Washington State University Wheat and Barley Research Progress Reports

2023-2024 Fiscal Year

2023-24 WSU Wheat & Barley Research Progress Reports to the Washington Grain Commission

Washington Grain Commission
2023 Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: *3019-3200*

Progress Report Year: *3 of 3*

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

PI: Robert Brueggeman

Cooperators Clark Neely, Max Wood, Xianming Chen, Deven See

Executive summary The Washington Grain Commission research funds were integral for the program's applied breeding efforts to meet the goals of developing and maintaining a world class barley breeding program. The program's major focus is the development of widely adapted spring and winter adjunct and craft malt barley varieties that make the American Malting Barley Association (AMBA) recommended list. To meet this goal, genetic, genomic, gene discovery and functional analysis research is utilized to fill knowledge gaps that leverage and enhance our breeding efforts. Additionally, this basic research is also applied to the development of biofortified hulless food varieties, and high yielding feed and forage barley varieties.
With the last three years of WGC funding, I focused on enhancing the genetics in the program to address deficiencies in malt and nutritional quality. The quality issues present in the program have been overcome by the introduction of new genetics through hundreds of crosses with elite malt and food barley lines collected from worldwide sources. Now that we have diverse quality genetics introgressed into the program we can continually focus on using genetic and genomic analysis, quality data and agronomic performance across environments to identify adapted experimental lines as parental materials for continual gains on quality, wide adaptability, and ultimately yield across diverse environments. We were fortunate to secure funding from the WGCto establish the state-of-the-art WSU Malt Quality Lab (WMQL) which allows for the generation of malt and food barley quality data on our experimental lines as they come off the field. We continue to innovate and evolve to add new capabilities in the WMQL. Now that we have addressed the quality issues in our WSU germplasm, we have four promising experimental lines (20WAM-248, 20WAM-487, 20WAM-721, and 20WAM-783) that were entered into the WSU and University of Idaho variety testing trials and AMBA pilot testing program in 2023 and we expect to release one or more as WSU malt barley varieties based on the AMBA and variety testing results in 2024. Thus, the timely WMQL malt quality data allows for intelligent early generation selection and high-quality data for late generation determination of lines to enter the variety testing trials and the AMBA testing program.

Introduction Washington state farmers harvested ~84 thousand acres (Ka) of barley in 2023, 40% more than 2022, ranking fourth in the nation behind; 1) Montana (1.015 Ma), 2) North Dakota (570 Ka), and 3) Idaho (540 Ka) (https://www.nass.usda.gov). As the WSU barley breeder my program is focused on applied research toward variety development and fundamental research that leverages breeding to enhance barley as a viable choice for producers and promote a positive trend in Washington barley acreage. Barley is an attractive option in rotation after winter wheat when consistent high yields are achieved and quality demand premium prices. However, when I began as the WSU breeder the goal was to transition the program to a malt barley breeding program, yet it became apparent that malt quality genetics were lacking in the germplasm coming down the pipeline. To meet this goal we introduced new genetics into the program, developed molecular and quality analysis infrastructure to expedite spring and winter malt, feed, food, and forage varieties release with wide adaptability to achieve consistent yield and quality across variable years and environments. The benefits of barley in rotation will also be achieved by the introgression of IMI tolerance into all classes of barley to insure productivity in rotation after IMI-resistant wheat.

Approach We continue to utilize traditional breeding techniques to combine positive genetic loci for traits of interest including malt quality, yield, and disease resistance in both spring and winter lines as well as winter hardiness and seedling vigor in winter lines. We use a modified pedigree breeding scheme that utilizes single-seed descent to advance spring and winter barley populations. We have revamped the breeding procedure in 2023 to include early generation selection of ~100,000 single early generation plants from 100 crosses a year which will allow us to evaluate much larger numbers of crosses and early generation progeny for agronomic traits including yield, standability, height, tiller numbers, winter survival and seedling vigor. Following this early generation visual selection, the reduced number of individuals can then be screened with molecular markers for malt and food quality. Incorporating this early generation selection with molecular markers targeting malt and food quality, disease resistance, and agronomic traits expedites early generation selection for the identification and advancement of superior genotypes through the breeding cycle. In the last three growing seasons 288 elite WSU malting lines were selected and sequenced with the 50k Illumina bead express single nucleotide polymorphism (SNP) chip. This 50 thousand marker panel allowed for high marker density to identify positive malt quality loci in our breeding program utilizing genome wide association studies (GWAS). From these identified marker trait associations, we are developing the Oxford Nanopore MinION DNA sequencing technology to genotype early generation material for marker assisted and genomic selection. This infrastructure fulfilled our needs of a fully integrated spring malt barley breeding program that will also be utilized in the winter malt barley, spring food barley, spring feed barley and spring forage barley selection processes as we advance progeny from crosses made for these different market classes in the program.

Results From the genetic, quality, and agronomic analysis of thousands of experimental lines multiple genotypes have been identified that meet AMBA quality parameters for the first time in the program. Four of these promising lines (20WAM-248, 20WAM-487, 20WAM-721, and 20WAM-783) were entered into the WSU and University of Idaho variety testing trials in 2023. The lines 20WAM-721 and 20WAM-783 outperformed the yield and malt quality check ACC Connect for average yield across rainfall zones. All four experimental lines were entered into the AMBA pilot testing program in 2023 and we expect to release one or more as WSU malt barley varieties based on the AMBA and variety testing results in 2024.

Impact We now have the genetics, quality phenotyping and genetic and genomic analysis infrastructure in place to establish and maintain a world class barley breeding program. Now we have an excellent pipeline of experimental barley lines coming down the pipeline for consistent gains on quality and yield for the release of excellent WSU barley varieties with measurable gains on the current varieties being produced.

Outputs and Outcomes:

Peer-Reviewed Publications (17 total) and Book Chapter (1 total):
Published, Accepted or Submitted between January 1, 2023 – December 31, 2023

1. Richards, J.K., Li,. J., Koladia, V., Wyatt, N.A., Rehman, S., **Brueggeman, R.S.**, and Friesen T.L. (**2023**) A Moroccan *Pyrenophora teres* f. *teres* population defeats the *Rpt5* broad-spectrum resistance on barley chromosome 6H. *Phytopathology*, (submitted) https://doi.org/10.1094/PHYTO-04-23-0117-R

2. Karki, M., Chu, C., Anderson, K., Nandety, R.S., Fiedler, J., Schachterle, J., **Brueggeman, R.S.**, Liu, Z. and Yang, S., (**2023**). Genome-wide association study of host resistance to Hessian fly in barley. *Phytopathology*, https://doi.org/10.1094/PHYTO-06-23-0192-R

3. 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).

4. Ellur, V., Wei, W., Ghogare, R., Solanki, S., Vandemark, G., **Brueggeman, R.**, & Chen, W. (**2023**). Unraveling the genomic reorganization of polygalacturonase-inhibiting proteins in chickpea. *Frontiers in Genetics*, *14*, 1189329-1189329.

5. Effertz K., Del Castillo, M., **Brueggeman, R.S.** (**2023**) First report of *Epicoccum nigram* causing barley leaf spot disease in North America. *Plant Disease* (Accepted).

6. 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.** (**2023**) *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* (Accepted).

7. Alhashel, A.F., Fiedler, J.D., Nandety, R.S., Skiba, R.M., **Brueggeman, R.S.**, Baldwin, T., Friesen, T.L., and Yang, S. (**2023**) Genetic and physical localization of a major susceptibility gene to *Pyrenophora teres* f. *maculata* in barley. *Theoretical and Applied Genetics* 136(5):118. doi: 10.1007/s00122-023-0436-1

8. Craine, E.B., Choi, H.M., **Brueggeman, R.S.**, Schroeder, K., Esser, A., and Murphey K.M. (**2023**) Spring barley malt quality in eastern Washington and northern Idaho. *Crop Science* https://doi.org/10.1002/csc2.20924

9. Clare, S.J., Oguz, A.C., Effertz, K., Karakaya, A., Azamparsa, M.R., and **Brueggeman, R.S.** (**2023**) Wild barley (*Hordeum spontaneum*) and landraces (*Hordeum vulgare*) from Turkey contain an abundance of novel *Rhynchosporium commune* resistance loci. *Theoretical and Applied Genetics* 136.1:15. https://doi.org/10.1007/s00122-023-04245-w

10. 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. (**2023**) 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

11. Poudel, R.S., Belay, K., Nelson Jr, B., **Brueggeman, R**. and Underwood, W. (**2023**) Population and genome-wide association studies of Sclerotinia sclerotiorum isolates collected from diverse host plants throughout the United States. *Frontiers in Microbiology*, *14*.

12. Parajuli, A., **Brueggeman, R.**, Wagner, S., Warburton, M., Peel, M., Yu, L., See, D. and Zhang, Z., (**2023**) Linking Phenotypes to Protein Characteristics in 3D Structures Predicted by Alphafold.

13. Parajuli, A., **Brueggeman, R.**, Wagner, S., Warburton, M., Peel, M., Yu, L., See, D. and Zhang, Z. (**2023**). Bulked Target Capture Sequencing Identified Numerous Genetic Loci Associated with Alfalfa Growth Vigor During Inbreeding.

14. Tang, Z., Wang, M., Schirrmann, M., Dammer, K.H., Li, X., **Brueggeman, R.**, Sankaran, S., Carter, A.H., Pumphrey, M.O., Hu, Y. and Chen, X. (**2023**) Affordable High Throughput Field Detection of Wheat Stripe Rust Using Deep Learning with Semi-Automated Image Labeling. *Computers and Electronics in Agriculture*, *207*, p.107709.

15. Li, J., Wyatt, N.A., Skiba, R.M., Kariyawasam, G.K., Richards, J.K., Effertz, K., Rehman, S., **Brueggeman, R.S.** and Friesen, T.L. (**2023**) Pathogen genetics identifies avirulence/virulence loci associated with barley chromosome 6H resistance in the *Pyrenophora teres* f. *teres*–barley interaction. *bioRxiv*, pp.2023-02.

16. Upadhaya, A., Upadhaya, S.G.C., and **Brueggeman, R.** (**2023**) Identification of Candidate Avirulence and Virulence Genes Corresponding to Stem Rust (*Puccinia graminis* f. sp. *tritici*) Resistance Genes in Wheat. *Molecular Plant Microbe Interactions* (Accepted).

17. Massman, C., Hernandez, J., Clare, S.J., Brooke, M., Filichkin, T., Helgerson, L., del Blanco, I.a., Rouse, M.N., Steffenson, B., **Brueggeman, R.**, and Hayes, P. (**2023**) Registration of the Woodies Multi-Rust Resistant Barley Germplasm. *Journal of Plant Registration* (Accepted).

Book Chapters:

1. **Brueggeman, R.S.** (**2023**) Barley; *6th edition of Agrios: Plant Pathology* (In Press)

WGC project number: 3019-3200
WGC project title: Improving Spring and Winter Barley Varieties for Malt, Feed and Food
Project PI(s): Robert Brueggeman
Project initiation date: July 1, 2021
Project year (3of 3-yr cycle):

Objective	Deliverable	Progress	Timeline	Communication
1	Progress towards the release of an adjunct malting barley cultivar suited for adjunct brewing with a malt profile that meets AMBA recommendation.	One advanced two-row malt barley has met or exceeded AMBA checks for adjunct malting in two years of testing. This line also outperformed ACC Connect in three rainfall zones in WSU and U of I variety testing. We also have a consistent pipeline of lines that met AMBA malt quality criteria with high yields, significant gain on ACC Connect, that will be entered into WSU and U of I variety testing and the AMBA testing program.	2024	Talks and presentations at field days; distribution of informative variety rack cards; Wheat Life articles; Pod Casts
1	Progress towards the release of a craft malting barley cultivar suited to craft all malt brewing with a malt profile that meets AMBA recommendation as well as lines with excellent quality that don't quite meet AMBA recommended parameters yet will perform well in craft malting, brewing and distilling.	Two advanced two-row malt barley haves met or exceeded AMBA checks for all malt brewing in two years of testing. One of the two line also outperformed ACC Connect in three rainfall zones in WSU and U of I variety testing. We also have a consistent pipeline of lines that met AMBA all malt quality criteria with high yields, significant gain on ACC Connect, that will be entered into WSU and U of I variety testing and the AMBA testing program..	2024	Talks and presentations at field days; distribution of informative variety rack cards; Wheat Life articles; Pod Casts
2	Progress towards the release of WSU winter malting barley varieties that meet AMBA recommended adjunct and all malt brewing specifications.	Two advanced two-row winter malt barley lines have met or exceeded AMBA checks for all malt brewing in two years of testing. The lines which were provided by Dr. Pat Haye's OSU program for testing also outperformed Thunder in the mediun (16” – 20”) rainfall zone in 2023 WSU variety testing. These lines will continue to be entered into variety testing and entered into the AMBA pilot testing program once we have adequate yield and quality data from sufficient site years. We also have hundreds of lines continueing down the pipeline from crosses made with selected parents for quality, yield, winter survival and seedling vigor in replicated yield trials.	2024	Talks and presentations at field days; distribution of informative variety rack cards; Wheat Life articles; Pod Casts
3	Progress towards the release of IMI-tolerant barley varieties with high yield and excellent disease resistance to complement Survivor. This could also be in the food or malt market classes.	We had hundreds of known IMI-tolerant barley lines in our breeding pipeline, yet yield testing did not warrant release. We have made crosses of selected parental material containing the IMI-tolarance gene into high yielding feed, malt, food and forage lines that will continue to undergo greenhouse and field trials as well as yield trials to identify the superior lines for release and breeding parents.	2024	Talks and presentations at field days; distribution of informative variety rack cards; Wheat Life articles
4	Progress towards the release of hulless, waxy food barley varieties to compliment non-waxy high beta glucan varieties Havener and Meg Song	Crosses have been made and hundreds of hulless, waxy, high Beta-glucan lines with high micronutrient accumulation are being selected. Some of the hulless, high Beta-glucan breeding lines performed well in single rep trials and will be included in advanced yield trials and quality analysis completed.	2024	Talks and presentations at field days; distribution of informative variety rack cards; Wheat Life articles; Pod Casts

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

Project #: **AWD005358**

Progress Report Year: **1 of 3**

Title: **Herbicide Resistance Monitoring in Eastern Washington Wheat**

Researcher(s): **Ian C. Burke**

Cooperators:

Executive summary: In 2022, a collection of downy brome was completed, and a survey of prickly lettuce and Russian thistle was completed in 2023. We will focus on mayweed chamomile and Italian ryegrass in 2024. We also continue to test farmer and consultant submitted samples. The herbicide resistance testing program continues to receive new samples and new kinds of resistance – to date 8 novel types of herbicide resistance have been identified that were previously unknown, including Russian thistle and downy brome resistant to glyphosate. In 2023, we identified two biotypes of downy brome potentially resistant to Aggressor herbicide, widespread Maverick and Powerflex resistance, a much higher incidence of imazamox and glyphosate resistance than expected, and we also identified the first case of multiple resistant downy brome – resistant to both glyphosate and Group 2 herbicides. Resistance testing and our outreach efforts have raised awareness that leads to incorporation of integrated strategies and more rapid responses to issues as they arise, which will lead to longer term system sustainability.

Introduction: Monitoring key weed species for herbicide resistance is a critical component of integrated weed management. The size of the region and the variety of problematic weed species means that we must focus on only a subset species each year. Testing submitted farmer-submitted samples for resistance often results in bias or overestimation of a resistance issue in a region. Samples collected from a randomized array of points from a large number of farms willing to participate would mitigate bias in the collection and facilitate an assessment reflective of the actual resistance situation for common weeds in eastern Washington.

Approach: Testing submitted farmer-submitted samples for resistance often results in bias or overestimation of a resistance issue in a region. Samples collected from a randomized array of points from a large number of farms would mitigate bias in the collection and facilitate an assessment reflective of the actual resistance situation eastern Washington. Each field sampled will be assessed by entering the field and walking a large M shaped pattern. Approximately 20 plants of the targeted weed will be collected if present. The seeds will be allowed to after-ripen, and then are grown and tested for resistance to commonly used herbicides for their control.

Results: In 2022, a collection of downy brome was completed, and a survey of prickly lettuce and Russian thistle was collected in the summer and fall of 2023. Screening of the downy brome collection was completed in 2023. We identified two biotypes of downy brome potentially resistant to Aggressor herbicide, widespread Maverick and Powerflex resistance, a much higher incidence of imazamox and glyphosate resistance than expected, and we also identified the first case of multiple resistant downy brome – resistant to both glyphosate and Group 2 herbicides. We have purchased a new phenotyping tool to allow us to collect digital biomass instead of more traditional methods, which should increase throughput of the testing program. Herbicide resistance in weeds is likely to only increase, as we are continuing to use the same active ingredients year after year. Testing for resistance will ideally be an integrated part of a management system.

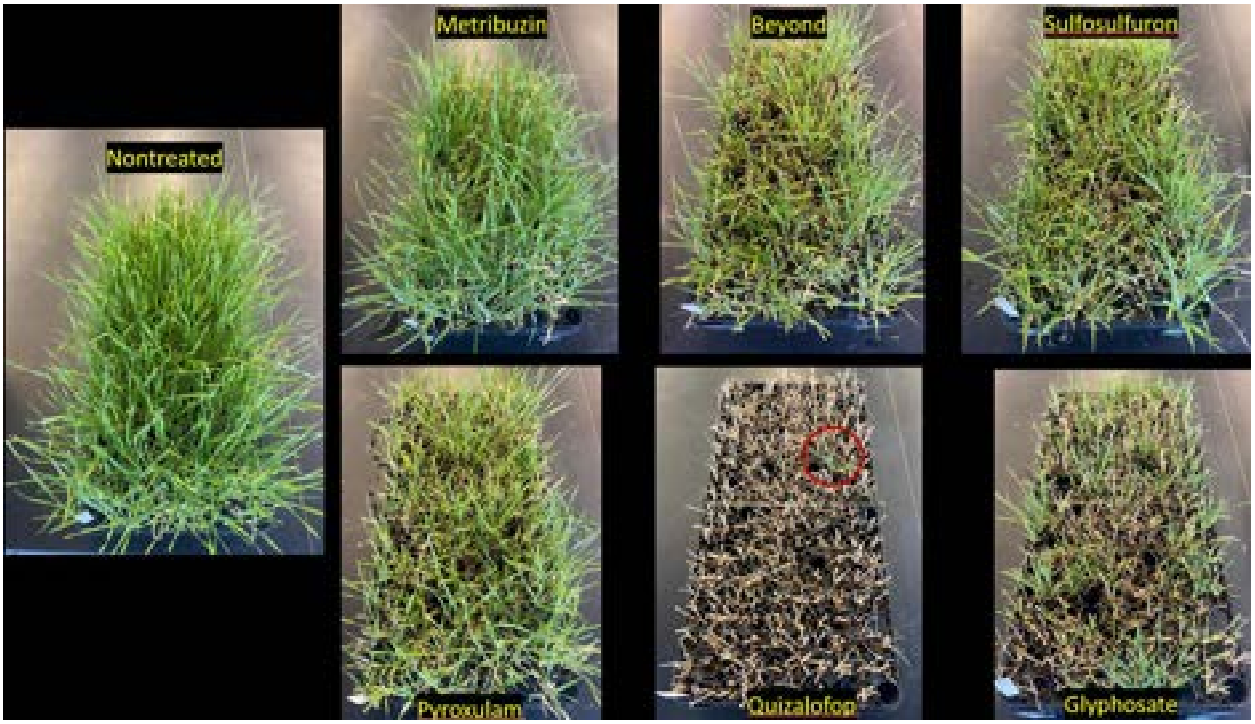


Figure 1. Example responses of downy brome biotypes to applications of metribuzin, Beyond, Maverick (sulfosulfuron), Powerflex (pyroxsulam), and Aggressor/Assure II (quizalofop), and glyphosate. Each individual plant is from a different wheat field.

Impact: Reporting of resistance occurs through extension presentations, bulletins, podcasts, and through the smallgrains website. Short term impacts include regular and frequent updates on our knowledge of herbicide resistance in important species in Washington. Longer term, farmers, agronomists, and consultants in the PNW are, in general, aware of herbicide resistance and typically respond by seeking to test weeds or by thoughtfully modifying their cropping system to improve management outcomes. Agronomists and consultants in the region have indicated to us that awareness generally leads to open conversations about incorporation of new techniques or formulation of long term management plans. Ultimately, the resistance testing and our out reach efforts has raised awareness that leads to incorporation of integrated strategies and more rapid responses to issues as they arise, which will lead to longer term system sustainability.

WGC project number:AWD005358
WGC project title: Herbicide Resistance Monitoring in Eastern Washington Wheat
Project PI(s): Ian C. Burke
Project initiation date: July 1, 2023
Project year (3 of 3-yr cycle): 1

Objective	Deliverable	Progress	Timeline	Communication
1) conduct a regional survey of resistance in mayweed chamomile and Italian ryegrass using standard methodology.		Statewide screening of downy brome using 2400 assessions from a total of 80 sites in WA occurred in 2022 and 2023. Downy brome was screened for resistance to the main herbicides used in winter wheat systems in the PNW (sulfosulfuron, pyroxulam, quizalofop, imazamox, glyphosate, and metribuzin). Many genotypes were found to be resistant to group 2 herbicides and these herbicides are inefficient for downy brome control at sites where downy brome was collected from. Genotypes with multiple herbicide resistance were found in the process as well as genotypes resistant to glyphosate. A single genotype from most likely CoAXium wheat systems was found resistant to Assure II (group 1) herbicide.	Initial screening was completed in 2023/23.	Annual weed control report, extension articles (WSU Timely Topic), annual meetings.
		Statewide collection of Russian thistle occurred in the fall/winter of 2023. Similar to Downy Brome, 80 sites were visited and the same screening process will occur in the spring/ summer of 2024. We collected seed bank samples from each site at the time of plant collection. These samples are stored in the freezer and will be processed to assess seed bank across WA state. The same collection of Prickly Lettuce is planned for the summer of 2024.	Collection was completed in 2023 and screening is going to be completed in the year of 2024	Annual weed control report, extension articles, annual meetings.

2. Operate a high-throughput herbicide resistance testing program for weeds in wheat.	Rapid reliable program to test weeds for herbicide resistance.	Two methods have been used: Genetic testing, and herbicide efficacy (spraying). Herbicide efficacy: 297 biotypes have been received, given an identification number, entered into a spreadsheet, and have (or will) undergone an initial screening for possible plant tolerances/resistance to screened herbicides. After satisfactory data is collected from an initial screening, the biotypes are than given a dose response of up to 128X the recommended rate. A report of procedure and results are than written up and delivered to the submitters. Methods for screening have been developed so all biotype undergo the same testing in a timely manner. We have also created methods to help deal with downy brome dormancy. The primary weeds tested are currently downy brome, wild oats, Italian ryegrass, common windgrass, and some broadleaf weeds. We recieve approximatley 15 - 30 new biotypes each year.	Continue refining methods. Research has emphasized important herbicide resistance cases, including glyphosate resistant Russian thistle, downy brome, and kochia, as well as Beyond resistant jointed goatgrass and clopyralid resistant mayweed chamomile. Rapid tests have been devised for older well know resistance cases, but are relatively more expensive compared to spraying. Aims to rapidly collect DNA and screen for specific resistances remain a goal of the program. The turnaround time for sample processing has continued to decrease, with submitters receiving results within 6 months of submission, or faster if requested. Advances in experimental methods have allowed us to overcome seed dormancy and increase sample	Journal articles; articles in Wheat Life, trade magazines and/or posted to WSU smallgrains website; winter Extension meetings. Interview on the WSU WheatBeat Podcast. Submitters receive full report for all samples submitted.

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

Project #: **AWD0001471**

Progress Report Year: 2 of 3

Title: **Weed Management in Wheat**

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

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

Introduction: Weed Management in Wheat facilitates non-biased research on new weed management products or approaches. The research will focus on control of difficult to manage weeds, rotational restrictions, variety tolerance and other aspects deemed necessary based on our expertise and through grower interaction. Trials and protocols will be determined cooperatively with public and private sector scientists and most importantly, with farmers. Improved management will be realized through new and expanded herbicide labels, more effective application timings, improved herbicide application technology, increased knowledge of the biology and ecology of the weeds, or other management practices.

Approach: Studies will be conducted on WSU Research Stations and in cooperating grower fields. Studies will be conducted in the low, intermediate, and high rainfall areas. Control of Italian ryegrass, downy brome, Russian-thistle, prickly lettuce, rush skeletonweed, smooth scouringrush, and mayweed chamomile will be the primary research focus, but work will also be conducted on other weed species in wheat, chemical fallow, or under land use that represents a source for infestation to wheat fields. The research will focus on weed control, herbicide resistance management, rotational restrictions, variety tolerance and other aspects deemed necessary. The exact number of trials and specific protocols will be determined cooperatively with public and private sector scientists and growers. Research into the biology of weeds and their interaction with crops will continue in an effort to identify more effective herbicide application timings and perhaps identify cultural methods for weed control, particularly for downy brome, rattail fescue, Italian ryegrass, and mayweed chamomile. Emphasis will be placed on minimizing crop-weed competition and developing a database for a decision support system based on economic loss and cost of control. Information from herbicide trials will be used to design integrated crop management research and Extension activities.

Results:

- The project continues to generate data and local guidance and new uses for various agrichemical companies to assist them in labeling their new herbicide products for weed control in wheat. Drs. Burke and Lyon are working with new herbicides from Corteva, Bayer, FMC, Valent, and Helm and well known herbicides from Syngenta, Albaugh and Gowan.
- A number of farmer driven projects were continued in the new cycle, including management of rush skeletonweed and Russian thistle in fallow and post harvest, management of scouringrushes in wheat, use of weed sensing sprayers in fallow, evaluation of preemergence herbicide systems for downy brome and Italian ryegrass control.
- Dr. Lyon continued to publish extension output in the form of webcasts and extension bulletins based on our research. Both Dr. Lyon and Dr. Burke regularly present at extension functions throughout the year.
- The yearly Weed Management report includes an array of research focused on small grains and critical rotational crops in Washington.

Impact: The WSU Weed Science Program impacts small grain 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 farmer faces, and using the most economical and effective treatment will improve the net income and long term sustainability of any operation. Weed losses due to weeds without weed management would likely exceed $200M per year.

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: 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
Evaluate herbicides	Efficacy and crop injury data to support use recommendations, new labels, and label changes to benefit WA small grain growers.	The 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/
		Finesse herbicide is effective for smooth scouringrush control when applied late spring in fallow; however, applications at other times may fit better in certain management strategies. Finesse is labeled for application anytime in fallow including just before fall seeding, and after one leaf but before the boot stage in wheat and barley. Smooth scouringrush stems usually begin emerging in May and persist until freezing temperatures in the fall. Therefore, it is possible that late fall or early spring applications of Finesse would be applied when smooth scouringrush is not present or not actively growing and the efficacy of these timings is unclear. It appears that preplant foliar Finesse applications in the fall can reduce smooth scouringrush density the following year, and it is important to apply to green standing stems. It is too early to determine the efficacy of the spring applications in the crop, but all treatments will be reevaluated in 2024.	This project will be completed in 2024.	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. Indaziflam controls downy brome up to 2 years after application at rates up to 3 oz/A. We plan on assessing the downy brome seedbank in response to indaziflam compared to a typical wheat fallow system.	This project will be completed in 2024.	Annual weed control report, extension publications, extension meetings and field days, and refereed journal articles

		Chemical fallow is used in reduced-tillage or no-till cropping systems to protect soil from erosion; however, control of ongoing flushes of Russian thistle through the summer requires repeat herbicide applications. Glyphosate is a common herbicide for weed control in fallow, but it has no soil residual, and repeat applications are often required. Herbicides with some soil residual could reduce the number of repeat applications, providing the herbicide is effective on Russian thistle. Timing of application and soil activity of the herbicide are important factors in Russian thistle control in chemical fallow. Early applications with herbicides with little or no soil activity will not control subsequent flushes. Later applications may have the potential to be effective if they include tank-mix partners that are effective on larger plants, but larger plants also have had time to deplete soil moisture.	This project will be completed in 2024.	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
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 B. tectorum and how self-fertilization impacts the ability of Downy Brome to invade new environments. We are now working on developing CRISPR in downy brome to directly study individual genes involved in dormancy, germination, and flowering time.	A large downy brome panel was phenotyped for flowering time. Initial analyses indicate that flowering time is highly heritible, 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.	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. In 2023, the Italian ryegrass infestation was such that the Cook Farm had to be rotated to winter pea to use Kerb. The herbicide was effective, and no Italian ryegrass germinated. We collected seedbank samples this year and will do so again in 2024 to assess the effect of this novel rotation on Italian ryegrass seedbank longevity.	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.

Project #: GR000010090. AWD 004416

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

Title: *Club wheat Breeding*

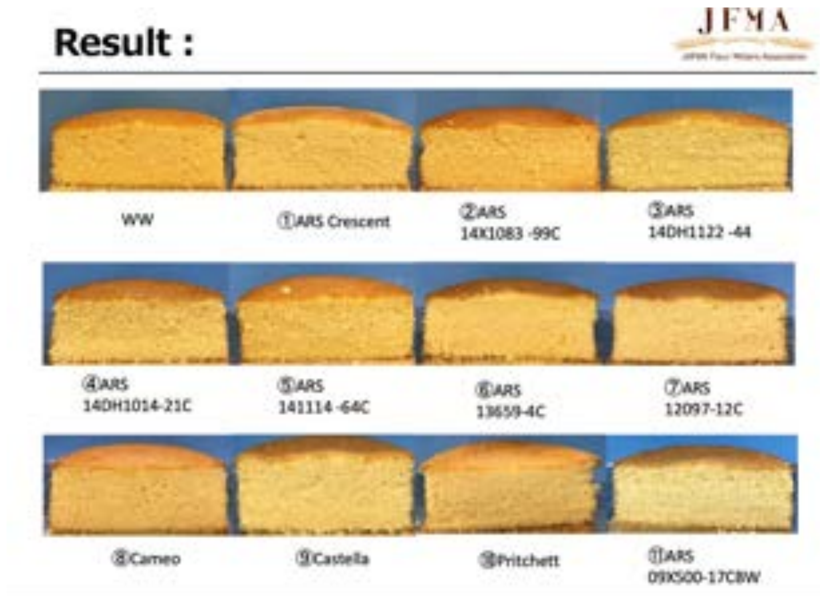
Cooperators: *Arron Carter, Michael Pumphrey*

Executive summary: Registered seed of Cameo club wheat was harvested in 2023. Cameo is targeted to the higher rainfall production region with 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. In addition, a club-COAX trial was planted at Hartline WA with breeding lines that were created by the WSU Winter wheat program. In the fall of 2023, we expanded our testing in the traditional club wheat growing area with new yield trials at Hartline with cooperator Ryan Poe and Almira with Highline Grain. We now have trials at 12 locations in Washington, Idaho, and Oregon.

Introduction: Club wheat is a superior quality product with an established demand that is uniquely grown commercially in the Pacific Northwest (PNW) of the US. Club wheat has a market in Japan and other countries in Asia. A premium is often required for the product because of the limited supply. In the market, club wheat is mixed in a 10-20% blend with PNW soft white wheat and sold as Western White. Club wheat has been selected to have soft textured flour with high flour milling extraction and clean separation from the bran, desired for fine-textured baked projects. Club wheat is remarkable for its consistent functionality, achieved by few other wheat classes, because most cultivars are developed from a single breeding program, the USDA-ARS program based in Pullman. This project is critical to meet the demand for new club wheat varieties that are agronomically competitive with alternatives market classes.

Approach: Each year approximately 300 crosses are made at the WSU plant growth facility for club wheat improvement. The best lines in the USDA club wheat program are intercrossed to combine traits and crosses are also made to lax soft wheat from the PNW and other regions for genetic diversity. Initial generations are advanced to the F4 using 'mini-bulks' in the PGF which enables us to select for club head type. Field selection in head rows is conducted for plant type and disease resistance. Marker assisted selection and selection for end use quality is initiated at this stage. The best 10% of those selections are entered in yield plots at Pullman and Lind and then at multiple locations. Genomic selection is incorporated in decisions at this point. In 2023 we expanded our testing footprint in the traditional club growing area of central WA. We now evaluate elite trials, comprising 96 entries, at 12 locations.

Results: 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 was proposed for release but it was decided to hold it so that our last release 'Cameo' could find its place in the market. We evaluated 79 IMI-resistant breeding lines in yield trials at Lind and Spillman and in sprayed trials at Lind. These lines were derived by crossing our best quality club wheats with Piranha CL+, Stingray CL+ and an Oregon CL+ breeding line and 37 or these were advanced to our multilocation trials at 12 locations. We evaluated resistance to snowmold, stripe rust, eye spot, and aluminum in dedicated stress trials and evaluated resistance to Cephalosporium stripe in collaboration with Chris Mundt at OSU, Brett Carver at OK State. We rated our upper-level breeding lines for tolerance to alpha amylase using the Phadebas enzyme assay in collaboration with the Steber and Thompson labs. Our mid-level breeding lines were evaluated for cold tolerance using the artificial freeze test. We sent 12 samples to the Japanese Flour Millers Technical Exchange for full mill and bake analysis. These included a sample of Western White and ARS Crescent, Cameo, Castella ad Pritchett as checks. All samples met expectations and several scored better than the ARS Crescent check for Mill score, cake volume, and mouthfeel texture (see figure).



Impact: Club wheat represented 4% of total soft white wheat production in Washington in 2023, comprising 75,373 acres for winter club and 8,890 acres for spring club. Castella was planted on 32,147 acres, and Pritchett on 33,828 acres. ARS Crescent (8,089 acres) and Coda (1,310 acres). All of these lines were released by the USDA breeding program, with the support from this project.The spring clubs are created by the WSU Spring wheat breeding program. Hedge Cl+ was on 3462 acres, JD on 3072, and ‘Melba’ on 2,357 acres. Club wheat production is sensitive to the carryover and premium. The current premium is between $0.25 and $0.50 per bushel, which 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. 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:

WGC Research Review, Feb 15, 2023
Plot tour, Pullman June 28, 2023
Japanese Trade Team, Aug 14, 2023
Wheat Academy, Dec 12, 2023

WGC project numb 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): 2

Objective	**Deliverable**	**Progress**	**Timeline**	**Communication**
Club wheat cultivar development	New populations for 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 2023 winter wheat variety trials. IMI-club breeding lines selected for agronomic performance at Spillman and Lind WA and advanced to multi-location testing in 2024. Registered seed of Cameo club wheat produced. The Japanese Flour Millers Association evaluated 10 club wheat samples including advanced breeding lines and found them to be acceptable and of good quality. In 2024, we decided to add two locations in the dryer 'traditional' club wheat growing region, Hartline adn Almira. We discontinued our trails at Walla Walla.	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 2023 using Phadebas assay. This technology is giving us an early warning for susceptibility to conditions that result in low falling numbers.	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 condcted for disease resistance, end use quality, nutritional quality.	Head rows for entire breeding program evaluated at Waterville and Mansfield for snow mold resistance an at Lind for emergence. Crosses made with soft breeding lines from PNW and eastern wheat breeding programs. Backcross populations advanced using minibulks. Marker assisted selection used for diseae resistance and end use quality.	2022-2025	Presentation at Research Review. Peer reviewed publications. Shared with regional breeders.

Project #: GR00010236. AWD004480

Progress Report Year: __2__ *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:
The freezers were serviced and re-calibrated in late 2022 which greatly improved the reliability and reproducibility of the screening. W screened 400 winter wheat breeding lines from the WSU Winter Wheat Program. We also screened 128 Soft and Hard Winter wheat lines and 58 hard and soft spring wheat lines from the Washington Variety Trials. Data was returned to the breeding program and included in the Small Grain Variety Selection tool. We conducted several trials to determine the correct temperature to screen winter barley breeding lines and are in the process of evaluating those lines now.

Introduction: Winterkill continues to be a major cereal production risk in the Pacific Northwest and globally. Winter injury affects winter cereals throughout their growing area in the PNW, especially under variable snow cover. Increased winter rain and decreased snow cover leaves crops more vulnerable to sudden temperature drops. The crop is especially vulnerable to winter injury in early and in late winter. In 2013 and 2021 we experienced winter kill in late November, before the crop was adequately acclimated. Sudden temperature swings in February and March damaged the crop in Washington in 2014, 2015 and 2017, 2019 and 2020 and are a problem in parts of the wheat growing region every year.

Approach: Screening for winter hardiness in the field is difficult because winterkill varies across a field. Therefore, we have developed artificial freezing trials at the WSU Plant Growth Facility that are correlated with winter injury in the field. Seedlings are germinated and exposed to 4^{o}C for 5 weeks for acclimation, then placed in a programmable freezer cabinet. The temperature is dropped to -3 ^{o}C, held for 16 hours, then dropped to the target temperature (-12 to -14 ^{o}C), held for 1 hour, and gradually increased back to 22^{o}C. Check cultivars ‘Eltan’ (resistant), ‘Norstar’ (resistant) and ‘Stephens’ (susceptible) are included in each run of the test as controls. Seedlings are moved to a growth room and survival is rated after three weeks. Spring wheat and. Barley are tested the same way with higher target temperatures (-7 to -9 ^{o}C).

Results: Over 200 wheat lines were evaluated at -13 ^{o}C in 4 replications in 2023. Spring wheat lines were evaluated at -9 ^{o}C but most lines did not survive. We will evaluate spring wheat lines at -7 and -8 ^{o}C next year to obtain more information about their relative survival. Winter barley checks were evaluated at -12, -9, -8 and -7 ^{o}C. Based on these results we decided to evaluate the winter barley breeding lines at -7 and -8 C and are doing that now.

Impact:

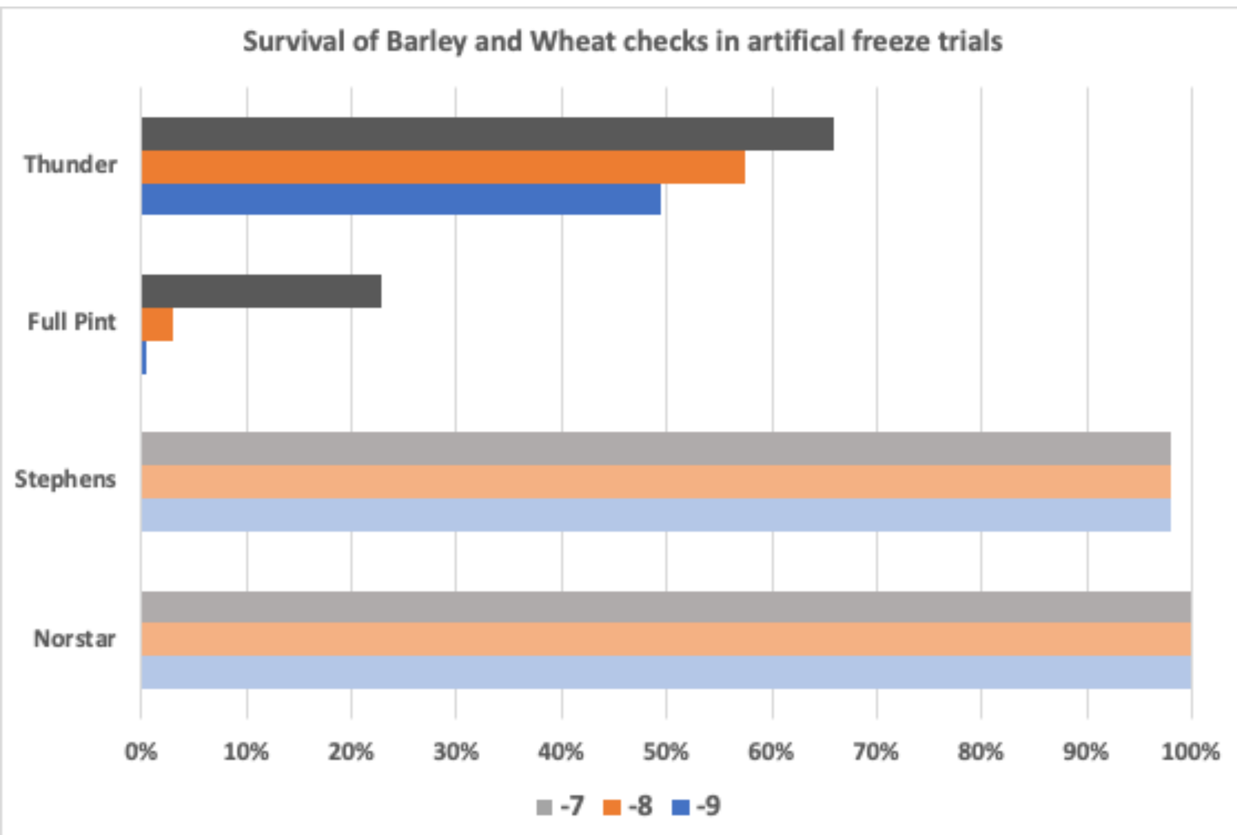
- The data from these cold tolerance trials is available in the small grains variety selection tool and by request.

- 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.
- Methods developed for this project are being used to evaluate cold tolerance of pulses, pennycress, and brassicas.
- Publications:

Garland Campbell, K. 2003. What's up with winter wheat? How plants survive, thrive during cold. Wheatlife Vol. 66(02) pp 51-53.

Oates, D. 2003. Identification of key cold-response determinants in Triticum aestivum: Elucidating the interaction between vernalization and photoperiod for cold temperature acclimation. Annual Meeting North American Plant Breeders, July 16-20. Greenville SC. Poster P-006.

Figures and Tables:



Percent Survival of Major Wheat Cultivars from the WA Cereal Variety Trials in Artificial Freezing Trials, over 4 Replications at the WSU Plant Growth Facility, 2023.

Winter Wheat				Spring Wheat	
Winter Wheat Test Temp: -13 °C				**Spring Wheat Test Temp: -9 °C**	
Name	**Percent Survival**	**Name**	**Percent Survival**	**Name**	**Percent Survival**
Soft White		**Winter Club**		**Hard Red**	
Piranha Cl+	95	Pritchett	65	WB9668	0
Norwest Tandem	61	Castella	54	AP Venom	63
VI Voodoo Cl+	1	ARS Crescent	93	WB9662	43
LCS Shine	35			Kelse	3
TMC M-Press	29	**Hard Red Winter**		Alum	0
Stingray CL+	40	LCS Jet	38		
LCS Blackjack	20	Keldin	67	**Soft White**	
Sockeye CL+	74	LCS Helix AX	71	Ryan	2
LCS Hulk	62	LCS Eclipse AX	44	Tekoe	10
LCS Dagger AX	47	Scorpio	30	Louise	2
Norwest Duet	74			Seahawk	64
LCS Artdeco	6	**Checks**		AP Mondovi Cl2	1
UI Magic Cl+	3	Norstar	95		
SY Assure	27	Eltan	90	**Checks**	
		Stephens	31	Norstar	99
				Eltan	96
				Stephens	92
				SY Gunsight	6

The survival ranking from these tests is highly correlated with field survival, but percent survival is relative to the checks in this test and is not the exact percent survival expected in the field. Field survival is expected to be higher.

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): **2**

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, analyzed and reported.	2023 reporting completed, 2024 trials are underway	Presentation at grower meetings, Wheat commission meetings, Wheat Life and Research Review. Published on WSU wheat variety selection tool Web-site. Paper in
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 programs. 2024 trials are underway.	Email to breeding programs.
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	Based on capacity, this objective may be postponed until summer 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 and presentations

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 greeness 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 2024, and complete in 2025	Presentation at Research Review. Peer reviewed publications. Direct communication with wheat breeders.

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

Project #: GR00010245

Progress Report Year: *2 of* 3

Title: Field Breeding Hard White and Red Winter Wheat

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

Executive summary: Hard wheat is a small but important market class for Washington, but fluctuations in production and concerns over trade-offs between yield and protein concentration has limited production. Identifying cultivars which can help mitigate these concerns will benefit growers in the state of Washington. This proposal aims to develop hard wheat cultivars which are tolerant to biotic and abiotic stress which occurs in Washington. Furthermore, the proposal aims to release cultivars which have both high yield and high grain protein content, and have stable yield across multiple production regions. Cultivars Sequoia, Scorpio, and Gemini have been released to meet the production constraints of hard wheat in Washington. Scorpio in particular combines the broadest adaptation in Washington, with multiple tolerances, high grain yield, and high protein concentration.

Introduction: 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 and 2023. In order to maintain and increase the number of acres of hard wheat in Washington, cultivars need to be developed which have the biotic and abiotic stress tolerance needed for our diverse production regions. Furthermore, agronomic characteristics for high economic return are needed, specifically combining high yield with high grain protein concentration. Additionally, high end-use quality properties are needed to maintain and increase market opportunities for hard wheat. By developing cultivars with these characteristics, and focusing on maintaining these characteristics across diverse cropping systems and climate variation, improvements in the stability of production of hard wheat in Washington can be achieved.

Approach: We are testing multiple populations of hard wheat across production systems, and have breeding lines in every stage of testing across the state. We focus on agronomic characteristics to improve production, meeting the unique demands of different cropping systems such as emergence from deep planting, cold tolerance, and earliness. Furthermore, we put focus on developing strong abiotic and biotic stress tolerance, by focusing on traits such as low pH tolerance, stripe rust resistance, and other important pests. Lines are tested at multiple locations across the state and selected on performance. Traits such as herbicide tolerance are being added to hard wheat in order to further improve performance and maintain high levels of productivity in various cropping systems.

Results: 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 2018-2023, 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 released a new line in 2023 named Gemini which has had very high grain yield in the intermediate rainfall locations, and carries good emergence and low pH soil tolerance for production in a wide range of cropping systems. Continued emphasis is placed on selecting breeding lines with superior quality and disease resistance. We also work on 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 starting the fall of 2021 due to the extremely dry planting conditions and emergence concerns. 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. It has been increasing in commercial production due to its high grain yield and grain protein concentration. Gemini has been released to provide additional cultivars with high grain yield, excellent end-use quality, and good stress 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: GR00010245
WGC project title: Development of hard red and white winter wheat
Project PI(s): AH Carter
Project initiation date: July 1, 2022
Project year: 2 of 3

Objective	Deliverable	Progress	Timeline	Communication
Develop hard red and white winter wheat cultivars	New cultivars released for production in WA	In 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 increased production in 2023. Gemini was released in 2023 for commercial production. We had over 3,100 plots and 12,000 rows of hard material under evaluation at various stages of the breeding process for 2023. In 2023, focus continues to be 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 three years.	Progress is reported through field days, grower meetings, commission reports, popular press, and peer-reviewed manuscripts, Wheat Life articles, and through the annual progress reports
	Agronomic traits	Field trials and agronomic data were conducted and collected at 14 locations in 2023. This includes emergence, winter survivability, heading date, test weight, plant height, and grain yield. All trials gave good data in 2023. Our snow mold locations gave a good rating of snow mold tolerance in 2023, although one location had snow mold so severe nothing survived. Planting went well in 2023, and all 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 2023 we communicated results of this project through the following venues: 8 peer-reviewed publications; 2 field day abstracts; various field days and grower interactions; 2 poster presentations; 3 popular press interviews; 1 podcasts; 1 grower meeting presentations; and 4 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-2024. 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 are being tested. The Clearfield and CoAXium systems are the basis of our current efforts.	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 #12235 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 #12235 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 #12235 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 #12235 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 #12235 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 #12235 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 #12235 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 #: GR00012235

Progress Report Year: *3 of 3*

Title: Use of biotechnology for wheat improvement

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

Executive summary: Many new tools and technology have emerged to improve the efficiency and effectiveness of plant breeding. This project aims to apply these tools and technology to the winter wheat breeding program, in order to enhance the selection and development of new winter wheat cultivars. This project has improved the introgression of new traits into hard and soft winter wheat germplasm. Many times we start with unadapted lines which contain the trait, and prebreeding efforts are undertaken to put these into backgrounds adapted to the PNW, which are then field tested under different funded projects. Marker-assisted selection, phenotypic-assisted selection, and genomic selection are all technology used to improve trait introgression and ultimately selection of new cultivars. These techniques also improve our ability to select parents to further develop new breeding populations for field testing.

Introduction: One of the most important factors in plant breeding is the rate of genetic gain. That is to say, how fast we can make genetic improvements in a trait of interest. This rate of gain is very slow, and is impacted by selection intensity, selection accuracy, population diversity, and cycle time. While selection intensity is somewhat a constant factor, the other three are directly influenced by this project. Marker and phenotypic introgression allow lines containing traits to get to field testing more quickly. Genomic selection helps improve the accuracy of selection. Genomic data also allows better prediction of crosses to enhance genetic diversity. All these lead to crossing elite lines in shorter time, thus improving cycle time. This project help improve rate of genetic gain and ultimately rate at which improved cultivars can be made commercially available.

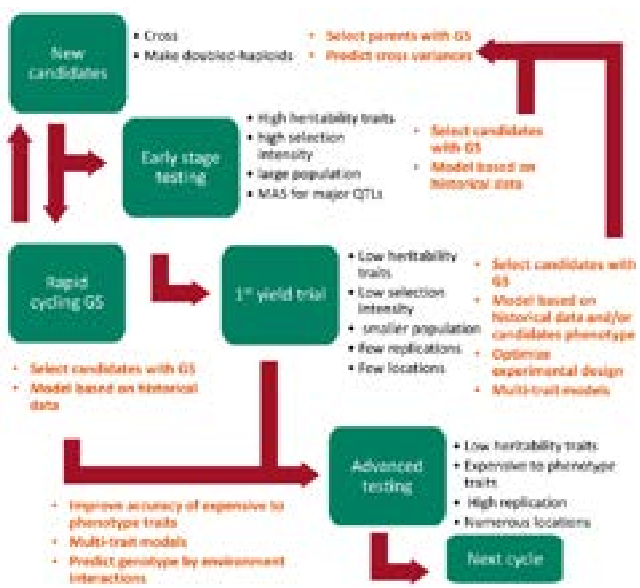

Figure 1 A graphical depiction of the genomic selection workflow within the winter wheat breeding program.

Approach: We are constantly looking for new sources of tolerance/resistance to production constraints in Washington. As these are identified, they are crossed into elite germplasm and selected either using diagnostic molecular markers or phenotypic selection. This confirms the presence of the trait before field testing, and allows more lines to be selected for other important traits. Each year the entire breeding program is genotyped, and past breeding lines are used in genomic selection models to predict performance of upcoming breeding lines. This is especially useful for disease resistance traits and end-use quality traits. Phenomic data collected through leveraged USDA funded projects are added to selection models to further enhance selection for climate variation. Outputs from the above methods are then used to better understand the phenotypes and genotypes of each line, which helps make cross predictions. All material from this project is planted in the field to verify selection and evaluate for commercialization potential. The above figure outlines certain aspects of our enhanced selection methods and where they fit in the breeding program.

Results: In 2023 we continued our effort to advance breeding lines as quickly and efficiently as possibly by employing both molecular marker analysis and single seed descent. 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 seventh 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 700 crosses consisting mainly of soft white and hard red germplasm. In 2023 we continued to screen large populations for herbicide tolerance in the greenhouse, and developed populations for pest and disease screening. 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, Rollie, Windust, Gemini) 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, phenotypic-assisted, and genomic selection.

WGC project number: GR00012235
WGC project title: Use of biotechnology for wheat improvement
Project PI(s): AH Carter
Project initiation date: July 1, 2021
Project year: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
Marker-assisted selection				Results are presented through annual progress reports, the research review, field tours, Wheat Life articles, and grower meetings
	Foot rot resistant lines	In 2023, 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 2023, 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 2023, populations that were selected for combinations glutenin genes during field selection. All breeding lines are screened for the presence of low PPO genes. Lines with beneficial gene combinations for end-use quality were added to the crossing block to further develop populations with these traits.	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 2023, 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 2015-2023 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 2023, 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 2023, 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. Samples were submitted to two new genotyping platforms to evaluate the effectivenss of these platforms compared to our normal procedure.	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 800 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 20% are in hard red backgrounds. Crosses were advanced to the F2 stage. Of these crosses, about 100 were specifically mate to introgress new traits into PNW germplasm 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 2023 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 2023 we finished out last DH production we had in process and prepared them for field screening. The goal is to have all lines produced go into 4-row observation trials at both Pullman and Lind. DH production is now focused on rapid trait introgression, and not routine populaiton development.	This is done annually, with the number of crosses/populations varying	

	Trait Introgression	We made crosses to germplasm containing resistance/tolerance to snow mold, stripe rust, end use quality, foot rot resistance, preharvest sprouting, Al tolerance, Ceph Stripe, SBWMV, vernalization duration, low PPO, Fusarium head blight, imazamox, the CoAxium 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
	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 CoAXium 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 2023. 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 #: GR00012238

Progress Report Year: *3 of* 3

Title: Field Breeding Soft White Winter Wheat

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

Executive summary: Production of soft white winter wheat is an important commodity in Washington to meet the growing demand. High and consistent production with good end-use quality is needed to keep wheat an economical option. This project aims to develop soft white winter wheat cultivars with high and stable agronomic performance, tolerance to biotic and abiotic stresses, and meet consumer demand for end-use quality attributes. Field testing in many diverse locations allows us to evaluate performance and make selections for these traits. This project has developed many soft white wheat cultivars which have helped support production in Washington. Most notable of those in current production are Piranha CL+, Stingray CL+, and Sockeye CL+.

Introduction: There are many production constraints to growing wheat in the state of Washington. Diverse climactic regions alter cropping system approaches and enhance abiotic stresses. These regions also vary for their prevalent diseases, which continue to spread throughout the state and chance race structure. New diseases are always on the threat of being introduced into the region. Annual climate variations can take growers from the best production year to the worst production year in a matter of months. Given all these difficulties, developing cultivars which can mitigate production concerns is an effective way to maintain high economic returns on wheat.

Approach: Due to the diversity of production constraints in Washington, the breeding program is set up to evaluate breeding lines in multiple locations for multiple traits. Efforts of other funded projects create diverse breeding populations containing the traits needed for Washington production. These lines are evaluated at over 18 locations in Washington to evaluate their agronomic performance. Furthermore, locations are used to screen to diseases such as snow mold, stripe rust, and foot rot. Additional screening locations are present for low pH soil tolerance. Other traits are screened for either in the greenhouse or through marker selection. Focus is put on broadening the germplasm base, by continuing to select more lines for traits such as SBWMV, Hessian fly tolerance, and Cephalosporium stripe. Agronomic traits are selected in a diverse set of locations to evaluate high and stable grain yield, crop maturity, and emergence from deep planting, among many other traits. All this data culminates into the selection of breeding lines for advancement in the program and ultimately released as new cultivars.

Results: The year 2023 provided many opportunities in the program to evaluate materials under diverse climactic regions throughout Washington. 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. Genomic selection has helped improve selection ability of field tested material. Many lines in the program able to perform well under diverse climate conditions were advanced in the breeding program. Several of these lines were also prepared for Breeder seed production in Othello. Nova AX, a soft white winter wheat carrying the AXigen trait used in the CoAXium system was released in 2023 and all Foundation seed was sold. We continue to evaluate Clearfield and CoAXium lines in the program, with an increased focus on improving tolerance, improving disease resistance, and improving agronomic traits and diversity. The breeding programs continues to maintain a high number of lines within testing at all levels of the program. Breeding populations are produced under single-seed descent, and then transferred to single row field testing for further selection. 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. A long winter in Douglas county produced good snow mold ratings, although at one location is was so severe the trial needed to be abandoned. In 2023 two new soft white wheat lines were approved for release, Rollie and Windust. These recent releases all have high grain yield, good disease resistance, and good end-use quality. We anticipate additional releases in 2024 of lines which performed well over the past years of testing and continue to fit into multiple cropping systems in Washington. Existing releases continue to be commercially produced and we work closely with growers and seed companies to identify new traits needed in upcoming lines to meet production demands.

Figure 1 Nova AX in Foundation Seed production near Pasco, WA.

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 34% of the acres in 2023. These include Piranha CL+, Stingray CL+, Sockeye CL+, Curiosity CL+, Devote, Otto, Resilience CL+, and Pritchett, along with the collaboratively released cultivar Castella. Many of these lines were again planted for production in 2024. Newly released Nova AX was in high demand and all Foundation seed of the variety was sold upon release. Nova AX combines broad adaptability, high grain yield, excellent end-use quality, and is approved for use in the CoAXium wheat production system.

WGC project number: GR00012238
WGC project title: Field Breeding Soft White Winter Wheat
Project PI(s): AH Carter
Project initiation date: July 1, 2021
Project year: 3 of 3

Objective	Deliverable	Progress	Timeline	Communication
Develop soft white winter wheat cultivars	New cultivars released for production in WA	We released the soft white lines Otto, Jasper, Puma, Purl, Stingray CL+, Devote, Piranha CL+, Sockeye CL+, Jameson, Inspire, Rollie, Windust, and Nova AX. 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. Newly released Nova AX has has interest from growers and all the Foundation seed has been sold. We have multiple breeding lines in statewide testing for consideration of release, many of which had excellent performance in 2022 and 2023. We have over 20,000 plots and 30,000 rows of soft white material under evaluation at various stages of the breeding process.	Each year we evaluate germplasm at each stage of the breeding process. Each year lines are entered into statewide testing for final release consideration. A cultivar is released, on average, every two years.	Progress will be reported through field days, grower meetings, commission reports, annual progress reports, Wheat Life articles, 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. An additional six have been added through collaborative testing. 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 2023 we communicated results of this project through the following venues: 8 peer-reviewed publications; 2 field day abstracts; various field days and grower interactions; 2 poster presentations; 3 popular press interviews; 1 podcasts; 1 grower meeting presentations; and 4 seed dealer presentations;
	Disease resistance	Disease resistance is recorded on our 18 breeding locations when 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 2023.	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 GR00012235 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 2023 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 GR00012235 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 GR00012235 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 2023	
	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 2023	

	Hessian Fly	Populations with new sources of resistance to Hessian Fly were screened in yield trials 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 at additional locations.	Populations were advanced in 2023 under yield trials. Additional field screening at more locations will be conducted in 2024.	
	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.	
	Other traits	Genes of interest to production regions in the PNW are being introgressed into soft white winter backgrounds. Upon completion, lines are tested for performance in Washington to being developing adapated germplasm in the SWW market class for production in Washington	Evaluation is completed once lines are produced from project GR00012235	
	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: 2 of 3 (2023)

Title: Managing Rusts of Wheat and Barley

Cooperators: K. Garland Campbell, A. Carter, M. Pumphrey, D. See, C. Neely & B. Brueggeman

Executive summary: In 2023, studies were conducted according to the objectives of the project proposal, and all objectives specified for the second 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.

Introduction: Wheat is grown in more than 2 million acres in the State of Washington (WA), and barley is an important crop for producing grain for animal feed, malting, and human food. Stripe rust, leaf rust, and stem rust all can damage wheat and barley crops, especially stripe rust that is the most important disease on wheat in the Pacific Northwest (PNW). Severe stripe rust occurs almost every year on wheat and has the potential to cause yield losses of over 90% on susceptible varieties with an average of potential yield loss of 41% in the PNW from 2002 to 2023. Despite most wheat varieties currently grown in the PNW have variable levels of resistance and the overall resistance in commercial varieties significantly reduces the potential grain yield loss from 41% to 7.8% on average. The 7.8% grain is over 100 million dollars for Washington wheat growers. To further reduce the yield losses of commercially grown varieties, growers need to spend multimillion dollars on fungicide application. Therefore, we will continue focusing on stripe rust and include leaf rust and stem rust in our programs. Our goal is to reduce rust damage to minimal using best possible approaches on a yearly basis. Meanwhile, we will conduct research for new knowledge, resources, and methods to improve control of the rust diseases. The specific objectives of this project are to 1) Improve the understanding of rust disease epidemiology and the pathogen populations; 2) Improve rust resistance in wheat and barley varieties; and 3) Improve the integrated management of rust diseases.

Approach: For Objective 1, we conducted field rust surveys and collect rust samples. We tested stripe rust samples on the wheat differentials and barley differentials to identify virulent races of the pathogens, and determine race frequencies, distributions, dynamics, and potential impact of new races on resistant germplasm, commercially grown varieties, and breeding lines; and select a set of races for evaluating germplasm and breeding lines. In addition, we used molecular markers in combination with the virulence data to identify population changes of the stripe rust pathogens. For leaf rust and stem rust, we collected samples from the PNW and send them to the ARS Cereal Disease Laboratory in Minnesota for identification of races and characterization of populations. 2) For Objective 2, we evaluated wheat and barley lines from breeding programs for resistance to rusts and provide data to breeding programs for developing and releasing new varieties with adequate and durable resistance. We have continue identifying and mapping effective and new genes in wheat and barley for resistance to stripe rust using both genome-wide association study (GWAS) and bi-parental populations. We collaborated with other programs in identifying and utilizing genes for resistance to stem rust and leaf rust. 3) For Objective 3, we tested new chemicals, together with registered fungicides, for their efficacy of controlling stripe rust in the fields for both winter and spring crops. We provided the chemical efficacy data to individual companies for registration of new fungicides. We will test major commercially grown varieties in field experiments under natural or artificial infection of the stripe rust pathogen with and without fungicide application to determine yield loss by stripe rust and yield increase by fungicide application for individual varieties. These data can be used to guide stripe rust management for individual varieties in combination with rust forecasts and field survey data.

Results: 1) In 2023, we made stripe rust forecasts based on the winter weather data in January and March, conducted field surveys and made recommendations for rust management throughout the crop season. Stripe rust was severe in western Washinton but occurred at a low level in the east part of the state due to the lasting drought conditions from May to July. 2) We identified 21 wheat stripe rust races and 5 barley stripe rust races from 287 samples from throughout the U.S., including 18 (86%) wheat stripe rust races and 4 (80%) barley stripe rust races identified from 213 (73%) samples collected by ourselves in Washington. 3) We have completed SSR (simple sequence repeat) genotyping of the stripe rust collections up to 2022 and used the data to determine the pathogen genetic changes. We conducted experiments to convert secreted protein (SP) gene-based single nucleotide polymorphism (SNP) markers to more efficient Kompetitive allele-specific PCR (KASP) markers for monitoring pathogen virulence. 4) We evaluated more than 16,000 wheat and barley entries for resistance to stripe rust in multiple locations and in the greenhouse with selected races of the pathogens. 5) We identified a new gene, officially named *Yr85*, for resistance to stripe rust in a wheat line used to differentiate races of the wheat stripe rust pathogen and in a collaborative study mapped five stable quantitative trait loci (QTL) for all-stage resistance and high-temperature adult-plant resistance in a new wheat germplasm PI 660122 previously developed in our program. 6) We tested 19 fungicide treatments for control of stripe rust on winter and spring wheats and tested 24 winter wheat and 24 spring wheat varieties for yield loss caused by stripe rust and yield increase by fungicide application. 7) In 2023, we published 17 journal articles and 3 meeting abstracts.

Impact: 1) The recommendations made based on the stripe rust forecasts and surveys avoided unnecessary use of fungicides, which saved growers multimillion dollars in 2023. 2) The race information is used for guiding breeding programs to use effective resistance genes and selecting rust races to be used in screening germplasm for developing resistant varieties. 3) Analyses of the molecular marker data together with the virulence data of the stripe rust pathogen populations have allowed us better understanding the pathogen genetic changes and the effects of cropping systems, variety resistance, and environmental factors on the dynamics of population variation. 4) From the germplasm screening, we identified new sources of resistance and resistant breeding lines for breeding programs to release new varieties for growers to grow. Using the germplasm screening data of the recent years, we collaborated with breeders in releasing, pre-releasing, or registration of 10 wheat varieties and 1 barley variety in 2023. The germplasm evaluation data were also used to update the Seed-Buying Guide for growers to choose resistant varieties to grow. 5) The identified stripe rust resistance genes/QTL and developed molecular markers are useful for monitoring races of the wheat stripe rust pathogen and developing new resistant varieties. 6) The data of the fungicide and variety tests are used for registering new fungicides and guiding the integrated control of stripe rust in the coming years. 7) Our publications have strong impact on guiding stripe rust research and management in the PNW and other regions in the U.S. and the world.

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: 2 of 3 (2023)				

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 2023 have been completed on time. There is not any major delay, failure, or problem to this objective. The race identification for the 2022 collection was completed and summarized. The data and summary were sent to growers, collaborators and related scientists in January 2023. In the 2023 crop season, we collected and received 287 stripe rust samples throughout the country, of which 213 samples (73%) were collected by ourselves from Washington (WA). We have completed the race ID work for the 2023 samples and detected 21 races of the wheat stripe rust pathogen and 5 races of the barley stripe rust pathogen, of which 18 (86%) wheat and 4 (80%) 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 for use in screening for breeding lines of wheat and barley with stripe rust resistance. We have completed SSR (simple sequence repeat) marker genotyping of the stripe rust collections up to 2022 and used the data to determine 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 conducted experiments to convert secreted protein (SP) gene-based single nucleotide polymorphism (SNP) markers to more efficient Kompetitive allele-specific PCR (KASP) markers for monitoring pathogen virulence and made some progress. 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 2022 stripe rust samples was completed, summarized, and distributed. The race identification work for the 2023 samples has also been completed; the data analysis been mostly done, and the results are being summarized; and the data and summary will be distributed in Janaury 2024. molecular marker work for the population genetic studies has been completed and published up to the 2017 collection, completed for the 2018-2022 collections, and is being conducted for the 2023 collection. Progress has been made for the development of KASP markers for monitoring virulence genes in the rust populations.	The rust survey and race data were communicated to growers and researchers through e-mails, websites, project reports, meeting presentations and publications in scientific journals.

2. Improve rust resistance in wheat and barley varieties.	**1) Stripe rust reaction data of wheat and barley germplasm and breeding lines. 2) Reactions to other diseases when occur. 3) New resistance genes with their genetic information and molecular markers. 4) New germplasm with improved traits. 5) New varieties for production.** The genetic resources and techniques will be used by breeding programs for developing varieties with diverse genes for stripe rust resistance, which will make the stripe rust control more effective, efficient, and sustainable.	In 2023, we evaluated more than 16,000 wheat and barley entries for resistance to stripe rust. The entries included germplasm, breeding lines, rust monitoring nurseries, and genetic populations from various breeding and extension programs. All nurseries were planted 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 the Pullman (artificailly inoculated) and Mt. Vernon (under natural infection) 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 2023, we collaborated with public breeding programs in releasing and registered 10 wheat varieties and 1 barley variety. 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 2023, we identified a new gene, officially named *Yr85* , for resistance to stripe rust in a wheat line used to differentiate races of the wheat stripe rust pathogen and in a collaborative study mapped five stable quantitative trait loci (QTL) for all-stage resistance and high-temperature adult-plant resistance in a new wheat germplasm PI 660122 previously developed in our program. In 2023, we obtained excellent stripe rust phenotypic data of 4 bi-parental mapping populations at both Pullman and Mount Vernon locations to validate resistance loci previously identified through the bulked analysis of 40 crosses and preliminarily mapped several stripe rust resistance loci in a couple of the bi-parental populations. 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.	All 2023 germplasm tests were completed, and the data were provided to collaborators on time. The 2024 winter wheat nurseries were planted in fields in October, 2023. The 2024 spring wheat and barley nurseries will be planted in March-April, 2024. The greenhouse tests of the 2023 winter nurseries were completed and sent to collaborators. The greenhouse tests of 2023 spring nurseries have been completed and will be distributed soon. The 2024 winter nurseries have been conducted during this winter, and will be completed by May 2024. All experiments of the molecular mapping studies scheduled for 2023 have been completed. Mapping populations of winter wheat were planted in fields in October, 2023 and those of spring wheat will be planted in April, 2024 for stripe rust phenotype data.	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.

3. Improve the integrated management of rust diseases.	**1) Data of fungicide efficacy, dosage, and timing of application for control stripe rust. 2) Potential new fungicides. 3) Stripe rust yield loss and fungicide increase data for major commercial varieties. 4) Stripe rust forecasts and updates. 5) Guidance for rust management. 6) *Wheat Life* 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.	In 2023, stripe rust was forecasted and monitored throughout the crop season, and rust updates and advises were provided on time to growers. The recommendations avoided unnecessary use of fungicides, saving growers multimillion dollars. In 2023, 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, increased grain test weight, and increaded grain yield compared to the non-treated check. The significant yield responses ranged from 23.5 bu/A (26.2%) to 50.3 bu/A (43.2%) with some of the new formulations providing best protection and highest yield. In the fungicide-winter wheat variety trial, the two applications of Quilt Xcel at 14 fl oz/A reduced overall severity value by 98.1% in the susceptible check plots. The fungicide applications also significantly reduced the severity values of 12 commercial cultivars (UI Magic, LCS Jet, Curiosity CL+, Otto, Mela CL+, Stingray CL+, ARS-Crescent, Piranha, Keldin, WB4303, Pritchett, and LCS Artdeco), and the reduction ranged from 3.3 to 56.3%. The fungicide applications significantly protected grain test weight of the susceptible check by 5.4 lb/bu and three commercial varieties (UI Magic, Curiosity CL+, and Stingray CL+) by 1.3 to 1.6 lb/bu. The fungicide applications made significant yield differences for the susceptible check (32.6 bu/A more in the sprayed plots) and six commercial varieties (UI Magic, LCS Jet, Curiosity CL+, Otto, Mela CL+, and Stingray Cl+) with 12.0 to 27.0 bu/A more grain in the sprayed plots. The remaining 17 commercial varieties (LCS Hulk, ARS-Crescent, Sockeye CL+, Piranga CL+, Kelding, WB4303, SY Assure, Pritchett, LCS Shine, Northwest Tandem, AP Exceed, Northwest Duet, LCS Jefe, LCS Artdeco, Resilience CL+, M-Press, and SY Dayton) showed no significant yield differences between the no-spray and spray treatments, indicating adequate resistance. These data indicated that stripe rust caused yield loss of 32.6 bu/A (32.6%) on the susceptible check and 6.7 bu/A (5.0%) yield loss on average across the commercially grown varieties under the disease pressure created by artificial inoculation in the experimental field. The fungicide test on spring wheat varieties did not show significant differences between no-spray and sprayed plots for any of the tested varieties, indicating that fungicide application is not necessary under the low rust. The significant yield differences among the varieties is useful for selecting high-yielding varieties to grow.	For this objective, all tests scheduled for 2023 were completed. For the 2023-24 growing season, the winter wheat plots of the fungicide and variety yield loss studies were planted in October, 2023, 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), 2024.	The 2023 results were communicated to growers and collaborators through e-mails, project reports and reviews, reported in *Wheat Life* (the 2022 data), and submitted scientific journals.

Project #:144176; AWD005706

Progress Report Year: _1___ of _3___

Title: Development of 21st Century alpha-amylase immunoassays to replace the archaic, much criticized Hagberg-Perten Falling Number method, to preserve wheat grain value and accelerate breeding for climate resilience.

PI: Amber Hauvermale

Cooperators WSU: Andrew G. McCubbin, Drew Lyon, and Clark Neely. **EnviroLogix:** Rob McPheeters, Adam Johnson, and Larry Pessolano. **USDA:** Byung-Kee Baik, Camille Steber, and Xianran Li. **Other Industry Partners**: HighLine Grain Growers; Paul Katovich, Geoff Schultz, The McGregor Co.; Alex McGregor, Leslie Druffel, and Cat Salois, The Wheat Marketing Center; Jayne Bock, and The Washington Grain Commission; Mary Palmer Sullivan, and Lori Maricle.

Executive summary**:** The current WGC project, supports through cash and in-kind matching, a successfully funded FFAR project awarded in 2023. First year WGC project accomplishments include: 1) the purification of alpha-amylase proteins which may be used as internal controls for rapid tests, 2) development and testing of three additional antibodies for use in rapid tests, 3) delivery of hundreds of curated grain samples to our industry collaborator for rapid test calibration and pilot-lot scale up, 4) recruitment of a new graduate student and initiation of a proteomics objective to identify immuno-markers for breeding, and 5) outreach and extension efforts; 2 Wheat Life articles, 2 Wheat Beat podcasts, 2 Timely Topics (WSU small grains), 18 PNW grain industry interviews, WSU variety trial field days, invited presentations at the Spokane Ag Expo, the PNW and Wheat Quality council, the Cereals and Gains Conference, and the Washington State Crop Improvement Association meeting, and 1 peer-reviewed publication associated with the WGC project objectives.

Introduction Meeting the falling number export standard without unnecessary agronomic or economic losses throughout the 'grain chain' is difficult because the Falling Number test is low-throughput, expensive, difficult to perform accurately, and is logistically impossible to perform in real-time at receival stations. These factors limit grain segregation at harvest. In years when weather related low falling number events are localized, the impact to the industry may be minor. However, when events are widespread, as in 2016, the economic impacts are devastating. Improvements to the timely identification of compromised grain in a given year in combination with the development of new wheat varieties with fewer problems will increase on-farm profitability resulting in significant positive agronomic and economic impacts on the Washington small grain industry.

Approach**:** A four-pronged approach has been implemented to address the need for rapid inexpensive tests that better facilitate grain sorting from farms to export terminals, the need to better understand and differentiate between different causes of elevated alpha-amylase (preharvest sprouting, and late maturity alpha-amylase), and the need to empower and accelerate breeding for higher falling numbers. Supporting project objectives include: 1) the development and commercialization new rapid tests, 2) identifying new proteins to be used as breeding markers for increased resistance to low falling numbers caused by PHS and LMA, 3) creating weather prediction models to be used as an early warning system for low falling number events in the field, and 4) the construction of a robust extension and education pipeline to end users.

Results: First year results include: 1) production of tagged (6XHIS) alpha-amylase proteins for use as controls in immunoblots and lateral flow immunoassays (Figure 1), as well as three new alpha-amylase antibodies that will help to distinguish between LMA and PHS; 2) acquisition and testing of hundreds of grain samples used for calibration and scale-up of pilot lot rapid tests in collaboration with EnviroLogix with larger scale stakeholder beta-testing to begin in 2024; 3) successful organization of extension/outreach networks to disseminate information about new technology though the WSU small grains website and WSU variety trials, Wheat Life Magazine, local industry interviews and grower meetings, and national conferences.

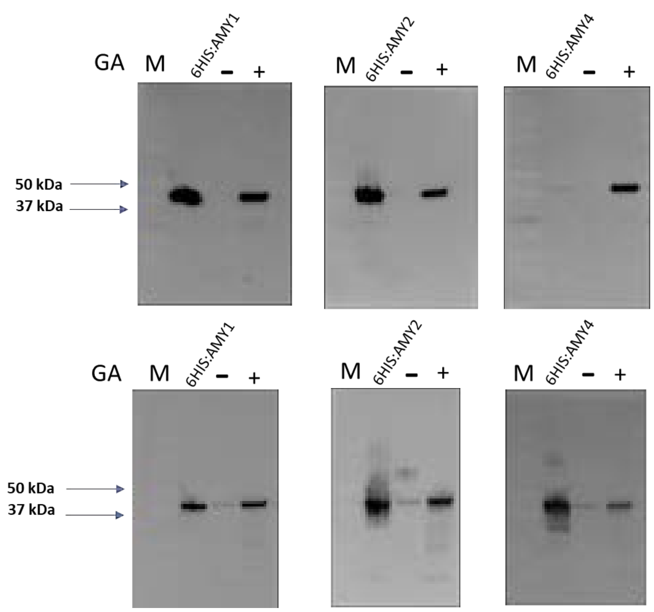

Figure 1: Immunoblots with purified alpha-amylase proteins 6XHIS:AMY1, 2 & 4 (lane 2) and proteins from wheat aleurones with or without (-/+) gibberellin treatment (GA). The top panel was detected using TaAMY1-C antibody described in Hauvermale et al., 2023. The bottom panel was detected with a newly developed alpha-amylase antibody. M = lane containing protein marker standards for determining protein sizes. Alpha-amylase proteins migrate between the 37 and 50 kDa standards.

Impact: In the last year measurable project impacts include: 1) successful leveraging of WMC funds for national funding through FFAR; 2) in collaboration with our collective grain industry team members, the acquisition, testing, and curation of hundreds of samples sent to EnviroLogix for rapid test calibration, and shared with USDA and university collaborators to develop different approaches to eliminate logistical and genetic issues associated with low falling numbers; 3) synthesis of specific tools (alpha-amylase protein standards, and immuno-markers for breeding) to improve rapid test performance and create other methods for pre- and post-harvest management of low falling numbers. Longer-term, deployment of innovative technologies will 1) reduce waste in the grain industry, 2) increased on-farm profitability, and 3) enhanced food production efficiency.

WGC project number: 144176; AWD005706
WGC project title: Development of 21st Century alpha-amylase immunoassays to replace the archaic, much criticized Hagberg-Perten Falling Number method, to preserve wheat grain value and accelerate breeding for climate resilience.
Project PI(s): Amber Hauvermale
Project initiation date: February, 2023
Project year (X of 3-yr cycle): 1 of 3-yr cycle

Objective	Deliverable	Progress	Timeline	Communication
1. Develop/produce purified α-amylases.	A renewable supply of protein standards used for immunoblots and rapid test.	Heterlogous expression and purification of the four classes of alpha-amylases is complete (Figure 1).	Year 1: 6-9 mos. Status: COMPLETE	**Publications: 1.** Development of Novel Monoclonal Antibodies to Wheat Alpha-Amylases Associated with Grain Quality Problems That Are Increasing with Climate Change. Hauvermale et al., 2023. **2.**The Development of Simple Wheat Meal Purification Methods for Diverse Testing Environments. Cereal Chemistry; intended submission, 2024.
2. Commercialize FN LFI and ELISA with ELX.	First phase rapid tests that provide a "bad/mediocre/good" metric based on falling number calibration.	This year EnviroLogix was able to calibrate pilot tests and is in the process of scaling up pilot lots for broad scale beta-testing. It is anticipated that beta-testing will begin early in 2024, and through harvest 2024.	Year 1-2 Status: ongoing and anticipated to be complete by the end of Year 2.	**Meetings: 1**. EnviroLogix visited the PNW in April as part of a series of industry interviews. **2.** EnviroLogix has delivered three research meetings and one broader stakeholder meeting and will continue to communicate as best-tests are ready and available.
3. Organization of extension/outreach networks.	Communication tools for reporting, teaching and training including podcasts, extension or popular media publications, presentations at conferences, and training sessions.	In year 1, progress achieved included two Wheat Life articles (WMC), two Wheat Beat Podcasts and two Timely Topics (WSU small grains),	Years 1 Status: COMPLETE Annual extension and outreach efforts will occur throughout the course of the project in conjunction with Objective 6.	**Conference Presentations: 1.** 2023 Spokane Ag Expo, Spokane, WA:CM Steber, AL Hauvermale, and AL Thompson. Low Falling Numbers in Wheat, An Update. **2.** 2023 Cereals and Grains Conference, Chicago IL: AL Hauvermale. Tools to Enhance Rapid Testing Platforms for Wheat Alpha-amylase Detection. **3.** 2023 WSCIA, Moscow, ID: AL Hauvermale and AL Thompson. Developing Strategies and Tools To Manage and Mitigate Loss Due To low Falling Numbers. **Wheat Life Articles: 1.** Reaching a new landmark: The development of an immunoassay to manage low falling numbers post harvest. Amber L. Hauvermale, Alison L. Thompson, Camille M. Steber. **2.** A Falling Numbers Fact Finding Mission. Alison L. Thompson and Amber L. Hauvermale. **Wheat Beat Podcasts: 1.**Evaluating Grain Quality and Mitigating Economic Loss. AL Hauvermale and AL Thompson. **2.** The Upside of a Falling Numbers Rapid Test. AL Hauvermale. **WSU Timely Topics and Media: 1.** A new grant to help grain farmers find low falling numbers faster. **2.** A new project aimed at combating low falling numbers. **WSU Variety Trials**: Walla Walla and Pullman WA. **Other Outreach**: 18 interviews conducted across the grain industry.
4. Proteomics pipeline for LMA/PHS immunomarkers.	Identified protein targets specific for PHS/LMA and used for immunomarkers for breeding	1. Pilot proteomics studies were performed to determine best conditions for large-scale experiments. 2. Samples were been submitted to TIMPL in December for large scale proteomics analysis of the differences between LMA and PHS in three different wheat varieties. Results are anticipated in the next few weeks, and data analysis will continue over the next 3 months.	Year 1-2 Status: ongoing but anticipated to be complete by summer of 2024.	**Anticipated Publications** :**1.** A wheat proteomics review paper with anticipated submission in Summer/Fall 2024. **2.** One to three proteomics research papers that describe differential expression of proteins with LMA and PHS to be submitted in 2024-2025.

5. Validate LMA/PHS-specific breeding LFI/ELISAs	Rapid tests that differentiate between LMA and PHS	Greenhouse and field studies with LMA and PHS are being collected in collaboration with WSU Variety Trials, and USDA scientists Camille Steber and Byung-Kee Baik. Once rapid tests are available for beta-testing these samples will be evaluated.	Years 1-3 Status: ongoing.	Nothing yet reported
6. Implement extension, education, outreach programs	Facilitation of LFI/ELISA product adoption, publicize/educate about the differing impacts of LMA and PHS on grain quality, develop market expansion for LMA grain, and train the next generation of agricultural scientists.	First year efforts have been to evaluate early adopters and to then work with EnviroLogix, the WMC, McGregor Co, the WGC, and HighLine grain growers, and other to build beta-testing platforms.	Years 1-3 Status: ongoing.	Nothing yet reported

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Washington Grain Commission
2023 Wheat and Barley Research Annual Progress Reports and Final Reports
Format

(Begin 2 page limit)
Project #: 3184

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

Title: **Breeder Quality Trials**

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

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 2022 has been analyzed using the standard *t*-Score and the results (and interpretation) returned to the breeder. Data generated from this trial in 2023 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.

Introduction: The PNW has produced approximately 250-300 million bushels of wheat per year with an export value (Portland) of approximately $2.5 billion per year. There are many reasons why we need new wheat varieties. However, inferior varieties—public or private—jeopardize our exports and reputation as a supplier of quality wheat. When flour mills go to other suppliers outside the PNW because of quality considerations, wheat prices and wheat producers suffer. Conversely, varieties with particularly good quality can be promoted and will better compete with Australian, Canadian, and 'Black Sea' wheat. Often the number of entries available to each breeder for the Variety Testing program is limited by space constraints. Additionally, when lines are very new, breeders may be hesitant to enter them into Variety Testing where the yield and quality data are all public. The Breeder Quality Trial program gives breeders the ability to enter up to ten lines at no cost to be grown throughout the state. Yield data are not taken and quality data are shared with breeders and others who ask specifically for those data, but are not publicized in the same way that Variety Testing data are. These aspects allow breeders to enter lines earlier in the breeding process and help with selections, without any public pressure around yield or quality scores.

Approach: A maximum of 10 soft white wheat (spring and winter combined) entries will be submitted per breeding program (four programs: AgriPro, Limagrain, WestBred, and WSU). A total of eight locations will be planted to ensure at least five locations are acceptable for quality testing. One replication will be planted per location for a maximum number of 40 plots per location or 320 plots per year. Breeder Quality Trials will be planted adjacent to variety trials planted by the WSU Cereal Variety Testing Program and managed the same. Quality analyses include the same standard grain, milling, and baking tests used for the G&E program. Quality data generated from this trial will be analyzed using the standard t-Score and the results and interpretation returned to the breeder.

Results: Each year the results have been made available to breeders in both the t-score format along with a general analysis of variance with the means for each line and each test. The data are available to the public upon request. We are available to any breeder wanting to discuss interpretation of the results. As mentioned in the Impact, several up-and-coming varieties with high quality have first been entered into this program and moved on to Variety Testing. Conversely, some lines with poor quality were dropped from the breeding programs and never entered Variety Testing.

Impact: The new varieties AP Exceed (Most Desirable), Rollie (Desirable), and TMC M-Pire (Desirable) all came from this Breeder Quality program of screening. 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.

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Outputs and Outcomes: Following is a summary of experimental lines evaluated under this program (harvest 2023): 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.

<table>
<tr><td colspan="5">WGC project number: 3184</td></tr>
<tr><td colspan="5">WGC project title: Breeder Quality Trials</td></tr>
<tr><td colspan="5">Project PI(s): Kiszonas & Neely</td></tr>
<tr><td colspan="5">Project initiation date: July 1, 2023</td></tr>
<tr><td colspan="5">Project year (1 of 3-yr cycle):</td></tr>
<tr><td>Objective</td><td>Deliverable</td><td>Progress</td><td>Timeline</td><td>Communication</td></tr>
<tr><td>Evaluate 10 advanced breeding lines from each of 4 programs at 5 locations</td><td>Complete end-use quality evaluation and t-Scores</td><td>Completed each year by early spring after prior year harvest</td><td>Completed by June 1</td><td>End-use quality data, t-Score, and interpretation shared with originating breeder</td></tr>
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Washington Grain Commission
2023 Wheat and Barley Research Annual Progress Reports and Final Reports
Format

(Begin 2 page limit)
Project #: 4721

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

Title: **Quality of Varieties & Pre-Release Lines: Genotype & Environment 'G&E' Study**

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

Executive summary: The 2023 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.

Introduction: Identifying the relative quality (advantages or short-comings) of varieties and pre-release lines, both public and private, requires robust, statistically-valid, objective comparisons. Similarly, quality data on an environment-by-environment basis is needed, especially for a wider array of commercial varieties and pre-release lines. The WWQL prioritizes resources to experimental breeding samples from Washington State University and ARS programs; in-depth analysis of commercial varieties, newly released varieties, and advanced pre-release lines is accomplished with this matching WGC support. This on-going study has identified varieties with exceptionally good quality and others that were considered to be inferior. In addition, this study contributes substantively to the WSU Variety Release process and release decisions.

Approach: Continued testing only new varieties and pre-release lines; discontinue testing varieties with 3 or more years of quality data. Included 1 historic and 1 prominent "benchmark" varieties in each class. Obtained grain samples from existing WSU Variety Testing Extension yield trials (utilized these samples because the cost of producing them is already covered) from 4-6 representative environments from each market class (8-12 from SWW given its greater acreage and market share). Conducted complete milling and baking quality analyses.

Results: The following varieties have been released and published in the Preferred Variety Brochure during this 3-year funding cycle of this project.

Market Class	Most Desirable	Desirable	Acceptable
Soft White + Club	AP Exceed	Appleby CL+	AP Dynamic
	Jameson	Inspire	WB 1532
	Nimbus	LCS Blackjack	AP Iliad
	Sockeye CL+	LCS Jefe	AP Coachman
	YSC-201	M-Press	
	YSC-215	OR2X2CLP	
	ARS Cameo	Piranha CL+	
	AP Mondovi	Sonic	
	UI Cookie	Stingray CL+	
	Hedge CL+	VI Presto CL+	
	Roger	VI Voodoo CL+	
Hard Wheat	Scorpio	WB4311	WB4303
	Guardian		WB4394
	Canvas		LCS Helix AX
	Millie		
	Hale		

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: July 1, 2021				
Project year (3 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
2023 Wheat and Barley Research Annual Progress Reports and Final Reports
Format

(Begin 2 page limit)

Project #: 4722

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

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

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

Executive summary: This WGC support provides for about 3 months of additional technician time. The additional work is devoted to evaluating breeder samples for quality from early October through mid-January. During this period, spring wheat samples are given priority over winter wheat samples. The aim is to coordinate with the WSU Wheat Quality Program, and complete as many analyses as possible before spring wheat planting decisions are made in early February. In this way, the spring wheat program is made more efficient because inferior quality lines are not planted and grown. The standing goal for WSU winter wheat breeding lines is to complete as many as possible before June 1. Milling and baking evaluations of the 2022 Crop were completed and 2023 Crop testing is well under way at the WWQL.

Introduction: Producers need new varieties with higher yield and better resistance to diseases, pests, and environmental stresses. An integral part of developing new varieties is the evaluation of end-use quality of breeding lines. The success rate is about 1 new variety for every 1,000 breeding lines evaluated for quality. The more breeding lines that can be evaluated and the more end-use quality tests that can be conducted on each, the greater our chances of success. Evaluating quality is a fundamental part of breeding new wheat varieties and is a high priority to the breeders.

Approach: Capacity of testing breeder samples is limited primarily by personnel. Current WGC funding provides 3+ months of additional technician time to the existing direct Federal support from the USDA. With the WGC supplemental support, more testing can be accomplished during the peak fall and winter months. The Oregon Wheat Commission provides a matching amount to support the analysis of the Oregon State University breeding programs and locations.

Results: Below is a table of the breeder samples for the duration of this 3-year funding cycle. This supplemental support ensures that we can evaluate the breeder samples in a timely manner so that breeders have as much information as possible for making selections and field decisions.

Breeder Samples Submitted to WWQL from WSU and ARS Breeding Programs				
Crop Year	WSU Winter Wheat	WSU Spring Wheat	ARS Club Wheat	Total
2020	902	607	507	2016
2021	1020	537	693	2250
2022	894	420	470	1784
2023	1137	504	676	2317

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 2 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 Flour Swelling Volume (FSV) (FSV is 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: July 1, 2021				
Project year (3 of 3-yr cycle): 3				
Objective	Deliverable	Progress	Timeline	Communication
Complete spring wheat samples	Full mill & bake data delivered to breeder by early Feb	Will be reported; progress on last year's crop is on track	Starts at harvest when samples come in, ends with completion of last nursery	Data delivered directly to breeder; dialogue may ensue as to 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: 2 of 3

Title: Extension Education for Wheat and Barley Growers

Cooperators: Joao Antonangelo, Cassandra Bates, Aaron Esser, Randy Fortenbery, Richard Koenig, Carol McFarland, Timothy Murray, Clark Neely, Surendra Singh, Dale Whaley, and Rachel Wieme

Executive summary: A new accessible and more mobile-friendly Wheat and Small Grains website was launched in 2023. Twenty-six new episodes of the WSU Wheat Beat Podcast were posted in 2023, a new episode every other week. There were also 42 new Timely Topics and 18 new Weeders of the West articles posted. The 2023 WSU Wheat Academy was held for the second time following the two-year break during the COVID-19 pandemic. We had 70 paid registrations and 64 attendees in 2023, which is ten more than in 2022, but still short of our 72-person limit.

Introduction: The Extension Dryland Cropping Systems Team was formed in 2013. Members of the team include extension specialists located on the Pullman campus and County Educators located in various counties in eastern Washington. The Team was formed in response to the loss of Extension Specialist positions because of university budget cuts and to provide increased coordination of educational efforts.

Approach: One of the first tasks of the Team was to build a website that would serve as a one-stop shop for information on wheat and barley production. Prior to the development of the Wheat and Small Grains website (smallgrains.wsu.edu), clientele complained of their inability to find information that was scattered amongst a wide array of individual websites. The Wheat and Small Grains website is designed to provide growers and consultants with easy access to this information.

Results: A new accessible and more mobile-friendly Wheat and Small Grains website was launched in 2023. This was no small task, as this website is one of the largest at WSU. The WSU Wheat Academy was held in 2023 for the second time since the two-year break during the COVID-19 pandemic. We had 70 paid registrations and 64 attendees in 2023, which is ten more than in 2022, but still short of our 72-person limit.

Vacant county positions on the Extension Dryland Cropping Systems Team remained a problem in 2023. Although the Walla Walla County position was filled in 2023, the former Columbia, Spokane, and Whitman County positions remain unfilled. We did add three new specialists to the team in 2023: Surendra Singh (Dryland Cropping Systems), Joao Antonangelo (Applied Soil Chemistry), and Richard Koenig (Soil Fertility).

Impact: For the 11-month period of January through November 2023, the site had 68,389 sessions with 50,812 unique users; this compares to 66,714 sessions with 52,639 unique users for the same period in 2022, and 63,417 sessions and 52,822 unique users for the same period in 2021. There were 107,718 pageviews, which is an increase from 98,580 pageviews in 2022 and 104,950 pageviews in 2021. We have 1,066 subscribers to our listserv. We have 1,154 followers (10.3% increase from 2022) on X (formerly Twitter), and 774 followers (7.5% increase from 2022) on Facebook. Most of the sessions from the US (42,506) were initiated from the state of Washington (14,640). From January through November, the WSU Wheat Beat Podcast had a total of 14,416 plays (39.5% increase from 2022). Through November, the Weeders of the West Forum had 9,282 pageviews (5%increase from 2022) and 101 people are subscribed to the forum listserv. Those who attended the 2023 WSU Wheat Academy rated the program highly (4.64 out of 5 based on 40 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): 2

Objective	Deliverable	Progress	Timeline	Communication
Add new resources to the Wheat and Small Grains website, including new publications, decision support tools and calculators, videos, and quizzes.	New and updated Extension publications, decision support tools and calculators, videos, and quizzes will be developed. Decision support tools and videos will be priortizied. An article will be written annually for Wheat Life magazine on our Extension activities.	A new accessible and more mobile-friendly Wheat and Small Grains website was launched in 2023. This was no small task, as this is one of the largets websites at WSU. Five new wheat variety videos from Lind were added to the website in 2023. Added the Straw removal Calculator Guide to supplement the Straw Removal Calculator.	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 (1,066 subscribers), social media platforms (X and Facebook), 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 2023, we posted 42 Timely Topics, 26 podcast episodes, and 18 Weeders of the West posts.	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 struggled to identifiy the best approach for this objective. Our first one-day educational event will be held in 2024.	The first one-day program will be held in Davenport in early 2024. We will adjust future programs based on what we learn at this inaugural Wheat Academy on the Road.	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.	We increased interactions with the GROW project, a national herbicide-resistance project led by the USDA-ARS in Beltsville, MD. Claudio Rubione, Outreach and Extension for GROW, interviewed and filmed four Washington wheat growers with impact mill systems. Links to these case studies and videos were added to our website and were promoted through our social media acccounts. The PNW is recognized as the leader in impact mill adoption by growers in the US.	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 throughoutthe year.

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Project #: 139311
Progress Report: Year 2 of 3
Title: EVALUATION OF BARLEY VARIETIES
Researcher: Clark Neely, Variety Testing Program Lead

EXECUTIVE SUMMARY:
The WSU Extension Cereal Variety Testing Program (VTP) continues to conduct spring barley variety trials at 12 locations throughout Eastern Washington. Newly added in 2023 was the addition of a winter barley trial at eight high rainfall locations with six entries total. This increased the total number of barley plots managed by the program by 17%. Data were posted in a timely manner following harvest and distributed via list serve, website, popular press articles, and in-person field days and grower meetings.

INTRODUCTION:
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 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.

APPROACH:
The VTP planted 12 spring barley and 8 winter barley variety trials in 2023. This is the first year the program conducted winter barley variety trials at the request of the WGC and WSU barley breeder. While the trial was small in 2023 (just four experimental lines and two commercial checks), two more commercial varieties were added for the 2024 season with more interest already expressed by private companies for the upcoming 2025 season. While all trials were harvested, data from Pullman spring and Dayton and St. John winter trials were not published due to high variability or lack of significant differences within each trial. 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 7% to 424 subscribers. The final technical report was posted on our website (http://smallgrains.wsu.edu/variety) at the end of December 2023.

RESULTS:
Barley varieties were covered at seven field days with a total of 175 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. Through conversations with the Whitman County Association Wheat Growers the plan will be to alternate years for the Spillman Farm Field Day.

Spring barley entries 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. In 2024, we plan to provide seed to Dr. Kim Garland-Campbell with USDA-ARS for cold tolerance screenings of winter barley entries. Seed was provided in 2023 for cold tolerance screening, but was used to fine tune growth chamber conditions to better detect varietal differences. Generated ratings will be uploaded on to the variety selection tool once data is compiled. Select harvested sample are also sent to the WSU Barley Breeding Program for micro-malting analysis

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 2023, 95,000 acres of spring barley were planted. When comparing the yield from the top four varieties in each trial to the trial average, there is approximately a 251 lb/a yield advantage. When multiplied across planted acres and using an average sales price of $321/ton, the VTP had the potential to generate an additional $3.8 million dollars in 2023 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, well over a hundred contacts are also 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, Hessian fly resistance 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 Four Varieties in Trials	Average Price of Feed Barley	Additional Income Generated
	# acres	lb/acre	$/ton	$
2022	71,000	570	$243	$4,917,105
2023	95,000	251	$321	$3,827,123
Total				**$8,744,228**

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): 2 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 trials harvested and data shared with growers iii.) 2024 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 barley entries: 40% public, 60% private iii.) All major barley breeding programs in the PNW are actively participating in the VTP. iv.) 2022 entries, locations, and maps all posted online v.) 2023 entries, locations, and maps all posted online vi.) Winter 2024 trial maps posted following 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. Will begin screening winter barley entries for cold tolerance in 2024.	Ongoing cooperation and collaboration that fit with timelines and other listed objectives.	Stripe rust and Hessian fly 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) ii.) 2023: 7 in-person field days (175 attendance)	June	*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 2023 data and trial updates delivered; total of 53 emails sent to subscribers in 2023	Data emailed out September through December; trial updates/observations posted throughout year.	i.) 2022 data and trial updates delivered to 395 subscribers; subscribers increased 11% in 2022 ii.) 2023 data and trial updates delivered to 424 subscribers; subscribers increased 7% in 2023
	d.) Website	i.) 2022 data and VT field maps posted ii.) 2023 data and VT field maps posted iii.) 2024 winter VT field maps posted	August through December	10,255 pageview for 2022 VT website TBD pageview for 2023 VT website
	e.) Annual Report	i.) 2022 final report posted in January ii.) 2023 final report posted in December	December-January	The final annual technical report is published online and in hard copy upon request.
	f.) WSCIA Seed Buyers Guides	2022 Guide completed 2023 Guide completed	February	Seed Buyers Guide published in February
	g.) Wheat Life	2022: Spring Barley VT article completed 2023: Spring Barley VT article completed	i.) Completed December 2022 for January 2023 publication. ii.) Completed December 2023 for January 2024 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	2022: 3,337 page views; 177 new app downloads 2023: TBD page views; 96 new app downloads

*2022 in-person Field Days included Dayton, Fairfield, Farmington, Mayview, Pullman, Reardan, St. John.
*2023 in-person Field Days included Fairfield, Dayton, Fairfield, Mayview, Reardan, St. John, Walla Walla.

Project #: 139312
Progress Report: Year 2 of 3
Title: EVALUATION OF WHEAT VARIETIES
Researcher: Clark Neely, Variety Testing Program Lead

EXECUTIVE SUMMARY: The WSU Extension Cereal Variety Testing Program (VTP) continues to conduct 102 annual winter and spring soft white and hard red wheat variety trials throughout 42 locations in Eastern Washington. Data were posted in a timely manner following harvest and distributed via list serve, website, popular press articles, and in-person field days and grower meetings. The program increased overall winter wheat plots by 14% in 2023 with the inclusion of new CoAXium entries.

INTRODUCTION: The primary goal of the 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. The VTP regularly conducts trials at 24 winter wheat, 18 spring wheat, and three fall planted spring wheat locations annually for a total of 102 individual wheat variety trials.

APPROACH: Replicated VTP field evaluation trials will be conducted for winter and spring wheat across each precipitation zone of the dryland wheat production areas (plus irrigated sites) in eastern Washington. Each location was planted and managed with a grower cooperator using practices typical for that growing area. The trials will include approximately 42 entries for common soft white winter wheat trials and 30 Clearfield® and CoAXium® winter wheat entries planted at 24 locations. The Clearfield® and CoAXium® winter wheat entries were split out into a separate trial beginning in 2023 to accommodate a greater number of requests without shrinking the available slots to test common winter wheat varieties. This led to a 14% increase in winter wheat plots from 84 entries in 2022 up to 96 entries in 2023. Another 30-36 entries are routinely planted at 16 locations for the hard red winter trials. Breeding programs can submit entries for planting at: 1) all locations; 2) locations receiving <12” precipitation; 3) locations receiving 12-16” precipitation; 3) locations receiving >16” precipitation; or 4) irrigated locations. Spring wheat trials consisted of 24 entries planted at 18 locations and breeding programs may choose to have entries planted at: 1) all locations; 2) rainfed locations; or 3) irrigated locations. Additional fall-planted HRS trials will be planted at both irrigated locations as well as one dryland location. Fertilizer rates for hard wheat trials will be adjusted according to yield goal, historical precipitation, soil test results, and cropping history.

RESULTS: The vast majority of trial yield data was available within 48 hours of harvest. This data was initially emailed out to the ‘prelimdata’ list serve which currently stands at 424 subscribers, up 29 from 2022. Once harvested, samples were brought to the lab, cleaned and analyzed for grain protein and test weight, and then data was compiled into tables and posted on our website (http://smallgrains.wsu.edu/variety). All individual winter wheat location yield data were posted by August 28 and regional summaries posted September 1. All spring wheat individual location tables (including test weight and grain protein) were completed by September 15. The final technical report was completed and posted at the end of December.

The VTP continues to share entry seed with a multitude of other programs inside and outside of WSU to screen varieties for agronomic traits including stripe rust, Hessian fly, cold tolerance, snow mold, aluminum tolerance, end use quality and falling numbers. The VTP also makes a concerted effort to collect additional ratings on emergence and lodging when possible. These ratings are then posted on our website and variety selection tool. The variety selection tool mobile app continues to garner interest reaching a total of 478 downloads since its launch in May of 2021. In coordination with growers, seed dealers, extension and other allied industry, the VTP held/attended 18 field days in the month of June and reached approximately 505 attendees at these events. In collaboration with the WSU Division of Academic Outreach and Innovation, "virtual" field days were again recorded at Lind (low rainfall varieties) and Pullman (high rainfall varieties) and posted on July 3 and July 19, respectively, on the CAHNRS YouTube Channel and have received a combined 307 views.

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. In 2023, 2.3 million total acres of wheat were planted. When comparing the yield from the top five winter wheat varieties and top four spring wheat varieties to the trial average, there is approximately a 5 and 3 bushel per acre advantage, respectively. When multiplied across 1.8 million winter wheat and 500,000 spring wheat planted acres using an average price of $6.50 per bushel, the VTP had the potential to generate an additional $68 million dollars in 2023. Both the variety testing website and the variety selection tool average over 8,000 page views each on an annual basis. Another 500+ 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 unquestionably 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 Varieties in Trials	Averaged Price of Wheat	Additional Income Generated
		# acres	bu/acre	$/bu	$
2022	Winter Wheat	2,300,000	9.6	$9.43	$208,214,400
	Spring Wheat	475,000	2.9	$9.43	$12,989,825
2023	Winter Wheat	1,800,000	5.3	$6.50	$58,500,000
	Spring Wheat	500,000	3.0	$6.50	$9,750,000
Total					**$289,454,225**

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): 2 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.) All 2022 trials harvested and posted ii.) All 2023 trials harvested and data posted by September 1 iii.) All 2024 winter trials planted iv. 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.) All 2022 trials harvested and posted ii.) All 2023 trials harvested and data posted by September 1 iii.) All 2024 winter trials planted iv. Collaborative trials are continuing with OSU at Eureka and Walla Walla.		
	c) 24 Clearfield/CoAXium winter wheat trials; 12-30 entries/trial	ii.) All 2023 trials harvested and data posted by September 1; first year for these trials iii.) All 2024 winter trials planted iv. Collaborative trials are continuing with OSU at Eureka and Walla Walla.		
	c) 18 soft spring wheat trials; 24 entries/trial	i.) All 2022 trials harvested and posted ii.) All 2023 trials harvested and data posted by mid-September iii.) 2024 call for entries to be sent out in mid-January		
	d) 18 hard spring wheat trials; 24 entries/trial	i.) All 2022 trials harvested and posted ii.) All 2023 trials harvested and data posted by mid-September iii.) 2024 call for entries to be sent out in mid-January		
	e) 3 hard red spring fall-planted trials; 18 entries/trial	i.) All 2022 trials harvested and posted ii.) 2023 trials harvested and data posted; Dayton planting prevented due to early cold snap in October/November iii.) All 2024 trials planted		
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.) 2023 winter trials 59% public, 41% private; spring trials 75% public, 25% private. Every major breeding program in the PNW is actively participating in the VTP. iii.) All 2023 entries, locations, and maps are posted on the variety testing website. 2024 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 entry seed, 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	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.

		survival. Ratings are updated annually and incorporated into the final technical report each year. They are also available via the variety selection tool/mobile app and in variety characteristics tables posted on the WSU small grains website.		
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	2022: Provided slides for Ritzville and Davenport grower meetings in January (unable to present in person). Presented at WSU Wheat Academy in December. 2023: Presented at Ritzville and Davenport grower meetings in January. 2024: Scheduled to present at Ritzville and Davenport grower meetings in January 2024.	Will attend meetings when invited.	Attend in person and present results through powerpoint presentation and handouts when appropriate.
	b.) Field Tours	i.) 2022: 20 in-person field days (605 attendance); 2 virtual field days (232 views to date). i.) 2023: 18 in-person field days (505 attendance); 2 virtual field days (307 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 prelimdata list serve
	c.) Email List Serve	1.) 2022 data and trial updates delivered; total of 37 emails sent to subscribers in 2022 ii.) 2023 data and trial updates delivered; total of 53 emails sent to subscribers in 2023	Data emailed out August through December; trial updates/observations posted throughout year.	i.) 2022 data and trial updates delivered to 395 subscribers; list serve membership increased 11% in 2022 ii.) 2023 data and trial updates delivered to 424 subscribers; list serve membership increased 7% in 2023
	d.) Website	i.) 2022 data and VT field maps posted ii.) 2023 data and VT field maps posted iii.) 2024 winter VT field maps posted	August through December	10,255 pageview for 2022 VT website TBD pageview for 2023 VT website
	e.) Annual Report	i.) 2022 final report posted in January ii.) 2023 final report posted in December	December-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 2023 Guide completed	February	Seed Buyers Guide published in February
	g.) Wheat Life	2022: winter and spring VT articles completed 2023: winter and spring VT articles completed 2024: winter VT article to be submitted in April using 2023 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	2022: 3,337 page views; 177 new mobile app downloads 2023: TBD page views; 96 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. *2023 in-person Wheat Field Days included: Horse Heaven, Connell, Ritzville, Douglas, Moses Lake, Harrington, Lind, Fairfield, Mayview, Reardan, Almira, St. John, Eureka, Walla Walla, Dayton, Farmington, Pullman, Bickleton.				

Washington Grain Commission
2023 Wheat and Barley Research Annual Progress Reports and Final Reports

Project #: 144786

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

Title: Rapid and inexpensive measurements of soil carbon and sequestration potential in grain systems

Cooperators: Haly Neely, Kirti Rajagopalan, Steve Culman, and Dani Gelardi

Executive summary: So far in Year 1, we had our initial team meeting (June 13, 2023) to discuss soil sampling timing and strategies. Based on prior team experience, we will begin collecting samples in March 2024. Sampling in the spring is preferred to fall sampling due to soil moisture conditions. PI Neely has hired a Visting Scholar who will assist in sample collection and processing. Samples will be sent to SoilTest Farm Consultants, Inc., after collection. We also plan to leverage the State of the Soils project co-led by Washington State Department of Agriculture (WSDA) and WSU. Collaborator Gelardi has access to hundreds of archived samples with associated laboratory data. These samples will be scanned in both Neely's and Culman's labs for additional data to build prediction models. We plan to begin scanning these samples in February.

Introduction: Carbon incentive programs are gaining traction in both the policy arena and the farming community. In addition to being a potential source of revenue, increasing soil organic carbon (i.e., soil organic matter) also provides important benefits including increasing soil moisture storage, nutrient storage and cycling, and overall soil health. Whether we want to increase soil organic carbon to sell carbon credits or to gain the potential soil health benefits, we need to know 1) what is the best sampling method to monitor carbon storage over time at the field-scale, 2) what are the best management practices to sequester carbon in each growing region, and 3) what is the maximum amount of carbon that a given soil can store? This project combines an experienced team, innovative sampling methodology, and cutting-edge technology to address these questions for Eastern Washington grain systems.

Approach: Over the course of the proposed 3-year project, we will collect soil samples from at least 25 fields across all grain production regions in Washington state. Within each field, we will use multiple datasets to help select 6-10 sampling locations that are representative of the field. We will run a suite of physical, chemical, and biological properties on samples including a focus on physical soil carbon fractions (particulate organic matter, POM; and mineral-associated organic matter, MAOM). In addition to lab-measured properties, soil samples will also be analyzed using mid-infrared (MIR) spectroscopy and we will identify specific spectral peaks that we can use as indicators of early soil carbon accrual and permanence. We will use the lab data and MIR spectra to build calibrated prediction models that translate MIR spectra to the fraction predictions we are interested in, allowing future efforts to rely on just spectral measurements instead of intensive soil sampling.

Results: No results to report.

Impact: Our ***long-term*** goal is to fill critical gaps in the measurement, monitoring, and verification of soil organic C levels, as well as the sequestration benefits from changing management practices. The global voluntary carbon credit market has been estimated to be worth over $50 billion by 2030 according to a report from McKinsey & Company (Blaufelder et al., 2021) and interest continues to grow as more and more companies pledge to achieve carbon neutral status. The Pacific Northwest represents a significant potential opportunity for long-term, stable carbon storage (Brown and Huggins, 2012) but presents unique challenges including highly complex landscapes and fewer options to build soil organic carbon through practices such as cover cropping. There are no private companies working in this area in the Pacific Northwest to provide field-scale carbon measurements, and any tools and/or recommendations developed in other regions are not likely to be applicable due to our unique soils and growing conditions. Without reliable assessments of soil carbon and sequestration potential, we can't make recommendations to farmers for which carbon credit program is the most profitable or work towards developing programs that reward farmers for the carbon they've already stored.

Our ***short-term*** goal is to develop predictions models for MIR spectroscopy so we can make more measurements in more locations. We will also identify primary drivers of soil organic carbon storage. Additionally, PI Neely has had conversations with SoilTest Farm Consultants, Inc. (Moses Lake, WA) about the potential to commercialize these methods. CEO Kyle Bair is very interested in this project, and we will continue to work with SoilTest and other commercial soil testing laboratories on making these methods available to farmers as quickly as possible.

Blaufelder, C., C. Levy, P. Mannion, and D. Pinner. 2021. A blueprint for scaling voluntary carbon markets to meet the climate challenge. https://www.mckinsey.com/capabilities/sustainability/our-insights/a-blueprint-for-scaling-voluntary-carbon-markets-to-meet-the-climate-challenge#/ Accessed on Jan. 5, 2024.

Brown, T.T., and D.R. Huggins. 2012. Soil carbon sequestration in the dryland cropping region of the Pacific Northwest. J. Soil Water Conserv. 67:406-415; DOI:10.2489/jswc.67.5.406

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WGC project number: 144786
WGC project title: Rapid and inexpensive measurements of soil carbon and sequestration potential in grain systems
Project PI(s): Haly Neely, Kirti Rajagopalan, Steve Culman, and Dani Gelardi
Project initiation date: July 1, 2023
Project year (X of 3-yr cycle): Year 1 of 3

Objective	**Deliverable**	**Progress**	**Timeline**	**Communication**
1. Develop MIR-spectroscopy calibrations for soil organic C fractions (POM, MAOM, POXC, etc.) including applying various predictive models to validate which models perform best for Washington state's grain production regions.	A soil library of hundreds of samples with laboratory data (including soil C fractions) and MIR spectra.	Additional projects to leverage have been identified and a plan for collecting MIR spectra has been established.	We expect to be able to complete this initial soil library in Years 1 and 2.	We take farmer privacy very seriously. The soils library will not be publicly available but data collected on fields will be provided to our collaborators.
	A preliminary model to predict soil C fractions from MIR spectra.		We expect to begin building this predictive model in Year 2 and have a validated model in Year 3.	Academic and extension publications, field day abstracts, and podcasts.
2. Validate sampling strategies for field-scale soil C assessment including quantifying uncertainty those C assessments across complex landscapes.	Detailed protocols for sampling complex landscapes for soil C and C fractions.	Soil sampling plan has been established and additional team member hired.	We expect to begin building these initial protocols in Year 2 and finalize them in Year 3.	Academic and extension publications, field day abstracts, and podcasts.

3. Begin to identify the major factors driving soil organic C sequestration at the field-scale (management practices, climate, landscape position, soil type, management history, etc.) in grain production systems including reference states for C sequestration potential.	Ranked lists of environmental and management factors driving soil C sequestration that are region-specific.		We expect to finalize this deliverable in Year 3	Academic and extension publications, field day abstracts, and podcasts.
	Identify preliminary reference states for each major rainfall zone		We expect to finalize this deliverable in Year 3	Academic and extension publications, field day abstracts, and podcasts.

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Final Report for Fusarium Grant 2021-2023

GR00008054. AWD 3581

Progress Report Year: **final report of three year cycle**

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

Investigators: Kimberly Garland-Campbell, Timothy Paulitz, and Rich Koenig (fund holder)

Cooperators Arron Carter, Mike Pumphrey, Nuan Wen, Ron Sloot and Patricia Demacon.

Executive summary Over the last three years, we have focused on developing a better greenhouse screening system to rate Fusarium resistance. We have optimized temperature, water stress, inoculum quantification and rating system to reduce variability and increase disease pressure. We are presently screening about 500 lines per year for resistance, including all of the Winter and Spring Regional Nurseries, and the advanced lines in the variety testing sites. We have identified several varieties with increased tolerance, including the winter wheat Devote. Secondly, we continue to develop collections of germplasm that are better adapted to PNW conditions, and these are being incorporated into the breeding programs.

Introduction:

Fusarium crown rot is the most widespread and chronic soilborne disease in the Pacific Northwest, causing an average of 10% yield loss and an estimated $ 80 million dollars in losses. There are presently no chemical controls, growers have to rely on cultural controls such as crop rotation or N management, which are not effective. Resistance or tolerance would be the best solution, but there is no major gene resistance present. In addition, the disease is highly affected by environmental conditions, increased with water stress, making screening difficult in the field. That is why we are optimizing greenhouse screening techniques and developing more effective germplasm.

Over the last 3 years, our main objectives have been to continue to identify new and existing sources of resistance that can be used in the WA breeding programs to create tolerant varieties. Finding tolerance or resistance to Fusarium crown rot is a much more intractable problem than finding single-major genes to control diseases such as stripe rust or cereal cyst nematode. There are no major genes identified for resistance against this disease. A much longer and better funded effort in Australia over the last 30 years has identified some varieties with moderate tolerance. They also have identified the most susceptible varieties, which is another goal of our program. The Australians have been able to obtain better resistance by combining sources of partial resistance. The other difficulty is the large genotype X environment interaction with this disease, which makes field screening much more difficult. Thus, much of our effort has gone into perfecting a reliable greenhouse and field screening methods, and we have recently made advances in getting higher disease levels by vernalizing and water stressing the plants and rating them at the boot stage rather than at the seedling stage. This has been used to screen all the advanced variety testing lines, both winter and spring, as well as the Winter and Spring Regional Nurseries. We are presently screening over 200 varieties/lines per year. But the biggest advance the last three years has been to expand our pool of germplasm collections to include exotic sources that are more amenable to incorporation into adapted germplasm.

Approach:

1). Develop consistent, accurate, and reproducible methods of phenotyping this disease. Unlike foliar diseases that are easy to rate and quantify, Fusarium crown rot symptoms are more difficult to rate and highly dependent on environmental conditions. To identify the quantitative (minor gene) sources of resistance, we need phenotyping data that will be consistent and show enough range of resistance or susceptibility. We have focused on inoculated greenhouse methods, and found that by vernalizing the lines, and adjusting temperature and water stress, we could get more consistent results (work of Yvonne Thompson supported by previous cycle). With the PhD research of Nikayla Strauss in this cycle, we developed a better method of quantifying inoculum. Rather than just placing whole millet seed next to the seedling, the inoculum was ground and spread around the surface for a more uniform coverage. In addition, we quantified the strength of the inoculum by serial dilution plating. We diluted the ground inoculum in water, created a suspension, and spread it on agar media to count the number of colonies. Then the total colony forming units in the original inoculum can be calculated. The other advance was in developing a faster more accurate method of phenotyping. We were using a 1-9 rating system, by comparing the appearance to photos corresponding to each disease level. Instead, by counting the number of discolored internodes, we can count faster and get more reproducible results. It is also easier to train rating personnel. We evaluated the methods with a power analysis, and found the new method took less than half the number of replicates to accurately rate the varieties. One way to overcome variation is to increase the number of replicates, but this takes more greenhouse resources.

The other challenge has been developing field screening methods. Fusarium crown rot resistance can be expressed in seedlings in the greenhouse, but to be effective in the field, they will need to express adult plant resistance. These methods have evolved over the last 20 years. Initial studies by just rating disease in variety testing sites and relying on natural inoculum has not been effective, because of the strong genotype X environment interactions. This is a disease driven by drought and water stress, and some years resistance would not be rated because of a lack of disease. It also assumed uniform inoculum in the field. One approach taken by Richard Smiley and others was to apply inoculum at the time of seeding in the field in paired rows. This is very time consuming, and can only be used for evaluating a few varieties. This program has not been continued by his replacement, Christina Hagerty. In this funding cycle, we optimized a method at Lind of using durum wheat the previous year to build up natural inoculum. Durum is highly susceptible to Fusarium crown rot. The durum wheat is seeded early grown with irrigation and fertilizer to produce large plants and then killed just after heading. The spring wheat cultivars are planted using no-till into the durum stubble the following spring. Alternate sides of the field are used each year. This is starting to produce good screening results.

2) Identifying novel and more adapted sources of resistance. This disease does not have major gene resistance, unlike stripe rust, eyespot and cereal cysts nematode. We have worked with a number of populations that encompass a large degree of genetic variation and possible resistance. These are outlined in more detail under the results. These include

a. A set of facultative synthetic wheat germplasm developed by CIMMYT in Turkey that were crossed with locally adapted varieties. Parent PNW varieties included spring wheats Chet, Ryan, DH11SRW070-14, and winter wheats Selbu, WA8252, Sequoia, and club wheat Cara.

b. Populations developed by backcrossing Iranian landrace AUS28451 to Louise.

c. Doubled haploid population from Cara X Xerpha cross.

d. The DNAM recombinant inbred lines developed by direct crosses between a hard white winter wheat and the wheat wild relative, *Aegilops tauschii,* that is the progenitor of the D genome of wheat.

Results:

Objective 1. Screen spring and winter variety trials and breeding lines for resistance in the greenhouse. The quickest way to get resistant varieties into growers' hands is to have a robust screening system to handle all the advanced material developed by our breeders. Over the last 2.5 years, we have screened over 500 lines from regional nurseries and variety testing for resistance to *F. culmorum* and *F. pseudograminarum* and are identifying the most resistant and susceptible. We have further optimized our greenhouse testing protocol to maximize disease and reduce variability by using a cold vernalization period followed by a water stress treatment at the end. We are reducing variation from run to run by more accurate quantification of the *Fusarium* inoculum and a better rating system**. For the first time, we have a released variety with a high degree of tolerance to Fusarium crown rot, as a result of our Fusarium screening.** This variety, Devote, is a soft white winter wheat adapted to low to intermediate rainfall areas. It can emergence from deep planting, but most importantly Devote combines strawbreaker foot rot resistance, snow mold resistance and tolerance to Fusarium. Strawbreaker foot rot and Fusarium crown rot often occur in a complex. For spring wheats, 'AP Coachman', 'JD', 'Ryan', 'Roger', 'CP3530', 'CP3119A', and 'Net Cl+', and several LDRC and WA breeding lines were as resistant as the resistant checks '2-49' and 'Sunco'. Winter wheats are more variable and more testing is needed but better resistance was demonstrated by 'AP-Exceed', 'Rosalyn', and 'TMC M-pire'.

We evaluated the spring and winter wheat variety trials using the greenhouse test. We confirmed our predictions that at least 8 replications were required for stable data.

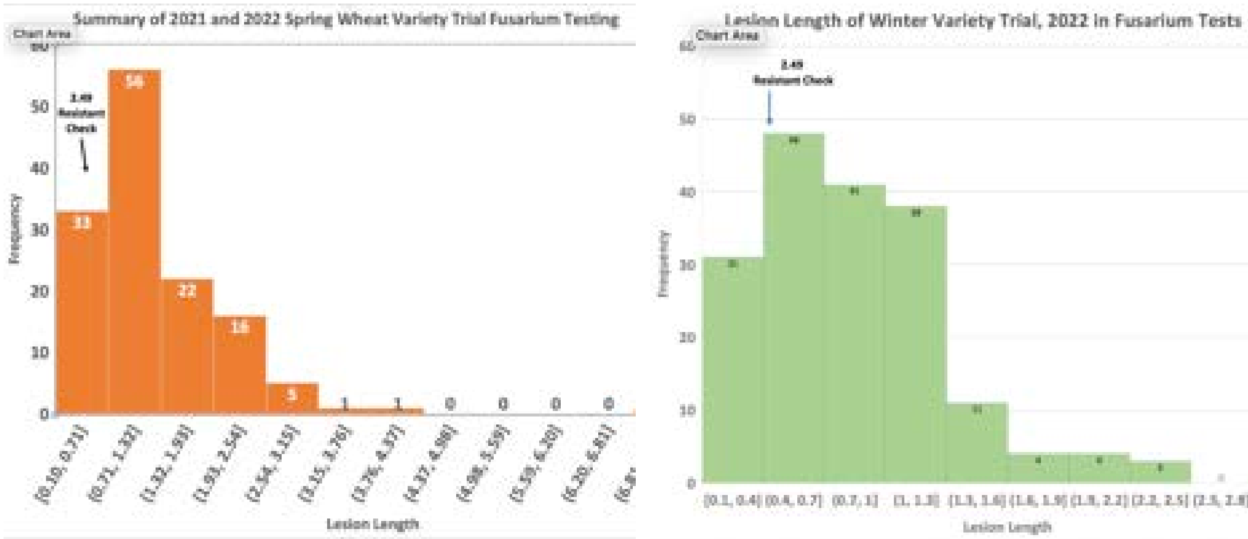


Fig. 1. Distributions of Fusarium resistance in spring and winter wheat variety trials. In both cases, there are cultivars that rated better than our resistant check, the Australian line '2.49'.

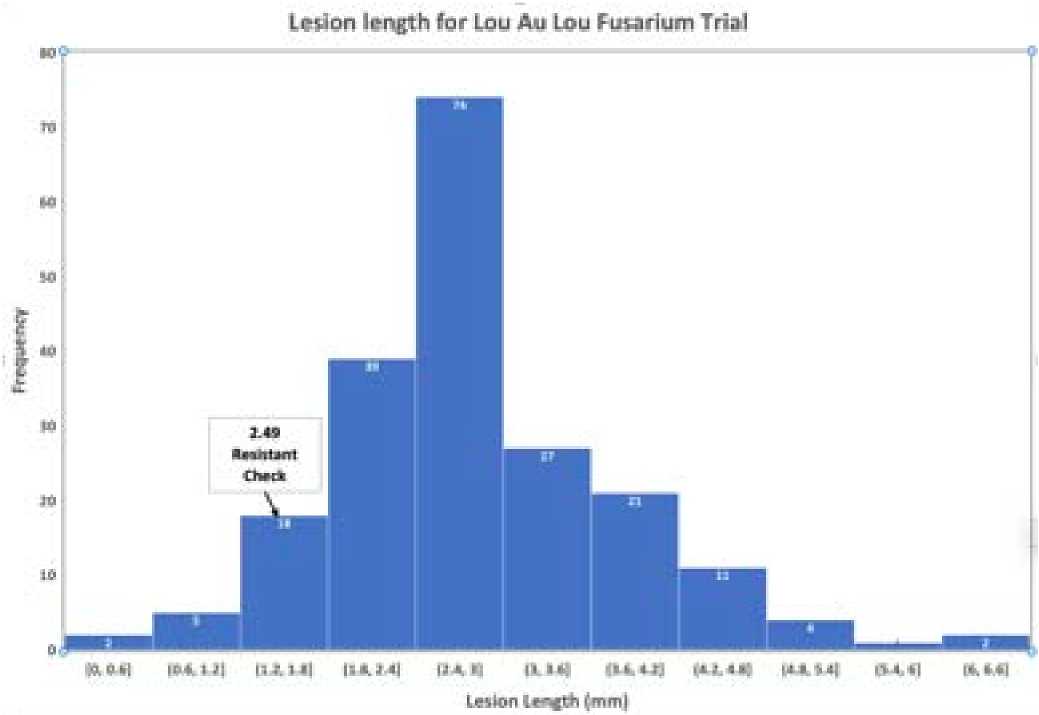
Objective 2. Look for new sources of resistance in a new set of synthetic wheat that was developed by CIMMYT in Turkey and in other collections.

We received this set of facultative synthetics in 2017 from the International Wheat Improvement Program with CIMMYT in Ankara, Turkey and spent a year increasing the seed. These synthetics recreate hexaploid wheat and have been selected to have multiple disease resistance traits. Synthetic wheat is derived from crosses between durum wheat and *Aegilops tauschii,* the donor of the wheat D genome. Since durum is susceptible to Fusarium, any resistance that we identify is from the D genome. This germplasm represents potential new sources of resistance and has been crossed with winter wheat breeding lines from the USDA and WSU breeding programs. The adapted parents included the spring wheats Chet, Ryan, DH11SRW070-14, and the winter wheats Selbu, WA8252, Sequoia, and club wheat Cara. We have increased these populations to advance them from the F2 to the F4 and will be evaluating them in 2024 and 2025.

We developed a doubled haploid population from Cara/Xerpha which was evaluated in the greenhouse. Fifteen lines showed lower disease ratings than Xerpha and Madsen. These lines can be introgressed directly into adapted soft white winter breeding lines. This population has not yet been incorporated into the breeding program.

Another source of resistance is from a DNAM population, specifically from the *A. tasuchii* parents U6713 and UC6716. Because these populations are only segregating for variation in the D-genome, we likely have identified novel resistance. This population was highly skewed toward resistance, with 32 progeny with Fusarium ratings below 2 on a 1-10 scale where 1 is the best. This population has not yet been evaluated.

We screened the Aus28451/Louise backcross population (Lou Au Lou) and discovered several lines that are more resistant than our resistant check. These will be crossed to our most resistant spring and winter wheat cultivars to combine resistance sources.



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).

We have used marker assisted selection to select for resistance to strawbreaker foot rot (eyespot) for stripe rust resistance and for end use quality. We have concluded that Fusarium is too complex a disease to select for with marker assisted selection. We will initially use marker assisted selection for other traits, then evaluate for Fusarium resistance.

Impact

We are increasing the Fusarium resistance and tolerance of WA varieties.

Ovcr the last three years, we have

1. Provided resistance ratings of spring and winter varieties grown in WA.
2. Contributed to release of a new soft white winter wheat variety, Devote, with high Fusarium crown rot tolerance as well as other soilborne diseases.
3. Developed new exotic sources of resistance that can easily be incorporated into adapted PNW varieties.

4. Optimized better greenhouse and field methodology for screening for Fusarium resistance in greenhouse.
5. Identified several spring and winter wheat germplasm lines that have shown resistance over multiple greenhouse and field screening assays. These lines will be used in recurrent selection breeding to improve and combine resistance to Fusarium crown rot with that of other soilborne diseases in both spring and winter wheat.

Refereed papers

Thompson, Y. A., Paulitz, T. C. and Garland-Campbell, K. A. 2020. Genome-Wide Association Study for Fusarium Crown Rot (*Fusarium culmorum*) Resistance in a Diverse Global Wheat (*Triticum aestivum* L.) Collection. Submitted to BMC Plant Biology, not accepted. We are resubmitting this to Crop Science this spring.

Strauss, N., Klarquist, E., Kaya, J., Thompson, Y, Paulitz, T. C. and Garland Campbell, K. 2022. Screening of Winter Wheat for Fusarium Crown Rot in a Controlled Environment. Frontiers in Plant Science (To be submitted)

Theses

Strauss, Nikayla. 2022. Identifying Novel Disease Resistance and Drought Tolerance Genes in a Synthetic NAM Population PhD Thesis, Washington State University

Popular articles

Paulitz, T. C. and Campbell, K.G. 2023. Fusarium Crown Rot of Wheat- It's Everywhere and Persistent Wheat Life, Dec. 2023

Podcasts

WSU Wheat Beat Podcast. Fusarium Crown Rot. Recorded and published December 2023.

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 3 2023-2024**

Objective	Deliverable	Progress	Timeline	Communication
Objective 1. Screen spring and winter variety trials and breeding lines for resistance in the greenhouse.	Ratings of varieties for *Fusarium* tolerance in the the WSCIA seed buyers guide and other publications.	In 2023 we screened the Lou-Au Lou population which includes genetic resistance derived from an Iranian landrace. We planted the 2024 WA winter wheat variety trials for screening. Growth chamber space limitations reduced the number of lines that we can screen each year, so we have changed the procedure slightly to use additional chambers and greenhouses to screen the 2024 WA winter wheat trials. After two years of screening spring variety trials, we can say that several cultivars including 'AP Coachman', 'JD', 'Ryan', 'Roger', 'CP3530', 'CP3119A', and 'Net Cl+', and several LDRC and WA breeding lines are as resistant as the resistant checks '2-49' and 'Sunco'. Winter wheats are more variable and more testing is needed but better resistance is demonstrated by 'AP-Exceed', 'Rosalyn', and 'TMC M-pire'.	Greenhouse screening will continue with optimized methods in 2024-2025	Paulitz, T. C. and Campbell, 2023. Fusarium Crown Rot of Wheat- It's Everywhere and Persistent. Wheat Life, Dec. 2023. Fusarium Crown Rot- Wheat Beat Podcast, recorded Dec. 2023
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.	Crosses have been made with soft white winter wheat lines such as NW Tandem, that are exhibiting more resistance to FCR. We will select progeny during early generation increase using our improved screening system, followed by marker assisted selection for resistance to other soil borne diseases such as strawbreaker foot rot.	Crosses will be evaluated, advanced, and intercrossed in 2024 and 2025.	Paulitz, T. C. and Campbell, 2023. Fusarium Crown Rot of Wheat- It's Everywhere and Persistent. Wheat Life, Dec. 2023. Fusarium Crown Rot- Wheat Beat Podcast, recorded Dec. 2023
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.	We did run a field trial at Lind this summer but weren't able to rate it due to the extremely dry and hot spring and a problem with the irrigation system. This was planted into durum wheat the previous year to build up inoculum. We've corrected the problem and plan to plant a spring trial at Lind this year as well as a winter trial in fall 2024.	Greenhouse screening of backcrosses will continue in 2024-2025.	Paulitz, T. C. and Campbell, 2023. Fusarium Crown Rot of Wheat- It's Everywhere and Persistent. Wheat Life, Dec. 2023. Fusarium Crown Rot- Wheat Beat Podcast, recorded Dec. 2023

Washington Grain Commission
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Project #: 3162

Progress Report Year: *__2__ of ___3_ (maximum of 3 year funding cycle)*

Title: ***Breeding Improved Spring Wheat Varieties for Washington***

Cooperators *All variety testing and evaluation-associated WSU/USDA personnel*

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 2023. *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 Butch CL+ was released, with Breeders and Foundation seed production in 2023. *WSU soft white spring wheat varieties accounted for 97% of certified soft white spring wheat production acres in Washington in 2023. WSU spring wheat varieties collectively were planted on ~80% of the certified spring wheat production acres in Washington in 2023.*

Introduction

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 2023, 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 2019-2023.

Approach

The focus of the WSU spring wheat breeding project is to:
Develop biotic and abiotic stress tolerant, system-based, high-yielding, and high-quality hard red, soft white, and club spring wheat varieties for diverse Washington production environments.
Improve PNW spring wheat germplasm to strengthen long-term variety development efforts/genetic gain by systematically incorporating diversity and stewardship.
Improve and implement cutting-edge scientific techniques and information to enhance current selection methods.

Results

Soft White Spring- 2022 & 2023
Analysis across all WSU VTP sites

Variety	Zone Average Rank	Yield % AVG >20"	Yield % AVG 16-20"	Yield % AVG 12-16"	Yield % AVG <12"	TW	PRO
WA8351	1.0	110%	111%	109%	112%	62.0	10.5
WA8327	2.0	108%	107%	106%	109%	61.2	10.7
Tekoa	5.0	103%	100%	103%	108%	61.3	11.0
Ryan	5.5	102%	107%	103%	99%	60.9	11.0
Roger (club)	6.3	102%	102%	104%	95%	62.4	10.4
Melba (club)	7.5	100%	98%	102%	104%	60.7	10.8
TMC Lochaven	7.5	99%	100%	104%	98%	61.6	11.7
Seahawk	8.8	99%	100%	97%	100%	61.1	11.1
Butch CL+	9.0	99%	101%	101%	92%	61.7	11.3
Hedge CL+	9.3	101%	96%	93%	106%	62.0	11.4
UI Cookie	10.0	99%	102%	96%	91%	60.4	11.7
IDO1902S	11.0	98%	98%	93%	99%	62.6	11.2
Louise	11.3	93%	92%	96%	103%	60.2	10.9
WB6211CLP	12.5	96%	94%	98%	89%	59.2	11.7
AP Mondovi CL2	13.5	91%	90%	94%	96%	60.2	12.4

Impact

In 2023, 97% of all Washington soft white spring wheat acres were planted to varieties from the WSU Spring Wheat Breeding Program, and 80% of all spring wheat acres. Continued genetic gain and regular variety replacement of this important rotation crop are key to supporting farm economics, efficient use of resources, and maintaining and expanding wheat markets.

WGC project number: 3162
WGC project title: Improving Spring Wheat Varieties for the Pacific Northwest
Project PI(s): Mike Pumphrey
Project initiation date: 1-Jul-22
Project year (X of 3-yr cycle): 3 of 3 year cycle

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 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 2023 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 new 2 gene CL+, Butch CL+ SWS and Roger spring club underwent Foundation seed production in 2023. We anticipate release of WA 8351 SWS as well.	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 2023. 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 2023 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 2023 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-throuput phenotyping, genomic selection, marker-assisted selection, drought tolerance, heat tolerance, yie3d, test weight, gluten strenth, etc.	This works has short, medium, and long term goals. We are already using new DNA markers discovered through this work to improve selection for quality and pest resistance.	

Washington Grain Commission
2023 Wheat and Barley Research Annual Progress Reports and Final Reports
Project #: 3163

Progress Report Year: *__2__ of ___3_ (maximum of 3 year funding cycle)*

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

Cooperators Mike Pumphrey, 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.

Introduction 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 2023. The first is a top-performing club spring wheat variety that is the first spring club to have

Hessian fly resistance: ‘Roger’. ‘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 2023.

Approach

1) 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.

2) Apply genome-wide DNA markers for genomic selection and enrich specific breeding lines by marker-assisted selection with stripe rust resistance, Hessian fly resistance, high end-use quality, aluminum tolerance, and Clearfield™ and Axigen herbicide tolerance as well as other traits when desirable.

3) Select early-generation breeding lines with good end-use quality potential by eliminating inferior breeding lines prior to expensive and capacity-limited yield tests.

Impact

In 2023, 97% of all Washington soft white spring wheat acres were planted to varieties from the WSU Spring Wheat Breeding Program, and 80% of all spring wheat acres. Continued genetic gain and regular variety replacement of this important rotation crop are key to supporting farm economics, efficient use of resources, and maintaining and expanding wheat markets.

WGC project number: 3163
WGC project title: Greenhouse and laboratory efforts for spring wheat variety development
Project PI(s): Mike Pumphrey
Project initiation date: 1-Jul-22
Project year (X of 3-yr cycle): 3 of 3 year cycle

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. One new variety was fast-tracked for variety release consideration in 2024 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 succesfully completed in 2023, with approximtaely 3000 lines evaluated through the various quality tests. Additional DNA markers for priority traits including test weight were tested and valdiated for use in our breeding materials. Aproximately 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 characterisitcs. This is where new varieties are born. Greenhouse operations also allow more rapid breeding cycles by advancing F1 and F5 generations every year as part of of our routine breeding efforts. Seedling evaluation of stripe rust resistance and herbicide tolerance screening are also major greenhouse activities.	We continued to use the expanded greeenhouse 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 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): 2 of 3 year cycle

Objective	**Deliverable**	**Progress**	**Timeline**	**Communication**
Early to late generation quality testing of WSU experimental lines to aid variety development	New spring wheat and winter wheat varieties that are superior to existing varieties. This effort includes all market classes of spring and winter wheat and all precipitation regions in Washington state. Milling and baking evaluation of over 1500 lines per year.	Over 1500 breeding samples were analyzed by numerous milling and baking quality tests in 2023. Four superior new wheat varieties are proposed for release in part due to this project and data in 2023 Others are planned for 2024 release.	The economic return for this work will manifest itself each breeding cycle with superior quality varieties and germplasm.	Progress has been 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 mulitple 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 2023, 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.	

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Washington Grain Commission
2023 Wheat and Barley Research Final Report

Project #: 3019-3687_GR00012279

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

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, which are becoming more frequent owing to changing weather patterns. 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 and also used the Chinese Spring variety of wheat as a reference for molecular and phylogenetic analyses.

Introduction

The overall goal of the project was to determine the role of lignin in wheat roots for drought tolerance and disease resistance and will provide insight into the genes that can be developed as markers for lignification during root development and in response to stress to select for more stress-tolerant root systems.

Approach

Our approach was to carefully characterize the differences in lignin content and drought responses between the Iranian landrace AUS28451, Louise, and the reference line Chinese Spring. First, we attempted several methods for lignin quantification and initiated a collaboration with Dr. John Ralph at UW-Madison. We also performed *in silico* characterization of the *CAD* gene family, developed quantitative markers for *CAD1* gene expression, performed RNAseq analysis in Louise and AUS28451 in response to drought.

Results

Overall, AUS has more lignin that Louise. 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. Due to time and scope of the project, we decided to focus on functional characterization of the CAD gene family (Fig. 1). We designed qRT-PCR experiments to determine how *CAD* genes are expressed in roots in response to different environmental cues, in different varieties, and at different growth stages (**Fig. 2**).

Figure 1. Phylogenetic analysis of the CAD gene family in hexaploid wheat

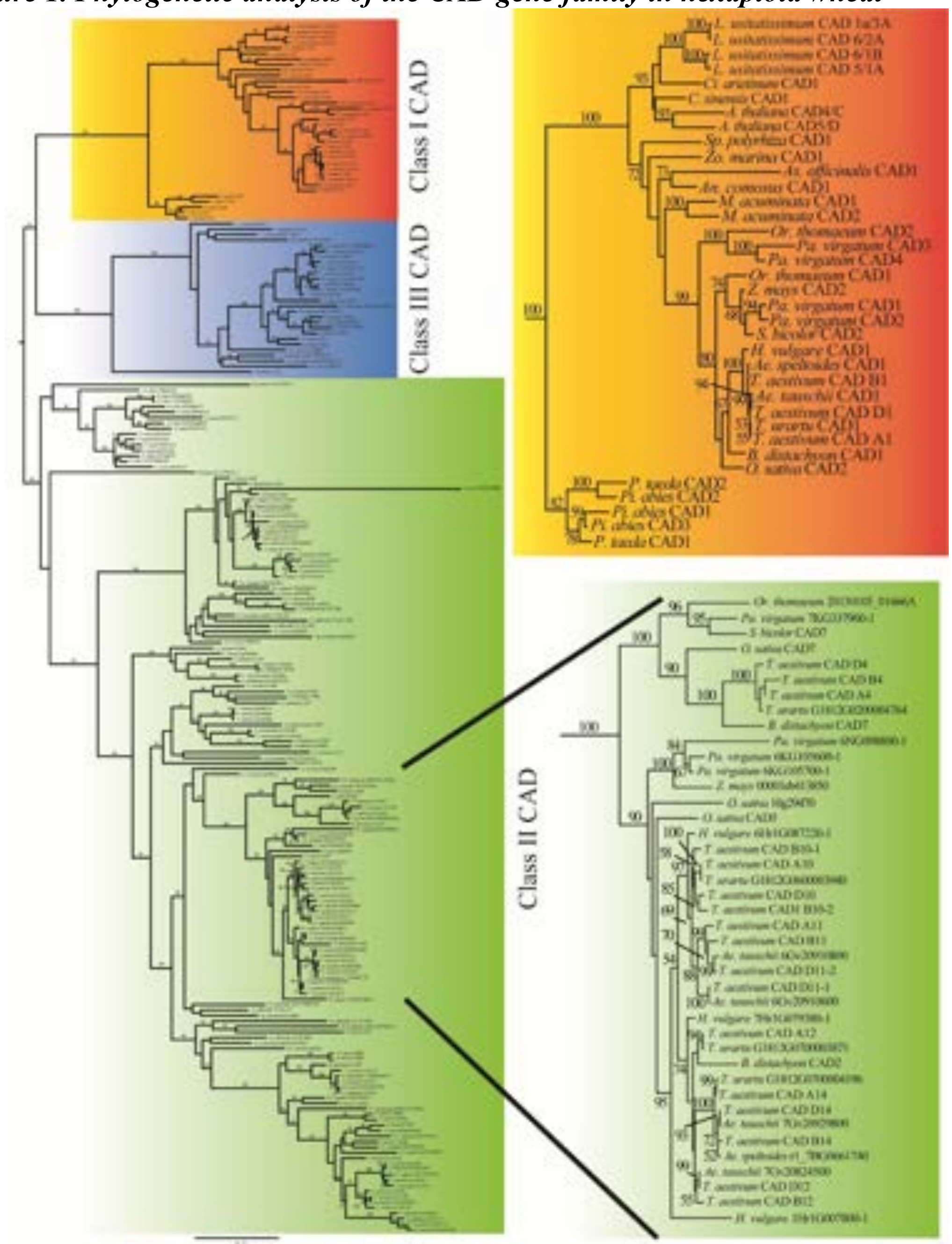
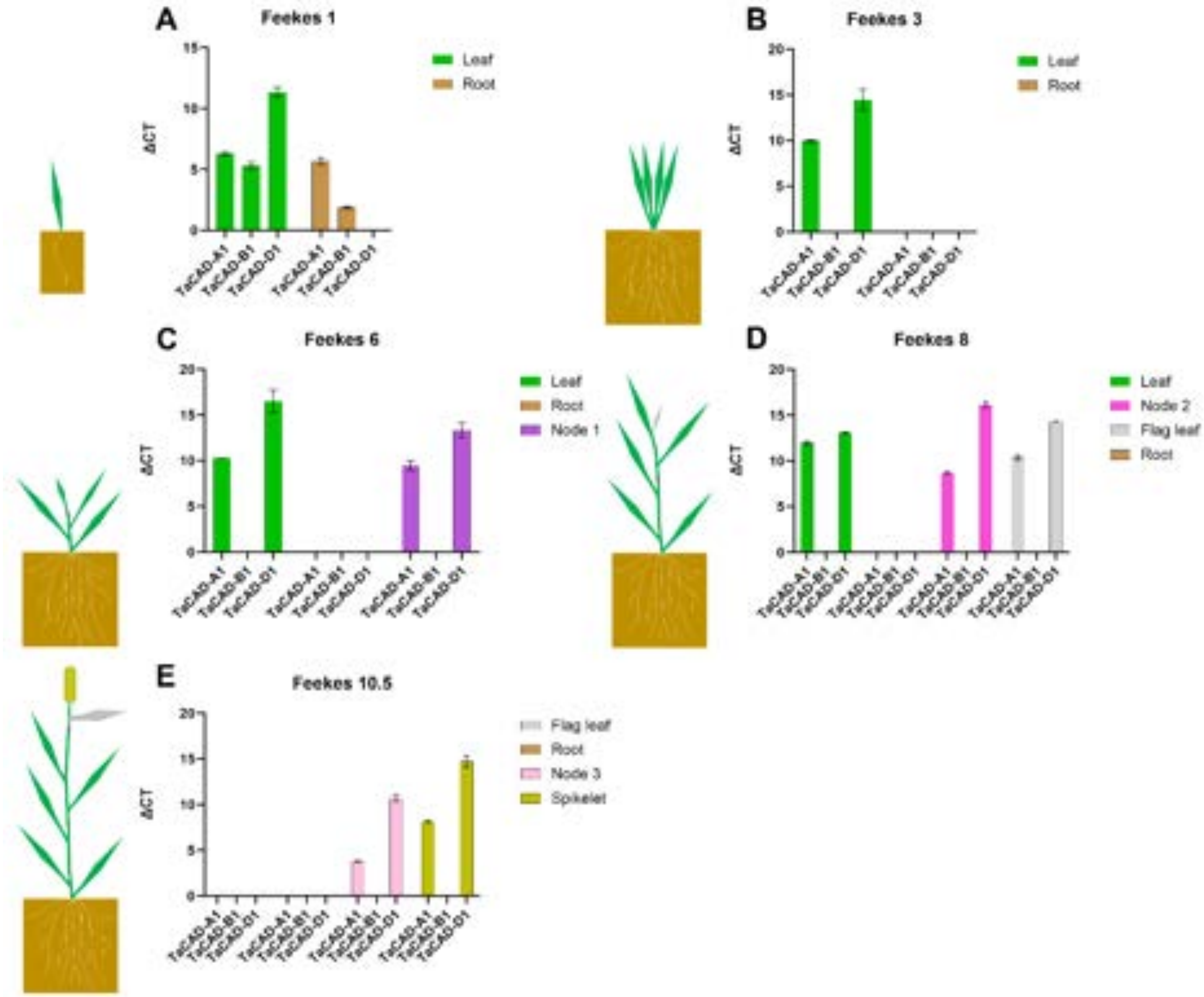


Figure 2. Expression of Class I CAD genes at Feels 1, 3, 6, 8, and 10.5 in roots, leaves, nodes 2 and the flag leaf using subgenome-specific primers in qRT-PCR



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. However, due to problems with sterility in the Kronos tilling likes that work ended up not being very fruitful. Therefore, we performed RNAseq analysis to look at the genes that are differentially expressed in AUS28451 vs Louise in both shoots and roots in response to drought. We are now working on analysis of these data with a focus on CAD and COMT genes as well as root-specific genes that are differentially expressed in response to drought. These data will lay the groundwork for the next funding cycle.

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. The short-term impact of this project is that we were able to characterize the *CAD* gene family in hexaploid wheat that and found all subgenome copies were expressed albeit at different developmental stages. We have laid the ground work for studying *CAD* gene expression and provided a phylogenetic framework. We also found quantification of root lignin to be very challenging and perhaps not the best breeding target because of the dynamic nature of lignin and differential responses to stress and depending on the developmental stage. This has allowed us to redirect efforts back into root development and nutrient use efficiency in future work.

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): 3 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 inconsistences between repeats. Mainly, aromatic analysis of root tissues is technically challenging. Therefore, we will regrew samples to repeat the analysis, and are still working on refining the data. In the meantime we have used other qualitative methods.	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 had technical challenges, which we are complementing with staining for root lignin in Louise and AUS	We are currently working on two manuscripts, one describing the total lignin analysis pipeline and the other will be a report of the disease resistancs and stress tolerance of the lines. All data will be shared with growers in field day abstracts, articles, and podcasts.
2. Identify the CAD and COMT lignin biosynthetic genes in wheat	Since we determined that there is more lignin in AUS root systems, this will enable us to determine if 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 *in silico* analysis was performed. In year 2 we desgined subgenome spcific 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 in silico analysis of the *CAD* gene familiy was completed in year 1. Years 2and 3 focused on the *CAD* gene family and experimental validation of markers for CAD and characterization of *CAD* and *COMT* gene expression in response to drought.	We are finalizing a paper for the *CAD* gene family in wheat tp be submitted in early 2024.. 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, we attempted to analyze individual mutant lines d for stress tolerance and root growth/architectural traits in year 3. As an alternative approach, we used pangenome comparisions to identify a CAD deletion in heaxploid wheat in the Lankmark variety.	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. In year 3, we will focus on individual CAD mutant in the Landmark hexaploid wheat line.	Growing Kronos and crossing the mutant lines was attempted in years 1-3, but we had poor germination and sterility in these line, which make confirmation of the mutants challenging. We took an alternative approach and identified a CAD mutant in Landmark which is being analyzed. Our data will be reported in a WheatLife article and prepared for a peer-reviewed publication. In addition, all data will be shared with growers in field day abstracts, articles, and podcasts.

Project #: 126593

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

Title: **Intelligent Prediction and Association Tool to Facilitate Wheat Breeding**

Cooperators *Dr. Michael Pumphrey, Dr. Kimberly Campbell, and Xianming Chen*

Executive summary *We updated one software package (GAPIT), released one new software package (LADDER), and submitted two articles partially under the support of this project in this fiscal year. The GAPIT software package updated for new functions to integrate GWAS (Genome Wide Association Study) into GS (Genomic Selection) (http://zzlab.net/GAPIT). GAPIT has received over 2500 citations, including the breeders at WSU and USDA-ARS. LADDER is a software for image labeling and integrating artificial intelligence to evaluate stripe rust (https://zzlab.net/Ladder). LADDER 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. LADDER 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 evaluation 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 were published.*

Introduction *Wheat plays a crucial role, contributing to 20% of human caloric intake and serving as the primary source of plant-based protein. Its significance is underscored by global wheat trade surpassing that of all other crops combined. Despite its pivotal role, wheat has historically trailed behind major crops like maize, soybean, and rice in genetic improvements. The current paradigm in wheat breeding primarily emphasizes augmenting variation to drive genetic progress. However, there exists untapped potential to make substantial gains in the other three factors of the breeder equation: selection intensity, accuracy, and interval. Recognizing this opportunity, our project aims to shift the focus towards these neglected aspects, positioning wheat breeding on the path of comprehensive and accelerated genetic enhancement.*

Approach

The project aims to streamline breeding processes through three key objectives. The first involves integrating artificial intelligence (AI) into genomic prediction for enhanced accuracy. The second focuses on creating cost-effective methods for rapid spectral-based falling number assessments using hyperspectral images, especially beneficial for farmers. Lastly, the third objective centers on a drone-based system for efficient stripe rust assessment in wheat, utilizing deep learning for automated image labeling. The overarching goal is to automate and improve breeding practices, addressing challenges in statistical method selection, falling number testing, and disease assessment, contributing to increased efficiency and accuracy in wheat breeding programs.

Results

We have significantly enhanced the MMAP cloud computing platform by seamlessly integrating multiple conventional genomic prediction methods with cutting-edge machine learning techniques. Accessible at https://zzlab.net/MMAP, the platform operates across various servers using JavaScript. Over the course of three years, we meticulously collected field images through drone surveys during peak stripe rust periods. Harnessing this extensive image dataset alongside annual stripe rust scores, we developed a highly efficient labeling method for artificial intelligence models, substantially augmenting our capacity to predict stripe rust. Additionally, we gathered spectral sensor data from wheat samples subjected to varying germination durations, successfully creating a cost-effective prototype, valued at $2000, capable of distinguishing wheat with low falling numbers from those with high falling numbers. Our accomplishments are underscored by six peer-reviewed articles that acknowledge the invaluable support from the WGC. Furthermore, our contributions extend to three articles for Wheat Life and impactful presentations at the WGC annual meeting and various national/international conferences. These collective endeavors underscore our unwavering commitment to advancing wheat research and technology.

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 conduct their data analyses with the most advanced statistical methods and computing tools. They gain more opportunities to find the causative genes controlling traits of interest and 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, Kimberly Campbell, and Xianming Chen*

Project initiation date: 1-Jul-21

Project year 3 of 3-year cylce

Objective	Deliverable	Progress	Timeline	Communication
1) Enhance Genomic Prediction with Artificial Intelligence	An updated cloud computing platform MMAP implementing both conventional and artificial intelligence genomic prediction methods and conducting optimization to improve prediction accuracy.	We updated the cloud computing platform MMAP with multiple conventional genomic prediction methods and artificial intelligence methods. The platform (https://zzlab.net/MMAP) consists multiple servers using Java Script. One peer review article was published by Bioinformatics, which acknowledged the support from WGC.	December 31, 2021: Add artificial intelligence genomic prediction methods to MMAP cloud computing platform; June 30, 2022: Optimize among conventional and intelligence genomic prediction methods.	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
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
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