**Project Title:** Accelerated development of two-row winter/facultative malting barley

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**Executive Summary**

By developing winter and facultative doubled haploid 2-row covered malting barley varieties, the Oregon State University Barley Project seeks to assist AMBA in meeting its mission and objectives. Winter growth habit is a relatively straightforward target. Facultative growth habit is a multi-dimensional challenge because (1) it requires genotypic data as a surrogate for photoperiod sensitivity, (2) it is not simple to exceed agronomic expectations under both fall-planted and spring-planted conditions, and (3) deployment of facultative varieties will require addressing the dangers of the green bridge. The varieties we are developing will provide the malting and brewing industries with an abundant supply of high quality malting barley meeting the quality specifications of AMBA members. Recognizing the different specifications required by adjunct and all-malt brewers, we are developing both types of varieties. These varieties will have outstanding 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 response variety development. Our major objectives are to use doubled haploids, molecular breeding tools, and collaborative phenotyping to efficiently address this issue.

*One-year objectives and outputs:*

* Submit promising new varieties to the AMBA approval system: Thunder made the AMBA-approved list. Great Western Malting has been the principal driver behind the commercialization of the variety. To date, results are promising from the agronomic and malting quality standpoints. Brewing data will tell the rest of the story. As shown in the accompanying tables, we have four submissions in the AMBA Pilot program (2018 crop) and drill strips of potential submissions are planted at cooperating locations (2019 crop). In this report we provide data on two promising selections that we plan to submit for consideration in the AMBA Pilot program (2019 crop). Most AMBA Pilot scale entries (or prospective entries) are in the 2018-2019 Winter Malting Barley Trial and/or Winter Barley Germplasm Nursery.
* Develop new germplasm: We continue to generate new winter/facultative doubled haploids and advanced them to preliminary, advanced, elite, and regional trials. The agronomic and malting quality profiles of these selections are promising. Most malting and malt analysis are conducted in collaboration with the Cereals Crops Research Unit. A subset of advanced lines and experimental materials are malted at the OSU Malt House and analyzed at the Hartwick Center for Craft Food and Beverage.
* Genotyping and phenotyping facultative growth habit: We have phenotyped facultative growth habit of elite breeding material in the greenhouse and in spring-sown plantings and genotyped the trait in a subset of experimental materials.
* Develop germplasm meeting all-malt brewer specifications: We have developed doubled haploids specifically to meet these quality specifications.
* Doubled haploid collaborations: The DH production facility is now focused on the needs of the US Wheat and Barley Scab Initiative (USWBSI), the Small Grains Genomics Initiative (SGGI), and our own program.

*Most significant accomplishments:*

* Thunder (10.0777) makes the AMBA recommended list for 2019.
* DH130939 and DH120304 were rated satisfactory in the AMBA Pilot Program (2017 crop) and are in another year of evaluation (2018 crop).
* Two additional doubled haploids were submitted to the AMBA Pilot Program (2018 crop): DH130910 and DH140088.
* Two doubled haploids (DH140963 and DH141132) are in increase blocks (2019 crop) for possible submission to the AMBA Pilot Program.
* Development of high yielding, lodging resistant winter/facultative 2-row malting barley germplasm with exciting malting quality profiles.
* Systematic introgression of European winter 2-row malting barley alleles into U.S.-adapted 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. Development is 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 AMBA-funded efforts are directed at winter/facultative 2-row covered barley. The expected benefit is assisting AMBA in meeting its mission and primary objectives.

***Methodology:***

* All germplasm is doubled haploid.
* Corvallis, OR is our principal test site. As germplasm advances, it is tested regionally, nationally, and internationally. The 2018/2019 nurseries are summarized in the accompanying tables.
* Malting quality assessments are conducted by the USDA/ARS CCRU. Dr. Cynthia Henson and colleagues collaborate on additional quality assays. Great Western Malting, Canada Malting, and Rahr Malting provides additional malting quality data on special projects and selections. The OSU Malthouse is online and is playing an increasingly important role in generating malts on elite breeding lines and potential varieties.
* Progress in our program depends on extensive collaboration. Kevin Smith at University of Minnesota is a key cooperator for providing winterhardiness data, as is Steve Baenziger at University of Nebraska-Lincoln. Mark Sorrells, Cornell University, tests for winterhardiness and scab resistance. Gongshe Hu (USDA/ARS; Aberdeen, Idaho) provides data from Aberdeen, Idaho and satellite locations. Juliet Marshall includes our advanced lines in the Idaho Extension nurseries. We exchange germplasm with European companies.

***Results:***

In the interest of space, in this report we provide only summary data on our AMBA Pilot Scale submissions and potential AMBA submissions in the AMBA Western Winter Barley Pilot Scale Nursery being grown throughout the Pacific Northwest.

**DH130939**

*Pluses:* Facultative potential. GN non-producer. Excellent yield, standard height but low lodging, good disease resistance: particularly scald. Winter survival fine in Oregon; elsewhere better than Endeavor, 10% lower than Wintmalt. Excellent plumps. Malt extract > Endeavor and Wintmalt. Moderate DP = good for all malt and adjunct specification. Good S/T. Plenty of FAN for adjunct brewers.

*Minuses:* Third year AMBA submission (2018 crop). One year reject, one year accept. 1 % higher protein than checks, but still in range. Borderline acceptable beta glucan. Too high a FAN for all-malt?

*Overall Impression:* Good agronomics. Less than stellar malt profile. The 0 GN does not follow through with high extract and high enzymes desired by craft distillers.

**DH120304**

*Pluses:* Passed first year AMBA Pilot. Excellent yield, taller than average but acceptable lodging. Excellent scald resistance. Winter survival fine in Oregon; elsewhere better than Endeavor and 10% less than Wintmalt. Excellent plumps. Malt extract = Endeavor and Wintmalt and close to Thunder. High enzymes and FAN for adjunct brewers. Good beta glucan.

*Minuses*: Stripe rust level not dangerous, but need to keep an eye on it. Acceptable but not extraordinary malt extract. Almost 1 % higher protein than checks, but still in range. Upper end of modification. Too high enzymes and FAN for all-malt.

*Overall Impression:* The pedigree might suggest an opportunity to explore for novel flavors. However, the malt profile could be more interesting for adjunct brewers who might not be searching for novel flavors.

**DH130910**

*Pluses*: Facultative potential. Good yield, taller than average but lodging = checks. Excellent stripe rust and scald resistance. Mixed reports on scab resistance: some are good, some are no better than checks. Winter survival fine Oregon; elsewhere better than Endeavor and comparable to Wintmalt. Excellent plumps. Malt extract = Endeavor and Wintmalt. Approaching an all malt profile, except perhaps for DP. Low alpha, beta glucan, FAN, with room for a little more modification. This entry is a piece of eye candy in the field.

*Minuses*: Acceptable but not extraordinary malt extract. Almost 1 % higher protein than checks, but still in range. Perhaps on the low side of enzymes for adjunct brewers.

*Overall Impression*: This is one to keep an eye on.

**DH140088**

*Pluses:* Facultative potential. 0 GN. Excellent yield. Average height and good lodging resistance. Excellent stripe rust and scald resistance. Winter survival fine in Oregon; elsewhere better than Endeavor and comparable to Wintmalt. Excellent plumps. Malt extract = Endeavor and Wintmalt.

*Minuses:* Acceptable but not extraordinary malt extract. Almost 1 % higher protein than checks, but still in range. Beta glucan on the edge of acceptability. Neither an all-malt or an adjunct profile.

*Overall Impression:* Nice agronomics. A curious malt profile – low DP, high alpha and high FAN: maybe one for the 0GN specialty?

**DH140963**

*Pluses:* Impressive yield. Taller than average but good lodging resistance. Excellent stripe rust and scald resistance. Winter survival fine in Oregon; elsewhere better than Endeavor and comparable to Wintmalt. Excellent plumps. Protein = checks. Malt extract = Endeavor and Wintmalt. Low DP, alpha, FAN – best all-malt type in the group.

*Minuses*: Acceptable but not extraordinary malt extract. Beta glucan on the edge of acceptability.

*Overall Impression*: Great agronomics and best all-malt type yet in the OSU program.

**DH141132**

*Pluses:* Impressive yield. Taller than average but good lodging resistance. Excellent stripe rust and scald resistance. Winter survival fine in Oregon; elsewhere better than Endeavor and comparable to Wintmalt. Good plumps. Protein = checks. Malt extract = Endeavor and Wintmalt. DP for adjunct brewers but other specs good for all-malt.

*Minuses*: Acceptable but not extraordinary malt extract. Beta glucan on the edge of acceptability.

*Overall Impression*: Great agronomics. Perhaps a good all-malt profile for those wanting a bit of extra DP.

**Other Barley Research and Future Direction of Program**

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

* Higher resolution analysis of the components of low temperature tolerance and facultative growth habit.
* Testing the hypothesis that barley can contribute to beer flavor.
* The Barley World Malt House producing ~ 200 lb. batches of malt from advanced lines in the mini-malter and new varieties and smaller batches of experimental selections using the CLP.
* Multi-use naked barley for organic systems.
* Genetic dissection of quantitative resistance to barley stripe, leaf, and stem rust and deployment of resistance genes in adapted germplasm.

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

* Daniela Carrijo, Post-Doc
* Brigid Meints, Post-Doc
* Tanya Filichkin, Senior Research Assistant
* Scott Fisk, Senior Research Assistant
* Laura Helgerson, Research Assistant

**Graduate students**

* Javier Hernandez, Graduate Research Assistant (PhD). Thesis research focuses on facultative growth habit and resistance to multiple rusts.
* Sarah Windes, Graduate Research Assistant (MS). Thesis research focuses on barley contributions to beer flavor and prospects for perennial malting barley.

**Publications (2018-2019)**

1. Belcher, A.R., A. Cuesta-Marcos, K.P. Smith, C.C. Mundt, X. Chen, and P. M. Hayes. 2018. TCAP FAC-WIN 6 elite barley GWAS panel QTL. I. Barley stripe rust (*Puccinia striiformis* f.sp. *hordei*) resistance QTL in winter/facultative 6-rowed malt barley breeding programs identified via genome-wide association studies. Crop Sci. 58:103-119
2. Belcher, A.R., A. Cuesta-Marcos, K.P. Smith, and P. M. Hayes. 2018. TCAP FAC-WIN 6 elite barley GWAS panel QTL. II. Malting quality QTL in elite North American winter/facultative 6-rowed barley identified via genome-wide association studies. Crop Sci. 58:120-132.
3. Meints, B., A. Corey, C. Evans, T. Filichkin, S. Fisk, L. Helgerson, A.S. Ross, and P. M. Hayes. 2018. Registration of ‘Buck’ Naked Barley, J. Plant Reg.12:1-6.
4. Meints, B.M. and P.M. Hayes. 2019. Breeding naked barley for food, feed, and malt. Plant Breeding Reviews. *In press*.
5. Hernandez, J., B.J. Steffenson, T. Filichkin, S.P. Fisk, L. Helgerson, B. Meints, K.J. Vining, D. Marshall, A. del Blanco, X. Chen and P.M. Hayes. 2019. Introgression of *rpg4/Rpg5* into barley germplasm provides insights into the genetics of resistance to *Puccinia graminis* f.sp. *tritici* race TTKSK and resources for developing resistant cultivars. Phytopathology*. In press.*

**Table 1. Oregon State University barley nurseries: 2018-2019.** The summary is divided into “Malting”, “Naked” and “Genetics”. Malting types are all covered and that is the focus of AMBA and Great Western funding. We view naked types as having multiple uses (malt, food, and feed), but research on the naked class is funded by other sources.

**Malting Barley**

***Overview:***

***Number of advanced and fixed lines: 594***

* 195 in yield trial plots
* 399 in single rows or mini-plots (doubled haploids)

***Details:***

***Oregon Malting Barley Elite Yield Trial***

* Corvallis, OR Fall-planted 30 entries, 3 rep, RCBD
* Lebanon, OR Fall-planted 30 entries, unreplicated w/checks
* Bozeman, MT Fall-planted 30 entries, 3 rep, RCBD
* West Lafayette, IN Fall-planted 30 entries, 3 rep, RCBD
* Wooster, OH Fall-planted 30 entries, 3 rep
* Lincoln, NE Fall-planted 30 entries, 2 rep
* Madison, WI Fall-planted 30 entries
* Blacksburg, VA Fall-planted 30 entries
* St. Paul, MN Fall-planted 30 entries

***Oregon Malting Barley Advanced Line Yield Trial***

* Corvallis, OR Fall-planted 40 entries, 2 rep, RCBD
* Lebanon, OR Fall-planted 40 entries, unreplicated w/checks

***Oregon Malting Barley Intermediate Yield Trial***

* Corvallis, OR Fall-planted 40 entries, 2 rep, RCBD

***Oregon Malting Barley Preliminary Yield Trial***

* Corvallis, OR Fall-planted 76 entries, unreplicated w/checks

***Romp of Otters Yield Trial***

* Corvallis, OR Fall-planted 9 entries, 2 rep, RCBD
* Lebanon, OR Fall-planted 9 entries, unreplicated w/checks
* Bozeman, MT Fall-planted 9 entries, 2 rep, RCBD
* Lincoln, NE Fall-planted 9 entries, 2 rep
* Wooster, OH Fall-planted 9 entries, 3 rep
* St. Paul, MN Fall-planted 9 entries
* Madison, WI Fall-planted 9 entries
* Aberdeen, ID Fall-planted 9 entries

***Winter Malting Barley Trial (US and International Cooperators)***

* Corvallis, OR Fall-planted 17 entries, 3 rep, RCBD

***Winter Barley Germplasm Nursery (US Cooperators)***

* Corvallis, OR Fall-planted 20 entries, 2 rep, RCBD

***AMBA Drill Strips***

* Corvallis, OR Fall-planted 12 entries (OSU & USDA-ARS)
* Lebanon, OR Fall-planted 12 entries (OSU & USDA-ARS)
* Aberdeen, ID Fall-planted 12 entries (OSU & USDA-ARS)
* Kimberly, ID Fall-planted 12 entries (OSU & USDA-ARS)
* Pullman, WA Fall-planted 12 entries (OSU & USDA-ARS)

***ROMP Drill Strips***

* Corvallis, OR Fall-planted 5 entries (OSU & USDA-ARS)
* Lebanon, OR Fall-planted 8 entries (OSU & USDA-ARS)

***Purification Head Rows***

* Corvallis, OR Fall-planted 4 entries

***Malt Doubled Haploid Mini-Plots***

* Corvallis, OR Fall-planted 337 entries, unreplicated w/checks

***Malt Doubled Haploid Single Rows***

* Corvallis, OR Fall-planted 62 entries, unreplicated w/checks

**Naked Barley**

***Overview:***

***Number of advanced and fixed lines: 92***

* 60 in yield trial plots
* 32 in single rows or mini-plots (doubled haploids)

***Number of populations/families in early generations:***

* 36 F3s

***Details:***

***Naked Barley Yield Trial***

* Corvallis, OR Fall-planted 20 entries, 3 rep, RCBD

***OREI Fall Regional Yield Trial (Organic)***

* Corvallis, OR Fall-planted 20 entries, 3 rep, RCBD
* St. Paul, MN Fall-planted 20 entries, 3 rep, RCBD
* Ithaca, NY Fall-planted 20 entries, 3 rep, RCBD
* Madison, WI Fall-planted 20 entries, 3 rep, RCBD
* Arlington, WI Fall-planted 20 entries, 3 rep, RCBD

***Observational Drill Strips/Seed Increase***

* Corvallis, OR Fall-planted 6 entries
* Corvallis, OR (Organic) Fall-planted 3 entries

***Purification Head Rows***

* Corvallis, OR Fall-planted 1 entry

***Naked Doubled Haploid Mini-Plots***

* Corvallis, OR Fall-planted 20 entries, unreplicated w/checks

***Naked Doubled Haploid Single Rows***

* Corvallis, OR Fall-planted 12 entries, unreplicated w/checks

***Naked Multi-use Barley F3s***

* Corvallis, OR Fall-planted 36 entries
* Corvallis, OR (Organic) Fall-planted 27 entries

***OREI Spring Regional Yield Trial (Organic)***

* Corvallis, OR\* Spring-planted 20 entries, 3 rep, RCBD
* Lamberton, MN\* Spring-planted 20 entries, 3 rep, RCBD
* Freeville, NY\* Spring-planted 20 entries, 3 rep, RCBD
* Ithaca, NY Spring-planted 20 entries, 3 rep, RCBD
* Madison, WI\* Spring-planted 20 entries, 3 rep, RCBD
* Arlington, WI Spring-planted 20 entries, 3 rep, RCBD

\*Not yet planted as of 2/22/19

**Genetics**

***Overview:***

***Number of advanced and fixed lines: 2048***

* 2048 in single rows

***Details:***

***Barley Stripe Rust Nursery (Corvallis); Fall-planted***

* Barley Stripe Rust Screening Trial 48 entries, 2 rep, RCBD
* 95SR316A/GZ Population 175 entries, 2 rep, RCBD
* Uniform Barley Winter-hardiness Nursery 30 entries, 2 rep, RCBD
* Multi-Rust Cycle 2 DH Germplasm Array 374 entries, 2 rep, RCBD
* Multi-Rust Cycle 3 DH Germplasm Array 386 entries, 2 rep, RCBD

***AMBA Low Temperature Tolerance Doubled Haploid Cooperative***

* Corvallis, OR Fall-planted 397 entries, 2 rep, RCBD

***OREI Fall Diversity Panel (Organic)***

* Corvallis, OR Fall-planted 384 entries, Type-2 Modified Aug. Design
* Madison, WI Fall-planted 384 entries, Type-2 Modified Aug. Design
* Ithaca, NY Fall-planted 384 entries, Type-2 Modified Aug. Design

***OREI Naked Barley Diversity Panel (Organic)***

* Corvallis, OR\* Spring-planted 254 entries, Type-2 Modified Aug. Design
* St. Paul, MN\* Spring-planted 254 entries, Type-2 Modified Aug. Design
* Ithaca, NY\* Spring-planted 254 entries, Type-2 Modified Aug. Design
* Madison, WI\* Spring-planted 254 entries, Type-2 Modified Aug. Design

\*Not yet planted as of 2/22/19

**Other**

***Adaptive Symbiotic Technologies***

* Corvallis, OR Fall-planted 2 entries, 3 treatments, 3 rep

Descriptors and status of OSU germplasm in the AMBA Pilot Program.



Agronomic data of OSU selections in the AMBA Pilot Program, compared to checks. **DH130939.**



Agronomic data of OSU selections in the AMBA Pilot Program, compared to checks.

**DH120304.**



Agronomic data of OSU selections in the AMBA Pilot Program, compared to checks. **DH140088.**



Agronomic data of OSU selections in the AMBA Pilot Program, compared to checks. **DH130910.**



Agronomic data of OSU selections in the AMBA Pilot Program, compared to checks. **DH140963.**



Agronomic data of OSU selections in the AMBA Pilot Program, compared to checks. **DH141132.**



Winter survival of entries and checks in the AMBA Pilot program where (1) there was differential survival in the trial and (2) all entries were present in the same trial.



Malting quality data of OSU selections in the AMBA Pilot Program, compared to checks. **DH130939.**



Malting quality data of OSU selections in the AMBA Pilot Program, compared to checks. **DH120304.**



Malting quality data of OSU selections in the AMBA Pilot Program, compared to checks. **DH140088.**



Malting quality data of OSU selections in the AMBA Pilot Program, compared to checks. **DH130910.**



Malting quality data of OSU selections in the AMBA Pilot Program, compared to checks. **DH140963.**



Malting quality data of OSU selections in the AMBA Pilot Program, compared to checks. **DH141132.**

