Project Title: The Oregon Barley Improvement Program

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Executive Summary

In order to assist AMBA in meeting its mission and to realize its primary objectives, OSU develops facultative/winter doubled haploid 2-row malting barley varieties. These will provide the malting and brewing industries with an abundant supply of high quality malting barley meeting the quality specifications of AMBA members. These varieties will have yield potential, making them attractive alternatives to competing crops. Our work is conducted within a larger framework of developing doubled haploid molecular breeding tools that will benefit all barley breeders working to advance the AMBA causes of mitigating risks and increasing acceptance rates.

The major issue for the OSU program is ensuring rapid and efficient development of facultative/winter 2-row malting barley varieties. Our major objectives are to use doubled haploids, molecular breeding tools, and collaborative phenotyping to quickly and efficiently address this issue.

One-year objectives and outputs:

- Submit promising new varieties to the AMBA approval system: The two OSU AMBA Pilot Scale entries (10.0777 and 10.0860) have attractive, balanced malt profiles for adjunct brewing. Nitrogen management and changes in malting protocol could make them (and particularly 10.0860) of interest to all-malt brewers. Agronomic performance is very good, particularly under irrigated conditions. Fungicides will be required in the higher rainfall areas of the Pacific Northwest for both the checks and the Pilot Scale candidates. Winter hardiness is generally superior to Charles and comparable to Endeavor. These selections, and others, are in currently in regional testing in OSU-coordinated trials. They are also included in the 2014-2015 Winter Malting Barley Trial and the Winter Germplasm Nursery. Both 10.0777 and 10.0860 are winters – they require vernalization.
- Develop new germplasm: Generated ~1,000 new facultative/winter doubled haloids and advanced them to regional/advanced/ preliminary trials. The malting quality profiles of these selections are promising, with profiles that could be of interest to adjunct and all-malt brewers.
- Target facultative growth habit: Initiated systematic characterization of facultative growth habit in all breeding material and will test facultative types in fall and spring-sown plantings beginning in 2015.
- Develop germplasm meeting all-malt brewer specifications: Developed doubled haploids specifically to meet these quality specifications.
- Increase and sustain doubled haploid production: Established a DH production facility that is meeting the needs of our own program and those of other programs, on a cost-recovery basis.

Most significant accomplishments:

- Moving 10.0777 and/or 10.0860 towards release as varieties.
- Transfer of disease resistance and the lodging resistant, semi-dwarf growth habit to facultative/winter 2-row malting barley.

- Systematic introgression of European winter 2-row malting barley alleles into U.S. germplasm.
- Generating interest in winter/facultative barley throughout the barley research and production communities.

Detailed Report on Objectives, Methodology and Results – AMBA Funded Project

Objectives and Expected Benefits:

Our objective is to develop superior varieties that meet AMBA specifications based on an understanding of the genetic basis of target traits. In winter/facultative barley, our primary traits of interest are: malting quality, productivity, winter hardiness and disease resistance. All our efforts are directed at 2-row. The expected benefit is assisting AMBA in meetings its mission and primary objectives.

Methodology:

- All germplasm we develop is doubled haploid. Our doubled haploid lab is providing a steady stream of germplasm for our own program and for other projects who contract our services.
- Corvallis, OR is our principal test site. As germplasm advances it is tested regionally, nationally, and internationally. The 2014/2015 nurseries are summarized in Table 1.
- Malting quality assessments are conducted by the USDA/ARS and Dr. Cynthia Henson and colleagues collaborate on additional quality assays. Rich Joy at Great Western Malting provided malting quality data on some of the 2014 crop samples.
- Progress in our program depends on extensive collaboration. Dr. Kevin Smith, University of Minnesota is a key cooperator. BARI has provided agronomic testing at Fort Collins, Colorado and test sites in South Idaho. Dr. Gonghse Hu (USDA/ARS; Aberdeen, Idaho) provides data from Aberdeen. Dr. Juliet Marshall includes our advanced lines in the Idaho Extension nurseries. Dr. Kevin Murphy at Washington State University grows our material at Pullman, Washington. At Pendleton, Oregon we work with Dr. Stephen Machado and at Hermiston, Oregon with Matt Kolding. Dr. David Hole, Utah State, screens varying numbers of lines at Logan, Utah. We exchange germplasm with European companies.

Results:

Our “2-row only” breeding program is well underway. Complete agronomic and quality data for OSU trials/germplasm are online at (http://barleyworld.org/breeding-genetics/data). In the interest of space, in this report we provide only summary data on our AMBA Pilot Scale candidates. 10.0777 and 10.0860 are compared to the checks (Charles and Endeavor) for malting quality traits (Table 2) and agronomic traits (Tables 3 a- 3c).

In terms of malting quality, both 10.0777 and 10.0860 have a higher average percentage of plump seed than the checks and a better range of values than Endeavor, which had exceptionally thin seed at some locations. The average grain proteins for 10.0777 and 10.0860 about 1% lower than the checks, but the ranges are similar. The averages and ranges for malt extract are better for both 10.0777 and 10.0860 than either of the checks. 10.0777 had the highest wort protein and S/T; 10.0860 was comparable to Endeavor. In terms of diastatic power, 10.0777 had an average value comparable to the checks, and a similar range of values, whereas 10.0860 was lower on average and in the range of values. There

was a similar pattern for alpha amylase, although for this trait 10.0777 was the highest of the set. The average wort beta glucans for both selections were substantially lower than for the checks, and the ranges were closer to AMBA specifications than for the checks. 10.0777 had the highest FAN, in terms of both average and range. Considering all available data, the two OSU experimental lines have higher malt extracts, lower wort beta glucans, similar grain proteins levels and enzymes, and substantially higher percentages of plump seed than the checks

The yield data (Table 3a) are broken out by three categories for the Pacific Northwest: high rainfall, irrigated, and dryland. There was one environment of data from the Midwest (St. Paul, Minnesota). On average, 10.0777 was the highest yielding of the four, followed by Endeavor, 10.0860, and Charles. The OSU experimental lines and checks were most productive under irrigated conditions in south Idaho, with 10.0777 yielding over 8,000 lbs/acre. Under irrigation, 10.0860 was similar to Endeavor and 500 lbs/acre better than Charles. Under dryland conditions, Charles and Endeavor had the highest yields. Under high rainfall conditions, the two OSU selections edged out Endeavor and Charles. However, these yields are depressed due to the effects of diseases, notably leaf rust in 2014. This is a new disease to the region. In the future, our research trials under high rainfall conditions will reflect production practices: fungicides will be used. Endeavor had the highest average test weight, followed closely by 10.0777 and 10.0860. Charles was a distant fourth. For kernel plumpness, however, 10.0860 was the highest, followed by 10.0777, Charles and Endeavor. Under irrigated and dryland conditions, all four exceeded 90% plump, but under high rainfall all four failed to meet the specification. The expectation is that with fungicide applications, yield, test weight, and plumpness will all increase under high rainfall conditions. In most trials contributing to this summary, there was 100% survival. However, where there was differential winter injury, 10.0860 had the highest survival, followed by Endeavor and 10.0777. Charles was a distant fourth. Heading dates are very similar for all varieties. Endeavor was the tallest variety, with the others being fairly similar in plant height. Lodging was not a major issue in any of the trials contributing to this summary. Brackling is a visual estimate of the percentage of straw breakage, on a plot basis. Both experimental selections were superior to the checks for this trait. All four entries are resistant/tolerant of stripe rust (data not shown) and susceptible to scald and leaf rust. The latter was formerly a minor pathogen in the Pacific Northwest – it is now a threat. These diseases are most common under high rainfall conditions, and as previously stated, fungicide protection of the checks, 10.0777, and 10.0860 will be required when these diseases are present. Considering all available data, the two experimental selections are generally equal to, or superior to the checks, for most agronomic traits.

Only one year of agronomic performance and malting data from full-size plots are available for the next crop of doubled haploids, but the results are very encouraging (http://barleyworld.org/breeding-genetics/data). There are higher levels of disease resistance, superior malting quality profiles, and many of the new entries are semi-dwarf types. This shorter, stiffer straw will maximize yield potential under irrigated and high rainfall conditions.

Other Barley Research and Future Direction of Program

In addition to winter malting barley development, the Oregon Barley Project is engaged in a number of other endeavors:

- Winter hardiness physiology and genetics using a genome wide association studies (GWAS) approach on a large panel evaluated at multiple locations around the world.

- Genetic dissection of malting quality, nitrogen use efficiency and stripe rust resistance using GWAS.
- Genomic selection for winter hardiness and malting quality.
- Testing the hypothesis that barley can contribute to beer flavor.
- Developing a malt lab whose primary function will be production and analysis of ~ 200 lb. batches of malt from advanced lines and new varieties.
- Winter barley for human nutrition.
- Genetic dissection of quantitative resistance to barley stripe rust.
- Breeding for UG99 stem rust resistance.
- Breeding for hooded forage barley varieties.

In the future, the Oregon Barley Program will continue its dual roles of stimulating economic development and contributing to the body of fundamental knowledge.

Project Personnel

- Patrick Hayes, Professor
- Tanya Filichkin, Senior Research Assistant
- Scott Fisk, Research Assistant
- Laura Helgerson, Research Assistant
- Araby Belcher, Graduate Research Assistant (PhD). Thesis research focuses on GWAS for malting quality, nitrogen use efficiency, and disease resistance.
- Dustin Herb, Graduate Research Assistant (PhD). Thesis research focuses on GWAS for low temperature tolerance-related traits and barley contributions to beer flavor.

- Alfonso Cuesta-Marcos (Employed by Seminis, 2014)
- Ryan Graebner, Graduate Research Assistant (Graduated, 2014). Thesis research focused on GWAS of tocols and development of tools for sampling genetic diversity. Currently pursuing PhD in potato breeding at OSU.
- Brigid Meints, Graduate Research Assistant (Graduated, 2014). Thesis
- Research focused on food barley breeding and genetics. Currently pursuing PhD in cereals breeding at WSU.

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8. Meints, B., A. Cuesta-Marcos, A. Ross, S. Fisk, T. Kongraksawech, J.M. Marshall, K. Murphy, and P.M. Hayes. Developing winter food barley for the Pacific Northwest of the U.S. Crop Sci*. In press.*
9. Meints, B., B. Brouwer, B. Brown, A. Cuesta-Marcos, S. Jones, M. Kolding, S. Fisk, J. Marshall, K. Murphy, S. Petrie, K. Rhinhart, A. Ross, and P.M. Hayes. 2015. Registration of #STRKR barley germplasm. J. Plant Reg. *In press.*
10. Mohammadi, M. T. Blake, A.D. Budde, S. Chao, P.M. Hayes, R.D. Horsley, D.E. Obert, S.E. Ullrich, and K.P. Smith. 2015. A genome-wide association study of malting quality across eight U.S. barley breeding programs. Theor. Appl. Genet. *In press*.

Table 1. Oregon State University barley nurseries: 2014-2015. The summary is divided into "Malting", "Food", "Forage/Feed", and "Genetics". In reality, these areas of endeavor are tightly integrated. This is especially true for feed barley as we generally don't breed specifically for this end-use however feed barley lines may stem from any of the other breeding areas. The emphasis of the program is on facultative growth habit in order to provide maximum flexibility in planting date (for growers) and breeding (for research and variety development).

Malting Barley

Overview:
Number of advanced and fixed lines: 1055

- 363 in yield trial plots
- 692 in single, double or mini-plots (doubled haploids)

Details:
Oregon Winter/Facultative Barley Statewide Yield Trial

• Corvallis, OR	Fall-planted	52 entries, 3 rep, RCBD
• Hermiston, OR	Fall-planted	52 entries, 3 rep, RCBD
• Pendleton, OR	Fall-planted	52 entries, 3 rep, RCBD
• Mt. Vernon, WA	Fall-planted	52 entries, 3 rep, RCBD
• Pullman, WA	Fall-planted	52 entries, 3 rep, RCBD
• Lebanon, OR	Fall-planted	52 entries, unreplicated

Oregon Malting Barley Advanced Line Trial

• Corvallis, OR	Fall-planted	81 entries, 2 rep, RCBD

- Lebanon, OR Fall-planted 81 entries, unreplicated
- St. Paul, MN Fall-planted 64 entries, observation
- Fort Collins, CO Fall-planted 38 entries, observation

Oregon Malting Barley Preliminary Yield Trial

- Corvallis, OR Fall-planted 132 entries, unreplicated

Oregon Facultative Barley Yield Trial

- Corvallis, OR Winter-planted 33 entries, 2 rep, RCBD

Oregon Promise Yield Trial

- Corvallis, OR Winter-planted 51 entries, 2 rep, RCBD
- Lebanon, OR Winter-planted 37 entries, 2 rep, RCBD
- Madras, OR Spring-planted 37 entries, 2 rep, RCBD

Winter Malting Barley Trial (US and International Cooperators)

- Corvallis, OR Fall-planted 24 entries, 3 rep, RCBD

Winter Barley Germplasm Nursery (US Cooperators)

- Corvallis, OR Fall-planted 18 entries, 3 rep, RCBD

AMBA Drill Strips

- Corvallis, OR Fall-planted 10 entries (OSU & USDA-ARS)
- Lebanon, OR Fall-planted 5 entries (OSU)

Observational Drill Strips/Seed Increase

- Corvallis, OR Fall-planted 2 entries
- Corvallis, OR Winter-planted 17 entries
- Lebanon, OR Winter-planted 10 entries

Purification Head Rows

- Corvallis, OR Fall-planted 3 entries, 72 rows each

Malt Doubled Haploid Mini-Plots

- Corvallis, OR Fall-planted 63 lines, unreplicated w/checks
- Corvallis, OR Winter-planted 86 lines, unreplicated w/checks

Malt Doubled Haploid Double Rows

- Corvallis, OR Fall-planted 71 lines, unreplicated w/checks
- Corvallis, OR Winter-planted 108 lines, unreplicated w/checks

Malt Doubled Haploid Single Rows

- Corvallis, OR Fall-planted 179 lines, unreplicated w/checks
- Corvallis, OR Winter-planted 185 lines, unreplicated w/checks

2-row Spring Barley Fertility Trial

- Willamette Valley Spring-planted 5 entries, 3 treatments, 4 rep, RCBD
- Klamath Basin Spring-planted 5 entries, 3 treatments, 4 rep, RCBD
- Northeastern Oregon Spring-planted 5 entries, 3 treatments, 4 rep, RCBD

Food Barley

Overview:

Number of advanced and fixed lines: 293

- 105 in yield trial plots
- 188 in single, double or mini-plots (doubled haploids)

Details:

International Food Barley Trial

- Corvallis, OR Fall-planted 54 entries, 2 rep, Lattice
- Mt. Vernon, WA Fall-planted 54 entries, 2 rep, Lattice
- Pullman, WA Fall-planted 36 entries, 2 rep, Lattice

- Dundee, Scotland Fall-planted 30 entries, 2 rep, Lattice
- Lleida, Spain Fall-planted 30 entries, 2 rep

Oregon Food Barley Advanced Yield Trial
- Corvallis, OR Fall-planted 22 entries, 2 rep, RCBD

Oregon Food Barley Preliminary Yield Trial
- Corvallis, OR Fall-planted 15 entries, unreplicated

Black Beaut Yield Trial
- Corvallis, OR Fall-planted 14 entries, 2 rep, RCBD

Observational Drill Strips/Seed Increase
- Corvallis, OR Fall-planted 3 entries
- Corvallis, OR Winter-planted 2 entries
- Lebanon, OR Fall-planted 1 entry

Purification Head Rows
- Corvallis, OR Fall-planted 1 entry, 72 rows

Food Doubled Haploid Mini-Plots
- Corvallis, OR Fall-planted 123 lines, unreplicated w/checks

Food Doubled Haploid Double Rows
- Corvallis, OR Fall-planted 36 lines, unreplicated w/checks

Food Doubled Haploid Single Rows
- Corvallis, OR Fall-planted 29 lines, unreplicated w/checks

Forage & Feed

Overview:
Number of advanced and fixed lines: 62
- 9 in drill strips
- 53 in single, double or mini-plots (doubled haploids)

Details:
On-Farm Strip Trial (Morrow County)
- Jepsen Farm Fall-planted 7 entries, 4 rep, RCBD
- Starvation Farm Fall-planted 7 entries, 4 rep, RCBD

Spring Forage Barley Drill Strips
- Corvallis, OR Winter-planted 2 entries

Observational Drill Strips/Seed Increase
- Corvallis, OR Fall-planted 3 entries
- Corvallis, OR Winter-planted 1 entry

Purification Head Rows
- Corvallis, OR Fall-planted 9 entries, 72 rows each

Forage Doubled Haploid Mini-Plots
- Corvallis, OR Winter-planted 38 lines, unreplicated w/checks

Forage Doubled Haploid Double Rows
- Corvallis, OR Winter-planted 7 lines, unreplicated w/checks

Forage Doubled Haploid Single Rows
- Corvallis, OR Winter-planted 8 lines, unreplicated w/checks

Genetics

Overview:
Number of advanced and fixed lines: 2331

- 2331 in single, double or mini-plots

Details:
UG99 Doubled Haploid Mini-Plots

- Corvallis, OR Winter-planted 93 lines, unreplicated w/checks

UG99 Doubled Haploid Double Rows

- Corvallis, OR Winter-planted 16 lines, unreplicated w/checks

UG99 Doubled Haploid Single Rows

- Corvallis, OR Winter-planted 14 lines, unreplicated w/checks

Barley Stripe Rust Nursery (Corvallis); Winter-planted

- Lenetah/GZ Population 154 entries, 2 reps, RCBD
- Barley Stripe Rust Screening Trial 40 entries, 2 reps, RCBD
- Winter/Facultative 2-row GWAS Panel 404 entries, 2 reps, RCBD
- Oregon Promise Population 202 entries, 2 reps, RCBD
- Violetta/Full Pint Population 178 entries, 2 reps, RCBD
- Uniform Barley Winter-hardiness Nursery 21 entries, 2 reps, RCBD

OSU-TCAP Low Temperature Tolerance Panel

- Corvallis, OR Winter-planted 941 entries, MAD (type 2)
- St. Paul, MN Fall-planted 941 entries, MAD (type 2)
- Aberdeen, ID Fall-planted 941 entries, MAD (type 2)
- Wooster, OH Fall-planted 941 entries, MAD (type 2)
- Lincoln, NE Fall-planted 941 entries, MAD (type 2)
- Dundee, Scotland Fall-planted 941 entries, MAD (type 2)
- Irlbach, Germany Fall-planted 384 entries, MAD (type 2)
- Martonvasar, Hungary Fall-planted 941 entries, MAD (type 2)
- Freising, Germany Fall-planted 941 entries, MAD (type 2)
- Zaragoza, Spain Fall-planted 941 entries, MAD (type 2)
- Lacombe, AB Canada Fall-planted 941 entries, MAD (type 2)
- Maule, France Fall-planted 941 entries, MAD (type 2)
- Champagne, France Fall-planted 941 entries, MAD (type 2)

Minnesota Genomic Selection

- Corvallis, OR Fall-planted 268 entries, MAD (type 2)

Other

Adaptive Symbiotic Technologies Drill Strips

- Corvallis, OR Fall-planted 7 entries, 2 treatments

Table 2. Malting quality of OSU AMBA Pilot Scale candidates vs. checks across years and locations. *Ranges are in italics*.

Variety Selection	Plump seed (% on 6/64)	Barley protein (%)	Malt extract (%)	Wort protein (%)	S/T (%)	Diastatic power (^{0}ASBC)	Alpha-amylase (20^0 units)	Beta glucan (ppm)	FAN (ppm)
10.0777	94 *79-99*	11.7 *10-14*	82.5 *81-85*	5.8 *5-7*	56 *47-66*	154 *92-216*	101 *49-126*	65 *21-193*	304 *250-394*
10.0860	95 *85-98*	11.6 *11-14*	82.4 *81-84*	5.2 *4-5*	50 *43-60*	132 *92-170*	80 *45-105*	82 *43-124*	247 *195-299*
Charles	88 *79-99*	12.3 *11-15*	80.9 *77-83*	5.4 *5-6*	48 *43-66*	152 *112-198*	90 *61-111*	175 *59-291*	255 *199-310*
Endeavor	84 *57-96*	12.2 *11-14*	81.3 *80-83*	5.4 *5-6*	50 *44-58*	155 *108-193*	92 *51-122*	168 *51-422*	246 *196-222*
Station years	7	7	8	8	8	8	8	8	8

Table 3a. Yield of OSU AMBA Pilot Scale candidates vs. checks across years and locations.

Variety/ Selection	Yield High rainfall (lbs/acre)	Yield Dryland (lbs/acre)	Yield Irrigated (lbs/acre)	Yield Midwest (lbs/acre)	Yield average (lbs/acre)
10.0777	4661	5229	8181	4205	5569
10.0860	4527	4701	7520	3954	5175
Charles	3596	5455	7018	4050	5029
Endeavor	4437	5415	7690	4309	5463
Station years	6	2	5	1	14

Table 3b. Test weight and % plump seed of OSU AMBA Pilot Scale candidates vs. checks across years and locations. *Note: The % plump data in this table are for all environments; those reported in Table 2 are only for samples submitted for malt analysis.*

Variety Selection	Test weight High rainfall (lbs/bu)	Test weight Dryland (lbs/bu)	Test weight Irrigated (lbs/bu)	Test weight average (lbs/bu)	% Plump High rainfall (6/64)	% Plump Dryland (6/64)	% Plump Irrigated (6/64)	% Plump average (6/64)
10.0777	47	53	53	51	75	97	97	89
10.0860	47	51	52	50	82	91	96	90
Charles	44	51	52	49	74	93	93	87
Endeavor	48	54	54	52	68	85	93	82
Station years	5	2	3	12	5	2	4	11

Table 3c. Winter survival (where there was differential winter injury), Heading date, Plant height, Brackling, Scald, and Leaf rust data for OSU AMBA Pilot Scale candidates vs. checks across years and locations.

Variety/ Selection	Winter survival (%)	Heading date (days after Jan 1)	Plant height (in)	Brackling (%)	Scald (%)	Leaf rust (%)
10.0777	81	139	34	36	58	73
10.0860	88	140	32	27	52	60
Charles	73	139	31	46	66	40
Endeavor	84	139	37	65	75	53
Station years	5	7	13	3	2	1