

Project #: 3019-3009; **Progress Report Year:** Year 1 of 3

Title: Improving Barley Varieties for Feed, Food and Malt

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Executive Summary: The major accomplishment of 2014 was the continued success of two new, two-row, spring *feed barley* varieties, Lyon and Muir. Lyon is a broadly adapted, high yielding spring barley with stem rust resistance intended to replace Bob, Baronesse and Lenetah across high rainfall zones of Eastern Washington. Muir performs particularly well in low rainfall environments of Eastern Washington, and has the most comprehensive disease resistance package of any commonly grown spring barley variety in Washington State. In the low rainfall zone, Muir is intended to replace Bob, Baronesse and Lenetah. On a scale of 1 to 9, Muir was rated as a 1 for resistance to stripe rust across 5 sites in 2014, replacing Bob as the standard barley for stripe rust resistance (rated as a 3 for moderately resistant). One of our advanced lines, 09WA-203.21, topped the WSU Variety Testing (VT) Nursery at three locations in 2014 and will be put forth for pre-release consideration in February 2015. 09WA-203.21 performs particularly well in the intermediate rainfall zone and therefore will be a valuable complement to Lyon (high rainfall) and Muir (low rainfall). Additionally, continued field trials of the imidazolinone (IMI) *herbicide tolerant barley* germplasm were performed in Pullman, and our elite breeding lines showed 100% survival after being sprayed by Beyond[®] herbicide at 2x the recommended rate. The top five of our elite breeding lines are currently being grown out and increased in our winter breeding nursery, and will be included in the WSU VT Nursery at ~10 locations in 2015. Our continued breeding efforts for an IMI-tolerant spring barley include the development of hundreds of advanced lines, extensive crossing, and utilization of double haploid technology to speed the breeding process. Our backcross and topcross lines show promise and will be the focus of our breeding program to expedite a release of an IMI-tolerant barley variety in the near future. For *food barley*, our best hulless breeding lines entered in the WSU VT program significantly outyielded the hulless control variety Meresse by approximately 400 pounds/acre across locations and rainfall zones over two years, and had exceptional test weight, β -glucan content and protein content when compared to hulled varieties. We anticipate nominating two hulless food barley varieties for release in February 2015. Finally, low protein, high-yielding breeding lines that showed excellent potential for future release of *malting barley* lines were identified. Several high yielding breeding lines had low protein (6.3 to 9.5%) and significantly higher yields than both Champion and Baronesse and are currently being tested for malting quality traits in collaboration with the American Malting Barley Association.

Impact: As newly released varieties, Muir and Lyon have yet to impact the market, however, due to their enhanced disease resistance and/or increased yield over currently grown spring barley varieties, we anticipate that if they are accepted by growers and grown on a large percentage of the barley acreage, their impact will be significant in terms of increased production. Seed of Muir and Lyon will be available from Washington State Crop Improvement Association on a limited basis for the first time in 2015. Additionally, at present, considerable winter wheat acreage is devoted to the planting of IMI-resistant varieties, which severely hinders spring barley production due to residual herbicide damage and associated plant back restrictions. Our herbicide resistant breeding lines with the potential for varietal release in the near future would have a significant positive impact on barley acreage and production.

Outputs and Outcomes:

Objective	Deliverable	Progress	Timeline	Communication
<p>1: Release new high-yielding two-row, spring feed barley varieties.</p>	<p>Two two-row, spring, feed barley varieties with superior yield, disease resistance, protein and agronomic characteristics were released in 2013, increased in 2014, and will be available in limited quantities in 2015.</p>	<p>09WA-203.21 topped all entries for yield in the 2014 WSU VT nurseries in Dayton, Reardon and Walla Walla, all intermediate rainfall zone locations. Our next feed barley release is intended to target the intermediate rainfall zone of barley to complement Lyon (high rainfall) and Muir (low rainfall). We intend to nominate 09WA-203.21 for pre-release in February 2015.</p>	<p>2015</p>	<p>Talks and presentations at field days in 2014 at Pullman, Lamont, St. John, Almira, Mayview, Fairfield, and Farmington. Informative variety rack cards of Lyon and Muir were distributed to growers at all field days. Washington State Crop Improvement Association Annual Meeting, Update of WSU Barley Breeding Program, November 10, 2014. Greater Spokane Incorporated Agribusiness Council, Overview of WSU Barley and Alternative Crop Breeding Program, Pullman, WA, October 28, 2014.</p>
<p>2: <i>Herbicide tolerance.</i> Expedite the development and future release of barley varieties that are highly tolerant to the imidazolinone (IMI) herbicides used in winter wheat production.</p>	<p>Development of hundreds of intermediate and advanced spring barley lines with documented tolerance to IMI-herbicides. In 2014, we selected the top five breeding lines. These we sent to our winter location to</p>	<p>We have hundreds of IMI-tolerant backcrossed and topcrossed lines in our breeding pipeline. In 2014, we made 58 successful crosses between spring feed, malt and food barley lines with IMI-resistant barley lines, and obtained 494 F₁</p>	<p>2015-2016</p>	<p>Talks and presentations at field days in 2014 at Pullman, Lamont, St. John, Almira, Mayview, Fairfield, and Farmington. Washington State Crop Improvement Association Annual Meeting, Update of WSU Barley Breeding Program, November 10, 2014.</p>

	increase the seed, and we will submit these five elite herbicide tolerant breeding lines to WSU Variety Testing for multi-location evaluations across barley growing regions of Washington State in 2015.	seeds.		
3: Capitalize on the leveraged funding from the American Malting Barley Association (AMBA) for <i>malting barley</i> research by focusing on the development of varieties that set new standards for malting quality.	We have extensive malting quality data on over 500 breeding lines. We identified the very best candidates with regards to yield and malting quality for inclusion in the WSU Variety Testing Program in 2015. Success of this objective will depend primarily upon the results of these and future malt quality trials.	a) Identification of malting quality molecular markers; b) Potential release of a malting barley cultivar.	a) 2015-2016 b) 2017	Talks and presentations at field days in 2014 at Pullman, Lamont, St. John, Almira, Mayview, Fairfield, and Farmington. Washington State Crop Improvement Association Annual Meeting, Update of WSU Barley Breeding Program, November 10, 2014. Greater Spokane Incorporated Agribusiness Council, Overview of WSU Barley and Alternative Crop Breeding Program, Pullman, WA, October 28, 2014.
4. Evaluate, select and develop high-yielding, hullless, heart-healthy <i>food barley</i> varieties with elevated levels of beta glucan, protein,	We identified two superior breeding lines with over two years of Variety Testing yield and agronomic data, as well as quality data from our lab, that significantly	Our hullless, high β -glucan breeding lines are surpassing all hullless check varieties in our breeding trials and in Variety Testing trials. We quantified over	2015-2016	Talks and presentations at field days in 2014 at Pullman, Lamont, St. John, Almira, Lewiston, Mayview, Fairfield, and Farmington. Washington State Crop Improvement

test weight, and other quality and nutritional characteristics.	and substantially exceed the yield and β -glucan content of Meresse. These two will be nominated for release in February 2015.	500 breeding lines in 2014 for β -glucan content, and are working to identify molecular markers associated with quality traits of interest.	Association Annual Meeting, Update of WSU Barley Breeding Program, November 10, 2014. Greater Spokane Incorporated Agribusiness Council, Overview of WSU Barley and Alternative Crop Breeding Program, Pullman, WA, October 28, 2014.
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Progress

Objective 1. Continue to develop and release high yielding, spring, two-row feed barley varieties with improved disease resistance, high protein and test weight, and excellent agronomic characteristics.

Two new feed barley varieties, ‘Muir’ and ‘Lyon’, were officially released by the WSU Barley Breeding Program in 2013, and showed continued success in 2014. For example, Lyon was the second highest yielding variety (or breeding line) over 3 years (9 location years) and 5 years (14 location years) in the WSU Spring Barley VT nursery in the high rainfall zone (Fairfield, Farmington & Pullman). Muir was the second highest yielding variety over 2 years and the third highest yielding variety over 3 years in the WSU VT nursery in the low rainfall zone. In addition, Muir is the new standard spring barley for stripe rust resistance, replacing Bob. Though these new varieties showed significant improvements in yield and disease resistance over previous WSU varieties (notably ‘Bob’ and ‘Baronesse’) and other commonly grown barley varieties, as always, there is room for improvement. Muir and Lyon now represent the best of the continuously moving target varieties that we aim to surpass each year with our elite breeding lines. We are increasing our number of crosses while improving our estimations of the breeding value of parent varieties to facilitate a larger and better group of breeding lines from which to select. Selection priorities include resistance to a wider spectrum of diseases, herbicide tolerance (see Objective 2), improved straw strength and decreased lodging, higher test weight, consistently plump kernels, tolerance to acidic soils, aluminum tolerance, and higher grain yield across a broad range of environments and rainfall zones. Our next feed barley release is intended to target the intermediate rainfall zone of barley to complement Lyon (high rainfall) and Muir (low rainfall). In 2014, three of the top four entries (10WA-106.18, 09WA-203.36 and 09WA-203.21) across the WSU VT intermediate rainfall zone locations of Dayton and St. John were WSU breeding lines. One of these lines, 09WA-203.21, also topped all entries for yield in the 2014 WSU VT nurseries in Dayton, Reardon and Walla Walla, all intermediate rainfall zone locations.

Objective 2. Continue to expedite the development and future release of barley varieties that are highly tolerant to the imidazolinone (IMI) herbicides used in winter wheat production.

In order to expedite the development of IMI-resistant barley varieties, we continue to use a combination of intensive hybridizations, doubled haploid technology, and greenhouse spray trials to get the improved, herbicide tolerant lines into the field for advanced spray and residue trials. In 2014, we made 58 successful crosses between spring feed, malt and food barley lines with IMI-resistant barley lines, and obtained 494 F₁ seeds. In the field, we use a two-pronged approach to test for and ensure herbicide tolerance. First, we continue to test our mutant backcross and topcross lines under 2x spray conditions in the field with susceptible control varieties (Bob and Champion) and one tolerant wheat variety as a resistant control. Each variety/breeding line is subjected to field sprayings of the 2X the recommended rates of Beyond[®] herbicide, which gives us valuable information on field resistance or susceptibility of our herbicide tolerant breeding line. The second approach is to plant a variety trial on ground sprayed with Beyond[®] on the preceding winter wheat crop, which provides us with data on the yield differences between our herbicide tolerant breeding line and standard spring feed barley varieties when grown in residual herbicide conditions. These are the conditions that would occur on-farm in a typical rotation that would have spring barley follow winter wheat. Due to hail damage in 2014, we lack statistically reliable field data on our herbicide tolerant lines, but through field observations we were able to select the top five breeding lines. These we sent to our winter location to increase the seed, and we will submit these five elite herbicide tolerant breeding lines to WSU Variety Testing for multi-location evaluations across barley growing regions of Washington State in 2015. Our focus will be to bring this important trait to a variety release as soon as possible.

Objective 3. Capitalize on the leveraged funding from the American Malting Barley Association (AMBA) for malting barley research by focusing on the development of varieties that set new standards for malting quality.

Year	Variety or Selection	Kernel Weight (mg)	Plump (%)	Malt Extract (%)	Barley Protein (%)	Wort Protein (%)	S/T (%)	DP (°ASBC)	Alpha-amylase (20°DU)	Beta-glucan (ppm)	FAN (ppm)	Yield lb/a
2014	10WA-111.24	41.4	97.1	78.5	12.1	3.47	29.6	92	49.1	410	144	4427
2014	10WA-113.10	39.3	93.5	78.0	11.2	3.14	28.3	50	34.7	501	121	4357
2014	10WA-116.14	37.7	94.3	76.0	13.1	3.48	26.6	78	36.4	357	128	5092
2014	AC Metcalfe	32.5	78.8	79.0	13.9	4.85	36.0	151	*98.4	55	238	4102
2014	Harrington	40.5	96.9	82.4	11.7	4.66	41.2	118	83.8	66	231	3473
2013	10WA-111.24	41.5	95.0	79.3	10.9	3.57	34.8	81	58.0	263	116	5031
2013	10WA-113.10	42.1	98.0	79.4	9.6	3.38	39.4	43	44.0	219	129	4843
2013	10WA-116.14	37.3	87.0	75.7	11.6	3.55	31.1	86	41.0	140	113	4471
2013	AC Metcalfe	36.9	95.4	81.9	10.1	4.39	46.5	89	92.6	43	194	4782
2013	Harrington	41.2	97.0	82.3	11.8	4.81	44.6	104	88.9	112	225	4362

In addition to adjunct malt quality standards, which are targeted towards lager beers (i.e., Budweiser, Coors, Pabst Blue Ribbon), **all-malt quality** standards are now in place to represent the microbrew, or all-malt, industry. Though only ~5% of domestic consumption of beer falls into the all-malt category, over 25% of all barley malted is for this all-malt, microbrew industry. This represents a significant portion of the malting barley grown in the U.S., and the standards for this type of barley are unique. Our program is now also actively selecting barley lines for the all malt market class.

Objective 4. Evaluate, select and develop high-yielding, hulless, heart-healthy food barley varieties with elevated levels of beta glucan, protein, test weight, and other quality and nutritional characteristics.

2014 was a productive year for our hulless food barley breeding trials. In our advanced yield trials and our Preliminary State Uniform Nursery trial, we had several promising lines yield statistically equal to the high-yield check variety Champion. In these same trials, we identified lines with significantly higher yields than the hulless check Meresse, and 30-40% higher β -glucan content. Our best hulless lines in Variety Testing yielded approximately 400 pounds per acre higher than the hulless check variety Meresse in several locations. In the high rainfall zone, 09WA-265.5 outyielded Meresse by 380 lbs/acre, and had a 2.8 lbs/bu test weight advantage over Meresse over two years (six location years). In the intermediate (six location years) and low (2 location years) rainfall zones, X05013-T1 out yielded Meresse by 420 lbs/acre and 390 lbs/acre, respectively, in 2013 and 2014. In Pullman in 2014, X05013-T1 and 09WA-265.5 had 20% and 10% higher β -glucan content than Meresse. Both these lines represent significant improvements, both in yield and β -glucan content, over Meresse, and our intention is to submit these lines for pre-release in February 2015. Additional food barley traits of interest include hulless, waxy types, proanthocyanidin-free types, and types with high soluble fiber content. New crosses are being made to combine the proanthocyanidin-free trait into waxy hulless types to produce better food types in terms of desirable color and color retention. Crosses have also been made to breed for low phytic acid types to improve mineral quality of barley and reduce phosphorus waste in feeding operations.

B. **Timeline:** see Excel template above

C. **Communication:**

Refereed Publications (published and/or accepted for publication in 2014):

Meints, B., A. Cuesta-Marcos, A.S. Ross, S. Fisk, T. Kongraksawech, J. Marshall, K. Murphy, P.M. Hayes (2015, accepted). Developing winter food barley for the Pacific Northwest of the U.S. *Crop Science* (in press).

Murphy, K., S. Ullrich, M. Wood, J. Matanguihan, S. Guy, V Jitkov, X. Chen (2015). Registration of ‘Lyon’, a two-row, spring feed barley. *Journal of Plant Registrations* 9:6-9.

Rustgi, S.[†], J. Matanguihan[†], J. Mejias, R.A. Brew-Appiah, N. Wen, C. Osorio, N. Ankrah, K. Murphy, D. von Wettstein (2014). Assessment of genetic diversity among barley cultivars and breeding lines adapted to the US Pacific Northwest, and its implications in barley breeding for imidazoline-resistance. *PLOS ONE* 9(6):e100998.

[†]These authors contributed equally to this work

Refereed Publications (submitted in 2014):

Meints, B., A. Cuesta-Marcos, S. Fisk, A.S. Ross, K. Murphy, P.M. Hayes (in review). Registration of ‘#STRKR’ barley germplasm. Submitted to *Journal of Plant Registrations*.

Murphy, K., S.E. Ullrich, M.B. Wood, J.B. Matanguihan, V.A. Jitkov, S.O. Guy, X. Chen, B.O. Brouwer, S.R. Lyon, S.S. Jones (in review). Registration of ‘Muir’, a two-row, spring feed barley. Submitted to *Journal of Plant Registrations*.

Presentations:

- **Washington State Crop Improvement Association Annual Meeting**, Update of WSU Barley Breeding Program, November 10, 2014.
- **Greater Spokane Incorporated Agribusiness Council**, Overview of WSU Barley and Alternative Crop Breeding Program, Pullman, WA, October 28, 2014.
- **Pullman Lions Club Program**, Overview of WSU Barley and Alternative Crop Breeding Program, Pullman, WA, October 27, 2014.
- **WSU Cereal Breeding Program Seed Dealer Tour**, Spillman Farm, Barley Breeding and Genetics, July 18, 2014.

2014 Field Day Presentations:

- **Lamont Variety Testing Field Day**, WSU Barley Breeding and Genetics, Lamont, WA July 16, 2014.
- **St. John Variety Testing Field Day**, WSU Barley Breeding and Genetics, St. John, WA July 16, 2014.

- **Farmington Variety Testing Field Day**, WSU Barley Breeding and Genetics, Farmington, WA July 16, 2014.
- **Mayview Variety Testing Field Day**, WSU Barley Breeding and Genetics, Mayview, WA, June 19, 2014.
- **Almira Variety Testing Field Day**, WSU Barley Breeding and Genetics, Almira, WA, June 18, 2014.
- **Fairfield Variety Testing Field Day**, WSU Barley Breeding and Genetics, Fairfield, WA, June 17, 2014.
- **Lewiston Food Barley Field Day**, Healthy Foods & Farms Program, Harvest Ridge Farm, Lewiston, ID, May 23, 2014.