



WASHINGTON STATE
UNIVERSITY

***Washington State University
Wheat and Barley Research
Progress Reports***



2022-2023 Fiscal Year

2022-23 WSU Wheat & Barley Research Progress Reports to the Washington Grain Commission

<u>Researcher / Title of Project</u>	<u>Page #</u>
Brueggeman / <i>Improving Barley Varieties for Feed, Food and Malt</i>	1
Burke / <i>Weed Management in Wheat</i>	10
Carter / <i>Field Breeding Hard White and Red Winter Wheat</i>	13
Carter / <i>Use of Biotechnology for Wheat Improvement</i>	17
Carter / <i>Field Breeding Soft White Winter Wheat</i>	22
Chen / <i>Improving Control of Rusts of Wheat and Barley</i>	26
Garland Campbell / <i>Club Wheat Breeding</i>	35
Garland Campbell / <i>Evaluation and Selection for Cold Tolerance in Wheat</i>	38
Kiszonas / <i>Breeder Quality Trials</i>	40
Kiszonas / <i>Quality of Varieties and Pre-Release Lines: Genotype & Environment – “G & E” Study</i>	42
Kiszonas / <i>Supplemental Support for Assessing the Quality of Washington Wheat Breeding Samples</i>	46
Lyon / <i>Extension Education for Wheat and Barley Growers</i>	48
Neely / <i>Evaluation of Barley Varieties</i>	50
Neely / <i>Evaluation of Wheat Varieties</i>	53
Paulitz / <i>Fusarium Crown Rot on Wheat: Prebreeding and Development of Tools for Genetic Disease Management</i>	57
Pumphrey / <i>Improving Spring Wheat Varieties for the Pacific Northwest</i>	59
Pumphrey / <i>End-Use Quality Assessment of Washington State University Wheat Breeding Lines</i>	61
Pumphrey / <i>Evaluation of WSU Wheat Breeding Lines for Management of Hessian Fly and Development of DNA Markers for Resistance Breeding</i>	63
Pumphrey / <i>Greenhouse and laboratory efforts for spring wheat variety development</i>	65
Sanguinet / <i>A Genetic Arsenal for Drought Tolerance, Getting to the Root of the Problem</i>	67
Zhang / <i>Intelligent Prediction and Association Tool to Facilitate Wheat Breeding</i>	69

Washington Grain Commission Barley Research Report

Project #: 3019-3200

Progress Report Year: 2 of 3

Title: Improving Spring and Winter Barley Varieties for Malt, Feed and Food

Researcher: Robert Brueggeman

Cooperators: Clark Neely, Max Wood

Executive Summary: During the second year of this grant excellent progress was made towards improving WSU barley varieties for malt quality. The Washington Grains Commission (WGC) funds were integral in transitioning the WSU breeding program into a spring and winter malt barley breeding program. With the infrastructure now in place for malt quality analysis the bar is set to develop both spring and winter adjunct, all malt and distilling barley varieties with consistent quality and agronomics to make the American Malting Barley Association (AMBA) recommended list.

We are currently malting and analyzing elite 2022 field season material from both the spring and winter yield trials. The spring lines are being prioritized by high yielding experimental lines derived from elite-by-elite malt barley parental crosses. The winter material is being prioritized by yield, malt quality and winter survival data from the 2021 and 2022 growing seasons. We are developing a molecular marker panel specific to the WSU breeding program targeting genetic loci associated with malt quality traits to expedite early generation selection and advancement of superior genotypes through the breeding cycle. The combination of early generation marker assisted, genomic selection and speed breeding techniques in the greenhouse will optimize early generation selection for efficient movement of F₅ generation material into the field enriched for malt quality, broad adaptability, and yield. Thus, the early generation spring head rows (~12,000/year), advanced single rep yield trials (~600/year) and multi rep yield trials (~60/year) will be enriched for malt quality so we can concentrate on selecting for farmer traits including yield, height, standability and disease resistance in the field utilizing traditional selection strategies. This will provide much more efficient use of the WGC funds and will allow for greater capacity to analyze later generation material that have already been screened for quality in the WMQL and via marker and genomic selection.

We have transitioned the program to a fully integrated malt barley breeding program with the genetics and phenotyping capabilities in place to develop both spring and winter classes of malt barley varieties that meet AMBA quality parameters. We identified several promising advanced spring and winter malt barley lines with excellent agronomics and malt quality data that met all AMBA parameters. The spring lines will be entered into the WSU variety testing program in spring 2023 and the winter lines were planted in the fall of 2023 in the inaugural year of the WSU winter barley variety testing trials planted at eight locations across high and medium rainfall zones. Three of the spring and three winter lines will be entered into the AMBA pilot evaluation program in 2023. If the data allows, we would like to release the best performing all malt (craft) and adjunct malt lines as varieties then pursue AMBA recommendation if they make it through the AMBA testing program.

Impact: In our efforts to maintain the spring malt barley development pipeline we made 83 new crosses focused on malt quality, targeted agronomic traits, and disease resistance. Individuals from 33 elite-by-elite crosses were selected and progeny advanced to plant an additional 12,000 F₃₋₄ head rows in the field for evaluation in the 2023 field season. In the 2022 field season we screened approximately 10,000 single head plots from our 2021 crossing block and selected 511 candidate malt barley progeny lines for single rep yield trials for the 2023 field season. All lines have been harvested and processing to collect data for selection and advancement of elite material. In the 2023 greenhouse the third spring malt barley crossing block was planted. The parental lines were selected based on quality, yield and disease resistance and additional crosses are underway. This season through the utilization of field and greenhouse crossing blocks we have now advanced our crossing such that we are ahead of schedule on progeny advancement and marker assisted and genomic selection such that we can put F₅ advanced and prescreened materials into the single head rows in 2024.

In the Fall 2020 and 2021 we planted 633 winter elite malting, advanced malting, and elite distilling lines from the Oregon State University winter barley breeding program (kindly provided by Dr. Pat Hayes; the Oregon State University barley breeder) in replicated trials at Spillman farm to determine yield potential, winter hardiness, lodging resistance, and malt quality performance. In collaboration with Dr. Pat Hayes, we have access to these materials to utilize as parental lines and an agreement for joint release of varieties coming from his material that perform well in Eastern Washington dryland production. Lastly, we have made 77 crosses with selected elite winter lines and are advancing these winter malt barley experimental lines including those containing winter hardiness introgressed from the lines 2MW18_4462-008 (University of Minnesota, provided by Dr. Kevin Smith) and RIL02WI-013 (Ohio State University, provided by Dr. Eric Stockinger). These lines contain Russian sources of extreme winter hardiness that survived the winters of the upper Midwest and have malt quality. These crosses along with winter hardy material provided by Dr. Gazala Ameen, South Dakota State University, are currently being advanced and utilized for additional crosses in the 2023 greenhouse.

Advanced spring malting lines will be entered into the WSU variety testing program in spring 2023 and the winter lines were planted in the fall of 2023 in the inaugural year of the WSU winter barley variety testing trials planted at eight locations across high and medium rainfall zones. Three of the spring and three winter lines will be entered into the AMBA pilot evaluation program in 2023. If the data allows, we would like to release the best performing all malt (craft) and adjunct malt lines as varieties then pursue AMBA recommendation if they make it through the AMBA testing program.

To aid rapid early generation selection, last season 288 elite WSU malting lines were selected and sequenced with the 50k Illumina bead express chip with an additional 288 selected from the 2022 field trials, which will also be genotyped with the 50K chip and additionally via genotype-by-sequencing. As this marker panel resolves positive malting loci in our breeding program utilizing genome wide association mapping (GWAS), Oxford Nanopore MinION DNA sequencing technology will be developed and utilized to genotype early generation material for genomic selection. The combination of early generation marker assisted, genomic selection and speed breeding techniques in the greenhouse will optimize early generation selection for efficient movement of F₅ generation material into the field enriched for malt quality, broad adaptability and yield. We have two MinION DNA sequencing instruments and experience utilizing the technology. This technology will be utilized for an adapted amplicon sequencing strategy to

generate genotyping data of over 2,000 experimental lines each year for early generation malt quality selection. Once this research is completed, we can begin utilizing the marker panel for marker assisted and genomic selection strategies early in our selection process with the markers associated with low grain protein, increasing malt extract, high alpha amylase and reduced wort β -glucan.

We are continuing to introgress resistance to the virulent population of *Puccinia graminis* f. sp *tritici* (stem rust) identified in Washington state from the World Barley Core Collection (WBCC) and the OSU barley breeding program. Because these novel stem rust resistance genes identified from the WBCC, and OSU did not consistently translate to adult plant resistance in the field in 2021 and 2022 we continued to screen the barley primary germplasm pool for effective resistances. We identified the *Rpg7* resistance gene from the wild barley diversity panel as a very effective resistance gene against these virulent isolates. We recently crossed this source of resistance into our materials in the 2023 greenhouse crossing block.

As we further optimize and streamline selection utilizing high throughput genotyping and phenotyping the infrastructure put into place early in the development of my program will have a measurable impact on optimizing the return on the WGC's investments. This investment in time and resources will expedite the development of AMBA recommended malt barley varieties in the future. As we move the breeding program forward these investments will have an 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 as water use efficiency, heat tolerance, stature and lodging resistance, disease resistance and ultimately yield.

The most measurable impact(s) this project has had in this funding cycle was that we have now identified high yielding spring and winter malt barley lines that meet AMBA malt barley specifications. These lines have been submitted to WSU variety testing and will be entered into the AMBA pilot malting evaluation program in 2023. Although, it may take a few years before I can report on the release of AMBA varieties, with the tools in hand it is only a matter of hard work to achieve this goal. We will focus on the goal of transforming the program into a top malt barley breeding program releasing varieties that will someday dominate Washington malt barley acreage to feed the domestic supply of quality malting barley as well as international markets.

Outputs and Outcomes:

Objective	Deliverable	Progress	Timeline	Communication
1	Release of a craft and adjunct malting barley cultivars suited to brewing	Several of the advanced malting barley breeding lines have met AMBA standards and outperformed our modern malt variety checks for yield. These lines will be entered into Variety Testing and AMBA	2025-2026	Talks and presentations at field days; distribution of informative variety rack cards; Wheat Life articles; Pod Casts

		pilot testing in spring 2023.		
2	Release of a WSU winter malting barley variety suited to adjunct and or all malt craft brewing	Several elite winter malting lines provided by OSU met AMBA standards and outperformed our modern malt variety checks for yield. These lines were planted in the first winter barley Variety Testing trials in Fall of 2022 and will be entered into AMBA pilot testing in fall 2023.	2024-2025	Talks and presentations at field days; distribution of informative variety rack cards; Wheat Life articles; Pod Casts
3	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.	2024	Talks and presentations at field days; distribution of informative variety rack cards; Wheat Life articles
4	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	2024-2025	Talks and presentations at field days; distribution of informative variety rack cards; Wheat Life articles; Pod Casts

Communications continued

Publications are listed here as the block above was too small.

Peer-Reviewed Publications (13 total):

Published, Accepted or Submitted from January 1, 2022 – December 31, 2022

Peer-Reviewed Publications:

1. Richards, J.K., Li, J., Koladia, V., Wyatt, N.A., Rehman, S., **Brueggeman, R.S.**, and Friesen T.L. (2022) A Moroccan *Pyrenophora teres* f. *teres* population defeats the *Rpt5* broad-spectrum resistance on barley chromosome 6H. *Theoretical and Applied Genetics* (submitted).
2. Li, J., Wyatt, N.A., Kariyawasam, G., Richards, J.K., Rehman, S., **Brueggeman, R.S.**, and Friesen T.L. (2022) Pathogen genetics identifies regions harboring avirulence genes associated with 6H host resistance in the *Pyrenophora teres* f. *teres* – barley interaction. *Theoretical and Applied Genetics* (submitted).
3. Effertz K., Del Castillo, M., **Brueggeman, R.S.** (2022) First report of *Epicoccum nigrum* causing barley leaf spot disease in North America. *Plant Disease* (Submitted).
4. Effertz K., Richards, J.K., Clare, S.J., Del Castillo, M., Sharma Poudel, R., Li, M., Zhang, J., Moscou, M.J., Friesen, T.L., and **Brueggeman, R.S.** (2022) *Rpt5* encodes a receptor-like protein that provides broad and effective net form net blotch (*Pyrenophora teres* f. *teres*) resistance in barley. *Plant Biotechnology Journal* (Submitted).
5. Alhashel, A.F., Fiedler, J.D., Nandety, R.S., Skiba, R.M., **Brueggeman, R.S.**, Baldwin, T., Friesen, T.L., and Yang, S. (2022) Genetic and physical localization of a major susceptibility gene to *Pyrenophora teres* f. *maculata* in barley. *Theoretical and Applied Genetics* (submitted).
6. Craine, E.B., Choi, H.M., **Brueggeman, R.S.**, Schroeder, K., Esser, A., and Murphey K.M. (2022) Spring barley malt quality in eastern Washington and northern Idaho. *Crop Science* (Accepted)
7. Clare, S.J., Duellman, K.M., Richards, J.K., Sharma Poudel, R., Merrick, L.F., Friesen, T.L., and **Brueggeman, R.S.** (2022) Association mapping reveals a reciprocal virulence/avirulence locus within diverse US *Pyrenophora teres* f. *maculata* isolates. *BMC genomics* 23 (1), 1-17
8. Tang, Z., Wang, M., Schirrmann, M., Dammer, K.-H., Li, X., **Brueggeman, R.**, Sankaran, S., Carter, A., Pumphrey, M., Hu, Y., Chen, X., and Zhang, Z., (2022) Affordable High Throughput Field Detection of Wheat Stripe Rust Using Deep Learning with Semi-Automated Image Labeling. Preprints doi: 10.20944/preprints202204.0177.v1. ?? (submitted)
9. Skiba, R.M., Wyatt, N.A., Kariyawasam, G.K., Fiedler, J.A., Yang S., **Brueggeman, R.S.**, and Friesen, T.L. (2022) Host and Pathogen Genetics Reveal an Inverse Gene-For-Gene Association in the *P. teres* f. *maculata*-Barley Pathosystem. *Theoretical and Applied Genetics* 135, 3597-3609.
10. Amezrou, R., Rehman, S., Pal Singh Verma, R., **Brueggeman, R.S.**, Belquadi, L., Arbaoui, M., and Gyawali, S. (2022) Identification of SNP markers associated with *Pyrenophora teres* f. *maculata* resistance/susceptibility loci in barley (*Hordeum vulgare* L.). *Euphytica* (Submitted).
11. Clare, S.J., Oguz, A.C., Effertz, K., Karakaya, A., Azamparsa, M.R., and **Brueggeman, R.S.** (2022) Wild barley (*Hordeum spontaneum*) and landraces (*Hordeum vulgare*) from Turkey contain an abundance of novel *Rhynchosporium commune* resistance loci. *Theoretical and Applied Genetics* (accepted)

12. Friskop, A., Halvorson, J., Hansen, B., Meyer, S., Jordahl, J., Arens, A., Chapara, V., Gautam, P., Kalil, A., Tjelde, T., Fonseka, D., Schatz, B., **Brueggeman, R.**, Baldwin, T., Gross, P., Deplazes, C., and Ransom, J.K. (2022) Effects of Fungicides and Cultivar Resistance on Fusarium Head Blight and Deoxynivalenol in Spring Barley from 2014 to 2019. *Plant Health Progress* <https://doi.org/10.1094/PHP-05-22-0045-RS>
13. Upadhaya, A., Upadhaya, S., and **Brueggeman, R.S.** (2022) The wheat stem rust (*Puccinia graminis* f. sp. *tritici*) population from Washington State contains the most virulent isolates reported on barley. *Plant Disease* DOI: 10.1094/PDIS-06-21-1195-RE.

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

Project #: AWD0001471

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, Italian ryegrass, 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 collaborating with Corteva, Bayer, FMC, and Syngenta with new products or mixtures, and also working with old herbicides from Albaugh and Gowan.
- 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, use of weed sensing sprayers in fallow, evaluation of preemergence herbicide systems for downy brome and Italian ryegrass control.
- Farmer engagement resumed at the beginning of the year with a resumption of normal extension activities. Dr. Lyon continued to publish extension output in the form of webcasts, podcasts, and extension bulletins based on our research, and several presentations were created using information from active field trials.

WGC project number: AWD0001471
WGC project title: Weed Management in Wheat
Project PI(s): Ian C. Burke and Drew J. Lyon
Project initiation date: July 1, 2022
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 hosts an outlet for our efficacy results see https://herbicideefficacy.cahnrs.wsu.edu/
		A 5-year field study 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 was completed in 2021. Two 6-year field studies were initiated in 2019 in the intermediate rainfall zone (Edwall and Steptoe) to determine the same thing in winter wheat-spring wheat fallow production systems. Studies were also initiated in 2019 and 2020 to look at the impact of various surfactants on the efficacy of glyphosate for smooth scouringrush control in fallow. Maria Savic, MS student, started in the summer of 2021. She has been investigating the effect of applying glyphosate to smooth scouringrush during the day vs. during the night.	Publication of the results from the long-term field studies in a scientific journal will have to wait until study completion in 2025. Results from the surfactant studies were published in Weed Technology in 2022. Marija will be completing her study and graduating in May of 2023. Results from her study will be submitted for publication in 2023.	Annual weed control report, Wheat Life magazine, extension publications, extension meetings and field days, and refereed journal articles.
		Field studies comparing various rates of picloram (Tordon 22K) applied broadcast or with a weed-sensing sprayer for the control of rush skeletonweed in fallow were initiated in 2019 and 2020 near Lacrosse and Hay, respectively. The subsequent winter wheat crops were harvested in 2021 and 2022.	The results from this study will be presented at the annual meeting of the Western Society of Weed Science in late February of 2023, and a manuscript will be submitted for publication in Weed Technology by the end of the summer of 2023.	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

		Indaziflam was tested for preemergence control of Italian ryegrass in wheat cropping systems in 2020 and 2021. Results indicated that no additional control of IR was achieved via applications of Indaziflam in 2021. This was likely due to abnormal drought conditions for the region, which negatively impacted weed germination and establishment. Results from 2022 indicate control of IR plant density and seed bank with no detrimental impact on yield of winter wheat.	This project was completed in the year of 2022.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles
		Indaziflam was tested for preemergence control of downy brome in wheat cropping systems in 2021 and 2022. Seedbank samples are still being assessed but there does appear to be some control of Downy Brome plant density.	This project will be completed in the year of 2023.	
Evaluate weed biology & ecology	Weed biology and ecology to aid in the design of effective and economic control strategies for troublesome weeds in WA small grain crops; decision support system database development.	A reference genome was assembled for Downy Brome to map genes for reproductive phenology and Sulfosulfuron resistance. Stochastic simulation techniques were used to identify mechanisms maintaining genetic variation in <i>B. tectorum</i> and how self-fertilization impacts the ability of Downy Brome to invade new environments.	A large downy brome panel was phenotyped for flowering time. Initial analyses indicate that flowering time is highly heritable, unlike growth or tillering. Highly heritable traits may facilitate ecological approaches to management of downy brome by field, and indicates that movement between fields should be minimized.	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.
		We conducted field studies to ascertain seed shattering in Italian ryegrass by harvest time in winter and spring wheat. In 2022, we initiated a field study to evaluate chaff lining for the management of Italian ryegrass in winter wheat.	The chaff lining experiments will monitored through 2024 for changes in Italian ryegrass density.	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 #: 3193

Progress Report Year: 1 of 3

Title: Field Breeding Hard White and Red Winter Wheat

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

Executive summary: Due to the price of hard red winter wheat being below that of soft white winter wheat in 2021, production of hard red winter wheat has remained somewhat steady in 2022. Scorpio was released in 2019 and commercial seed is available of this line. Scorpio is broadly adapted to many intermediate and high rainfall growing areas of the state, and has very good end-use quality, very good stripe rust resistance, is resistant to Hessian fly, and tolerant of low pH soils. Scorpio also continues to be one of the best performing lines in multi-year summaries from 2018-2022, indicating the ability to perform even under drought stress conditions. This combination of traits makes it a desirable cultivar for many production areas. We continue to work with seed dealers to make this cultivar available to growers. We will continue to watch the hard red market and in discussion with seed dealers and growers, determine when new cultivars need to be released to enter the market. We have several lines which have been performing well in trials and will continue to evaluate these for release potential. Continued emphasis is 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 (Clearfield and CoAXium systems are our main targets), snow mold tolerance, and aluminum tolerance. 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.

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. It was once again in demand the fall of 2021 due to the extremely dry planting conditions. Although grown on limited acres, we continue to develop lines with excellent emergence for those regions which need this trait to reduce risk to planting failures under deep planting conditions when moisture is limited. Scorpio is a WSU hard red cultivar targeted to multiple rainfall zones and provides growers with a high yielding line with good disease resistance, aluminum tolerance, and Hessian fly tolerance. 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 and white winter wheat
Project PI(s): AH Carter
Project initiation date: July 1, 2009
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 2019 we released Scorpio, which combines high yield, good protein content, stripe rust resistance, low pH soil tolerance, and Hessian fly tolerance in one line. Seed of Scorpio was increased by the seed industry and was commercially planted in 2022 with very good performance. No new hard red lines were released in 2022, although a new hard red line will be proposed for release in 2023. We had over 3,000 plots and 10,000 rows of hard material under evaluation at various stages of the breeding process for 2022. In 2022, more focus was put on developing hard red winter lines with herbicide tolerance.	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 2022. This includes emergence, winter survivability, heading date, test weight, plant height, and grain yield. Our Kahlotus trials gave a very good screen for emergence potential in fall 2022. Our snow mold locations gave a good rating of snow mold tolerance and appears to be poised to do the same in 2023. 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 2022 we communicated results of this project through the following venues: 11 peer-reviewed publications; 3 field day abstracts; various field days and grower interactions; 3 poster presentations; 1 popular press interviews; 4 podcasts; 2 grower meeting presentations; and 3 seed dealer presentations;
	Biotic and Abiotic stress resistance	Lines were screened for snow mold, stripe rust, eyespot foot rot, nematodes, Cephalosporium stripe, SBWMV, Hessian fly, 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 or better milling characteristics were advanced to baking trials. Data should be back in early-2023. Lines with inferior performance will be discarded from advancement.	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, Prescott, Davenport, and Pullman for herbicide resistance. The hard red material had a lower priority (based on production acreage) for development when we started compared to the soft white germplasm, but we now have multiple populations and advanced lines being tested. Crossing has been initiated to incorporate novel herbicide resistance into hard red lines.	Evaluation is done annually at multiple locations across the state	Advanced hard red lines with herbicide tolerance are in final stages of testing for release consideration.
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.	
	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. We have also started mapping populations to find markers linked to these genes.	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.	
	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.	
	Herbicide tolerance	Hard red lines with herbicide tolerance are being field tested in both the Clearfield and CoAXium systems. Populations are first screened in the greenhouse, then transitioned to field testing.	Crosses made through the project #5195 will be evaluated under field conditions upon MAS.	

	Hessian fly tolerance	With the identification that Scorpio was tolerant to Hessian fly, we have been able to go into our crossing block and find crosses and populations with Scorpio as a parent to begin making selection. These lines were screened at the University of Idaho as part of the Hessian fly proposal and were advanced to field testing. One additional line, WA8368, has been identified as having Hessian Fly tolerance.	Crosses made through the project #5195 will be evaluated under field conditions upon MAS. Screening will be done through project #3674	
	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, M Pumphrey, D See

Executive summary: In 2022 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 focus for marker-assisted selection are foot rot resistance, stripe rust resistance, herbicide tolerance, and end-use quality. All these traits are already in established breeding lines and have very good markers to track them. Additional traits include aluminum tolerance, SBWMV, dwarfing genes, low PPO, Fusarium head blight, Hessian fly, and nematode resistance. While we have established some breeding lines with these traits, we are working to increase the number of lines carrying these traits, using markers to track their presence. Thousands of data points were collected on multiple populations to confirm presence of traits of interest. All lines which go through marker testing are then transferred to field testing to confirm the expected phenotype is expressing. Markers were also used to screen all advanced breeding lines to identify presence of known genes. This information, along with field data, was used for selection and advancement purposes as well as for selecting lines which should be cross-hybridized to create future populations. Our genomic selection efforts are proceeding and we have completed our sixth year of phenotypic evaluations in the field and genotyping. Selection models for multiple traits, through the efforts of graduate students funded on various other competitive grant funding, have been validated and are being used. In the greenhouse, we made approximately 600 crosses consisting mainly of soft white and hard red germplasm. In 2020 we started a large crossing block to incorporate new traits of interest, mainly herbicide resistance and pest resistance traits. These lines have been advanced in the breeding program to field screening, with some of them returning to the crossing block for back-crossing. Our screening process continues to be adjusted to improve efficiency as new techniques and traits come into the program for screening.

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 abiotic and biotic stress, and agronomic adaptability and stability of released cultivars. All cultivars released (Otto, Puma, Jasper, Sequoia, Devote, Stingray CL+, Scorpio, Purl, Piranha CL+, Sockeye CL+, Inspire, Jameson) have benefited through this project by incorporation of disease, herbicide resistance, 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 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 SSD/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, 2009
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 2022, all lines under field testing were screened for both Pch1 and Pch2 markers. This information was used to assist selection of lines for further testing under the field program. As more lines are selected for advancement and recycled in the breeding program for new cross-hybridizations, fewer populations will be segregating for this trait.	Each year new crosses are made to Pch1 and Pch2 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 2022 we communicated results of this project through the following venues: 11 peer-reviewed publications; 3 field day abstracts; various field days and grower interactions; 3 poster presentations; 1 popular press interviews; 4 podcasts; 2 grower meeting presentations; and 3 seed dealer presentations;
	Stripe rust resistant lines	In 2022, all lines under field testing were screened for six stripe rust resistance markers to identify presence of genes useful in the PNW. New populations segregating for resistance to Yr5 and Yr15 were screened in the laboratory as well as under field conditions.	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 2022, populations that were selected for combinations of the GBSS genes (waxy) and the glutenin genes were selected in field testing. All breeding lines are screened for the presence of low PPO genes, and populations were advanced of lines containing none of the PPO genes to field testing.	Each year new crosses are made to lines containing unique end-use quality genes. These are subsequently developed, screened, and advanced to state-wide yield trials. At any given time, lines are in every stage of development	
	Reduced height lines	In 2022, 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, we verify presence of dwarfing genes in all material to assist with selection of lines with enhanced emergence potential.	

	Genomic selection	With the assistance of graduate students, we continue to build genomic prediction models for traits of interest. Lines from the 2015-2021 breeding program have been genotyped and used for model building. We have begun incorporating high-throughput phenotyping measurements in these selection models, which has improved selection accuracy and efficiency. In 2022, early generation lines were evaluated for genomic selection, and estimated breeding values were used as selection criteria.	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. Eight manuscripts have been published on this research.
Genotyping advanced breeding lines	Provide useful information regarding genetic diversity and gene profiles to better estimate crossing potential	In 2022, the advanced germplasm was screened with DNA markers for about 25 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 2022 we made approximately 500 crosses which were targeted for herbicide resistance, low rainfall and high rainfall production. About 80% of these are in soft white backgrounds, and the remaining 100 are in hard red backgrounds. Crosses were advanced to the F2 stage. We also made about 100 crosses for trait introgression to continue to build germplasm for traits which are important to PNW growers.	This is done annually, with the number of crosses/populations varying	
	Single-seed descent	In 2020 we began developing more SSD populations to better standardize the production of lines from our crossing program. We are fine-tuning the protocols to maximize the number of lines which can be tested. In 2022 we produced over 400 populations, many of which were ready for planting in the field for evaluation.	This is done annually, with the number of crosses/populations varying	
	Doubled haploid	In 2022 our DH production focused on finalizing many populations we had in process and preparing them for field screening. The goal is to have all lines produced go into 4-row observation trials at both Pullman and Lind.	This is done annually, with the number of crosses/populations varying	

	Trait Introgression	We made crosses to germplasm containing resistance/tolerance to snow mold, stripe rust, end use quality, foot rot resistance, preharvest sprouting, AI tolerance, Ceph Stripe, SBWMV, vernalization duration, low PPO, Fusarium head blight, imazamox, the CoAxiom system, and other herbicides (in coordination with Dr. Burke). Herbicide tolerant lines are screened in the greenhouse for tolerance, as well as with markers, before going into field trials. We now have markers for many of these traits, and can efficiently screen for their presence. After advancement, all populations are transferred to the field program to undergo further testing.	This is done annually, with the number of crosses/populations varying	
Trait assessment				Results are presented through annual progress reports, with the outcomes of this research being realized in new cultivars
	Coleoptile length	Lines are screened and selected for coleoptile length.	Screening and selection will continue in 2022. Superior lines were planted in the field and crossed back into the breeding program.	
	Herbicide Tolerance	We now have a strong pipeline of germplasm tolerant to imazamox, and continue to develop and screen populations. We have many soft white lines using the CoAxiom system under field evaluation, and continue to make crosses for this trait. We have expanded to select for both hard and soft germplasm, and work with all three tolerance genes. In collaboration with Dr. Burke, we have new sources of herbicide tolerance which are being tested under both greenhouse and field conditions for tolerance.	Screening and selection will continue in 2022. Superior lines were 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 continue in 2022. Superior lines were planted in the field and crossed back into the breeding program.	

	Stripe rust	Because many sources of resistance in our germplasm are uncharacterized, we have begun developing genomic selection models to use for selection in our breeding populations. We have started the development of more populations to identify more of the genes which are contributing to resistance in our germplasm. These are being advanced in the greenhouse to create recombinant inbred lines.	Screening and selection will continue in 2023 after very good disease pressure in 2022. Superior lines were planted in the field and crossed back into the breeding program. Genetic populations are in development to determine genes associated with resistance.	
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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, KG Campbell, XM Chen, TD Murray

Executive summary: The year 2022 provided many opportunities in the program to evaluate materials under cool spring and summer conditions with additional summer precipitation. Due to the dry 2021 planting conditions, and the variation of spring rain and temperatures, there was a wide range of production scenarios. The continued advantage of evaluation of lines in contrasting years allowed us to view material under very different climatic conditions and identify varieties that continue to perform well under this variation. Many lines in the program that were able to perform well under these diverse climate conditions were advanced in the breeding program. Several of these lines were also prepared for Breeder seed production in Othello. Lines with the Axigen trait used in the CoAXium system were further evaluated in 2022 and lines with release potential were advanced to seed production. These lines underwent their last year of qualification testing in 2022 and have been approved to be used in the CoAXium system. We hope to be able to release some of these lines in 2023 and continue to give growers in Washington options for weed control. We continue to work with novel herbicide resistance traits to bring new options for weed management into production. The breeding programs continues to maintain a high number of lines within testing at all levels of the program. Double haploid lines are continuing to be produced, along with lines produced under single-seed descent, which is less technically intensive. We continue to have multiple locations where yield testing occurs, along with numerous sites dedicated to testing stress resistance such as snow mold, stripe rust, and low pH soils. Planting into dry conditions in 2021 allowed for extreme pressure on emergence, and screening continues to identify lines with excellent emergence potential. In 2022, two new soft white wheat lines were approved for release. These recent releases all have high grain yield, good disease resistance, and good end-use quality. We anticipate additional releases in 2023 of lines which continue to fit into multiple cropping systems in Washington.

Impact: Traditionally, over 85% of the wheat crop in Washington is soft white 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 28% of the acres in 2022. These include Pritchett, Curiosity CL+, Stingray CL+, Piranha CL+, Mela CL+, Resilience CL+, Otto, Puma, Sockeye CL+, and Devote. Many of these lines were also again planted for production in 2023.

WGC project number: 6195
WGC project title: Field Breeding Soft White Winter Wheat
Project PI(s): AH Carter
Project initiation date: July 1, 2009
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+, Devote, Piranha CL+, Sockeye CL+, Jameson, and Inspire. Collaborative releases include Curiosity CL+, Mela CL+, Resilience CL+, Pritchett, ARS-Castella, and ARS-Cameo. Our CL+ lines have shown excellent grain yield over multiple years and are widely grown. We have multiple breeding lines in statewide testing for consideration of release, many of which had excellent performance in 2021 and 2022. We have over 18,000 plots and 25,000 rows of soft white material under evaluation at various stages of the breeding process.	Each year we evaluate germplasm at each stage of the breeding process. Each year lines are entered into statewide testing for final release consideration. A cultivar is released, on average, every two years.	Progress will be reported through field days, grower meetings, commission reports, annual progress reports, and peer-reviewed manuscripts
	Agronomic traits	We have 18 locations across the state representing diverse climatic zones in which advanced breeding lines are evaluated for agronomic characteristics. Early generation material is selected for in Lind and Pullman. This year we moved all DH and SSD 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 2022 we communicated results of this project through the following venues: 11 peer-reviewed publications; 3 field day abstracts; various field days and grower interactions; 3 poster presentations; 1 popular press interviews; 4 podcasts; 2 grower meeting presentations; and 3 seed dealer presentations;
	Disease resistance	Disease resistance is recorded on our 18 breeding locations as disease is present, with certain locations being selected specifically for disease pressure (Waterville for snow mold, Pullman for stripe rust, etc.). Additional locations are planted in cooperation with plant pathologists to screen other diseases of importance in WA.	Evaluation is done annually at multiple locations across the state.	

	End-use quality	All SSD/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 2022.	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 and field tested 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 2022 we evaluated multiple populations in both early and preliminary yield trials, with very good screening conditions. Focus is on pyramiding all-stage and adult-plant resistance	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. Both Phc1 and Pch2 are being evaluated. 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 recently made many crosses to resistant material and are now field screening them for selection of resistant material.	Evaluation were done in field locations in WA in 2022	
	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. Genes for aluminum tolerance are being backcrossed into multiple backgrounds.	Evaluation were done in field locations in WA in 2022	

	Hessian Fly	Multiple F2 populations with new sources of resistance to Hessian Fly were screened under field conditions. Selections made had previously been confirmed resistant to Hessian fly. Many lines were selected for good agronomic features and are being further evaluated under field conditions.	Populations were advanced in 2022 under field conditions. Additional field screening will be conducted in 2023.	
	Nematodes	Nematode screening has been done in collaboration with Dr. Paulitz and Dr. Campbell.	Lines with resistance continue to be advanced in the breeding program.	
	End-use quality	Lines are continually screened for end-use quality. We submitted an additional 10 lines for statewide testing to begin generating quality scores prior to release decisions.	Validated genomic prediction models were available for selection in 2022.	

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**Washington Grain Commission
Wheat and Barley Research Annual Progress Report**

Project #: 137088

Progress Report Year: 1 of 3 (2022)

Title: Managing Rusts of Wheat and Barley

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

Executive summary: In 2022, studies were conducted according to the objectives of the project proposal, and all objectives specified for the first year of this funding cycle were completed on time. 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, resistance, and mechanisms of interactions between the rust pathogens and plants.

Impact: 1) Stripe rust was forecasted and monitored throughout the 2022 crop season, and rust updates and advises were provided on time to growers. In January and March 2022, stripe rust was forecast at a moderate level and the disease was significant at the relatively late growth season. The recommendations made based on the forecasts and rust survey for rust management helped save growers multimillion dollars. 2) We identified 22 races of the wheat stripe rust pathogen and 12 races of the barley stripe rust pathogen from 330 samples throughout the U.S., of which 20 (91%) races of the wheat stripe rust pathogen and 12 (100%) races of the barley stripe rust pathogen were identified from 206 (62%) samples collected in Washington. The race information is useful in screening breeding lines and germplasm for developing stripe rust resistant varieties. 3) We completed and published the studies of molecular characterization of the U.S. stripe rust collections up to 2017 using simple sequence repeat (SSR) markers for determining genetic diversity, differentiation, and dynamics of the pathogen. The results have improved the understanding of stripe rust epidemiology and management. We completed SSR genotyping of the 2018 to 2021 stripe rust collections. We developed more than 200 secreted protein (SP) gene-based single nucleotide polymorphism (SNP) markers and used them to identify SP-SNP markers associated to virulence. 4) We evaluated more than 20,000 wheat and barley entries for resistance to stripe rust. From the tests, we identified new sources of resistance and resistant breeding lines for breeding programs to release new varieties for growers to grow. 5) in 2022, we collaborated with public breeders in releasing, pre-releasing, or registered 13 wheat varieties. The germplasm evaluation data were also used to update the Seed-Buying Guide for growers to choose resistant varieties to grow. 6) We completed a study of identifying a new gene for stripe rust resistance in club wheat ‘Tres’, mapped the gene on the short arm of chromosome 1B, determined its difference from other stripe rust resistance genes, and officially named the gene as *Yr85*. The results make the gene important in differentiating wheat stripe rust races and monitoring pathogenic variation in the pathogen populations. 7) We tested 19 fungicide treatments for control of stripe rust on winter and spring wheats and provided the data to chemical companies for registering new fungicides and tested 23 winter wheat and 23 spring wheat varieties for yield loss caused by stripe rust and yield increase by fungicide application. The data of the fungicide and variety tests are used for guiding the integrated control of stripe rust. 8) In 2022, we published 22 journal articles and 5 meeting abstracts.

Outputs and Outcomes:

WGC project number: 137088				
WGC project title: Managing Rusts of Wheat and Barley				
Project PI(s): Xianming Chen				
Project initiation date: 7/1/2022				
Project year: 1 of 3 (2022)				
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 2022 have been completed on time. There is not any delay, failure, or problem in studies to this objective. The race identification for the 2021 collection was completed and summarized. The data and summary were sent to growers, collaborators and related scientists in February 2022. In the 2022 crop season, we collected and received 330 stripe rust samples throughout the country, of which 206 samples (62%) were collected by ourselves from Washington (WA). We have completed the race ID work for the 2022 samples and detected 22 races of the wheat stripe rust pathogen and 12 races of the barley stripe rust pathogen, of which all 20 (91%) wheat and 12 (100%) barley stripe rust races were detected in WA. The frequency and distribution of each race and virulence factors in WA and the whole country have been determined. Predominant races have been identified. The information on races and virulence factors 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 for breeding lines of wheat and barley with stripe rust resistance. We completed and published the studies of molecular characterization of the U.S. stripe rust collections up to 2017 using SSR markers for determining genetic diversity, differentiation, and dynamics of the pathogen. The results have improved the understanding of stripe rust epidemiology and spore movement among different regions in the U.S. We completed experiments the stripe rust collections from 2018 to 2021 using the set of SSR markers and have been analyzing the data for new genotypes. We developed more than 200 secreted protein (SP) gene-based single nucleotide polymorphism (SNP) markers and used them to characterize the wheat stripe rust collections and identified SP-SNP markers associated to virulence. The virulence and molecular studies have improved the understanding the epidemiology, biology and genetics of the pathogen, and provided information and resources for more efficiently monitoring and managing stripe rusts on wheat and barley.	The race identification work for the 2021 stripe rust samples was completed, summarized, and distributed. The race identification work for the 2022 samples has been completed; the data are being analyzed and summarized; and the data and summary will be distributed soon. Molecular work for the population genetic studies has been completed and published up to the 2017 collection, completed for the 2018-2021 collections, and is being conducted for the 2022 collection. Preliminary results have been obtained for the development of Kompetitive (KASP) markers for monitoring virulence genes in the rust populations.	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).

<p>2. Improve rust resistance in wheat and barley varieties.</p>	<p>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.</p>	<p>In 2022, we evaluated more than 20,000 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 at both Pullman and Mt. Vernon locations, and some of the nurseries were also tested in Walla Walla, Central Ferry, 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. Excellent stripe rust data were obtained from all locations. The disease data of regional nurseries were provided to all breeding and extension programs, while the data of individual programs' 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 2022, we collaborated with public breeding programs in releasing and registered 13 wheat varieties. Varieties developed by private breeding programs were also resulted from our germplasm screening program. Through our evaluation, 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 2022, we completed a study of identifying a new gene for race-specific resistance in club wheat 'Tres', mapped the gene on the short arm of chromosome 1B, determined its difference from other stripe rust resistance genes on chromosome 1B, and officially named the gene as <i>Yr85</i>. The results make the gene important in differentiating wheat stripe rust races and in monitoring pathogenic variation in stripe rust pathogen populations. In 2022, we obtained excellent stripe rust phenotypic data of 3 bi-parental mapping populations at both Pullman and Mount Vernon locations to validate resistance loci previously identified through the bulked analysis of 40 crosses. 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.</p>	<p>All 2022 germplasm tests were completed, and the data were provided to collaborators on time. The 2023 winter wheat nurseries were planted in fields in September and October, 2022. The 2023 spring wheat and barley nurseries will be planted in March-April, 2023. The greenhouse tests of the 2022 winter nurseries were completed and sent to collaborators. The greenhouse tests of 2022 spring nurseries and 2023 winter nurseries have been conducted during this winter, and will be completed by May 2023. All experiments of the molecular mapping studies scheduled for 2021 have been completed. Mapping populations of winter wheat were planted in fields in October, 2022 and those of spring wheat will be planted in April, 2023 for stripe rust phenotype data.</p>	<p>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-Buying Guide, and 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).</p>
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<p>3. Improve the integrated management of rust diseases.</p>	<p>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. 6) <i>Wheat Life</i> articles. 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.</p>	<p>In 2022, stripe rust was accurately forecasted and monitored throughout the 2022 crop season, and rust updates and advises were provided on time to growers. Moderate stripe rust was forecasted in January and March and occurred in the late growth season. The recommendations prevented major yield loss and reduced unnecessary use of fungicides, saving growers multimillion dollars. In 2022, we planted field nurseries at Pullman, WA for evaluating 19 fungicide treatments on winter wheat and spring wheat, and 23 winter and 23 spring wheat varieties, plus a non-treated check in each nursery. In the fungicide test on winter wheat, all 19 fungicide treatments significantly reduced stripe rust severity and increased grain yield compared to the non-treated check, with 2 treatments provided the best control of stripe rust. Three treatments had higher grain test weight than the non-treated check. The significant yield responses ranged from 10.0 bu/A (85.7%) to 55.1 bu/A (469.6%). In the fungicide test on spring wheat, all 19 fungicide treatments significantly reduced stripe rust severity and increased grain yield compared to the non-treated check; and 17 treatments had higher test weight than the check. The significant yield responses ranged from 21.5 bu/A (51.9%) to 46.7 bu/A (115.5%). In the test of 23 winter wheat varieties plus a susceptible check, the two applications of fungicide significantly reduced stripe rust of 12 commercial varieties; protected grain test weight of the check by 3.1 lb/bu and 4 commercial cultivars by 1.5 to 14.3 lb/bu; made significant yield differences for the susceptible check (53.4 bu/A more in the sprayed plots) and 17 commercial varieties with 9.7 to 68.3 bu/A more grain in the sprayed plots. Six commercial varieties showed no significant yield differences between the no-spray and spray treatments. These data indicated that stripe rust caused yield loss of 53.4 bu/A (87.6%) on the susceptible check and 16.8 bu/A (14.4%) yield loss on average across the commercially grown varieties under the extremely severe disease pressure from early inoculation of the pathogen in the experimental field. Similarly, in the test of 23 spring wheat varieties plus a susceptible check, the two applications of fungicide significantly reduced stripe rust severity on the susceptible check and 8 commercial varieties; protected grain test weight of the check by 6.7 lb/bu and 2 commercial varieties by 3.1 to 5.3 lb/bu; made significant yield differences for the susceptible check (39.4 bu/A more in the sprayed plots) and 3 commercial varieties with 13.1 to 31.8 bu/A more grain in the sprayed plots, indicating that stripe rust caused yield loss of 51.9% on the check and 6.3% on average across the commercially varieties.</p>	<p>For this objective, all tests scheduled for 2022 were completed. For the 2022-23 growing season, the winter wheat plots of the fungicide and variety yield loss studies were planted in October, 2022, and the spring plots will be planted in April, 2023. The tests will be completed in August (for winter wheat) and September (for spring wheat), 2023.</p>	<p>The results were communicated to growers and collaborators through e-mails, project reports and reviews, and published in scientific journals.</p>
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Publications:

Scientific Journals:

Zhang, G. R., Martin, T. J., Fritz, A. K., Li, Y. H., Seabourn, B. W., Chen, R. Y., Bai, G. H., Bowden, R. L., Chen, M. S., Rupp, J., Jin, Y., Chen, X. M., Kolmer, J. A., and Marshall, D. S. 2022. Registration of ‘KS Hamilton’ hard red winter wheat. *Journal of Plant Registrations* 16(1):73-79. <https://doi.org/10.1002/plr2.20190>

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Popular Press Articles:

January 10, 2022. First Stripe Rust Forecast for 2022, January 10, 2022. Xianming Chen, E-mail sent to cereal group. <https://striperust.wsu.edu/2022/01/10/first-stripe-rust-for-2022-january-10-2022/>

February 2022. Watch for stripe rust with smartphones, Zhiwu Zhang and Xianming Chen, *Wheat Life*, February 2022, page 51. <https://wagrain.org/articles/watch-for-stripe-rust-with-smartphones/>

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Presentations and Reports:

In 2022, Xianming Chen and associates presented invited talks at the following regional, national, and international meetings:

May 19, 2022. Xianming Chen presented field experiments and research progress to faculty and students of the Ecological Agriculture Program, Evergreen College at Mount Vernon, WA.

June 13, 2022. Xianming Chen presented stripe rust management at Hermiston Irrigated Cereal Field Day.

June 30, 2022. Xianming Chen presented field experiments and progress of stripe rust research at Spillman Farm Field Day.

September 12-15, 2022. Chen, X. M., Wang, M. N., Bai, Q., Li, Y. X., Sprott, J., Evans, K. 2022. Development of new resources for improving control of wheat stripe rust. Abstracts of 2nd International Wheat pp. 452. September 12-15, 2022, Beijing, China. (Xianming Chen attended the meeting through Zoom).

September 23, 2022. Xianming Chen, invited to give an oral presentation “Changes of Barley Stripe Rust Races and Populations in the United States from 1993 to 2021” at 23rd North American Barley Researchers Workshop (NABRW) and 43rd Barley Improvement Conference, UC Davis, California, September 22-24, 2022.

September 28, 2022. Xianming Chen, invited to give a plenary presentation “Stripe rust epidemiology and control: recent highlights” through Zoom, International Symposium on Plant Immunity and Green Agriculture, Yangling, China, September 27-29, 2022.

Xianming Chen attended the APS Plant Health 2022 annual meeting and presented “Characterization of *Puccinia striiformis* races causing barley and wheat stripe rusts in the United States in 2021 (Authors: Meinan Wang and Xianming Chen), August 7-10, 2022, Pittsburgh, Pennsylvania.

Reports:

Report of race summaries of the 2021 stripe rust collection in the US. February 2022. <https://striperust.wsu.edu/races/data/>

Stripe data of more than 50 wheat and barley germplasm nurseries tested in 2022. August 2022. <https://striperust.wsu.edu/nursery-data/2022-nursery-data/>

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Progress Report 1 of 3 (maximum of 3 year funding cycle)

Year: Title: *Club wheat Breeding*

Researcher: ***Kimberly Garland Campbell***

Cooperators: *Arron Carter, Michael Pumphrey*

Executive summary: In 2023, the breeding lines, ARS12097-12C and ARS15X1460-8CBW were entered into the < 16 in. rainfall zone winter wheat variety trials in WA; ARS09X500CBW and ARS14X1114RS-3CBW were entered into the >16 in rainfall zone nurseries. ARS09X500CBW is under consideration as our next release and was also entered into the Oregon and Idaho soft winter wheat variety trials. Foundation seed of our most recent club wheat release, Cameo, was harvested in 2022. Cameo has better agronomic performance than other clubs in trials on the Palouse, better stripe rust resistance than ARS Crescent, and tolerance to eyespot, soilborne wheat mosaic virus, acid soils and Hessian fly.

We evaluated 1742 IMI-resistant breeding lines in 2022 and selected the 76 best lines for further evaluation at multiple locations. These lines were derived by crossing our best quality club wheats with Piranha CL+, Stingray CL+ and an Oregon CL+ breeding line. We evaluated resistance to snowmold, stripe rust, eye spot (footrot) and aluminum in dedicated stress trials and evaluated resistance to Cephalosporium stripe and Hessian Fly in collaboration with Chris Mundt of OSU and Stephen Odubiyi of UI. We rated our upper-level breeding lines for tolerance to alpha amylase using the Phadebas enzyme assay in collaboration with the Steber lab.

Impact: Club wheat represented 8% of total soft white wheat production in Washington in 2022, comprising 138,018 acres for winter club and 36,386 acres for spring club. Castella was planted on 59,068 acres, followed by Pritchett (48,118 acres), ARS Crescent (21,348 acres), Bruehl (4,554 acres) and Coda (4,930 acres). The spring clubs 'Melba' were planted on 33,611 acres and 'JD' on 2775 acres. The total production of 174,404 acres was an increase from the 105,224 acres produced in 2021 and 119,124 in 2020. White club bids were between \$8.40 and \$8.90 with an average of \$8.75 in Portland on Jan 6, 2023 as compared to soft white wheat (maximum 10.5% protein) bids between 8.25-8.70 averaging \$8.44. This approximately \$0.25 premium is closer to sustainability for club wheat purchases than the premiums over \$1.00 that we experienced in 2021. When the premiums are high, the markets shift to other classes. We sent six samples and a sample of Western White from the 2021 crop to the Japanese Flour Millers Association as part of the USDA-Japan Club wheat technical exchange. The results were highly complementary to our club wheat even after a growing season that resulted in higher proteins than desired. Members from the JFMA were able visit Pullman in 2022 after two years of zoom meetings. This means that our club wheat crop remains competitive in the field and desired by our primary customers which provides market alternatives for wheat growers in the Pacific Northwest.

Communication:

Garland-Campbell, K.A., 2022. Club Wheat—A Review of Club Wheat History, Improvement, and Spike Characteristics in Wheat. *Plant Breeding Reviews, Volume 46*, p.421.

Garland-Campbell, K., Bellinger, B.S., Carter, A.H., Chen, X., DeMacon, P., Engle, D., Hagerty, C.H., Kiszonas, A., Klarquist, E., Murray, T. and Morris, C., Neely, C., Odubyi, S., Rashad, A., See, D., Steber, C., Wen, N., 2022. Registration of 'Cameo' soft white winter club wheat. *Journal of Plant Registrations*, 16(3), pp.585-596.

Garland-Campbell, K. (2022) Breeding for Seed Shape, Quality, and Nutrition in Club Wheat [Abstract]. ASA, CSSA, SSSA International Annual Meeting, Baltimore, MD.
<https://scisoc.confex.com/scisoc/2022am/meetingapp.cgi/Paper/142655>

Steber, C. M., Wigen, J., Sjoberg, S., Martinez, S. A., Carter, A. H., & Garland-Campbell, K. (2022) *Qphs.Wsu.2D* Is a Major QTL Providing Wheat Preharvest Sprouting Tolerance [Abstract]. ASA, CSSA, SSSA International Annual Meeting, Baltimore, MD.
<https://scisoc.confex.com/scisoc/2022am/meetingapp.cgi/Paper/142336>

WGC project number GR000010090 AWD 004416
WGC project title: Club wheat Breeding
Project PI(s): Kim Garland-Campbell, Arron Carter
Project initiation date: July 2022
Project year (1 of 3-yr cycle): 1

Objective	Deliverable	Progress	Timeline	Communication
Club wheat cultivar development	New populations for high rainfall and low rainfall club wheat production. Club wheat breeding lines evaluated in nurseries for disease resistance, agronomic performance and end use quality. New club wheat breeding lines tested in regional and state variety nurseries. New club wheat cultivars released.	Four club wheat breeding lines entered into 2022 winter wheat variety trials and they performed better than trial averages. Three breeding lines entered into 2022 Western Regional trials. ARS09X500-CBW will be proposed for release 2023. IMI-club breeding lines selected for agronomic performance. 76 advanced to multi location testing in 2023. Foundation seed of Cameo club wheat produced. Japanese Flour Millers Association evaluated 6 club wheat samples including advanced breeding lines and found them to be acceptable	2022-2025	Presentation at grower meetings, Wheat commission meetings, Wheat Life and Research Review. Published on WSU small grains Web-site
Development of high quality club wheat germplasm with resistance to low Falling Number	Club wheat breeding lines evaluated for trait associated with low falling numbers.	Alpha amylase evaluated on Pullman nurseries in 2022. New method will be used for as many breeding samples as possible in 2022 using Phadebas assay.	2022-2025	Results posted on Falling Numbers web site. Presentation at Wheat Research Review, Included in peer reviewed publications.
Club wheat population improvement	Population improvement conducted for disease resistance, end use quality, nutritional quality.	Head rows for entire breeding program evaluated for snow mold resistance at Waterville for snow mold resistance. Method development for other traits.	2022-2025	Presentation at Research Review. Peer reviewed publications. Shared with regional breeders.

Project #: GR00010236. AWD004480

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

Title: Evaluation and Selection for Cold Tolerance in Wheat and Barley

Researcher(s): Kimberly Garland Campbell, Karen Sanguinet

Cooperators: Bob Bruggeman, Arron Carter, Clark Neely, Mike Pumphrey.

Executive summary:

Screening for wheat cold tolerance using the artificial freeze test was conducted on 400 winter wheat breeding lines. Data was returned to the wheat breeders. Screening was also conducted on the Winter Wheat Variety Trials and the Winter Regional nurseries. Data is being analyzed. Preliminary test results indicated that the freeze chambers needed to be calibrated. They were serviced in Oct. 2021 and multiple tests were run to assess the evenness of the freeze test results. Even though the interior of the freeze test chamber is small, entries can be exposed to lower or higher temperature if the chambers aren't calibrated. We have purchased new probes and monitoring stations to continue to assess and improve the consistency of our results in 2023 and following. Therefore, while the assessment of variety trials and breeder trials was conducted using multiple replications, we have not assessed genetic populations or barley. We plan to do so in 2023.

Impact:

- The data from these cold tolerance trials will be published in the seed buyers guide so that farmers can select winter wheat varieties that are 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 can incorporate better cold tolerance into our early generation breeding lines.

Outputs and Outcomes: Data returned to breeders, No publications in 2022.

WGC project number: GR00010236. AWD004480
WGC project title: Evaluation and Selection for Cold Tolerance in Wheat and Barley
Project PI(s): Kim Garland-Campbell, Karen Sanguinet
Project initiation date: July 2022
Project year (1 of 3-yr cycle): 1

Objective	Deliverable	Progress	Timeline	Communication
Evaluate Washington Winter Cereal Variety trials, Washington Variety Testing hard spring wheat trials and Wheat regional nurseries for survival after freezing.	Data collected, analyzed, reported to Cereal Variety Testing and to growers	Data has been collected and is being analyzed	Data analysis will be completed by Jan 30, 2023 and continued in 2024 and 2025	Presentation at grower meetings, Wheat commission meetings, Wheat Life and Research Review. Published on WSU small grains Web-site
Evaluate freezing tolerance of advanced breeding lines contributed by the WSU and USDA-ARS wheat and barley breeding programs.	Data collected, analyzed, reported to Winter wheat breeding program	Data was collected, analyzed and returned to winter wheat breeding program. Waiting for submissions from Barley breeding program	Data returned to breeding program by summer 2022 and continued in 2024 and 2025	Email results to regional nursery cooperators and publish on regional nursery web sites.
Evaluate cold tolerance of F ₃ -F ₅ (early generation) wheat populations that are segregating for cold tolerance and select resistant progeny.	Tests run to determine correct temperatures for selection	Populations for screening have been selected	Screening accomplished by Dec 2023 and continued in 2024 and 2025	Presentation at Research Review. Peer reviewed publications. Direct communication with wheat breeders.
Identify genes controlling cold hardiness in winter wheat.	Major genes identified and molecular markers. Development of breeder friendly markers.	Major genes for cold tolerance have been identified on chromosomes 1A, 1B, 1D, 2A, 2B, 2D, 3B, 3D, 4A, 4B, 5A, 5B, 6B, 7A, and 7B.	Additional screening of segregating populations is underway. Complete in 2024	Presentation at Research Review. Peer reviewed publications. Direct communication with wheat breeders.
Determine if UAV can be used to assess plant health in research trials in the spring and correlate with our freeze test results.	UAV flights in early spring analyzed for greenness and results correlated with Freeze test results.	UAV flights were conducted but need to be repeated earlier in the season.	Initial correlation results by Dec 2023, and complete in 2025	Presentation at Research Review. Peer reviewed publications. Direct communication with wheat breeders.

Washington Grain Commission
2022 Wheat and Barley Research Annual Progress Reports and Final Reports
Format

(Begin 1 page limit)

Project #: 3184

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

Title: Breeder Quality Trials

Researchers: Alecia Kiszonas & Clark Neely

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

Executive summary: A new program commenced in FY 2019/20 to ‘pre-screen’ experimental breeding lines before they are entered into the WSU Wheat Variety Trials. This pre-screening was aimed at increasing the likelihood that newly released soft white wheat varieties meet industry standards before gaining substantial acreage and influencing the overall quality of the grain being exported from the Inland PNW. Quality data generated from this trial in 2021 has been analyzed using the standard *t*-Score and the results (and interpretation) returned to the breeder. Data generated from this trial in 2022 is being analyzed and will be returned to the breeder. The data can also be included in the analysis used for the *Preferred Variety* brochure. The check variety has been drawn from the adjoining Variety Testing nursery.

Impact: Although the program is relatively new, we have seen lines both public and private entered into the Breeder Quality trials that have been excellent and moved on to Variety Testing, and some that have sub-par quality and have been withdrawn for further consideration in the Variety Testing program. We anticipate that the project will continue to provide value to growers in two significant ways: First, it documents and highlights the quality of varieties so that breeders –public and private –are aware of the importance of quality and will hopefully continue to include quality in their selection and variety release decisions.

(End 1 page limit)

Outputs and Outcomes: Following is a summary of experimental lines evaluated under this program (harvest 2022): There were 27 SWW lines submitted and they were evaluated at five locations. The SWW lines were submitted by WSU (Dr. Arron Carter), Limagrain, and Westbred. In total there were 140 samples evaluated.

WGC project number: 3184				
WGC project title: Breeder Quality Trials				
Project PI(s): Kiszonas & Neely				
Project initiation date:				
Project year (3 of 3-yr cycle):				
Objective	Deliverable	Progress	Timeline	Communication
Evaluate 10 advanced breeding lines from each of 4 programs at 5 locations	Complete end-use quality evaluation and t-Scores	Completed each year by early spring after prior year harvest	Completed by early spring after prior year harvest	End-use quality data, t-Score, and interpretation shared with originating breeder

Washington Grain Commission
2022 Wheat and Barley Research Annual Progress Reports and Final Reports
Format

(Begin 1 page limit)

Project #:

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

Title: Quality of Varieties & Pre-Release Lines: Genotype & Environment ‘G&E’ Study

Researcher: *Alecia Kiszonas*

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

Executive summary: The 2022 harvest sample analysis is roughly half done; the project is on-going. 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.

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

ALUM	HRS
ARROWHEAD	HRW
ARS09X492-6CBW	CLUB
ARS14DH1122-26	CLUB
ARS14DH1122-44	CLUB
ARSX09500-14CBW	CLUB
ARSX09500-17CBW	CLUB
ARSX12015-68CBW	CLUB
ARSX12097-8D	CLUB
ARSX12099-158	CLUB
ASSURE	SWW
BOBTAIL	SWW
BRUEHL	CLUB
BRUNDAGE96	SWW
BRUNEAU	SWW
CASTELLA	CLUB
CHET	HRS
CLEARSTONE	HRW
COMMAND	SWW
CRESCENT	CLUB
CURIOSITY	SWW
DAYN	HWS
DEVOTE	SWW
DUET	SWW
EARL	HWW
FARNUM	HRW
FUSION	HRS
GLEE	HRS
GUNSIGHT	HRS
HULK	SWW
INCLINE	HRW
JASPER	SWW
JD	CLUB
JET	HRW
KELDIN	HRW
KELSE	HRS
LOUISE	SWS
MADSEN	SWW
MAGIC	SWW
MELA	SWW
MELBA	CLUB

MONARCH	HWW
NORWEST553	HRW
ORCF102	SWW
OTTO	SWW
PIRANHA	SWW
PRITCHETT	CLUB
PUMA	SWW
PURL	SWW
RESILIENCE	SWW
ROSALYN	SWW
RYAN	SWS
SCORPIO	HRW
SEAHAWK	SWS
SELBU2	SWW
SEQUOIA	HRW
SOCKEYE	SWW
SPRINTER	HRW
STEPHENS	SWW
STINGRAY	SWW
TANDEM	SWW
WA8290	SWW
WA8293	SWW
WA8307	SWW
WA8309	HRW
WA8310	HRW
WA8312	CLUB
WA8317	SWW
WA8318	HRW
WA8319	SWW
WA8321	SWS
WA8323	SWS
WA8325	CLUB
WA8330	SWW
WA8335	SWW
WA8336	SWW
WA8337	SWW
WA8342	HRS
WA8343	HRS
WA8344	HRS
WB528	SWW
WB9668	HRS
WHETSTONE	HRW

WGC project number: 4721				
WGC project title: G&E Study				
Project PI(s): Kiszonas				
Project initiation date:				
Project year (2 of 3-yr cycle):				
Objective	Deliverable	Progress	Timeline	Communication
Complete milling and baking analyses	Data set complete	Winter and spring wheat datasets are complete	All tests are complete	Internal
Analyze data set for t-scores	Grain, Milling, Baking, and Overall t-scores are calculated	Final data set is being processed	Complete in January	Internal
Rank varieties, assign quality classification, deliver final consensus to WGC	Final consensus classification of cereal chemists across the PNW	We will meet at the PNW Wheat Quality Council meeting to reach consensus on Classification	We had scheduled a meeting at the PNW Wheat Quality Council	Meeting with PNW cereal chemists from USDA, WSU, U of I, and OSU at the PNW-WQC; then communicate results to WGC

Washington Grain Commission
2022 Wheat and Barley Research Annual Progress Reports and Final Reports
Format

(Begin 1 page limit)

Project #: 4722

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

Title: Supplemental support for assessing the quality of Washington Wheat Breeding Samples

Researcher: Alecia Kiszonas

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 2021 Crop were completed and 2022 Crop testing is well under way at the WWQL.

Impact: This work contributes directly to the 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.

(End 1 page limit)

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, 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).

WGC project number: 4722				
WGC project title: Supplemental Support for Assessing the Quality of WA Wheat Breeding Samples				
Project PI(s): Kiszonas				
Project initiation date:				
Project year (2 of 3-yr cycle):				
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 interpretation
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 interpretation

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

Project #: AWD004714

Progress Report Year: 1 of 3

Researcher: Drew Lyon

Title: Extension Education for Wheat and Barley Growers

Cooperators: Cassandra Bates, Brook Brouwer, David Crowder, Aaron Esser, Randy Fortenbery, Isaac Madsen, Carol McFarland, Timothy Murray, Clark Neely, Stephen Van Vleet, and Dale Whaley

Executive summary: New resources were added to the Wheat and Small Grains website in 2022. The results from the 2022 cereal variety testing program were added to the website, the Variety Selection Tool, and the phone app. Two wheat variety field day videos were also added to the website. The 2021 WSU Weed Control Report was posted as was a new Weed ID quiz. Twenty-five new episodes of the WSU Wheat Beat Podcast were posted in 2022, a new episode every other week. There were also 26 new Timely Topics posted. The 2022 WSU Wheat Academy was held for the first time since 2019. Although attendance did not meet expectations, those that attended rated the event highly.

Vacant positions on the Extension Dryland Cropping Systems Team remained a problem in 2022. The Team will enter 2023 three county positions down from where it was in 2018, the same as this year. Although the Walla Walla County position will be filled in early 2023, the Spokane County and Columbia County positions are still open. Dr. Stephen Van Vleet (Whitman County) retired in October of 2022. The status of that position is unknown at this time. The team also lacks a soil fertility Extension Specialist since the departure of Dr. Haiying Toa in 2021.

Impact: The Wheat and Small Grains website continues to be an important source of information. For the 11-month period of January through November 2021, the site had 66,714 sessions with 81,088 unique users; this compares to 63,417 sessions with 52,822 unique users for the same period in 2021, and 63,155 sessions and 34,808 unique users in 2020. There were 98,580 pageviews, which is down from 104,950 pageviews in 2021 and 114,379 pageviews in 2020. We have 1,034 subscribers to our listserv. We have 1,046 followers on Twitter, and 720 follows on Facebook. Most of the sessions from the US (38,929) were initiated from the state of Washington (13,112). From January through November, the WSU Wheat Beat Podcast had a total of 10,141 plays. Through November, the Weeders of the West blog had 8,840 pageviews and 101 people are subscribed to the blog listserv.

The WSU Wheat Academy was held in 2022. The event was not held in 2020 or 2021 because of COVID-19 restrictions. We filled only 54 of the 72 slots despite buying a half-page Ad in Wheat Life and a two-week radio Ad campaign. People were obviously not looking for the event this year. Those who attended the 2022 WSU Wheat Academy rated it highly (4.35 out of 5 based on 17 returned surveys).

WGC project number: TBD

WGC project title: Extension Education for Wheat and Barley Growers

Project PI(s): Drew Lyon

Project initiation date: July 1, 2022

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 prioritized. An article will be written annually for Wheat Life magazine on our Extension activities.	Two wheat variety field day videos were added to the website. A new PNW Extension publication on wild oat was added. A straw removal calculator was developed and added to the website.	This will be an ongoing process throughout the duration of the project.	The development of new resources will be shared with growers through Timely Topic posts on the Wheat and Small Grains website, email messages sent to the smallgrains listserv (1,015 subscribers), an annual article in Wheat Life magazine, and at various education events held throughout the year.
Provide Timely Topics, podcast episodes, and blog posts 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. A new blog article will be posted every other week.	In 2022, we posted 26 Timely Topics, 25 podcast episodes, and 21 blog articles.	This will be an ongoing process throughout the duration of the project.	Timely Topics, Wheat Beat Podcast episodes, and Weeders of the West Blog posts will be posted to the home page of the Wheat and Small Grains website on a regular basis.
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.	We continue to struggle with the task of identifying the best approach for this objective. A significantly reduced team did not help the situation.	Planning for the new educational program will begin in 2022, with delivery of the first program held in 2023.	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 has gained extra attention with recent federal funding for the PNW Herbicide Resistance Initiative (PNWHRI). The Wheat and Small Grains website will be a critical resource for the PNWHRI project going forward. We increased interactions with the GROW project, a national herbicide-resistance project led by the USDA-ARS in Beltsville, MD. We added links to their website (GROWIWM.org) and they added links to resources on our website.	This will be an ongoing process throughout the duration of the project.	Educational resources and programming developed to address issues of concern will be shared with growers through Timely Topic posts on the Wheat and Small Grains website and at education events throughout the year.

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 #: 139311
Progress Report: Year 1 of 3
Title: EVALUATION OF BARLEY VARIETIES
Researcher: Clark Neely, Variety Testing Program Lead

EXECUTIVE SUMMARY:

The primary goal of the WSU Extension Cereal Variety Testing Program (VTP) is to provide growers, the agribusiness industry, university researchers, and other interested clientele with comprehensive, objective, and independent information on the adaptation and performance of spring barley cultivars across the intermediate and high rainfall dryland production regions of eastern Washington where barley is grown. Major decisions or changes made by the program are run by an advisory committee composed of representatives from the WGC, WAWG, seed industry, and WSU Extension. The committee meets twice a year and provides valuable feedback on how the program can best support industry and grower needs.

The VTP planted 12 spring barley variety trials in 2022. While all 12 were harvested, data from Almira and Reardan were not published due to high variability within the trials. Lamont was not published due to aerial herbicide drift that damaged the barley. All data is posted on our website and email notifications were sent out via the ‘prelimdata’ list serve when data were available. In the past year, the number of members on this list has increased 11% to 395. We will continue to publish our final technical report on our website at (<http://smallgrains.wsu.edu/variety>), which will be completed by January 31, 2023. Once the final report is completed, the variety selection tool will be updated with the 2022 data as well. This will include both desktop and mobile app versions of the tool.

Barley varieties were covered at seven field days with a total of 172 attendees. Dr. Neely led efforts to revive the Spillman Farm Field Day in 2022, where 82 attendees listened to numerous researchers, including Dr. Bob Brueggeman who shared his breeding program updates and attendees heard about the newest spring barley varieties being tested in the VTP. At the request of the WSU Barley Breeding Program, the VTP also began conducting winter barley variety trials in fall 2022 at all eight of our high rainfall winter wheat variety trial sites. These currently consist of six entries, but are expected to expand in the future as more cold tolerant breeding lines move through the breeding pipeline. Spring barley entries from 2022 were also submitted to University of Idaho for screening of Hessian fly resistance, which will be a new addition to the list of variety characteristics. Generated ratings will be uploaded on to the variety selection tool once data is compiled.

IMPACT:

The economic value (impact) of the WSU VTP is measured by providing information to growers and seed industry personnel leading to variety selections that maximize profitability and minimize risk. Choosing an appropriate barley variety to plant is one of the easiest ways that a grower can increase production and decrease costs (through decreased inputs). In 2022, 72,000

acres of spring barley were planted. When comparing the yield from the top three varieties in each trial and comparing their average yield to the trial average, there is approximately a 570 lb/a yield advantage. When multiplied across harvested acres and using an average sales price of \$243/ton, the VTP had the potential to generate an additional \$5 million dollars in 2022 alone as shown in the table below. The VTP strives to disseminate information to growers as widely as possible. Both the variety testing website and the variety selection tool average over 8,000 page views each on an annual basis. Typically, another 200+ contacts are made through field days and grower meetings each year. While yield is important there are multiple traits that growers look for in a variety, which vary in importance from region to region. The VTP publishes data on test weight, grain protein, plump seed, plant height, maturity, and stripe rust resistance. An additional impact of the VTP comes through the evaluation of breeding lines, providing valuable information to aid breeders in variety release decisions, leading to new and improved barley varieties available to growers in Washington.

Year	Harvested Barley Acres	Average Yield Gain for Top Five Varieties in Trials	Average Price of Feed Barley	Additional Income Generated
	# acres	lb/acre	\$/ton	\$
2022	72,000	570	\$243	\$4,984,718

WGC project number: 139311				
WGC project title: Evaluation of Barley Varieties				
Project PI(s): Clark Neely				
Project initiation date: 07-01-2022				
Project year (X of 3-yr cycle): 1 of 3				
Objective	Deliverable	Progress	Timeline	Communication
1. Conduct representative and objective barley variety field trials at locations that represent major production areas of Washington.	i.) 12 spring barley trials; 24 entries/trial ii.) 8 winter barley trials; 6 entries/trial	i.) 2022 trials harvested and data shared with growers ii.) 2023 winter trials planted	Trials planted in the spring and fall, data results are available to growers at end of each harvest season.	Results from the variety trials are communicated via Extension programming and are detailed under Objective #4.
2. Include commercially relevant entries in trials including currently grown varieties and advanced breeding lines from major public and private breeding programs in the region	All widely grown, commercially available varieties and promising experimental lines are included in trials.	i.) 2022 spring barley entries: 29% public, 71% private. ii.) 2023 winter barley entries: 83% public, 17% private iii.) Every major spring feed and malt barley breeding program in the PNW is actively participating in the VTP. iv.) 2022 entries, locations, and maps were all posted on the variety testing website shortly after spring planting season concluded. Winter 2023 trial maps posted following fall planting.	i.) Deadline for spring entry requests are February 1 and seed is due February 11. ii.) Deadline for winter entry requests is August 8 and seed is due by August 22.	i.) Send out 'call for entries' letter by mid-January requesting spring barley entries. i.) Send out 'call for entries' letter by mid-July requesting winter barley entries. ii.) 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 and ratings from other projects/ programs.	Cooperation with breeders, pathologists, seed dealers, WSCIA, other universities, and Extension. Data are used by breeders for variety release and promotional materials. Began screening barley lines for Hessian fly resistance for first time in 2022.	Ongoing cooperation and collaboration that fit with timelines and other listed objectives.	Stripe rust ratings presented 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	No invitations to speak at meetings on barley specifically to date.	Will attend when invited	Attend in person and present results with slides and handouts when appropriate.
	b.) Field Tours	i.) 2022: 7 in-person field days (172 attendance)	June-July	*List of Field Days provided below; provide paper handouts of data at events; List of dates posted on website and emailed through prelimdata list serve
	c.) Email List Serv	2022 data and trial updates delivered; total of 37 emails sent to subscribers in 2022	Data emailed out September through December; trial updates/observations posted throughout year.	2022 data and trial updates delivered to 395 subscribers; list serve membership increased 11% in 2022
	d.) Website	2022 data posted; single-site, multi-year averages still being generated for tables; 2023 winter VT field maps posted	September through December	10,255 pageview for 2022 VT website
	e.) Annual Report	2022 final report planned completion by January 31, 2023. Delayed due to new database software issues.	January	Annual report is published as a WSU technical report online and in hard copy upon request.
	f.) WSCIA Seed Buyers Guides	2022 Guide completed	February	Seed Buyers Guide published in February
	g.) Wheat Life	2022: Spring Barley VT article completed	Spring Barley VT article: Completed in December 2022 for January 2023 publication.	Article published in Wheat Life in January each year.
	h.) Variety Selection Tool (smallgrains.wsu.edu)	Selection tool is updated once the final technical report is completed.	January 2023	2022: 3,337 page views; 177 new mobile app downloads
*2022 in-person Field Days included Dayton, Fairfield, Farmington, Mayview, Pullman, Reardan, St. John.				

Project #: 139312
Progress Report: Year 1 of 3
Title: EVALUATION OF WHEAT VARIETIES
Researcher: Clark Neely, Variety Testing Program Lead

EXECUTIVE SUMMARY:

The primary goal of the WSU Extension Cereal Variety Testing Program (VTP) is to provide growers, the agribusiness industry, university researchers, and other interested clientele with comprehensive, objective, and independent information on the adaptation and performance of winter and spring wheat cultivars across the climatic regions of eastern Washington where wheat is grown. Major decisions or changes made by the program are run by an advisory committee composed of representatives from the WGC, WAWG, seed industry, and WSU Extension. The committee meets twice a year and provides valuable feedback on how the program can best support industry and grower needs.

The VTP has continued to invest in the infrastructure of the program during FY 2022. With the remainder of Dr. Neely's start-up funds, a new gooseneck trailer and a new primary towing vehicle were purchased in 2022 to ensure reliable transport of equipment to and from trial sites. Also, a new second technician was hired in June 2022 to replace the previous technician who departed in January 2022.

Rapid turnaround time for generating data at harvest time continues to be a major priority for the program with the vast majority of trial yield data being available within 48 hours of harvest. This data is initially emailed out to the 'prelimdata' list serve which currently stands at 395 subscribers, up 40 from 2021. Once harvested samples are brought to the lab, cleaned and analyzed for grain protein and test weight, data is compiled into tables and posted on our website (<http://smallgrains.wsu.edu/variety>). Though 2022 data was generally posted in a timely manner, issues with our new database software Genovix greatly delayed multi-year and regional analyses and summaries. As a result, the final comprehensive technical report will be finished by end of January 2023 instead of the December 2022 target date. Once completed, the variety selection tool (desktop and mobile versions) will be updated as well.

Recently, the VTP has added additional ratings for some varieties. Most notably, in collaboration with University of Idaho, ratings were posted for Hessian fly resistance in winter wheat varieties as another tool for growers to help manage this pest and reduce pressure on spring wheat in their rotations. Also, 2022 provided some good cold tolerance notes for our fall planted hard red spring wheat entries which were shared with growers and the industry. In 2023, also expect to see new ratings posted for lodging potential, emergence and aluminum tolerance in winter wheat varieties based on data gathered in 2022. The Variety Selection Tool mobile app continues to garner interest reaching a total of 381 downloads since its launch in May of 2021.

The number of WSU Extension Variety Testing field days was back to pre-COVID numbers, but attendance per field day continued to see a downward trend which was present even before

COVID. Still, the program reached approximately 605 attendees at these field days and revived the WSU Spillman Farm field day which had not been held for a number of years with approximately 82 in attendance. In collaboration with the WSU Division of Academic Outreach and Innovation, “virtual” field days were again recorded at Lind and Pullman and posted on the CAHNRS YouTube Channel (<https://www.youtube.com/user/WSUCAHNRS/playlists>). So far, these videos have received a combined 232 views. These videos walk viewers through each wheat variety and viewers are now able to find specific varieties by rolling their mouse arrow over the time lapse bar at the bottom of the screen for more efficient viewing.

In response to a greater volume of entry requests in fall 2022 due to additional material submitted with the CoAXium® trait, any winter wheat variety with either the Clearfield® or CoAXium® trait will be split off into a separate trial adjacent to the common soft white winter and hard red winter wheat variety trials at all trial sites. Furthermore, at the request of the WSU Barley Breeding Program, the VTP began a winter barley variety trial in 2023 at all high rainfall sites (8 total). In all, the number of individual trials increased 29% and the total plots managed has increased 10% in the past year.

IMPACT:

The economic value (impact) of the WSU VTP is measured by providing information to growers and seed industry personnel leading to variety selections that maximize profitability and minimize risk. Choosing an appropriate wheat variety to plant is one of the easiest ways that a grower can increase production and decrease costs (through decreased inputs). In 2022, 2.3 million acres of wheat were harvested. When comparing the yield from the top five varieties in each trial and comparing their average yield to the trial average, there is approximately a 8.2 bu/a yield advantage. When multiplied across acres harvested and using an average sales price of \$9.43/bu, the VTP had the potential to generate an additional \$178 million dollars in 2022. The VTP strives to disseminate information to growers as widely as possible. Both the variety testing website and the variety selection tool average over 8,000 page views each on an annual basis. Another 1,000+ contacts are made through field days and grower meetings each year. While yield is important there are multiple traits that growers look for in a variety, which vary in importance from region to region. While more difficult to assess economic impact, traits such as falling numbers, winter survival, rust resistance, hessian fly resistance, aluminum tolerance, emergence, and snow mold resistance unquestionable have the potential to greatly improve yield or decrease inputs for some growers and in certain environments. The data generated by the Western Wheat Quality Lab using samples from the VTP helps also ensure released varieties maintain superior grain quality, thereby maintaining overseas markets for PNW wheat which supports prices. An additional impact of the VTP comes through the evaluation of breeding lines, providing valuable information to aid breeders in variety release decisions, leading to new and improved wheat varieties available to growers in Washington.

Year	Harvested Wheat Acres	AVG Yield Gain for Top Five Varieties in Trials	Averaged Price of Wheat	Additional Income Generated
	# acres	bu/acre	\$/bu	\$
2022	2,300,000	8.2	\$9.43	\$177,849,800

WGC project number: 139312				
WGC project title: Evaluation of Wheat Varieties				
Project PI(s): Clark Neely				
Project initiation date: 07-01-2022				
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 white winter wheat trials; 36-54 entries/trial	i.) 2022 trials harvested and posted; multi-year summaries to be completed by January 31, 2023 ii.) 2023 winter trials planted iii.) Collaborative trials are continuing with OSU at Eureka and Walla Walla.	Each year trials are planted in the spring or fall. Plots are maintained throughout the year and heading dates/plant heights are collected before harvest. Data results are available to growers at the end of the harvest season, which runs from mid-late July through September.	Results from the variety trials are communicated via Extension programming and are detailed under Objective #4.
	b) 16 hard winter wheat trials; 24-36 entries/trial	i.) 2022 trials harvested and posted; multi-year summaries to be completed by January 31, 2023 ii.) 2023 winter trials planted iii.) Collaborative trials are continuing with OSU at Eureka and Walla Walla.		
	c) 24 Clearfield/CoAXium winter wheat trials; 12-30 entries/trial	i.) 2023 trials planted		
	c) 18 soft spring wheat trials; 24 entries/trial	i.) 2022 trials harvested and posted; multi-year summaries to be completed by January 31, 2023		
	d) 18 hard spring wheat trials; 24 entries/trial	i.) 2022 trials harvested and posted; multi-year summaries to be completed by January 31, 2023		
	e) 3 hard red spring fall-planted trials; 18 entries/trial	i.) 2022 trials harvested and posted; multi-year summaries to be completed by January 31, 2023 ii.) 2023 winter trials planted; Dayton planting prevented due to early cold snap in October/November		
2. Include commercially relevant entries in trials including currently grown varieties and advanced breeding lines from major public and private breeding programs in the region.	All widely grown, commercially available varieties and promising experimental lines are included in trials.	i.) 2022 winter trials 53% public, 47% private; spring trials 71% public, 29% private. Every major breeding program in the PNW is actively participating in the VTP. ii.) All 2022 entries, locations, and maps have been posted on the variety testing website. 2023 winter entries and maps are posted online as well. iii.) Hard paper copies of field maps are available in PVC tubing on-site as well following spring field work.	i.) Deadline for winter entry requests is August 8 and seed is due by August 12 (low rainfall) and 22 (high rainfall). ii.) Deadline for spring entry requests are February 1 and seed is due February 11.	i.) Send out 'call for entries' letter by mid-July requesting winter entries. ii.) Send out 'call for entries' letter by mid-January requesting spring entries. iii.) 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/entries.	Participation and ratings of variety characteristics from other projects/ programs.	Cooperation with breeders, pathologists, entomologists, quality lab, FGIS, seed dealers, WSCIA, other universities, and Extension. Data gathered and summarized to produce ratings for falling numbers susceptibility, end use quality, stripe rust resistance, hessian fly resistance, snow mold resistance, aluminum tolerance, emergence, and winter survival. Ratings will be finalized and compiled into the 2022 final technical report and the variety selection tool by January 31, 2023.	Ongoing cooperation and collaboration that fit with timelines and other listed objectives.	Quality results in preferred variety pamphlet, falling number results presented by corresponding project, disease ratings presented in seed buyers guide, VTP data used for variety release and PVP applications. All data/ratings included in variety selection tool.
4. Deliver an Extension education program to make the results and interpretation of the variety trials	a.) Grower meetings	2022: Provided slides for Ritzville and Davenport grower meetings in January (unable to present in person). Presented at WSU Wheat Academy in December. 2023: Invited to speak at Ritzville and Davenport grower meetings	Will attend meetings when invited.	Attend in person and present results through powerpoint presentation and handouts when appropriate.

available to growers, the seed industry, and other clientele.		in January.		
	b.) Field Tours	i.) 2022: 20 in-person field days (605 attendance); 2 virtual field days (232 views to date).	June-July; actual dates posted on website	*List of Field Days provided below; provided paper handouts of data; List of dates posted on website and emailed through preldata list serve
	c.) Email List Serve	2022 data and trial updates delivered; total of 37 emails sent to subscribers in 2022	Data emailed out August through December; trial updates/observations posted throughout year.	2022 data and trial updates delivered to 395 subscribers; list serve membership increased 11% in 2022
	d.) Website	2022 data posted; single-site, multi-year averages still being generated for tables; 2023 winter VT field maps posted	August through December	10,255 pageview for 2022 VT website
	e.) Annual Report	2022 final report planned completion by January 31, 2023. Delayed due to new database software issues.	January	The annual report is published as a WSU technical report online and in hard copy upon request.
	f.) WSCIA Seed Buyers Guides	2022 Guide completed	February	Seed Buyers Guide published in February
	g.) Wheat Life	2022: winter and spring VT articles completed 2023: winter VT article to be submitted in April using 2022 data	Spring VT article: January Winter VT article: May	Articles published in Wheat Life in January and May each year.
	h.) Variety Selection Tool (smallgrains.wsu.edu)	Selection tool is updated once the final technical report is completed.	January 2023	2022: 3,337 page views; 177 new mobile app downloads
*2022 in-person Wheat Field Days included: Horse Heaven, Connell, Ritzville, St. Andrews, Moses Lake, Harrington, Lind, Fairfield, Mayview, Anatone, Reardan, Almira, St. John, Lamont, Eureka, Walla Walla, Dayton, Farmington, Pullman/Spillman, Bickleton.				

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

Project # GR00008054. AWD 3581

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**

Researchers: **T. Paulitz, K. Garland-Campbell, and R. Koenig.**

Cooperators: Emily Klarquist, WSU; Nikayla Strauss, WSU; Nuan Wen, WSU; Patricia Demacon, WSU; Arron Carter, WSU; Michael Pumphrey, WSU; and Christina Hagerty, OSU

Executive summary:

- The 2021 and 2022 spring and winter wheat, 2022 spring barley and 2021 Western regional nurseries were evaluated for Fusarium resistance using our improved greenhouse screening system.
- The best lines from our previous evaluation of the spring wheat core collection were retested using our new screening system.
- Spring wheat varieties AP Coachman and YSC605 were consistently more resistant over two years and varieties WB9303 and AP Mondavi were consistently more susceptible over two years.
- When evaluated together with our adapted wheat varieties, several of the previously identified sources of resistance from the spring wheat core collected were still rated as resistant
- The Western Regional Winter Wheat Nursery was screened, and identified WA 8315, WA8321 and WA 8330 with a higher level of tolerance to Fusarium.
- Winter wheat requires more replications (10-15) to reliably identify susceptible and resistant germplasm.

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
- Spring wheat parents for a crossing block to improve Fusarium resistance in adapted wheat.

WGC project number:
WGC project title: Fusarium Crown Rot on Wheat: Prebreeding and Development of Tools for Genetic Disease Management
Project PI(s): K. Garland-Campbell, T. Paulitz and R. Koenig
Project initiation date: 7/1/2021
Project year: Year 2 2022-2023

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 <i>Fusarium</i> tolerance in the the WSCIA seed buyers guide and other publications.	We screened the 2021 and 2022 spring and winter wheat variety trials, the 2022 spring barley trial and and 2021 regional nurseries for resistance to Fusarium using our greenhouse testing protocol. Data is being analyzed and will be shared with via the variety selection tool and wheat life.	Greenhouse screening will continue with optimized methods in 2023-2024	Strauss, N. M., Klarquist, E. F., Kaya, J., Thompson, Y. M., Paulitz, T. C. and Garland-Campbell, K. 2022. Screening of Winter Wheat for Fusarium Crown Rot in a Controlled Environment. Frontiers in Plant Science: in revision Strauss, N. M. 2021. Identifying novel disease resistance and drought tolerance genes in a synthetic DNAM population. PhD Thesis, Washington State University.
Objective 2. Look for new sources of resistance in a new set of synthetic wheat that was developed by CIMMYT in Turkey and in other collections	Resistant sources that can be used for variety development.	We screened the best lines from the spring wheat core collection to verify their resistance in 2022. In 2023, we will rescreen the Louise X AUS28451 population and our crosses with wheat synthetics. The most resistant in all these collections will be used in Recurrent selection strategy in Objective 3.	Crosses will be evaluated, advanced, and intercrossed in 2023 and 2024.	Strauss, N. M., Klarquist, E. F., Kaya, J., Thompson, Y. M., Paulitz, T. C. and Garland-Campbell, K. 2022. Screening of Winter Wheat for Fusarium Crown Rot in a Controlled Environment. Frontiers in Plant Science: in revision Strauss, N. M. 2021. Identifying novel disease resistance and drought tolerance genes in a synthetic DNAM population. PhD Thesis, Washington State University.
Objective 3. Breed for Fusarium crown rot resistance using our greenhouse and field screening systems and marker assisted selection for other important traits for wheat in the Pacific Northwest, (for example: eyespot and stripe rust resistance; grain quality, reduced height, and cold tolerance)	Resistant sources that can be used for variety development.	These populations will be composed of the best adapted soft white winter and spring wheat cultivars and breeding lines from the screening listed above. This crossing block will be completed in 2023.	Greenhouse screening of backcrosses will continue in 2023-2024.	

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, Wycliffe Nyongesa, Josh DeMacon, Sheri Rynearson

Executive summary:

The WSU spring wheat breeding program's elite material and recently released varieties continue to be the top performers in statewide variety trials and for growers. *Hale* hard red spring wheat is a superior, broadly adapted replacement for dryland spring wheat acres and led performance in WSU and UI Variety Testing trials in 2022. *Roger* spring club wheat is early and high yielding and will be the first in its class with Hessian fly resistance. A new 2-gene Clearfield soft white spring wheat is scheduled for release consideration in February 2023, *WA 8354 CL+*, with Breeders and Foundation seed production in 2023.

WSU soft white spring wheat varieties accounted for 94% of certified soft white spring wheat production acres in Washington in 2022. Our widely available soft white spring wheat varieties, *Ryan*, *Seahawk*, *Tekoa*, *Hedge CL+*, 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 widely adopted by seed dealers in the PNW and *Ryan* was by far the leading variety in the state again in 2021. *Net CL+* and *Hale* has been rapidly adopted. *WSU spring wheat varieties collectively were planted on ~80% of the certified spring wheat production acres in Washington in 2022.* 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 to 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, yield protection, and end-use quality. Our latest releases package excellent yields with superior quality and key yield protection traits. Public wheat breeding programs at WSU and across the country consistently pay back on research dollars invested. *With 80% or more of the spring wheat acres in Washington planted to WSU spring wheat varieties in 2022, growers continue to realize a substantial return on research dollars invested in this program.* The yield of our top three released soft white spring wheat varieties (*Ryan*, *Seahawk*, *Tekoa*) averages 105-115% of the top three varieties from other programs, using multi-year data from over 70 variety trials across precipitation zones from 2018-2022.

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: 2022

Project year: 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
Develop biotic and abiotic stress tolerant, high-yielding, and high-quality hard red, soft white, and club spring wheat varieties for diverse Washington production environments.	New spring 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 generated significant positive economic impact for PNW growers in 2022 by our varieties being planted on >80% of spring wheat acres. The top three WSU SWS wheat varieties across all locations demonstrated that our market-leading varieties produced >110% of the top three varieties from other breeding programs. A Hessian fly resistant club wheat, Roger, and a hard red spring wheat, Hale, underwent Foundation seed production in 202. Our 2-gene Clearfield breeding efforts have matured, and we anticipate release of WA 8254 CL+.	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 2022. Extensive crossing blocks for irrigated hard red spring wheat germplasm development were also advanced to field selection. Two large fall-seeded spring wheat trials were conducted in 2022 with irrigation. Backcrossing of the AXigen trait for CoAXium wheat production system was continued into both soft white and hard red spring wheat germplasm and numerous doubled haploid three-gene AXigen lines were evaluated in field plots.	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 genomic selection, 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 evaluated in 2022 to help long term breeding efforts. Scientific products of our efforts through multiple projects over the past three 3 years include ~20 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-throughput phenotyping, genomic selection, marker-assisted selection, drought tolerance, heat tolerance, yield, test weight, gluten strength, etc.	This work 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 #: 3208

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, USDA-ARS WWQL*

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 70 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:

Sockeye CL+, Jasper, Puma, Piranha CL+, Devote, Stingray CL+, Otto, Scorpio, Sequoia, Net CL+, Glee, Alum, Chet, Tekoa, Seahawk, Ryan, Melba, Hedge CL+, Hale, and Roger are examples of top-performing and widely grown WSU variety releases that were released by WSU winter and spring wheat breeding programs in recent years 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 yield 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: 3208
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-23
Project year (X of 3-yr cycle): 1 of 3 year cycle

Objective	Deliverable	Progress	Timeline	Communication
Early to late generation quality testing of WSU experimental lines to aid variety development	New spring wheat and winter wheat varieties that are superior to existing varieties. This effort includes all market classes of spring and winter wheat and all precipitation regions in Washington state. Milling and baking evaluation of over 1500 lines per year.	Over 1200 breeding samples were analyzed by numerous milling and baking quality tests in 2022. Four superior new wheat varieties are proposed for release in part due to this project and data in 2022. Others are planned for 2023 release.	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 and Mike Pumphrey participate in multiple US Wheat trade tours and we host many trade teams annually
Support germplasm development and genetic analysis of end-use quality to identify desirable alleles and to predict end-use quality through new genotyping methods	Improved germplasm and selection procedures which translate to more efficient, cost-effective, and consistent genetic gain for end-use quality.	Multiple special milling and baking trait experiments were evaluated in 2022, including new germplasm with Hessian fly resistance, herbicide resistance, and other introgressed traits.	The reward for this work will compound each year and will fully be realized for many years to come as these lines continue to be crossed into existing breeding lines. We expect this effort to result in routine selection of outstanding quality wheat.	

Washington Grain Commission

Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: 3019 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

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 2022. 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 and winter wheat variety trials. NEW DNA markers that allow diagnostic tracking of the previously unknown spring wheat resistance source that is in most spring wheat varieties were validated and fully implemented in 2021 and markers for “Louise” resistance source in 2022..

Impact: Spring wheat production has averaged ~30 million bushels in WA in recent years. A conservative state-wide Hessian fly 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, new club release WA8325 (Roger) and hard red spring wheat varieties Hale, 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: attached

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: 2021
Project year: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
Screen WSU Spring Wheat breeding populations and advanced breeding lines for resistance to Hessian fly in the laboratory	Information on Hessian fly resistance of >100 elite breeding lines and variety trial entries on an annual basis; updated Variety Selection Tool and Seed Guide data	Newly released varieties and elite variety candidates are Hessian fly resistant. Variety Testing Program including and Winter Wheat varieties and breeding lines screened. Data has been shared with Extension personnel, through the Variety Selection Tool, WSCIA	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. Backcross derived elite lines with H13, H22, H26, H32, an unknown gene, and combinations with HKelse	New DNA markers developed through this effort in routine use. Peer reviewed article published in 2022. DNA markers for Louise resistance source validated and new markers developed to track now both primary sources of resistance in spring wheat.	Annually	

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

Project #: 3163

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

Title: Greenhouse and laboratory efforts for spring wheat variety development

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

Executive summary:

Spring wheat varieties with high yields, good grain traits, complex stripe rust resistance, Hessian fly resistance, aluminum tolerance, superior end-use quality, and broad adaptation benefit Washington wheat producers by adding millions of dollars to annual returns. This project supports core efforts of the WSU Spring Wheat Breeding program by providing 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 and germplasm development 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 continue to shape our overall breeding efforts and directly contribute to variety release and on-farm profitability.

Impact

Our release of top-yielding spring wheat varieties continues to be of substantial economic benefit to growers in Washington. The consistency, broad adaptation, disease and pest resistances, aluminum tolerance, sound grain traits, most desirable end-use quality, good falling numbers, and overall performance of these varieties reflect the outputs of comprehensive wheat breeding and genetics research efforts. Each new WSU variety released under Pumphrey's leadership has most desirable quality, is top yielding, pest and disease resistant, and has been accepted and adopted by seed dealers and farmers.

Two new releases/Foundation seed increases were advanced in 2022. The first is a top-performing club spring wheat variety that is the first spring club to have Hessian fly resistance: 'Roger'. Roger 3-year average yields in 12-16, 16-20, and >20 inch precipitation areas is comparable to the highest yielding soft white spring wheat varieties. 'Hale' is a broadly adapted hard red spring wheat with excellent yield, disease resistance, Hessian fly resistance, quality, and slightly higher protein than our current top-end yielding dryland varieties. Hale has the highest two and three-year average yields across all precip zones and was a top performer in the highly stressful 2021 trials and very productive 2022 trials.

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: 2022

Project year: 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
Apply genome-wide and specific DNA markers to select breeding lines for numerous quantitative and qualitative traits.	Elite variety candidates will result, in part, due to these molecular selection activities. These breeding populations will be ideal for marker optimization, new genetic mapping studies, and potentially the basis of new competitively funded projects.	Axigen trait introgression continued, and we have made BC4 and BC5-derived doubled haploid breeding lines with this new herbicide tolerance to date. We have developed new DNA markers for a previously undocumented Hessian fly resistance locus that allow us to track resistance in most of our germplasm for the first time. KASP assays have been developed. Two new varieties were fast-tracked for variety release consideration in 2023 based on marker-assisted selection and other selection efforts through this project.	Activities are cyclical and occur annually throughout the normal breeding cycles.	Pumphrey will attend/present at numerous WSU field days, workshops/meetings, PNW wheat Quality Council, WSCIA Annual Meeting, 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.	Another year of selection was successfully completed in 2022, with approximately 3000 lines evaluated through the various quality tests. Additional DNA markers for priority traits including test weight were tested and validated for use in our breeding materials. Approximately 1500 lines per year are being genotyped with genome-wide markers for genomic selection.	Return on investment is realized each year, since lines with poor end-use quality are not tested in expensive and capacity-limited field 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 characteristics. 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 our routine breeding efforts. Seedling evaluation of stripe rust resistance and herbicide tolerance screening are also major greenhouse activities.	We continued to use the expanded greenhouse space to our advantage to increase breeding and research materials, make crosses, and conduct experiments.	Greenhouse multiplication and crossing is completed annually, including two large crossing blocks and thousands of breeding lines advanced.	

**Washington Grain Commission
Wheat and Barley Research Annual Progress Report**

Project #: 13C-3019-3687 (55); AWD003580

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, Kimberly Garland-Campbell, Timothy Paulitz*

Executive summary: Dryland farms in eastern Washington experience yield losses due to drought stress and disease pressure from soil-borne pathogens and 2021 was no exception. Improving wheat root structure can help to resist such stresses by increasing access to water as well as selecting for traits that confer tolerance to belowground stresses. Changes in tillage practices have changed the soil structure and pathogen load, altering root-microbiome interactions. Thus, there is an urgent need for understanding and improving both the root system and structure to improve stress tolerance. We found cooler canopy temperatures were associated with better yield under drought and healthier roots suggesting that breeding for more efficient root systems can improve the performance of Washington wheat under drought. Lignin content and accumulation has been linked with different stress tolerances and responses in crop plants because it lends rigidity to plant cell walls and increases in response to drought, heavy metals, salinity, and pathogen attack. Therefore, managing overall lignin content is a key step for generating wheat lines with improved stress tolerance. We have been working to understand how lignin content and deposition in winter wheat roots contributes to stress tolerance. To this end, we study a landrace from Iran called AUS28451 and the winter wheat variety Louise, which have different lignin contents in their root systems. We found that both roots and shoots of AUS contain less S lignin than G lignin, whereas Louise has higher amounts of S lignin. S-lignin is correlated with the ability to breakdown biomass (i.e. more S lignin means plant biomass breaks down more easily). We also performed in silico characterization of the *CAD* and *COMT* gene families that help biosynthesize lignin. We have identified root-specific *CAD* and *COMT* genes and are working to understand how they are regulated in response to stress. In addition, we are running qRT-PCR experiments to determine how lignin genes are expressed in roots in response to different environmental cues and in different varieties. We have also identified *cad* and *comt* mutants in the Kronos background and in a hexaploid wheat line to examine loss of function phenotypes and contributions of the subgenome copies to root architecture and stress responses.

Impact: According to USDA data, farmers in Washington planted 70,000 acres of wheat in 2021, down from 90,000 in 2020 with decreased yields of 2.6 million bushels at an average 38 bushels per acre compared to 6.4 million bushels at 90 bushels per acre in 2020. In years where water is sparse like in 2021, wheat yields can decrease by more than half. Our research goal is to improve the reliance of wheat root systems and understand the contribution of lignin to improved drought and stress tolerance. Certainly, there is a long way to go, but our goal is to help breeders and farmers by understanding the physiological constraints to water movement in wheat and hope to improve resource allocation from roots to the shoots as well as optimize lignin composition and ratios.

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, Timothy Paulitz
Project initiation date: 7/1/2021
Project year (X of 3-yr cycle): 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
1.Examine accumulation of lignin and other aromatic polymers in wheat roots in Louise, AUS28451 and correlate that with stress responses	Determination of the lignin content of shoots versus roots of Louise and AUS28451 as well as other aromatic polymers that may contribute to stress tolerance. We will be able to determine if lignin or potentially another compound contributes to stress tolerance in AUS roots	In year 1, we were able to determine the lignin content in roots and shoots of AUS28451 via a collaboration with Dr. John Ralph at UW-Madison. In year 2, we processed data and determined a repeat analysis was needed to clear up some inconsistencies between repeats. Mainly, aromatic analysis of root tissues is technically challenging.	In year 1, lignin and aromatic analysis was performed in shoot and roots of the parental lines. We performed data analysis on the aromatic profiles and it was determined that we will need to repeat these on independent samples in year 2/3.	We are currently working on two manuscripts, one describing the total lignin analysis pipeline and the other will be a report of the disease resistances and stress tolerance of the lines. A paper was submitted in collaboration with Dr. Smertenko's group and published in 2022 (Hickey et al.; 2022; https://doi.org/10.3390/cells11111765).
2. Identify the CAD and COMT lignin biosynthetic genes in wheat	Since we determined that there is more lignin of AUS root systems, this will enable us to determine which of the CAD and COMT enzymes contribute to lignin content in both wheat roots and shoots. This will then serve as a marker for breeders to assess lignin content.	In year 1, the <i>in silico</i> analysis was performed. In year 2 we designed subgenome specific primers to examine activity of the CAD gene expression. We also grew and harvested roots for RNAseq analysis in roots to assay expression of all CAD genes in normal vs. drought conditions. We also worked on characterization and phylogenetic analysis of CAD and COMT families.	The <i>in silico</i> analysis of the CAD gene family was completed in year 1, whereas, year 2 will focus on the COMT gene family. Molecular follow-up experiments will be run in year 3.	We have drafted a paper for the CAD gene family in wheat are finalizing qRT-PCR data as a final step prior to submission. Characterization of the COMT gene family will occur in year 2/3. We are also working with a review article regarding stress lignin with Dr. Laura Bartley's group in the IBC at WSU. All data will be shared with growers in field day abstracts, articles, and podcasts.
3.Determine the influence of CAD and COMT on root architecture and stress resistance in the Kronos tilling population of wheat	Our data as well as a recent publication in sorghum indicate that there is a link between lignin content, disease responses within the plant and root architecture. Therefore, we will use the Kronos TILLING population of wheat to functionally test the role of mutations in CAD and COMT on stress tolerance and root architecture.	In year 1, mutations in CAD and COMT genes of interest were identified in Kronos. In year 2, the lines were grown out, but there were issues with sterility in some of the lines either from other background mutations or from CAD/COMT. Therefore, the individual mutant lines will be analyzed for stress tolerance and root growth/architectural traits in year 3. As an alternative approach, we used pangenome comparisons to identify a CAD deletion in hexaploid wheat.	In year 1, mutations in CAD and COMT genes were identified and planted in the greenhouse. In year 2, we found much sterility and failed crossing to generate double mutants. Therefore, in year 3, we will focus on individual mutants in Kronos and in a hexaploid wheat line.	Growing Kronos and crossing the mutant lines was attempted in years 1/2. We will therefore examine individual mutants as well as a hexaploid wheat line with a putative CAD deletion in year 3 as well. Our data will be reported in a WheatLife article and prepared for a peer-reviewed publication.

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. Kimberly Campbell, and Xianming Chen

Executive summary: *We updated one software package (GAPIT), released one new software package (ROOSTER), and submitted two articles partially under the 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 has received over 2000 citations, including the breeders at WSU and USDA-ARS. ROOSTER is a software for image labeling and integrating artificial intelligence to detect stripe rust for early fungicide applications (<https://zzlab.net/Rooster>). Rooster integrate both labeling and prediction in a single user-friendly graphic user interface with interactive deep learning to reduce the laborious human labeling for fast development of machine vision systems. Rooster provides fully automatic labeling for abundantly available initial images of wheat stripe rust to gain essential predictability. The navigation of integrating prediction with labeling benefit human adjustment to iteratively improve predictability. Development of detection system for wheat stripe rust was presented as a use case to demonstrate the efficiency of using interactive deep learning to develop machine vision systems. The two manuscripts on the methodology and software implementation are under peer review.*

Impact: *Our collaborative research positions the WSU/USDA-ARS research team as one of 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 benefits Washington but will also benefit the entire world through the dissemination of knowledge. In short term, breeders can conduct the most of data analyses without frustration on data formatting and selecting different analytical functions. They have more opportunities to find the causative 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, Kimberly Campbell, and Xianming Chen*
Project initiation date: 1-Jul-21
Project year: 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
2) Develop Drone-based Stripe Rust Assessment	A drone based computer system to evaluate wheat stripe rust.	We have collected field images using drones during the peaks of stripe rust for two years. With these images and the annual stripe rust scores, we have developed an efficient methods to generate labels to artificial intelligence models to predict stripe rust.	December 31, 2022: Collect images over three years to train models to predict stripe rust scores from images; June 30, 2023: A drone based computer system to evaluate wheat stripe rust.	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