Project Title:	The Oregon Barley Improvement Program
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Executive Summary

How the OSU program helps AMBA realize its mission and primary objective:
The OSU program seeks to help AMBA by developing (1) six-row winter malting barley varieties that will assist AMBA in meeting its mission of providing the malting and brewing industries with an abundant supply of high quality malting barley and (2) molecular breeding tools that will benefit all barley breeders working to advance the AMBA cause. We are addressing AMBA's primary objective – ensuring that barley is a competitive crop – by incorporating malting quality into high yielding winter habit varieties that provide growers with a profitable and productive cropping option.

Major issues, solutions, and expected benefits:
We have developed a winter barley germplasm base suitable for making the elite x elite crosses from which most malting barley varieties derive. This germplasm base is expected to deliver a sustained stream of submissions to the AMBA Pilot program. Molecular breeding tools will allow us to make judicious infusions of new germplasm into this delivery stream.

One-year objectives and outcomes:
We developed, tested, characterized, and selected winter germplasm at multiple locations. We have advanced lines with excellent yields under irrigated and dryland conditions. These high yielding lines have good disease resistance and attractive malt profiles. We have developed markers for target traits and implemented these in our breeding program. Malting data received from 2007 crop samples are very encouraging.

Most significant accomplishments:
Integration of our breeding efforts with the Barley CAP and the US Barley Genome Mapping Project endeavors is leveraging molecular breeding resources. We have systematically introgressed spring malting quality alleles into our winter germplasm. This long-term effort will serve as an essential standard against which to compare our future molecular marker assisted conversion of spring malting varieties to winter habit.

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

Objectives:

Our objective is to develop superior varieties that meet AMBA specifications based on an understanding of the genetic basis of target traits. Our genetics research is conducted in the context of an ongoing breeding program involving agronomically relevant germplasm. This effort received a tremendous boost with funding of the Barley CAP. The idea is that we will make progress towards our goal and when we reach the goal, we'll know how we got there. In winter barley, our primary traits of interest are: malting quality, productivity, winter hardiness and disease resistance.

Methodology:

We work cooperatively on a regional basis. In Idaho we work with Dr. Don Obert (USDA/ARS, Aberdeen, Idaho) to realize the potential of winter malting barley via exchange of advanced yield trials and site visits. In order to expand our testing of elite lines in the AMBA Pilot program, and prospective submissions to the program, we expanded our testing in South Idaho to include Drs. Juliet Windes and Brad Brown. Dr. Steve Ullrich is our cooperator in Washington. Our primary winter barley testing site in Oregon is Pendleton, where we work with Dr. Steve Petrie. Dr. Lee Jackson, UC Davis, provides disease screening. Dr. Blake Cooper and Mr. Scott Dorsch, BARI, provide winter hardiness screening at Fort Collins, CO. In 2007, we added a test site in Montana, kindly provided by BARI. We continue a program of controlled freeze testing with the Martonvasar Research Institute in Hungary. Dr. David Hole, Utah State, participates in screening of winter barley head rows at Logan, Utah.

Our winter barley field phenotyping efforts are based on regional evaluation of variety candidates, replicated multi-environment testing of advanced lines, screening of preliminary yield trials, advance of segregating generations, and crossing to accumulate favorable alleles. The 2007/2008 winter nurseries are summarized in Table 5. Our laboratory program directly supports the winter malting barley breeding program. Malting quality assessments are conducted by Mr. Al Budde, USDA/ARS and Dr. Cynthia Henson collaborates on additional quality assays.

Results:

Breeding program activities and results are detailed in the following tables. These tables show data only for *selections* in the AMBA Pilot program in 2008. The complete data are too voluminous for inclusion in this report; they are available on request.

Three lines were submitted from the 2007 crop for AMBA Pilot Scale testing and passed pre-screening. These lines are OR71 (Stab47/Kab51-7), OR72 (Maja/Kab51-20) and OR76 (Stab47/Kab51-20). STAB 47 was the doubled haploid line, of that number, derived from the F1 of Strider/88Ab536. Kab 51 the doubled haploid line, of that number, derived from the F1 of Kold/88Ab536.Maja is a doubled haploid from the cross of Strider/88Ab536 (tested as STAB113). OR71 and OR76 are sister lines (derived from the 7^{th} and 20^{th} selected rows, respectively, of the same cross). OR71 and OR72 were submitted to the AMBA Pilot program from the 2006 crop. OR71 did not qualify – it is a resubmission in the current cycle; OR72 qualified in last year – it is now in the second year of AMBA Pilot testing.

Quality: Quality data from the 2005,'06, and '07 harvests are summarized in Table 1. All three selections have plumper seed than all the checks. Malt extract values for all three selections are within AMBA specifications and equal to or higher than the malt check (88Ab536). These data show a pattern of lower grain protein (and consequently lower enzyme activity). However, this is a consequence of nitrogen fertilization practices, not genetic propensity. An advantage of winter over spring barley will be nitrogen management options. Fall/Spring split applications of N will allow for more precise targeting of protein and enzyme levels. Although at the lower end of the AMBA specification for S/T, the values for the OR71 and OR76 are superior to the malt check (88Ab536). OR72 is 0.4% less than 88Ab536. OR76 has the best diastatic power in the data set and is within AMBA specifications. The DP values for OR71 and OR72 are low but we have observed them to fall into the acceptable range in higher protein environments. All three selections have alpha amylase levels within AMBA specifications. OR76 is notably high. Beta glucan levels for all selections are high in this average data set. They do fall within specifications in individual environments.

Winter hardiness: The data shown in Table 2 make three important points. First, it is difficult to get good winter hardiness data. Second, check varieties and the three experimental lines are all facultative growth habit. Third, in the environments sampled, winter vs. spring growth habit is not correlated with degree of cold tolerance. To elaborate on these points, at Pendleton, Fort Collins, and Aberdeen, there was winter injury. However, the cold injury was not consistent across the field, leading to large standard errors and no significant differences. Under the controlled environment conditions of the Martonvasar phytotron, there were significant differences between the entries chosen for comparison. The three experimental lines were superior to the malt check (88Ab536) and not significantly different from the winter hardy check (812). The vernalization score data corroborate that the three selections are facultative – this offers interesting options for planting date and germplasm advance.

Agronomics: As shown in Table 3, the yield potential of winter barley is truly impressive, with OR71 at an average of nearly 7,000 lbs per acre (140 bu/acre, assuming 50 lbs/bu). Most notable is the small difference in yield between the selections and feed barley checks; the lowest yielding selection (OR72) was 97% the yield of 812, the yield check. The selections all have high test-weight and a high percentage of plump seed (plump data are shown in Table 1). Heading data indicate that, under fall-sown conditions, winter and facultative barley types show a relatively modest difference in heading (10 days). Irrigated winter barley will save at least one application of scarce and expensive water compared to spring barley grown at the same location. Disease data, as compared to check varieties, are shown in Table 4. All selections showed good stripe rust resistance compared to the malt (88Ab536) and yield check (812). All selections showed levels of stripe rust resistance comparable to the resistance check (Strider), except OR76 at Corvallis in 2007. This was a particularly intense epidemic (e.g., 99% severity for 88Ab536). The 30% stripe rust severity for 812 is due to the fact that scald had reached such a level that there was no green tissue left for the rust to feed on. Under the "world class" scald epidemic conditions at Corvallis, all experimental lines showed an acceptable level of tolerance.

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:

Basic research:

- Genetic dissection of malting quality
- Winter hardiness physiology and genetics
- Barley CAP - association mapping
- Genetic dissection of quantitative resistance

Applied research

- Winter barley for human nutrition
- Barley straw for algae control
- Hooded forage barley
- Ornamental barley

We plan to continue these areas of endeavor in the future.

Project Personnel

Patrick Hayes, Professor
Alfonso Cuesta-Marcos, post-doc
Peter Szucs, post-doc
Ann Corey, Senior Research Assistant
Tanya Filichkin, Senior Research Assistant
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Juan Rey, Graduate Research Assistant
Phinyarat Kongprakhon, Visiting Scholar
Katherine Pillman, Visiting Scholar
Andrea Uhrin, Visiting Scholar

Recent Publications (2007 - 2008)

1. Szucs, P., J. Skinner, I. Karsai, A.Cuesta-Marcos, K.G. Haggard, A.E. Corey, T.H.H. Chen, and P.M. Hayes. 2007. Validation of the *VRN-H2*/*VRN-H1* epistatic model in barley reveals that intron length variation in *VRN-H1* may account for a continuum of vernalization sensitivity. Mol. Genet. Genomics . 277:249-261.
2. Limin, A., A.Corey, P. Hayes, and D. B. Fowler. 2007. Low-temperature acclimation of barley cultivars used as parents in mapping populations: response to photoperiod, vernalization and phenological development. Planta. 226:139-146.
3. Bregitzer, P., L. Cooper, P. Hayes, P. Lemaux, J. Singh, and A. Sturnbaum. 2007. Viability and bar expression are negatively correlated in Oregon Wolfe Barley Dominant hybrids. Plant Biotech. J. 5: 381-388.
4. Pino, M., J. S. Skinner, E. Park, Z. Jeknic, P. Hayes, M. Thomashow, and T. Chen. 2007. Use of a stress inducible promoter to drive ectopic *AtCBF* expression improves

potato freezing tolerance while minimizing negative effects on tuber yield. Plant Biotechnology Journal. 5: 1-14.

5. Pino, M., J. S. Skinner, E. Park, Z. Jeknic, P. Hayes, A.H. Soeldner, M. Thomashow and T. Chen. 2007. Ectopic *Atcbf1* overexpression enhances freezing tolerance and induces cold acclimation-associated physiological modifications in potato. Plant Cell and Environ. Online:12/2007.
6. Hayes, P.M. 2007. What's your barley? Brewer's Guardian. 136:46.
7. Cuesta-Marcos, A.., A.M. Casas, P.M. Hayes, M.P. Gracia, J.M. Lasa, F. Ciudad, P. Codesal, J.L. Molina-Cano, E. Igartua. 2008. Yield QTL affected by heading date in Mediterranean grown barley. Plant Breeding. In press.
8. Castro, A.J., P.M. Hayes, L. Viega, and I. Vales. 2008. Transgressive segregation for phonological traits in barley is explained by a limited number of QTL alleles with additive effects. Plant Breeding. In press.
9. Lacaze, X. P.M. Hayes, and A. Korol. 2008. Genetics of phenotypic plasticity: QTL analysis in barley, *Hordeum vulgare*. Heredity. In press.

Table 1. Malting quality data for OSU winter 6-row malting lines and check varieties. Data are averages of 2005, 2006 and 2007 crop years from multiple locations; malt data were generated by the CCRU.

Variety/ Selection	Plump seed (% on 6/64)	Malt Extract (%)	Barley Protein (%)	Wort Protein (%)	S/T (%)	DP (°ASBC)	Alpha amylase (20°DU)	Beta-glucan (ppm)
88Ab536*	76	79.2	11.8	4.7	41.3	139	59.9	237
	*13 ***	*13*	*13*	*13*	*13*	*13*	*13*	*13*
Strider	79	77.9	11.4	3.5	32.9	52	36.0	568
	10	*10*	*10*	*10*	*10*	*10*	*10*	*10*
Maja	77	81.0	10.5	4.4	44.4	120	53.7	95
	14	*14*	*14*	*14*	*14*	*14*	*14*	*14*
812*	60	75.2	12.4	4.8	39.7	136	41.5	233
	6	*6*	*6*	*6*	*6*	*6*	*6*	*6*
OR71	85	81.0	10.9	4.3	42.1	106	56.4	243
	13	*13*	*13*	*13*	*13*	*13*	*13*	*13*
OR72	80	79.8	11.1	4.3	40.9	120	51.4	210
	14	*14*	*14*	*14*	*14*	*14*	*14*	*14*
OR76	89	80.0	12.0	5.0	43.5	142	71.0	163
	12	*12*	*12*	*12*	*12*	*12*	*12*	*12*

*88Ab536 and 812 are the AMBA winter quality and agronomic checks, respectively. Because Eight-twelve is a feed variety with no malting quality, samples were not submitted for quality analysis prior to AMBA's recommendation to include it as a check. Strider is an OSU feed variety and Maja was a would-be OSU malt variety that was ultimately rated unsatisfactory in the AMBA Pilot program. These two varieties are included as internal checks to measure progress in terms of agronomic performance and quality.

** # station years

Table 2. Winter survival data for OSU winter 6-row malting lines and check varieties.

Variety/ Selection	Winter survival (%) Pendleton, Oregon 2007	Freeze test survival (%) at -13.5 ^{o} C Martonvasar, Hungary 2007	Winter survival score Fort Collins, Colorado 2007*	Winter survival (%) Aberdeen, Idaho 2007**	Vernalization score Corvallis, Oregon 2006/2007***
88Ab536	60a	60b	5.8a	57a	49
Strider	48a	58b	6.6a	53a	122
Maja	66a	78a	7.3a	72a	34
812	75a	82a	7.1a	79a	123
OR71	50a	84a	8.1a	55a	29
OR72	60a	80a	7.6a	63a	31
OR76	55a	77a	8.3a	54a	38

*Means based on values of two replicates and two different dates of measurement. There is a third date of measurement but is not considered here since it has a lower correlation with the other two. Luca and Dicktoo are used as checks in each incomplete block. The phenotypic value estimated for each line is adjusted with the phenotypic values of the checks in each incomplete block. A False Discovery Rate multi-test adjustment was used for mean separation at alpha=0.5.
**Means are based on the portion of the plot "not in a tire track depression".
*** Vernalization score calculated as days to heading (after Jan. 1) for spring planting minus days to heading (after Jan. 1) for fall planting.

Table 3. Agronomic data for OSU winter 6-row malting lines and check varieties. Data are averages of 2005, 2006 and 2007 crop years from multiple locations.

Variety/ Selection	Yield (lbs/A)	Test weight (lbs/bu)	Heading (days > Jan. 1)	Height (in)	Lodging (0 – 9)	Lodging (%)
88Ab536	6034	51	127	42	3	24
	*7 **	*8*	*6*	*8*	*4*	*4*
Strider	6825	52	134	39	3	18
	7	*8*	*6*	*8*	*4*	*4*
Maja	6894	53	133	40	2	17
	7	*8*	*6*	*8*	*4*	*4*
812	6798	49	134	37	8	10
	7	*8*	*5*	*8*	*2*	*5*
OR71	6978	52	137	45	2	25
	7	*8*	*6*	*8*	*4*	*4*
OR72	6578	52	132	44	3	37
	7	*8*	*6*	*8*	*4*	*4*
OR76	6850	52	128	44	2	18
	7	*8*	*6*	*8*	*4*	*4*

* # station years

Table 4. Stripe rust and scald data for OSU winter 6-row malting lines and check varieties.

Variety/ selection	Barley stripe rust (% disease severity) average			Scald rating (9 = lesions on flag leaf)	
	Corvallis, 2006	*Corvallis, 2007*	*UC-Davis, 2005/2006*	*Corvallis, 2006*	*Corvallis, 2007*
88Ab536	90	99	60	6	9
Strider	8	1	0	3	6
Maja	6	10	42	5	8
812	93	30	70	7	9
OR71	3	1	0	3	5
OR72	11	1	0	4	6
OR 76	3	30	0	7	5

Table 5. 2007/2008 Oregon winter barley nurseries.

OSU AMBA Drill strips
(88Ab536, Charles, OR71, OR72, OR76)

- Corvallis, Oregon
- Pendleton, Oregon
- Aberdeen, Idaho
- Parma, Idaho
- Rupert, Idaho
- Pullman, Washington

OSU elite lines and checks - screening trial

- Lochow-Petkus, Germany
- Breun, Germany
- St. Paul, MN

OSU-CAPI; 96 entries; Oregon 2006 CAPI Lines

- Corvallis 1 rep, crossing block
- Other locations: Disease screen with Lee Jackson, UC Davis; Food Quality with Mitch Wise, USDA Madison, WI; LOX, and Beta glucanase with Paul Schwarz, NDSU; BSR screen with Xianming Chen, USDA, Pullman, WA; Food Quality with Byung-Kee Baik, WSU, Pullman, WA; Septoria Screen with Brian Steffenson, UMN, St Paul, MN; Net Blotch Screen with Ruth Dill-Macky, UMN, St Paul, MN; Leaf Rust Screen with Carl Griffey, VT, Blacksburg, VA

OSU-CAPII Winters; 71 entries; Oregon 2007 CAPII Winter Lines

- Corvallis 1 rep, crossing block
- Corvallis Fungicide 1 rep, Augmented Design
- Corvallis 1 rep, Augmented Design
- Pendleton 1 rep, Augmented Design, 91 entries
- Martonvasar, Hungary Freeze test

Tapa Fria; 69 entries; OSU lines and European varieties

- Corvallis, Fall 1 rep, Observation Crossing Block
- Corvallis, Spring 1 rep, Observation Crossing Block
- Pendleton 1 rep, Augmented Design
- Aberdeen 1 rep, Augmented Design

- Pullman (49 ent) 1 rep, Augmented Design
- Logan (49 ent) 1 rep, Augmented Design
- Ft. Collins (27 ent) 1 rep, Augmented Design

OBYT; 27 entries; ORELT and Trial B selections

- Corvallis, Fall 1 rep
- Corvallis, Spring 1 rep
- Pendleton 3 rep, RBD
- Aberdeen 3 rep, RBD
- Pullman 3 rep, RBD

Pendleton PYT; 124 entries; selections from F4 and F5 Head Rows

- Corvallis HR, purification plot
- Pendleton 1 rep, Augmented Design

Head Rows (all at Corvallis)

- F3 Head Rows, 24 entries, variable rows per entry
- F3 Head Rows from Top Crosses, 5 entries, variable rows per entry
- F4 Head Rows, 67 entries, variable rows per entry
- Kold/Hoody selections and F3 and F4 Head Rows, 550 rows
- Food Barley Head rows, 800 rows

Early generation segregating Trial from F2's, F3's, Top Cross's, and F4's 260 entries Augmented Design

- Pendleton
- Ft Collins

85 F1 crosses (Corvallis)