium Carbonate Added (lb/ac)

Project #: 3043-3327

Progress Report Year: *1 of 2 (maximum of 3 year funding cycle)*

Title: Hessian Fly Management: An Emerging Research Issue in Wheat

Researchers: **Laura Lavine, Mike Pumphrey**

Cooperators: *Arash Rashed, Arron Carter, Kim Garland-Campbell*

Executive summary: The Hessian fly *Mayetiola destructor* is an emerging economic threat to wheat grown in the inland Pacific Northwest. While screening for Hessian fly for wheat improvement has been funded by the Washington growers for several years (Pumphrey, Bosque-Pérez, & Rashed), it is critical to have new research on insect management practices for Hessian fly in Washington state based on its emergence as a new economic threat. The overall goal of this project is to increase the profitability and sustainability of Washington wheat-based cropping systems via evidence-based insect management decisions. Our specific goal is to provide new biological and ecological information on this important insect pest that will lead to improved Hessian fly management. We will accomplish this (1) providing a comprehensive review of known environmental factors contributing to Hessian fly outbreaks in the inland Northwest through surveys and collaboration with scientists, growers, and extension specialists and (2) focus specifically on genetic virulence of Hessian fly to new wheat germplasm development in several new and current genetic lines including Louise to precise recommendations for management.

Accomplishments since July 1, 2019 when this project was funded. We have recruited and begun training the Entomology M.S. student, Daniel Gallegos. He has begun working with members of Mike Pumphrey's lab and Arash Rashed's lab to go into the field to collect Hessian Fly samples. Daniel and Laura have also attended field days, Daniel attended the Wheat Academy, and both have had meetings with our wheat and grain extension faculty as we put together information on needs for the Hessian Fly biology literature review and extension bulletin. He is in the process of setting up the Hessian Fly wheat screening program at WSU modeled on the facility at the University of Idaho so that we can increase the capacity of genetic lines screened. And we have formed a Hessian Fly reading group that meets twice a month to review the most relevant scientific information on Hessian Fly biology and management.

Impact:

Hessian fly resistance in the inland Northwest is valued from $45 to $104 per acre based on a study led by Dick Smiley at Oregon State University. Applying these values, a very conservative Washington state-wide loss estimate without resistant varieties is over $10,000,000 per year, not including lower-level losses to winter wheat crops. Hessian fly infestations are widespread through the state every year and sampling with pheromone traps produces hundreds to thousands of flies at all locations sampled.

Hessian fly is largely controlled through genetic resistance maintained by expert screening of germplasm and by farmer adoption of resistant varieties. Typical insect pest management regimens for Hessian fly rely on prevention measures. From 2016-2018, we've seen heavy infestations at more sites, with heavier pressure than has been seen in over ten years or more. While newly released WSU varieties Glee, Alum, Chet, Seahawk, Tekoa, and Ryan are Hessian fly resistant due to the Hessian fly screening program funded by Washington growers, this work not only needs to continue, but the insect can and does adapt to resistant varieties. Therefore, additional research on Hessian fly population genetics and Hessian fly virulence is critical for successful management now and in the future.

No measureable impact has yet been shown in this project in the most recent funding cycle as we are setting up the foundational work for Hessian fly screening at WSU as we show in our output and outcomes table below.

Outputs and Outcomes:

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

A. Progress:

Objective	Deliverable	Progress
1: Comprehensive review of PNW Hessian fly biology	Published literature review of updated Hessian Fly biology; new extension bulletin published.	Surveys are being formulated; literature has been reviewed; manuscript will be written in spring 2020
2: Field collections of HF; screen against varieties in greenhouse	New MS grad student; HF screening at UI and at WSU (new).	New cages are being built, a greenhouse at WSU has been identified, HF samples are stored from field collections this summer and fall to be used in screenings this Jan-June

C. Timeline:

Objective	Timeline
1: Comprehensive review of PNW Hessian fly biology	Spring 2020 with extension bulletin submitted to peer review by June 1, 2020
2: Field collections of HF; screen against varieties in greenhouse	Jan-June HF screening at WSU and UI; Wheat Life article after August 2020

D. Communication:

Objective	Communication
1: Comprehensive review of PNW Hessian fly biology	Presentations at Field Days; peer reviewed extension bulletin
2: Field collections of HF; screen against varieties in greenhouse	Presentations at Field Days; peer reviewed scientific publication to be prepared; article for Wheat Life

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

Project #: 4150-1227

Progress Report Year: 1 of 3

Title: Extension Education for Wheat and Barley Growers

Cooperators: Drew Lyon, Timothy Murray, David Crowder, Randy Fortenbery, Haiying Tao, Clark Neely, Aaron Esser, Stephen Van Vleet, Paul Carter, Dale Whaley, and Isaac Madsen

Executive summary: New resources were added to the Wheat and Small Grains website in 2019. We added the Herbicide Resistance Resources page in response to increased concern about herbicide resistance in the PNW. A new PNW Extension publication on harvest weed seed control was also published to address the issue of herbicide resistance. Other new Extension publications included PNW492, FS158E, FS331E, and FS333E. The results from the 2019 cereal variety testing program were added to the website and the Variety Selection Tool. The 2018 WSU Weed Control Report was posted as were three new Weed ID quizzes. Twenty-five new episodes of the WSU Wheat Beat Podcast were posted in 2019, a new episode every other week, except during the December campus shutdown. There were also 34 new Timely Topics posted. The 2019 Wheat Academy was once again full, with 36 growers and 39 industry representatives attending the event.

There were several membership changes on the Extension Dryland Cropping Systems Team in 2019. Dr. Clark Neely joined the team as the Extension Agronomist/Variety Testing Lead in August of 2019. Aaron Esser had been managing the Cereal Variety Testing Program since early 2018 when Ryan Higginbotham left WSU. Relieving Aaron of that responsibility will allow him to focus on his areas of interest and expertise. Karen Sowers left the team in 2019 and Dr. Isaac Madsen replaced her on the team. He will provide expertise in oilseed production.

Impact: The Wheat and Small Grains website saw increased use again in 2019. For the 11-month period of January through November, the site had 49,175 sessions with 36,002 unique users; this was up from 42,484 sessions and 29,001 unique users for the same period in 2018, and 39,747 sessions and 25,534 unique users in 2017. There were 63,951 unique pageviews. The most visited pages were pages related to the variety testing program (18,078 pageviews), the common weed list (6,962 pageviews), and the home page (6,438 pageviews). The majority of the sessions from the US were initiated from the state of Washington (13,793). From January through November of 2019, the WSU Wheat Beat Podcast had a total of 9,093 plays.

WGC project number: 4150-1227 (FY 2019-2022)
WGC project title: Extension Education for Wheat and Barley Growers
Project PI(s): Drew Lyon
Project initiation date: July 1, 2019
Project year (X of 3-yr cycle): 1

Objective	Deliverable	Progress	Timeline	Communication
Add new resources to the Wheat and Small Grains website, including new publications, decision support tools and calculators, videos, and quizzes.	New and updated Extension publications, decision support tools and calculators, videos, and quizzes will be developed. Decision support tools and videos will be priortizied. An article will be written annually for Wheat Life magazine on our Extension activities.	"Not your grandparent's Extension service" was published in the 2019 August/September issue of Wheat Life magazine. The Herbicide Resistance Resources page was added in 2019 as were two PNW Extension publications (PNW492 and 730), three WSU Extension Fact Sheets (FS158E, 331E, and 333E), three weed ID quizzes, the 2018 WSU Weed Control Report, and the 2019 Variety Testing Data.	This will be an ongoing process throughout the duration of the project.	The development of new resources were 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 various education events held throughout 2019.
Provide Timely Topics and podcast episodes on a regular and frequent basis.	We will post at least one Timely Topic every other week and one podcast episode in the alternate weeks so that we have at least one new item on the home page every week.	Twenty-five new episodes of the WSU Wheat Beat Podcast were posted in 2019; one every other week, except during the December campus shutdown. Thirty-four Timely Topics were posted in 2019, but we did not always manage to have a new Timely Topic posted every other week as intended.	The proposed schedule will be initiated at the start of the funding cycle and continue throughout the durationof the project.	Timely Topics and Wheat Beat Podcast episodes were posted to the home page of the Wheat and Small Grains website.
Develop a new one-day educational program along the lines of the Wheat Academy that can be held outside of Pullman.	A new one-day educational program held each year in at least one location outside of Pullman.	No progress was made on this objective in 2019.	Planning for the new educational program will begin in 2019, with delivery of the first program in 2020.	Information on the new educational event will be communicated to growers and crop consultants through Timely Topic posts and in future advertisements for the program, including advertising in Wheat Life.
Respond to issues of concern to the wheat industry with educational programming that is timely and relevant.	In-depth educational programs, publications, articles, videos, and decision support tools as called for by the particular issue.	Herbicide resistance was identified as an issue of concern in 2019. In response, the Herbicide Resistance Resources page was added to the Wheat and Small Grains website. A PNW Extension publication (PNW730) on Harvest Weed Seed Control was published and a session on the topic was held at the 2019 Tri-State Grain Convention.	This will be an ongoing process throughout the duration of the project.	Educational resources and programming developed to address issues of concern were shared with growers through Timely Topic posts on the Wheat and Small Grains website and at education events held in 2019.

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

Project #:

Progress Report Year: __1__ *of _1___ (maximum of 3 year funding cycle)*

Title: Imaging and Rhizosphere Microbial Analysis of Wheat Seedlings Experiencing Root Rot Caused by *Rhizoctonia solani* AG8

PI: Isaac Madsen

Cooperators: Rick Lewis, Tarah Sullivan, Christine Jade Ermita

Executive summary:

Root rot is a yield reducing fungal disease in the inland Pacific Northwest. *Rhizoctonia solani* AG8 is a fungal pathogen responsible root rot and bare patch in wheat. The present methods for assessing disease severity are subjective and/or expensive disease analysis. This project set out to initiate the development of objective and inexpensive methods for assessing disease severity. The method proposed in this project is an innovative imaging method which uses a scanner based rhizbox and allows for non-destructive observations of disease progression. Four successful experimental runs have been conducted and the project is currently in the analysis phase. The initial experiments demonstrated the ability of the rhizobox methods to detect disease symptoms on infected roots, but has not successfully led to the differentiation between tolerant and susceptible wheat genotypes. The current difficulties in detecting varietal differences are likely due to a lack of variation in tolerance between the wheat varieties used in the study. In a corresponding screening experiments utilizing the conventional screening methods, no differences were found between the varieties used in the trial of the rhizobox method. However, as we are endeavoring to find a more sensitive technique than the conventional technique we intend to continue using image processing and analysis to attempt to delineate between the genotypes. Additionally, we intend to use different wheat genotypes in at least two more experimental runs with the rhizoboxes. These additional runs will focus on using what are known to be highly susceptible varieties of wheat in order to maximize the variation. In addition to the development of the imaging methods described above the soil microbiome of the rhizosphere (soil near the root) and the bulk soil are being analyzed. To date the rhizosphere and bulk soil have been sampled and the DNA has been successfully extracted from the soil. DNA sequencing will be completed by the spring of 2020 and analysis will follow shortly after.

Impact:

The primary immediate impact of the project is the demonstration of rhizoboxes as an effective means of differentiating between diseased and non-diseased wheat plants. These results have been presented at two international meetings. In the short-term we plan to demonstrate the effectiveness of this technique in differentiating between susceptible and tolerant wheat lines. The successful differentiation between wheat lines will lead to accelerated wheat breeding. In the long-term we hope the microbial analysis conducted in this study may help develop biocontrol agents for root pathogens.

WGC project number: NONE
WGC project title: Imaging and Rhizosphere Microbial Analysis of Wheat Seedlings Experiencing Root Rot Caused by Rhizoctonia solani
Project PI(s): Isaac Madsen, Ph.D., Rick Lewis, Ph.D., Tarah Sulivan Ph.D., Scot H. Hulbert, Ph.D. and Christine Jade
Project initiation date: July 1, 2019
Project year (1 of 3-yr cycle):

Objective	Deliverable	Progress	Timeline	Communication
Develop method of assessing root - pathogen interactions using a flatbed scanner mounted rhizobox.	A method to assess root-pathogen interactions through time that will result in more objective assessment of root injury and/or pathogen tolerance	Preliminary results suggest lesions and spear tips induced by *R. solani* can be observed and enumerated over time by examing scans of rhizoboxes. Videos demonstrating root responses to the fungal pathogen have already been generated. Results suggest some differences among wheat genotypes in terms of lesion formation. Root growth rate data strongly indicates the evectiveness of the proposed methods for detecting lessions. A wheat beat podcast is scheduled for 2020 and we expect to submit a manuscript shortly.	November, 2019	Wheat Beat Podcast (incomplete), Peer Reviewed Journal Article (incomplete), results presented at Agronomy Society of America and Rhizosphere 5 (international conference)
Improve techniques for assessing pathogen tolerance.	Identification/validation of wheat genotypes resistant to *R. solani* .	We have not sucesfully been able to detect tolerance in wheat varities. However, this may be due an actual lack of variation in the wheat genotypes.	November, 2019	Wheat Beat Podcast (incomplete), Peer Reviewed Journal Article (incomplete), results presented at Agronomy Society of America and Rhizosphere 5 (international conference)
Assessment of microbiome associated with infection in wheat varietires and lines having various degress of tolerance/susceptibility to *R. solani* AG8	Tangible information regarding the effect of microbime on disease.	Rhizosphere soil soils have been sampled and sent off for sequencing microbial sequencing should be complteded within the next month.	June, 2020	Wheat Beat Podcast, Wheat Life Article
Examine alterations in predicted bacterial community function associate with tolerance/susceptibility	Data which supports the development of potential biocontrols.	Not yet initiated	June, 2020	Wheat Beat Podcast, Wheat Life Article
Exammine the role of plant genotpye on rhizosphere recruitment of bacteria.	Tangible information regarding the potential for developing biocontrol in conjunction with resistant varieties	Not yet initiated	June, 2020	Wheat Beat Podcast, Wheat Life Article

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WGC project number: NONE
WGC project title: Imaging and Rhizosphere Microbial Analysis of Wheat Seedlings Experiencing Root Rot Caused by Rhizoctonia solani
Project PI(s): Isaac Madsen, Ph.D., Rick Lewis, Ph.D., Tarah Sulivan Ph.D., Scot H. Hulbert, Ph.D. and Christine Jade
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Assessment of microbiome associated with infection in wheat varietires and lines having various degress of tolerance/susceptibility to *R. solani* AG8	Tangible information regarding the effect of microbime on disease.	Rhizosphere soil soils have been sampled and sent off for sequencing microbial sequencing should be complteded within the next month.	June, 2020	Wheat Beat Podcast, Wheat Life Article
Examine alterations in predicted bacterial community function associate with tolerance/susceptibility	Data which supports the development of potential biocontrols.	Not yet initiated	June, 2020	Wheat Beat Podcast, Wheat Life Article
Exammine the role of plant genotpye on rhizosphere recruitment of bacteria.	Tangible information regarding the potential for developing biocontrol in conjunction with resistant varieties	Not yet initiated	June, 2020	Wheat Beat Podcast, Wheat Life Article

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

Project #: 4721

Progress Report Year: *2 of 3*

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

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

Executive summary: The 2019 harvest sample analysis is more than half done; the project is on-going with the most recent project covering the second of three 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 cereal chemists.

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

Outputs and Outcomes:

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
WA8234	Purl	SWW
WA8235	--	SWW

Advanced winter lines under consideration 2019:
WA8271, WA8268, WA8275, WA8252, WA8290, WA8293

New entries for the 2019 *Preferred Wheat Varieties* pamphlet:

Purl	WSU	SWW
WB1376CLP	WB	SWW
SY Coho	AP/SY	HRS
SY Gunsight	AP/SY	HRS

Preferred Wheat Varieties 2019 following page

SOFT WHITE WINTER

Brundage96	UI	MD
UI Castle CL+	UI	MD
Bobtail	OSU	MD
Kaseberg	OSU	MD
Bruneau	UI	MD
Jasper	WSU	MD
UI Palouse CL+	UI	MD
UI WSU Huffman	UI/WSU	MD
Puma	WSU	MD
ARS-Selbu	ARS	D
Mary	OSU	D
ORCF101	OSU	D
SY Command	AP/SY	D
Skiles	OSU	D
LCS Shark	LCS	D
LCS Drive	LCS	D
WB 523	WB	D
SY Ovation	AP/SY	D
UI Sparrow	UI	D
UI Magic CL+	UI	D
Eltan	WSU	D
SY Dayton	AP/SY	D
WB-528	WB	D
Norwest Duet	OSU/LCS	D
Resilience CL+	WSU	D
Otto	WSU	D
Stephens	OSU	D
SY Assure	AP/SY	A
LCS Hulk	LCS	A
LCS Artdeco	LCS	A
WB1604	WB	A
Purl	WSU	A
ORCF103	OSU	A
Madsen	ARS	A
WB-1070CL	WB	A
Mela CL+	WSU	A
Curiosity CL+	WSU	A
Norwest Tandem	OSU/LCS	A
ORCF102	OSU	A
Rosalyn	OSU	A
WB1529	WB	A
WB-1066CL	WB	A
WB1376CLP	WB	LD
WB 456	WB	LD
Xerpha	WSU	LD
SY107	AP/SY	LD
SY Banks	AP/SY	LD
WB1783	WB	LD

SOFT WHITE SPRING

UI Stone	UI	MD
Tekoa	WSU	MD
Diva	WSU	MD
WB6341	WB	MD
Louise	WSU	MD
Alturas	UI	MD
SY Saltese	AP/SY	MD
Ryan	WSU	MD
Whit	WSU	MD
Seahawk	WSU	MD
Babe	WSU	MD
WB6121	WB	D
WB-1035CL+	WB	UCS

CLUB

ARS Castella	ARS	MD
ARS Crescent	ARS	MD
Cara	ARS	MD
ARS Pritchet	ARS	D
Bruehl	WSU	D

SPRING CLUB

Melba	WSU	MD
JD	WSU	MD

HARD WHITE WINTER*

UI Silver	UI	MD
Earl	WSU	A

HARD WHITE SPRING*

UI Platinum	UI	MD
WB Hartline	WB	D
Dayn	WSU	D

ABBREVIATIONS

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

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

HARD RED WINTER

UI SRG	UI	MD
Whetstone	AP/SY	MD
WB4623CLP	WB	MD
AP503 CL2	AP/SY	D
Norwest 553	OSU	D
LCS Evina	LCS	D
LCS Rocket	LCS	D
Farnum	WSU	D
Sequoia	WSU	D
LCS Jet	LCS	A
Keldin	WB	A
Esperia	Societa Produttori Sementi Spa	A
SY Touchstone	AP/SY	LD
Residence	Cebeco	UCS
Estica	Cebeco	UCS
Symphony	Tanio Tech	UCS

HARD RED SPRING

Hollis	WSU	MD
Alum	WSU	MD
SY605 CL	AP/SY	MD
SY Selway	AP/SY	MD
SY Coho	AP/SY	MD
SY Steelhead	AP/SY	MD
Glee	WSU	MD
Chet	WSU	MD
LCS Luna	LCS	MD
LCS Iron	LCS	D
WB9411	WB	D
WB9229	WB	D
Kelse	WSU	D
WB9668	WB	D
Jefferson	UI	D
Bullseye	AP/SY	D
SY Gunsight	AP/SY	D
WB9518	WB	D
WB9879CLP	WB	A
Buck Pronto	LCS	A

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

Project #: 4722

Progress Report Year: *2 of 3*

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

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

Executive summary: This WGC support provides for about 3 months of additional technician time. The additional work is devoted to evaluating breeder samples for quality from early 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 are made 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 2018-Crop were completed and 2019-Crop testing is well under way at the Western Wheat Quality Lab.

Outputs and Outcomes: 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.

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,

Progress Report

Project #: 3682

Progress Report Year: 1 of 3

Title: Control of 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 conducted in 2018-19 and are in progress for 2019-20. Forty-two new varieties and advanced lines were evaluated for resistance to eyespot and tolerance to Cephalosporium stripe in inoculated field trials. Sixty lines were planted for each trial in September 2019 for evaluation in June 2020. Data from these plots will be used to update disease ratings in the Washington State Crop Improvement Association Seed Buyers Guide and the WSU Extension Small Grains variety selection tool.

Experiments to map disease resistance genes for eyespot in a Madsen population were conducted to determine whether the same genes control resistance to both pathogens. Phenotyping and genotyping were completed; data analysis is in progress now. In collaboration with colleagues in China, we mapped resistance to both species of cereal cyst nematode (CCN) in the same Madsen population and demonstrated that it carries two different genes, one each to *H. avenae* and *H. filipjevi*, both derived from VPM-1, the source of eyespot resistance. That work was published and available to breeders.

Field experiments on the use of variety mixtures for eyespot and Cephalosporium stripe control and spore-trapping of the eyespot fungi to better understand its epidemiology were completed. Data has been summarized, analysis is in progress, and papers being prepared for publication.

Impact: Cephalosporium stripe and eyespot continue to be significant yield-limiting diseases for winter wheat production. Nearly all public and private breeding programs in the PNW are addressing these diseases because resistant/tolerant varieties are the most effective way to limit their impact. This project is the only place where all new varieties and advanced breeding lines are evaluated side-by-side for their reaction to eyespot and Cephalosporium stripe. The data we generate are shared with wheat breeders to support variety release and growers at variety testing field tours, online at the WSU Extension Small Grains website, and is used to provide ratings in the WSCIA seed buyer's guide and the WSU Small Grains Variety Selection tool for use by growers in making variety selection decisions.

The gene present in Madsen is the primary source of resistance in all PNW eyespot-resistant varieties and understanding its genetic control will insure it remains effective. We suspect differences in effectiveness among resistant varieties may be the result of minor genes that have not been identified and/or differences in resistance to the two eyespot fungi. Identifying minor genes affecting eyespot resistance and molecular markers for them will allow breeders to develop new varieties with more effective eyespot resistance. Screening wild relatives of wheat for new sources of eyespot resistance is an important long-term goal.

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: 7/1/2019
Project year (X of 3-yr cycle): 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Evaluate advanced breeding lines and new varieties for resistance to eyespot and Cephalosporium stripe in field plots	Provide unbiased data on the resistance reactions of advanced selections and new varieties to eyespot and Cephalosporium stripe.	**2020:** Forty-two winter wheat cultivars and breeding lines were evaluated for their resistance/tolerance to eyespot and Cephalosporium in inoculated field trials in June 2019. Another 60 lines were planted in September for evaluation in 2020.	**2020**: This was the third year of testing in collaboration with the WSU Variety Testing program and WSU Winter Wheat Breeding. This activity will continue annually.	Results from these plots are 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. Data are used to update variety ratings in the Washington State Crop Improvement Seed Buyer's Guide, the WSU Extension Small Grains Variety Selection tool, and published online in Plant Disease Management Reports so they are available to the larger wheat research community.
2. Screen wild wheat relatives and other genetic populations to identify and map potential new eyespot resistance genes	Identify potential new eyespot resistance genes for use by breeders to improve effectiveness of resistant varieties.	**2020**: Conducted two experiments to screen 135 lines from a Cappelle Desprez x Whetstone population for eyespot resistance; one study each with Oy and Oa was completed and data have been summarized. A third experiment was setup in December for the second round of screening. DNA was collected from all lines and submitted for genotyping. We anticipate completing the screening experiments in late spring and then follow with analysis of the data.	**2020**: We anticipate beginning work on populations of the wheat relative Dasypyrum villosum in collaboration with Chinese wheat breeders in early summer or fall 2020.	Results of this research will be shared with breeders, presented at field days, variety testing plot tours, and other talks to grower and industry groups. Data also will be published in appropriate scientific journals.
3. Evaluate fungicides currently registered for eyespot control for effectiveness and determine the potential for development of fungicide resistance	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.	**2020:** Two field trials were planted in September 2019; one for the evaluation of eight seed treatments and another for spring-applied foliar fungicides for eyespot control.	**2020**: Fungicides will be tested annually depending on interest and support from industry. Work on resistance has not begun.	Results from this research will be presented at field days, variety plot tours, and other talks to grower and industry groups, and availble online at the Extension Small Grains Team website. Results also will be published in Plant Disease Management Reports so they are available to the larger small grains pathology community.
Prepare an article for Wheat Life during the three-year project.	Prepare an article for Wheat Life during the three-year project.	**2020:** Management options for wheat diseases in the Inland PNW published in January Wheat Life	**2020**: One article published in January	

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

Project #: 4127-1605
Progress Report Year: *1 of 3*
Title: Evaluation of Barley Varieties
Researcher: Clark Neely
Cooperators: Aaron Esser, Robert Brueggeman

Executive summary: During 2019, leadership of the Variety Testing Program transitioned from Aaron Esser to Clark Neely who assumed responsibilities in August. Of the 12 spring barley variety trials planted, Endicott was the only data not distributed due to high unexplained variability within the trial. The trials included nine feed, six malt, two hulless food varieties, and seven experimental lines. Four private companies and two land grant breeding programs entered material into the trial. Persistent spring rains delayed spring plantings and rainfall in August/September further delayed harvest. All 2019 variety trial data was uploaded by December on to the WSU Small Grains website (http://smallgrains.wsu.edu). The final report with additional information is being finalized for the official 2019 booklet and should be completed by mid-January 2020. In addition to our website and final technical report, variety performance information is delivered to barley growers and other clientele through field tours, grower meetings, emails with preliminary results after harvest (over 200 recipients), Wheat Life article, WSCIA seed buying guide, direct contact with clientele, and reports to the Washington Grain Commission. Scheduling 2020 field tours of variety trials is currently in progress.

Impact: Variety selection is a major decision on most farms and influences not only yield potential, but other management factors (input costs) such as insect and disease (pesticide applications), fertility, and herbicide program. The WSU spring barley VT has two important direct impacts: 1) Provides critical and unbiased data for growers to make informed decisions on which barley varieties are best adapted for their environment and management practices and 2) provides breeders, seed companies and seed dealers reliable information to make decisions regarding experimental line advancement, varietal releases/seed increases, and marketing strategies. Plant pathologists also use these trials to rate disease reactions. On average in 2019, there was a 570, 570, and 640 lb/a advantage between the highest yielding spring barley variety and the trial average in the >20”, 16-20”, and 12-16” precipitation zones, respectively. At $5.00/cwt, potential additional income generated ranges from $28 to $32/acre. Multiplied across 85,000 acres of harvested barley, these trials have the potential to generate approximately $2.6 million across the state.

WGC project number: 4127-1605
WGC project title: Evaluation of Barley Varieties
Project PI(s): Clark Neely
Project initiation date: 07-01-2019
Project year (X of 3-yr cycle): 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Conduct representative and objective barley variety field trial evaluations at locations that represent major production areas of Washington.	12 spring barley trials; 24 entries/trial	2019 trials completed (24 entries/trial) 2020 trials in planning	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 the variety trials are communicated via Extension programming and are detailed under Objective #4.
2. Entries in trials will include: currently grown varieties and promising advanced breeding lines from the major public and private breeding programs in the region.	All widely grown, commercially availabe varieties and promising experimental lines are included in trials.	2019 barley entries; 50% public, 50% private. Every major breeding program in the PNW is actively participating in the VTP.	Entries confirmed by February 15th.	Solicit entries by Februay 1. Maintain positive relationship with breeding programs to ensure future participation.
3. Provide access to variety trials and harvested grain enabling other researchers and supporting projects to gather information from the trials.	Participation from other projects/ programs.	Data is used by breeders for varietiey release and promotional materials.	Ongoing cooperation and collaboration that fit with timelines and other listed objectives.	Disease ratings pesented in seed buyers guide and variety selection tool, VTP data used for variety release and PVP applications.
4. Deliver an Extension education program to make the results and interpretation of the variety trials available to growers, the seed industry, and other clientele.	a.) Grower meetings	Several planned for 2020 (Adams Co. Grower Mtg, PNW Farm Forum, Wheat Academy, etc.)	Will attend when invited	Attend in person; present results through powerpoint presentation and handouts.
	b.) Field Tours	10 planned for 2020	June-July 2020	*List of Field Days provided below; provide paper handouts of data
	c.) Email List Serv	2019 results delivered	November through December	Email list serve: Data sent to 213 members as it becomes available
	d.) Website	Up to date with 2019 data	November through December	Over 20,000 page views of the VTP section of the small grains website.
	e.) Annual Report	All data analysis is complete; site management information and supplemental tables being added.	January 2020	The annual report will be published as a WSU technical report online and hard copy.
	f.) WSCIA Seed Buyers Guides	Tables in preparation	January-February 2020	2020 Seed Buyers Guide to be published in January-February 2020
	g.) Wheat Life	Spring barley VT article completed	Barley VT article completed January 2020	Articles published in Wheat Life in February 2020.
	h.) Variety Selection Tool (smallgrains.wsu.edu)	Selection tool needs to be updated with 2019 data	January-February 2020	The variety selection tool has over 6,000 page views in 2019.
*Anticipated 2020 Barley Field Days: Horse Heaven, Walla Walla, Dayton, Moses Lake, Reardan, Mayview, St. John, Lamont, Farmington, Palouse				

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

Project #: 4127-1604
Progress Report Year: *1 of 3*
Title: Evaluation of Wheat Varieties

Researcher: Clark Neely
Cooperators: Aaron Esser, Arron Carter, Kim Garland-Campbell, Mike Pumphrey,

Executive summary: During 2019, leadership of the Variety Testing Program transitioned from Aaron Esser to Clark Neely who assumed responsibilities in August. Of the 24 SWWW, 16 HRWW, 18 SWSW, and 18 HRSW trials planted, a total of five trials were lost due to equipment issues or high variability within the trial. Persistent spring rains delayed spring plantings and rainfall in August/September further delayed harvest. Delayed harvest complicated planting and thus delayed planting 2020 winter trials in many cases. Still, all winter locations were planted with the exception of Pasco, due to a last minute cancellation from the cooperator. All 2019 variety trial data was uploaded by November 22 on to the WSU Small Grains website (http://smallgrains.wsu.edu). The final report with additional information is being finalized for the official 2019 booklet and should be completed by mid-January 2020. Scheduling 2020 field tours of variety trials is currently in progress.

Impact: With over 90% of Washington wheat planted with certified seed, variety selection is a major decision on most farms and influences not only yield potential, but other management factors (input costs) such as insect and disease (pesticide applications), fertility, and herbicide program. The WSU variety testing program provides critical and unbiased information for growers to make informed decisions on which wheat varieties are best adapted for their environment and management practices. On average in 2019, there was an 11, 8, 12, and 7 bu/a spread between the highest yielding SWWW variety and the trial average in the >20”, 16-20”, 12-16”, and <12” precipitation zones, respectively. At $5.00/bu, potential additional income generated ranges from $35 to $60/acre. Multiplied across the 2.2 million acres of harvested wheat, these variety trials have the potential to generate approximately $105 million across the state. In addition to grower benefits, breeders, seed companies and seed dealers rely on this information to make decisions regarding experimental line advancement, varietal releases/seed increases, and marketing strategies. Samples and data generated from these trials are also critical for wheat quality testing and development of the Preferred Wheat Varieties brochure. This information is important for promoting adoption of high-quality wheat varieties and helps secure overseas markets.

WGC project number: 4127-1604
WGC project title: Evaluation of Wheat Varieties
Project PI(s): Clark Neely
Project initiation date: 07-01-2019
Project year (X of 3-yr cycle): 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Conduct representative and objective wheat variety field trial evaluations at locations that represent major production areas of Washington.	a) 24 soft winter wheat trials; 48-60 entries/trial	a) 2020 winter trials planted; 2019 results finished Collaborative trials are continuing with OSU at Eureka and Walla Walla.	Trials are planted in the spring or fall, data results are available to growers at the end of the harvest season. Field tours in summer.	Results from the variety trials are communicated via Extension programming and are detailed under Objective #4.
	b) 16 hard winter wheat trials: 18-30 entries/trial	b) 2020 winter trials planted; 2019 results finished		
	c) 18 soft spring wheat trials; 24 entires/trial	c) 2019 results finished		
	d) 18 hard spring wheat trials; 30-36 entires/trial	d) 2019 results finished		
2. Entries in trials will include: currently grown varieties and promising advanced breeding lines from the major public and private breeding programs in the region.	All widely grown, commercially availabe varieties and promising experimental lines are included in trials.	2020 winter trials; 36% public, 64% private. Every major breeding program in the PNW is actively participating in the VTP. 2020 winter entries, locations, and maps can be viewed on the variety testing website.	2020 winter entries were confirmed by August 15th and spring enties will be confirmed by February 15th.	Solicit winter entries by August 1 and spring entries by Februay 1. Maintain positive relationship with breeding programs to ensure future participation.
3. Provide access to variety trials and harvested grain enabling other researchers and supporting projects to gather information from the trials.	Participation from other projects/ programs.	Cooperation with breeders, pathologists, entomologists, quality lab, FGIS, seed dealers, WSCIA, other universities, and 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 pesented in seed buyers guide and variety selection tool, VTP data used for variety release and PVP applications.
4. Deliver an Extension education program to make the results and interpretation of the variety trials available to growers, the seed industry, and other clientele.	a.) Grower meetings	Several planned for 2020 (Adams Co. Grower Meeting, PNW Farm Forum, Wheat Academy, etc.)	Will attend when invited	Attend in person and present results through powerpoint presentation and handouts.
	b.) Field Tours	21 planned for 2020	June-July 2020	*List of Field Days provided below; provide paper handouts of data
	c.) Email List Serv	2019 results delivered	October through December	Email list serve: Data sent to 213 members as it becomes available
	d.) Website	Up to date with 2019 data	October through December	Over 20,000 pagviews of the VTP section of the small grains website.
	e.) Annual Report	All data analysis is complete; site management information and supplemental tables being added.	January 2020	The annual report will be published as a WSU technical report online and hard copy.
	f.) WSCIA Seed Buyers Guides	Tables in preparation	January-February 2020	2020 Seed Buyers Guide to be published in January-February 2020
	g.) Wheat Life	Spring VT article completed; Winter VT article to be written in April 2020	Spring VT article: Jan 2020 Winter VT article: April 2020	Articles published in Wheat Life in February and May 2020.
	h.) Variety Selection Tool (smallgrains.wsu.edu)	Selection tool needs to be updated with 2019 data	January-February 2020	The variety selection tool has over 6,000 page views in 2019.
*Anticipated 2020 Wheat Field Days: Horse Heaven, Ritzville, Dusty, Connell, Lind, Harrington, St. Andrews, Eureka, Walla Walla, Dayton, Moses Lake, Creston, Reardan, Mayview, Anatone, Fairfield, St. John, Lamont, Bickleton, Farmington, Palouse				

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

(Begin 1 page limit)

Project #:3061-7667

Progress Report Year: *_1___of _3___(maximum of 3 year funding cycle)*

Title: **Management of Nematode Diseases with Genetic Resistance**

Scot Hulbert, Kimberly Garland Campbell and Timothy Paulitz

Executive summary:

- Over the last 2 funding cycles, we have developed a greenhouse method to screen PNW varieties and germplasm for resistance to cereal cyst nematode (CCN) which has become a problem in eastern Washington, first recognized in 2010. We have screened over 1000 lines, but are limited by finding field inoculum with high levels of the nematode. The populations in some of our field sites has declined, so we have had to locate new sources of inoculum. This resulted in less lines screened this year. Working in the greenhouse, we are constrained by the number of lines that can be screened.
- The ideal solution to phenotyping in the greenhouse is to develop DNA markers linked to CCN resistance. To that end, we have developed two series of markers. The first was from mining the Chinese Spring genome and looking for sequences close to know *Cre* genes. These were converted to KASP markers which can be run in a high throughput fashion. We have identified four potential markers that show a correct reaction on a set of differentials with known *Cre* genes and resistance. The second set of SSR markers for Cre 3, 5, 8, and X were designed from the literature. But only *Cre* 3 and 8 worked, and it appears that lines in the differential set may have more than one *Cre* gene in them. Both sets of markers will now be tested on a wider range of PNW material.
- To identify new resistance genes in PNW material, we crossed known resistant varieties such as Chara and ARS Crescent and susceptible lines Alpowa, Seahawk, Bruehl, Ouyen and Louise. We are now backcrossing them to develop a mapping population which will be phenotyped, so we can locate new QTL or resistance genes.
- We imported differential lines for identification of CCN pathotypes from Turkey. We have done preliminary pathotype screening with this set of differentials, and our isolates of *H. filipjevi* do not match know races. We also made a new collection of cysts from a number of locations in Aug. 2019 and a colleague in Turkey extracted cysts to take back to Turkey to also run the pathotype test. In addition, we developed a collection of fungi from the cysts that may be potential biocontrol agents.

Impact:

- By developing molecular markers for CCN resistance genes, we can greatly enlarge the amount of germplasm and variety testing, since we will not be reliant on lengthy greenhouse testing and dependent on field inoculum which may not be stable.
-
- **What measurable impact(s) has your project had in the most recent funding cycle?**

    - We have a set of markers that may be useful in detecting multiple *Cre* genes, and will be tested with a wider range of PNW varieties to determine their utility.

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:7/1/2019
Project year 1: 2019-2020

Objective	Deliverable	Progress	Timeline	Communication
1. Continue to identify CCN (specifically *H. filipjevi* and *H. avenae*) resistance in wheat varieties adapted to PNW.	List of resistant US and PNW varieties and lines, knowledge of what *Cre* genes we have in our backgrounds	To date, we have screened over 1000 lines in our greenhouse assay, using infested field soil. However, our source of soil for *H. filipjevi* declined in population, but we located another hot location in Aug. 2019. We have collected soil for vernalization, to use in 2020, along with *H. avenae* soil.	Will continue greenhouse testing next year using vernalized, infested soil in the greenhouse.	Paulitz, T. C. 2019. "Root Disease Research at ARS Pullman-What's New?" Spokane Farm Forum, Ag Expo, Feb. 26 2019. (presentation).
2. Develop more knowledge about specific resistance genes and develop molecular markers	Usable markers that can be incorporated in the breeding programs.	We have made considerable progress this year. Using the *Cre* 1 sequence from the database, we mined the genome of Chinese Spring and found a number of *Cre* suscepts. We developed KASP markers and tested them on the Australian differentials with know Cre gene resistance. A number of markers look good, and seem to identify both *Cre* 1 and *Cre* 3. The best is IWA3381 which will now be tested on PNW lines with know resistance. SSR markers were developed for *Cre* 3, 5, 8, and X based on published literature. The markers for *Cre* 3 and 8 worked, but in the differential collection, many lines with supposedly a single *Cre* gene also were detected with *Cre* 3 and 8 . This indicates that these lines may have multiple *Cre* genes. Despite the fact that these markers seem to pick up multiple *Cre* genes, they will be useful for germplasm screening.	Markers will be tested in 2020 on PNW material with known resistance and susceptibility	
3. Identify unknown resistance genes in adapated PNW material.	New resistance genes for cereal cyst nematode	Lines (NILs) will be developed by crossing CCN resistant lines Chara and ARS-Crescent with CCN susceptible lines Alpowa, Seahawk, Bruehl, Ouyen and Louise, then backcrossing. We have made all the initial crosses, and will continue to develop these mapping populations	Backcrosses will be made in 2020	
4. Determine pathotypes of *H. filipjevi* and *H. avenae* , using differential lines being imported from Turkey.	knowledge of pathotypes of *H. filipjevi* and H. *avenae*	Collections of CNN populations were made in Aug. 2019, with a Borlaug Fellow from Turkey. We will pathotype these on our differential varieties imported from Turkey, but he also took back a collection to pathotype there. In addition, we isolated a collection of fungi from cysts to look for potential biocontrol agents	Pathotyping will be done in WA and Turkey in 2020	

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Washington Grain Commission

Wheat and Barley Research Annual Progress Reports and Final Reports

Project #:	**3019 3162**
Progress Report Year:	*_1___ of __3__ (maximum of 3 year funding cycle)*
Title:	**Improving Spring Wheat Varieties for the Pacific Northwest**
Cooperators:	Mike Pumphrey, Vadim Jitkov, 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. *A new 2-gene Clearfield hard red spring wheat was released in 2019, Net Cl+*. Foundation and registered seed of Ryan, Seahawk, Tekoa, Alum, Chet, and Glee spring wheats and JD and Melba spring club wheats was produced and sold in 2019. 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. *WSU soft white spring wheat varieties accounted for 88% of certified soft white spring wheat production acres in Washington in 2019*. 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 Ryan was by far the leading variety in the state in its first year of widespread availability. Glee, Chet, and Alum are leading dryland hard red spring wheat varieties. WSU hard red spring wheat varieties were planted on 25% of the certified hard red spring wheat production acres in Washington in 2019. 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. We emphasize traits like stable falling numbers, Hessian fly resistance, stripe rust resistance, and aluminum tolerance, and hold the entire industry to a greater standard for yield and yield protection. 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 consistently pay back on research dollars invested. *With 60% or more of the spring wheat acres in Washington planted to WSU spring wheat varieties in 2019, growers continue to realize a substantial return on research dollars invested in this program*.

Outputs and Outcomes: File attached

WGC project number: 3019 3162
WGC project title: Improving Spring Wheat Varieties for the Pacific Northwest
Project PI(s): Mike Pumphrey
Project initiation date: 2019
Project year: 1 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.	WSU released varieties Seahawk, Glee, Alum, Chet, Tekoa, Melba, and Ryan continued to lead yield trials in their classes in 2019, and have widespread seed availability. Significant positive economic impact for PNW growers is generated by our varieties on 60% of spring wheat acres. We had very good test plots across regions in 2019. Good data quality is fundamental to making solid selections. Our 2-gene Clearfield breeding efforts have matured, and we released our first hard red spring wheat in 2019, and a spring club CL+ line is planned for 2020 release. 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, Trade tours/international buyer groups. 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 2019. A primary focus in 2019 was backcrossing new Hessian fly resistnce genes into spring wheat germplasm. Extensive crossing blocks for irrigated hard red spring wheat germplasm development were also completed. A large fall-seeded spring wheat trial was planted for the second year in October 2019 with irrigation. Backcrossing of the AXigen trait for CoAXium wheat production system was continued in 2018. We are backcrossing into both soft white and hard red spring wheat germplasm.	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.	
Discover/improve/implement scientific techniques and information to enhance current selection methods.	Current projects 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, and the development of high-throughput field phenomics selection methods.	Several specific trials and locations were again evaluated in 2019 to help long term breeding efforts. Scientific products of our efforts through multiple projects in 2019 include eight 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 #: **3163**

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

Title: **Greenhouse and laboratory efforts for spring wheat variety development**

Cooperators: Mike Pumphrey, Vic DeMacon, Sheri Rynearson, Wycliffe Nyongesa, Vadim Jitkov

Executive summary:

This project is integral to core efforts of the Spring Wheat Breeding program. This project provides funding to make crosses and develop breeding populations in the greenhouse, staff support for management and selection of breeding materials in the field and greenhouse, and supports/enables the most effective end-use quality 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 conduct research projects of direct relevance to our breeding efforts. This project also supports our two-gene Clearfield and AXigen breeding efforts, Fusarium head blight resistance gene introgression, Hessian fly resistance gene introgression, and expanded irrigated hard red spring wheat breeding efforts. Our progress in each of these areas is consistent, and these outputs shape our overall breeding efforts.

Impact:

This project is critical to the spring wheat breeding program and with project 3162, establishes our core breeding efforts. 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 adequate pest resistance, and numerous other DNA-marker selectable traits. Spring wheat varieties with complex stripe rust resistance, Hessian fly resistance, aluminum tolerance, superior end-use quality, and broad adaptation are critical for Washington wheat producers by adding millions of dollars of annual return. Over the past five years, we have released Chet, Alum, Seahawk, Tekoa, Melba, Ryan, and Net Cl+. They have been rapidly adopted by seed dealers and growers and are top-volume sellers through the Washington State Crop Improvement Association Foundation Seed program. 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. A new release, Net Cl+, will provide growers a top-performing two-gene Clearfield spring wheat variety beginning in 2020, and a two-gene Clearfield spring club variety is planned for release and Foundation seed increase in 2020.

Outputs and Outcomes: File attached

WGC project number: 3019 3163
WGC project title:Greenhouse and laboratory efforts for spring wheat variety development
Project PI(s): Mike Pumphrey
Project initiation date: 2019
Project year: 1 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.	One Wheat Life article was written/contributed in 2019, as well as supporting other articles. Axigen trait introgression continued in 2019, and we have made BC2 materials with this new herbicide tolerance to date. Nineteen DNA markers were applied to elite selections, crossing parents, and early generation lines for selection. Four hessian fly resistance genes were backcrossed into elite germplasm to the BC3 or BC4 stage and those derived lines were tested in yield trials in 2019. Fusarium heab blight MAS lines, and other MAS populations were advanced in 2019	Activities recur annually. The two-gene Clearfield™ breeding effort resulted in a hard red spring wheat release in 2019. Activities are cyclical and occur annually throughout the normal breeding cycles.	Pumphrey attended/presented 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 January 2020, we completed evaluation of ~3200 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 2020.	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 development.	
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. The primary focus in 2019 was Hessian fly resistance selection in club wheat, Axigen wheat backcrosses, and introgresssion of new Hessian fly resistance genes in elite backgrounds,	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
Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: 3680

Progress Report Year: ___*3_ of _3*___ *(maximum of 3 year funding cycle)*

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

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

Executive summary:

WSU spring and winter wheat variety development programs heavily emphasize selection for superior end-use quality. 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 USDA-ARS Western Wheat Quality Laboratory efforts.

The majority of wheat from the PNW is exported to overseas markets. To maintain current markets and penetrate new 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 export countries necessitates enhancing the end-use quality of our wheat. The loss of overseas markets would continue to cause a reduction in the demand and therefore the price of wheat, resulting in losses to Washington farmers. Washington wheat growers, as well as grain buyers and exporters, 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, Chet, Alum, Seahawk, Melba, Tekoa, Ryan, Whit, and Dayn are examples of top-performing WSU variety releases that are widely grown that also have very good to excellent end-use quality. One of our primary 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. This short, medium, and long-term impact is of paramount importance to the Washington grain industry.

Outputs and Outcomes: File attached

WGC project number: 3680
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-17
Project year (X of 3-yr cycle): 3of 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 of this project. 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 2018, and anohter three in 2019**	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. Arron Carter participates in mulitple US Wheat trade tours and we hosted many trade teams in 2018.
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 2017-2019. Milling and baking analysis of a bi-parental winter wheat mapping population has also been completed. A genetic map of hard red spring wheat quality QTL was generated, and this work presented at the PNW Wheat Quality Council with a peer-reviewed manuscript in preparation.	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
Format

Project # 3019-3685

Progress Report Year: __2__ *of* _3___ *(maximum of 3 year funding cycle)*

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

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

Cooperators: Yvonne Thompson, WSU, Nuan Wen, WSU, Arron Carter, WSU; Chris Mundt and Christina Hagerty, OSU

Executive summary:

- In 2019, 197 lines from a cross of Louise and a resistant Iranian land race (IWA8608077), further backcrossed to Louise, were tested in the field and greenhouse assays. The field test was at Lind, planted into land previously cropped with durum, highly susceptible to Fusarium. We had very high disease pressure in the field nursery. In the greenhouse, higher disease was seen in the adult plant assay than the seedling assay. The population was genotyped with GMS markers in the Western Small Grains Genotyping lab and 245 markers were selected to look for QTLs. The population has also been genotyped with GBS markers which are still being analyzed. Several of the lines had yields similar to Louise, indicating that this population may be useful for introgression.
- Twenty-one additional land Iranian land races were evaluated in the greenhouse, and six showed consistent tolerance in seedling assays (AUS28329, AUS28452, AUS28459, AUS28706, AUS28714 and AUS28723). AUS28452 also showed good adult plant resistance in the greenhouse. These lines are being increased for further evaluation.
- A doubled haploid population from Cara/Xerpha was evaluated in the greenhouse. Fifteen lines showed lower disease ratings than Xerpha and Madsen.
- To reduce variability in the greenhouse test, we experimented with grinding the millet inoculum and quantifying it with dilution planting. The previous method relies on whole millet seed. Future work will examine different inoculum amounts, covering the inoculum with soil, the effects of humidity, different methods to standardize the rating system itself, and the number of plants that have to be rated to achieve a consistent result.

Impact: The economic impact of this disease continues to be large and affects all growing areas of Washington including both high and low precipitation zones

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 for greenhouse screening
-The first QTLs for resistance to *F. culmorum* have been identified.

WGC project number: 3019-3685
WGC project title: Fusarium Crown Rot on Wheat: Prebreeding and Development of Tools for Genetic Disease Management
Project PI(s): M. Pumphrey, K. Garland-Campbell, and T. Paulitz
Project initiation date: 7/1/2018
Project year: Year 2 2019-2020

Objective	Deliverable	Progress	Timeline	Communication
Objective 1. Screen spring and winter variety trials and breeding lines for resistance in the greenhouse.	Ratings of varieties for *Fusarium* tolerance in the the WSCIA seed buyers guide and other publications.	We continue to screen varieties in the greenhouse, and are still trying to optimize the methods to reduce variability. We experimented with grinding the millet inoculum and quantifying it with dilution planting. The previous method relies on whole millet seed. Future work will examine different inoculum amounts, covering the inoculum with soil, the effects of humidity, different methods to standardize the rating system itself, and the number of plants that have to be rated to achieve a consistent result.	Greenhouse screening will continue with optimized methods in 2020-2021	Paulitz, T. C. and Campbell, K.G. 2019. Fusarium crown rot: Disease is prevalent, persistent, pernicious. Wheat Life, June 2019
Objective 2. Select for QTLs associated with resistance in segregating populations	Resistant sources that can be used for variety development.	A doubled haploid population from Cara/Xerpha was evaluated in the greenhouse. Fifteen lines showed lower disease ratings than Xerpha and Madsen. These lines can be introgressed directly.	Because this population is already PNW adapted soft white wheat, the lines with better resistance will be crossed to some of our better Fusarium resistance sources in 2020.	Yvonne, M., Paulitz, T. C. and Campbell, K. G. 2019. Genome-wide association study for Fusarium crown rot in a diverse wheat germplasm. Manuscript in Preparation. Paulitz, T. C. and Campbell, K.G. 2019. Fusarium crown rot: Disease is prevalent, persistent, pernicious. Wheat Life, June 2019
Objective 3. Look for new sources of resistance in a new set of synthetic wheat that was developed by CIMMYT in Turkey.	Resistant sources that can be used for variety development.	We are developing populations between the synthetics and Chet, Ryan, DH11SRW070-14, Selbu, WA8252, Sequoia, and Cara. We chose good breeding lines from each market class. These are currently at the BC1F2 stage and we'll begin screening them this year for various traits.	Greenhouse screening of backcrosses will begin in 2020-2021.	
Objective 4. Screen the population of AUS28451 X Louise in the greenhouse for tolerance to *Fusarium*, to identify new possible sources of resistance.	Resistant sources that can be used for variety development.	In 2019, 197 lines from a cross of Louise and a resistant Iranian land race (IWA8608077), further backcrossed to Louise, were tested in the field and greenhouse assays. The field test was at Lind, planted into land previously cropped with durum, highly susceptible to Fusarium. We had very high disease pressure in the field nursery. In the greenhouse, higher disease was seen in the adult plant assay than the seedling assay. The population was genotyped and 245 markers were selected to look for QTLs (still being analyzed). Several of the lines had yields similar to Louise, indicating that this population may be useful for introgression. Twenty-one additional land Iranian land races were evaluated in the greenhouse, and two showed consistent tolerance in seedling assays (AUS28329 and AUS28714).	QTL analysis will be conducted in 2020, since both genotyping and phenotyping have been completed.	Paulitz, T. C. and Campbell, K.G. 2019. Fusarium crown rot: Disease is prevalent, persistent, pernicious. Wheat Life, June 2019

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Washington Grain Commission

Wheat and Barley Research Annual Progress Reports and Final Reports

Project #:	**3019 3674**
Progress Report Year:	*_2___ of __3__ (maximum of 3 year funding cycle)*
Title:	**Evaluation of WSU wheat breeding lines for management of Hessian fly and development of DNA markers for resistance breeding**
Cooperators:	Mike Pumphrey, Arash Rashed

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 Washington. Advanced breeding lines, new sources of resistance genes *H13*, *H26*, and two unknown resistance sources, along with winter wheat varieties were screened for Hessian fly resistance in 2019. Backcross populations were developed with four new sources of resistance, and progeny advanced to select homozygous resistant lines. Winter wheat populations and varieties were screened to introgress HF resistance into winter wheat. This project supported the screening of all new entries in WSU Variety Testing Program spring wheat trials.

Impact:
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. Our recent emphasis on winter wheat is due to infestations increasingly observed in winter wheat in the region. While not as severe as spring wheat infestations, we believe the value of Hessian fly resistance in winter wheat is underestimated, and increasing.

Our most recently released soft white spring wheat varieties Seahawk, Tekoa, and Ryan, and hard red spring wheat varieties Net Cl+, Glee, Alum, and Chet, are resistant to Hessian fly because of selection activities carried out by this collaborative project. Given their broad acreage in Washington State, this represents a major economic impact to Washington farmers.

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

WGC project number: 3674
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: 2 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 300 spring wheat lines, 40 winter wheat varieties, numerous spring wheat breeding populations, and new entries into the WSU Wheat Variety Testing Program were screened in 2019.	Annually	Progress was presented by M. Pumphrey 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. These Dayn-Hessian fly resistant introgression lines were evaluated in yield plots and for grain quality in 2019, and elite performers used in routine breeding crosses in fall 2019. Also, JD and Melba were used to introduce four new resistance sources through backcrossing with phenotypic selection.	Annually	

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

Project #: 13C-3019-3687

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

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

Cooperators: *Karen A. Sanguinet (CSS) , Kim Garland-Campbell (USDA/ARS; CSS), Xiao Zhang (WSU, Tri-cities, CEB), Timothy Paulitz (USDA/ARS; Plant Pathology)*

Executive summary: Lignin content and accumulation in stems, leaves and roots has been linked with different stress tolerances in crop plants. Lignin confers rigidity to plant cell walls, and increases in response to drought, heavy metals, salinity, and pathogen attack. Therefore, managing overall lignin content, as well as its proportion in the roots versus shoots of crop plants is important for improved stress tolerance. Few studies have investigated the role of lignin in grass root systems at present. Reports on maize and wheat showed that lignin content in the root was higher than in the shoot, and that these levels varied depending on genotype. In wheat, lignin concentration was shown to decrease in seedlings and roots when exposed to mineral deficiencies and increase in response to toxic minerals. Given these findings, our preliminary results, there is a need to further investigate the role of lignin in roots. The overall goal of the project is to determine the role of lignin in wheat roots for drought tolerance and disease resistance and to develop a high-throughput method for lignin analysis is wheat roots and straw. We have worked on processing stem and root tissues for overall lignin content using two independent assays as well as sending pulverized stem and root tissues for analysis of monomers to the Zhang lab at WSU-TC. We had good success with lignin extraction in stems, but are still working on lignin extraction from root tissues. As such, we are outsourcing the lignin chemistry to a collaborator who works with grasses and lignin in roots and has already developed protocols. We have also begun to implement drought studies using the Phenospex drought spotter in the wheat greenhouse. In the coming year, we will refine the methodology and complete the analyses on the Lou/Au backcross populations in terms of lignin content, drought performance, and disease resistance for soil-borne pathogens.

Impact: In addition to stress tolerance, lignin has important implications for the rhizosphere and agricultural soils, particularly since it is a stable component of soil organic matter (SOM). There is evidence that lignin slows down the mineralization of nutrients from crop residues. For example, the ratio of lignin to nitrogen is used as an indicator for litter degradation. Studies have shown that lignin negatively affects short-term nitrogen release from different types of green manures that differ in lignin content and that time is a key factor in the lignin/nitrogen equation. Since SOM contains roughly two-thirds of global terrestrial carbon storage and lignin is an important component of SOM, lignified biomass represents a promising source of sustainable fertilizer, which is a concern for Washington state farmers and globally. Our research has shown the lignin monomer content and not total lignin content in winter wheat stems is important for residue breakdown and thus management. Long-term our data will shed light on the role of lignin in rhizosphere processes as well—such as soil-borne pathogen management and improving overall plant responses to abiotic stresses like drought, salinity, changes in pH, and cold.

WGC project number: 13C-3019-3687
WGC project title: A Genetic Arsenal for Drought Tolerance, Getting to the Root of the Problem
Project PI(s): Karen A. Sanguinet, Kim Garland-Campbell, Xiao Zhang, Timothy Paulitz
Project initiation date: 7/1/18
Project year (X of 3-yr cy year 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
1. Quantification of lignin content in roots and stems	A robust and reliable method to accurately determine lignin content in root samples in a high-throughput manner is the main deliverable of this objective.	The first rounds of lignin extractions were performed with the parental lines: AUS28451 and Louise in 2018 both for total lignin and for lignin monomers. Following optimization of the protocols for root extractions, the Lou/Au BC1F6 populaitons were analylzed in 2019, but another repetition is needed. We have also identified some additional backcross lines of interest, There were technical issues with quantification of the full aromatic	The quantification of lignin and optimization of the extraction methods was performed for total lignin. Three independent methods have been used for lignin quantification. We are now going to perform an entire aromatic profile for Aus28451 and Louise.	We developed a robust and high-throughput method for lignin quantification, and are planning a methods protocol for publication in addition to another peer-reviewed publication with the aromatic profiles.
2. Assessment of the role of lignin in drought	If lignin in roots is associated with drought, this can then be a desirable trait and selected/screened for in breeding populations.	The parental lines have been assessed and protocols established for the greenhouse trial in years 1 and 2 so the selected BC can be assessed in year 3.	Assessment of the parental lines was completed in 2018 and is being followed by two rounds of greenhouse trials with the backcross lines in year 3.	The findings and protocols will be reported at field days and in peer-reviewed publications.
3. Root lignin and soil-borne disease	If lignin in roots is associated with disease reisistance as hyprothesized, this can then be selected/screened for in breeding populations.	The parental lines have been assessed and protocols established for the greenhouse trial in years 1 and 2 so the selected BC can be assessed in year 3.	Assessment of disease resistance was assayed in spring 2019, but needs to be repeated in 2020.	The findings and protocols will be reported at field days and in peer-reviewed publications.

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

Project #:3144

Progress Report Year: *1_ of _3*

Title: ***Breeding Wheat Varieties With Efficient Control of ROS Production***

Cooperators: *N/A*

Executive summary: *This project aims to advance toolbox for breeding drought and heat tolerant spring wheat varieties. Our approach is based on the fact that harsh environmental conductions, including heat and drought, increase production of free radicals also known as Reactive Oxygen Species (ROS). ROS damage plant cells and in this way diminish the yield. Plants with good capacity to alleviate the impact of ROS using so-called "scavenging" mechanisms are expected to yield better in hot and dry climates. We want to develop technology for identification of genotypes with efficient ROS scavenging. Previously, our laboratory developed a technique for measuring capacity of plants to scavenge ROS under the greenhouse condition. During the first year we tested suitability of our technique for plants grown under field conditions using 7 soft white and 7 hard spring wheat varieties: Diva, Louise, Melba, Ryan, Whit, Seahawk, Tekoa, LCS Luna, SY Selway, Alum, Chet, Dayn, Glee and Kelse. All varieties were grown by the WSU Variety Testing Program at three locations: Spillman Farm, Lind, and Moses Lake. We collected half of a square inch of flag leaf from 15 plants at each location. Then we measured the efficiency of ROS homeostasis in the total extracts from the collected material. The most robust ROS scavenging was in the varieties Diva, Melba, Alum, Chet and Glee whereas less robust ROS scavenging was in varieties LCS Luna, SY Selway, and Whit. Varieties Luise, Ryan, Dylan, Kelse, Tekoa and Seahawk had a medium efficiency of the ROS scavenging. During this year we build the foundation for analyzing breeding lines in year 2.*

Impact: *We demonstrated: (i) our technique for measuring ROS scavenging is applicable to plants growth in the field; (ii) there is genetic diversity of ROS scavenging trait amongst the tested varieties; and (iii) climate has a considerable impact on activity of ROS scavenging system. Measurable impacts: post-doctoral scientist (Taras Nazarov) and professor (Andrei Smertenko) were trained to collect and analyzed the field-grown plants.*

WGC project number: 3144
WGC project title: **Breeding Wheat Varieties With Efficient Control of ROS Production**
Project PI(s): Smertenko
Project initiation date: June 10, 2019
Project year (X of 3-yr cycle): 1 of 3

Objective	Deliverable	Progress	Timeline	Communication
Objective#1. Determine correlation between peroxisome abundance and ROS homeostasis under drought and heat stress.	Measure peroxisome abundance in spring wheat varieties grown under different climate condutions.	Measured peroxisome abundance in 7 soft white and 7 hard sping wheat varieties Diva, Louise, Melba, Ryan, Whit, Seahawk, Tekoa, LCS Luna, SY Selway, Alum, Chet, Dayn, Glee and Kelse grown at Spillman Farm, Moses Lake, and Lind.	Completed	Will be communicated at the annual 2020 Review Meeting.
	Measure gene expression	This taks is posponed untill summer 2020. We will collect leaf material for this task during 2020 growth season.	Scheduled to be completed in August 2020	Will be communicated at the annual 2021 Review Meeting.
	Measure ROS homeostasis	This taks is posponed untill summer 2020. We will collecte leaf material for this task during 2020 growth season.	Scheduled to be completed in August 2020	Will be communicated at the annual 2021 Review Meeting.

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Washington Grain Commission
Wheat and Barley Research Annual Progress Report

Project #: 3690
Progress Report Year: *_2__ of _3__ (maximum of 3 year funding cycle)*

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

PIs: Camille M. Steber, Michael O. Pumphrey, Arron H. Carter, and Kimberly Garland Campbell
Cooperators: Deven See, Craig Morris, Aaron Esser, and Drew Lyon

Executive summary: The goal 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 low FN problems through evaluation of the WSU cereal variety trials, and with sprouting and LMA problems through greenhouse and field testing. We have identified molecular markers linked to LMA and PHS resistance to allow selection in early breeding lines. We improved LMA methods.

Objective 1. Identify varieties with stable FN by performing FN tests and statistical analysis of variety trials in environments that have preharvest sprouting and/or LMA
FN data from the soft white winter WSU variety trials was analyzed using five statistical methods designed to examine the impact of genetics and the environment. FN is difficult to analyze because it is impacted by multiple environmental factors leading to preharvest sprouting or LMA. The factor analytic model provided the best fit for this complex dataset, and will be used to compare variety performance for falling number and how stable that falling number is in challenging environments.

Objective 2. Screen winter and spring wheat breeding lines for preharvest sprouting and/or LMA. In 2018, 1,335 lines were screened for LMA and 708 lfor preharvest sprouting susceptibility by spike-wetting test. In 2019, 1113 samples were screened for LMA, and 810 were screened for PHS susceptibility by spike-wetting test.

Objective 3. Identify molecular markers linked to LMA susceptibility in northwest wheat.
a. We completed a genome-wide association study of the hard red spring TCAP population (250 lines) and identified six putative genes/loci associated with LMA phenotype. Of these 6, two were previously identified in Australian wheat. We will examine if these markers predict LMA in PNW breeding lines. b. Two winter RIL populations were screened for LMA in 2019.

Objective 4. Develop molecular markers for selection of PHS resistance in northwest wheat. Genome-wide association mapping was conducted in two related populations. Some loci linked to good seedling emergence did not correspond to loci for preharvest sprouting resistance, suggesting that we may be able to select preharvest sprouting resistant without compromising seedling emergence. A preliminary geomic selection model was developed in the hope of selecting PHS tolerance without compromising emergence.

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 enable the selection of new varieties with more stable FN. Posting of FN data on the WSU small grains website and the PNW FN website makes this data available to farmers and to breeders.

WGC project number:	3690
WGC project title:	Developing Washington Wheat with Stable Falling Numbers (FN) through resistance to preharvest sprouting and LMA
Project PI(s):	Camille M. Steber, Michael O. Pumphrey, Arron H. Carter, and Kimberly Garland Campbell
Project initiation date:	July 1, 2018
Project year (X of 3-yr cycle):	This is year 2 of 3 of the funding cycle.

Objective	Deliverable	Progress	Timeline	Communication
1. Identify varieties with stable FN by performing FN tests and statistical analysis of variety trials in environments that have PHS and/or LMA.	**1.** FN testing results posted on the PNW FN website (steberlab.org). **2.** Development of statistical methods to compare varieties for performance and stability of FN. **3.** A new FN comparison tool.	**1.** FN testing of spring and winter varieties has been completed for all variety trial locations that showed a low FN problem in 2017 and 2018. **2.** FN data from the WSU soft white winter variety testing in 2013, 2014, and 2016 has been analyzed using five different statistical approaches. A first article was published in Crop Science. Ongoing research using a factor-analytic model in AMSREML appears to provide the best tool for comparing both how well a variety performs for falling number, and how stable the falling number is over changing environments. **3.** We discovered that as an FN machinie ages, it can give highly inaccurate FN measurements in the FN 250-350 sec range. **4.** Based on a survey of 2019 WSU variety trial locations: LMA resulted in low FN in SWW wheat due in the lower rainfall zones (Connell, Dusty, and Lind); preharvest sprouting resulted in serious problems with low FN in SWW in Creston, Almira, and Reardan; PHS is also likely the cause of low FN in spring wheat in Fairfield, Lamont, Palouse, and Pullman.	**1.** Annually. FN testing of susceptible varieties will be used to determine which WSU Cereal Variety locations will be subject to FN testing. **2.** In 2018 and 2019, compare various methods for ranking varieties for FN. **3.** In 2019, complete statistical analysis of soft white winter FN data from 2013, 2014, and 2016. **4.** In 2020, select a method for annual analysis of variety trial FN data.	Results of annual FN testing will be made available on the PNW FN website and on the WSU small grains website. Information will be published in peer-reviewed journals, summarized in a Wheat Life article, presented during field days, and presented at the annual Wheat Review.

2. Screen winter and spring wheat breeding lines for PHS and LMA susceptibility.	Data obtained will allow selection for increased resistance to LMA and preharvest sproutng in winter and spring wheat breeding programs at WSU. This should indirectly lead to release of variaties with increased resistance to low FN.	**1.** In 2018, the LMA field-testing method was used to induce LMA in a total of 1,335 lines. This included 72 spring wheat breeding lines, 168 winter wheat breeding lines, 185 variety trial and parental lines, 426 TCAP spring wheat mapping plots, and 484 QAM winter wheat mapping lines. FN testing of this material is still in progress. **2.** Preharvest sprouting resistance was tested using greenhouse spike-wetting tests of spikes harvested at physiological maturity from the field. Testing results were obtained for 495 soft white winter and 213 spring wheat lines. **3.** Experiments were performed to optimize the temperature, humidity, and developmental timing of LMA induction. The goal of using the Chemwell-T robot to optimize alpha-amylase enzyme assays (Megazyme SD assay) met with serious problems in 2018. The programming of the robot does not allow it to maintain a consistent 5 minute reaction time, making results inconsistent. This meant that over 1000 samples had to be repeated using the Phadebas enzyme assay.	**1.** Perform field LMA testing annually of about 1000 lines annually for breeding and mapping. **2.** Perform spike-wetting tests annually. **3.** Continue improving methods to increase efficiency.	Information will be published in peer-reviewed journals, summarized in a Wheat Life article, presented during field days, and presented at the annual Wheat Review.
3. Identify molecular markers linked to LMA susceptibility in northwest wheat.	**1.** Molecular markers linked to LMA resistance allowing selection in earlier generation breeding lines. **2.** Mapped LMA genes/loci linked to LMA resistance and susceptibility in the soft white spring TCAP population. **3.** Mapped LMA genes/loci linked to LMA resistance and susceptibility in recombinant inbred line populations.	**1.** We have completed 4 greenhouse and two field LMA testing experiments for the spring TCAP population. Preliminary genome-wide association mapping was completed in 2019, and identified 6 loci associated with the LMA trait. **2.** In 2019, LMA testing was performed on 1,113 samples including 603 breeding and variety trial samples. We were unable to test the TCAP in 2019 due to problems with Hessian fly. **3.** The parents for 10 spring RIL populations and 20 winter RIL populations have been screened in a single greenhouse LMA experiment. Two promising populations for LMA mapping, Cara x Xerpha, and Xerpha x Bobtail were screened in the field in 2019. 4. LMA testing results revealed that tall wheat (rht wild-type) tend to induce LMA without a cold shock treatment. Because this LMA phenotype was much more consistent than any we've seen, future mapping efforts will focus on tallxtall crosses.	**1.** The goal to complete TCAP LMA screening in 2018 must be extended into 2019. **2.** Genome-wide association mapping in the TCAP was to be completed in 2019. **3.** RIL populations for LMA mapping will be identified by 2019, and LMA screening initiated in 2019 and 2020.	Information will be published in peer-reviewed journals, summarized in a Wheat Life article, presented during field days, and presented at the annual Wheat Review.

4. Develop molecular markers for selection of preharvest sprouting resistance in northwest wheat.	**1.** Molecular markers that can be used to select for resistance to preharvest sprouting. **2.** Identify markers that can select for sprouting resistance without compromising field emergence.	**1**. Mapping results for preharvest sprouting were based on FN and sprouting scores from spike-wetting tests. Mapping was also preformed for emergence based on field emergence and coleoptile/seedling elongation. Comparison found that there were some strong genes/loci lined to emergence that were not linked to preharvest sprouting susceptibility. This is a preliminary result, but suggests that this mapping approach may be used successfully in soft white winter wheat populations. **2.** A preliminary genomic selection model was developed. **3.** Spike-wetting tests were performed for 461 doubled-haploid winter wheat breeding lines derived from parents in the QAM and SNP winter wheat mapping populations. These data can be used to confirm marker-trait associations for molecular markers.	**1.** In 2018, GWAS was performed in a second population to confirm marker-trait associations. **2.** In 2018, spike-wetting tests were performed on winter doubled haploid populations. **3.** In 2019 and 2020, we will develop a genomic prediction model.	Information will be published in peer-reviewed journals, summarized in a Wheat Life article, presented during field days, and presented at the annual Wheat Review. The goal in to summarize these markers on the PNW fallng number website to make it easier for wheat breeders to access this information.

Project #: 126593

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

Title: Intelligent Prediction and Association Tool to Facilitate Wheat Breeding

PI: *Dr. Zhiwu Zhang*

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

Executive summary: *We updated one software package, released a new software packages, and published one article partially under support of this project in this fiscal year. The GAPIT software package updated for new functions for both GWAS (Genome Wide Association Study) and GS (Genomic Selection) (http://zzlab.net/GAPIT). GAPIT is R Package for users with programming skills in R language. Analyses can be programmed to process large amount of analyses with same settings. The new software package is GbyE (http://zzlab.net/GbyE). Both of these packages implemented a new method we published by Huang and et al. (Giga Science, 2019). We also publish an article on Wheat Life in October of 2019 entitled " Party game ignites satellite, drone research effort". A podcast was also published by Wheat Science about the stories behind the research project.*

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-18

Project year: 2 of 3

Objective	**Deliverable**	**Progress**	**Timeline**	**Communication**
2) Develop methods for examining GxE for large datasets, facilitating the selection of varieties with broader adaptability and optimum performance.	A standing alone software package was released (http://zzlab.net/GbyE) to model G by E	We have developed BLINK method with previous WGC support. BLINK is about hundred time faster than existing methods and had higher statistical power for detecting additive genetic effect. The BLINK was used as the foundation to model G by E.	December 31, 2019: We developed source code to model G by E; June 30, 2020: Complete system testing on real data from all the Co-Pis	1) One article for Wheat Life; 2) One presentation at WGC annual meeting; 3) One presentation at national/international conference; and 4) one paper on academic journal