Project Title:	The Oregon Barley Improvement Program
Researchers:	Dr. Patrick Hayes, Dr. Alfonso Cuesta-Marcos, Ms. Ann Corey, Ms. Tanya Filichkin, Mr. Scott Fisk
Department:	Dept. of Crop and Soil Science
Institution:	Oregon State University, Corvallis, OR 97331

Executive Summary

Note: Throughout this report "winter" barley refers to fall-planted barley and does not differentiate between facultative and vernalization-requiring types. This report integrates research on doubled haploid production and winter 2-row variety development.

How the OSU program helps AMBA realize its mission and primary objective:

OSU develops:

- winter 2-row malting barley varieties that provide the malting and brewing industries with an abundant supply of high quality malting barley
- doubled haploid genomic selection tools that will benefit all barley breeders working to advance the AMBA cause
- novel germplasm that will increase diversity in U.S. barley. 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 profitable and productive cropping options.

Major issues, solutions, and expected benefits:

We completed testing of winter 6-rows with the 2012 harvest and have made the switch from 6-row to 2-row. Our crossing strategy for the 6 to 2 shift was based on 6 x 2 crosses (to introgress disease resistance and low temperature tolerance from our 6-rows) and 2 x 2 crosses for disease resistance and malting quality. We are in the process of implementing doubled haploid genomic selection for malting quality in winter 2-rows. Our efforts in six-row are leveraged: the best in the program are being tested in the USDA-AFRI Triticeae Cap (TCAP) Nitrogen Use Efficiency (NUE) and Water Use Efficiency (WUE) experiments. Additional six-row lines not in the TCAP were sent to Dr. Bob Brunnick (Miller-Coors) for assessment. The expected benefits are a stream of agronomically competitive winter 2-row malting varieties.

One-year objectives and outcomes:

We completed testing of winter six-rows at multiple locations. Full agronomic and malting quality data are presented in the online annual report (http://barleyworld.org/breeding-genetics/data). Our latest release "Alba" (winter 6-row, feed) was a top performer across locations. We established a doubled haploid (DH) production facility and have produced over 1,400 DH lines. We are offering DH production services on a cost-recovery basis. Our expected annual production capacity for DH seed is ~ 5,000 lines. We field-tested our first winter two-row doubled haploids. The malting quality results were very encouraging (Table 1). Agronomic data are not available since these selections were only in head rows. These selections, and others, are in regional testing at eight locations (Table 2), planted in fall, 2012. 1,416 doubled haploids tracing to 43 different pedigrees were planted at Corvallis in fall

2012/winter 2013 (Table 2 and online at http://barleyworld.org/breeding-genetics/data (2012-2013 malting DH link).

Most significant accomplishments:

- The doubled haploid lab is up and running.
- Malting data on the first 2-row doubled haploids (2012 harvest) are encouraging (Table 1).
- Over 1,400 DH lines are in field testing for 2013 harvest(Table 2).
- We are implementing doubled haploid genomic selection (DHGS), shown graphically in Figure 1.
- Systematic introgression of European 2-row alleles into Oregon winter germplasm. Our key cooperators are Breun, KWS-Lochow, Limagrain and SECOBRA.
- Generating interest in winter barley throughout the barley research and production communities. At every opportunity we promote the merits of winter barley.
- A global understanding of the implications of facultative growth habit. Our data indicate that maximum cold tolerance can be achieved with facultative growth habit. The OrNe project (Fisk et al. 2013. Theor. Appl. Genet.) provided corroborating evidence. We will be able to rigorously and definitively test this hypothesis in the upcoming T-CAP supported association mapping of cold tolerance in a sample of the world's winter and facultative germplasm.

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. In winter barley, our primary traits of interest are: malting quality, productivity, winter hardiness and disease resistance. All our efforts are directed at 2-row.

Methodology:

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. Bob Brunick (MillerCoors) also tests our germplasm 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 and she conducted a seeding rate study with "Maja". Dr. Kevin Murphy at Washington State University grows our material at Pullman, Washington. At Pendleton, Oregon we work with Dr. Steve Petrie 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. Our field trials are nearly all doubled haploid.

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 2012/2013 winter nurseries are summarized in Table 2. Our doubled haploid laboratory program directly supports the winter malting barley breeding program. Malting quality assessments are conducted by the USDA/ARS and Drs. Cynthia Henson and Mark Schmitt collaborate on additional quality assays.

Results:
We completed testing of winter six-rows at multiple locations. Full agronomic and malting quality data are presented in the online annual report (http://barleyworld.org/breeding-genetics/data). Since 6-row is no longer a priority, in this report we'll only share results from "Alba" (winter 6-row), a top performer across locations: 10,302 lbs/acre (202 bu/acre); 51 lb test weight and 92% plump at Rupert, Idaho (Table 9). 8,909 lbs/acre (168 bu/acre); 53 lb/bu test weight and 94% plump at Corvallis, Oregon.

We received our first malting quality data on two-row winter DH lines. As shown in Table 1, there are some attractive, balanced malt profiles in this material. These selections, and others, are in regional testing at eight locations (Table 2), planted in fall, 2012. We established a doubled haploid (DH) production facility and produced over 1,400 DH lines that are in field trials at Corvallis, Oregon. These lines trace to 43 different pedigrees (available online at http://barleyworld.org/breeding-genetics/data). We are offering DH production services on a cost-recovery basis. Our expected annual production capacity for DH seed is ~ 5,000 lines.

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:

- Association mapping of nitrogen use efficiency, water use efficiency, stripe rust resistance and low temperature tolerance
- Genetic dissection of malting quality
- Winter hardiness physiology and genetics
- Genetic dissection of quantitative resistance to barley stripe rust
- Breeding for UG99 resistance
- Winter barley for human nutrition

The human nutrition program has expanded, with support from the Oregon Wheat Commission and Idaho Barley Commission.

Project Personnel

Patrick Hayes, Professor
Alfonso Cuesta-Marcos, Research Assistant Professor
Ann Corey, Senior Research Assistant
Tanya Filichkin, Senior Research Assistant
Scott Fisk, Research Assistant
Laura Helgerson, BioTech Aide II
Brigid Meints, Graduate Research Assistant
Araby Belcher, Graduate Research Assistant
Ryan Graebner, Graduate Research Assistant

Publications (2012 - 2013)

1. Castro, A., F. Gamba, S. German, S. Gonzales, P.M. Hayes, S. Pereyra, C. Perez. 2012. QTL analysis of spot blotch and leaf rust resistance in the BCD47 x Baronesse barley mapping population. Plant Breeding. 13: 258-266.
2. Blake, V.C., J. Kling, P.M. Hayes, J.L. Jannink, S. R. Jillella, J. Lee, D. E. Matthews, S. Chao, T.J. Close, G.J. Muehlbauer, K. P. Smith, R.P. Wise, J.A. Dickerson. 2012. The Hordeum Toolbox: the Barley Coordinated Agricultural Project genotype and phenotype resource. The Plant Genome. 5:81-91.
3. Fisk, S.P., A. Cuesta-Marcos, L. Cistué, J. Russell, K.P. Smith, P.S. Baenziger, Z. Bedo, A. Corey, T. Filichkin, I. Karsai, R. Waugh and P.M. Hayes. 2013. FR-H3: A new QTL to assist in the development of fall-sown barley with superior low temperature tolerance. Theor. Appl. Genet. 126:33 5–347.
4. Locatelli, A. A. Cuesta-Marcos, L. Gutiérrez, P.M. Hayes, K.P. Smith, and A. Castro. 2013. Genome-wide association mapping of agronomic traits in relevant barley germplasm in Uruguay. Mol. Breeding. In press.
5. Haggard, K. G., N. S. Geiger, P. M. Hayes, and A. J. Milligan. 2013. Suppression of cyanobacterial growth of Aphanizomenon flos-aquae by vascular plant decomposition products in Upper Klamath Lake, Oregon. Lake Reserv. Manag. 29: 13-22.

Table 1. Malting quality data (courtesy of USDA/ARS-CCRU, Madison, WI) on winter doubled haploid lines grown at Corvallis, OR.

Variety or Selection	Rowed	Kernel Weight (mg)	on 6/64" (%)	Barley Color (Agtron)	Malt Extract (%)	Wort Color	Wort Clarity	Barley Protein (%)	Wort Protein (%)	S/T (%)	DP (°ASBC)	Alpha-amylase (20°DU)	Beta-glucan (ppm)	FAN (ppm)
10.0856 - Wintmalt/Charles	2	41.5	98.0	34	84.0	1.7	1	9.9	4.90	54.1	150	82.6	38	225
10.0844 - Wintmalt/Bari 2B08-3149	2	41.0	95.2	28	83.8	2.3	1	9.3	4.95	59.2	113	93.7	55	282
10.0764 - Wintmalt/Bari 2B08-3149	2	34.9	96.7	25	83.7	2.2	1	8.4	4.67	60.7	105	109.1	23	246
10.0777 - Wintmalt/Charles	2	38.2	96.6	27	83.3	2.4	1	9.5	5.22	60.2	116	122.3	21	294
10.0860 - Wintmalt/Charles	2	40.2	98.1	37	83.0	2.0	1	10.7	5.11	52.7	126	92.5	79	241
10.0740 - Wintmalt/Bari 2B08-3149	2	43.4	97.7	22	82.8	2.0	1	9.4	5.21	60.1	106	99.4	85	286
10.0739 - Wintmalt/Bari 2B08-3149	2	44.1	96.3	26	82.6	2.4	1	8.9	4.98	58.1	106	99.1	42	276
10.0627 - Wintmalt/Bari 2B08-3145	2	35.6	92.6	33	82.6	2.5	1	9.7	5.20	58.2	117	108.6	39	288
10.0761 - Wintmalt/Bari 2B08-3149	2	40.4	96.8	28	82.3	2.4	1	8.9	4.98	61.1	75	98.0	30	279
10.0849 - Wintmalt/Charles	2	35.4	95.7	35	82.2	1.6	1	9.5	4.16	48.8	113	74.8	62	198
10.0834 - Wintmalt/Bari 2B08-3145	2	39.6	95.1	26	82.2	1.6	1	10.1	4.45	48.7	116	62.7	37	219
10.0835 - Wintmalt/Bari 2B08-3149	2	40.7	96.6	23	82.2	2.1	1	9.8	4.61	51.5	120	70.6	36	237
10.0782 - Wintmalt/Charles	2	36.2	96.1	33	81.8	2.2	1	10.1	5.26	55.9	126	100.7	71	272
10.0852 - Wintmalt/Charles	2	38.4	96.6	39	81.7	1.7	1	10.2	5.15	54.6	122	109.6	107	289
10.0787 - Wintmalt/Charles	2	37.5	97.1	27	81.4	1.3	1	9.7	3.91	42.6	115	53.3	123	178
10.0736 - Wintmalt/Bari 2B08-3149	2	37.6	97.1	31	80.9	2.4	1	9.4	4.42	49.8	117	64.1	28	221
Violetta	2	42.7	99.1	26	80.9	1.7	1	11.6	4.77	43.4	202	54.9	149	187
Charles	2	25.8	*80.8	32	76.6	2.1	1	12.8	5.23	43.4	173	98.2	291	252

Table 2. Oregon State University winter barley nurseries. The summary is divided into "Malting", "Food", and "Genetics". In reality, these three areas of endeavor are tightly integrated. For example, the T-CAP FAC Association mapping panel is comprised of the final selections from our 6-row malting program. Likewise, some malting germplasm has potential food applications, and vice versa. 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). The list does not include 2013 spring-planted trials, as these are still under development.

Winter malting barley

Overview:

Number of advanced and fixed lines: 1810

- 101 in yield trial plots
- 1709 in single, double or six row plots (doubled haploid head rows)

Number of purification head rows:

- 360 (one genotype)

Details:

Winter Malting Barley Trial; Fall-planted; 22 entries from US and International Cooperators

- Corvallis, OR 3 rep, RCBD

Oregon Barley Winter/Facultative Statewide Yield Trial; Fall-planted; 28 entries

- Corvallis, OR 3 rep, RCBD
- Hermiston, OR 3 rep, RCBD
- Pendleton, OR 3 rep, RCBD

Oregon Two-row Malting Barley Trial; Fall-planted; 22 entries

- Corvallis, OR 3 rep, RCBD
- Idaho Falls, ID 1 rep w/repeated check
- Hazelton, ID 1 rep w/repeated check
- Rupert, ID 1 rep w/repeated check
- Fort Collins, CO Observation
- Wooster, OH Observation
- Aberdeen, ID Observation
- St. Paul, MN Observation

Oregon Two Row Malting Barley Preliminary Yield Trial; Fall-planted; 23 entries

- Corvallis, OR Unreplicated

Doubled Haploid Mini-Plots (6 rows of head rows/DH); Fall-planted; 98 entries

- Corvallis, OR Unreplicated

Doubled Haploid Single Rows (Corvallis)

- 144 lines. Fall-planted; Type 2 augmented design
- 630 lines. Winter-planted; Unreplicated nursery
- 611 lines. Late Winter-planted; Unreplicated nursery
- 226 lines. Full Pint/Golden Promise Population; Winter-planted; 1 rep w/repeated check

Purification Head Rows (Corvallis); Late Winter-planted

- Full Pint 360 rows

Observational Drill Strips (Corvallis); Fall-planted; 6 entries

- European Two Rows and OSU Lines

Winter food barley

Overview:
Number of advanced and fixed lines: 364

- 146 in yield trial plots
- 43 in six row plots (doubled haploid head rows)

Number of segregating head rows:

- 492 (F3 to F5)

Details:
Oregon Winter Food Barley Trial; Fall-planted; 16 entries

- Corvallis, OR 3 rep, RCBD
- Hermiston, OR 3 rep, RCBD
- Pendleton, OR 3 rep, RCBD
- Pullman, WA 3 rep, RCBD
- Aberdeen, ID 3 rep, RCBD
- Mt. Vernon, WA 3 rep, RCBD

Oregon Hull-less Food Barley Trial; Fall-planted; 15 entries

- Corvallis, OR 3 rep, RCBD
- Pullman, WA 2 rep, RCBD
- Mt. Vernon, WA 2 rep, RCBD

Oregon Colored Food Barley Trial; Fall-planted; 25 entries

- Corvallis, OR 2 rep, RCBD
- Pullman, WA 2 rep, RCBD
- Mt. Vernon, WA 2 rep, RCBD

Oregon Food Barley Preliminary Yield Trials (Corvallis); Fall-planted; 76 entries total

- F5 Two Rows Unreplicated nursery; 45 entries
- Doubled Haploids Unreplicated nursery; 31 entries

Food Barley Reference Panel (YT Plots); Fall-planted; 10 entries

- Corvallis, OR Unreplicated nursery

Doubled Haploid Mini-Plots (6 rows of head rows/DH); Fall-planted; 43 entries

- Corvallis, OR Unreplicated nursery

Head Rows (Corvallis); Fall-planted; 492 segregating head rows

- F4 Black Beaut Head Rows 156 rows
- F5 Colored Food Barley Head Rows 56 entries, 336 rows

Observational Drill Strips (Corvallis); Fall-planted; 4 entries

- European and OSU Lines

Genetics

Overview:
Number of advanced and fixed lines: 2591

- 306 in yield trial plots
- 2285 in single or double row plots

Details:
OSU-TCAP Facultative 6 row trial; Fall-planted; NUE; Hi, Lo N, 303 entries

- Corvallis, OR Type 2 augmented design

OSU-TCAP Low Temperature Tolerance Panel; Fall & Winter-planted; 1000 entries

- Corvallis, OR Type 2 augmented design

OSU-TCAP NSGC Winter Barley Core; Winter-planted; 376 entries

- Corvallis, OR Augmented design

ARS BSR Mapping Population; Winter-planted; 346 entries

- Corvallis, OR Unreplicated

Madre Selva/Butta-12 Population; Winter-planted; 191 entries

- Corvallis, OR Unreplicated

Minnesota Genomic Selection; Fall-planted; 256 entries

- Corvallis, OR Type 2 augmented design

Kurtford Conversion; Winter-planted; 97 entries

- Corvallis, OR 2 rep, RCBD

Uniform Barley Winter Hardiness Nursery; Winter-planted; 14 entries

- Corvallis, OR 2 rep, RCBD

Oregon/Nebraska (OrNe); BSR; Winter-planted; 5 entries

- Corvallis, OR 2 rep, RCBD

Hull-less YT; BSR ; Winter-planted; 3 entries

- Corvallis, OR 4 rep, CRD

Figure 1. Doubled haploid genomic selection scheme for winter malting barley development.