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

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**Executive Summary**

In order to assist AMBA in meeting its mission and to realize its primary objectives, at OSU we continue developing facultative/winter doubled haploid 2-row malting barley varieties. The emphasis is on facultative, but all good winters will be given full opportunity! These varieties 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 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: ORW1 and ORW2 (both winters) are in the AMBA Plant Scale program, with seed increases underway in Idaho under the auspices of Great Western Malting. We have five submissions to the AMBA Pilot program, all facultative. These selections are included in the 2016-2017 Winter Malting Barley Trial, Winter Barley Germplasm Nursery, and the Uniform Barley Winter Hardiness Nursery.
* Develop new germplasm: We generated ~1,000 new facultative/winter doubled haploids and advanced them to regional/advanced/preliminary trials. The agronomic and malting quality profiles of these selections are promising.
* Targeting facultative growth habit: We systematically characterize facultative growth habit of elite breeding material in the greenhouse and in spring-sown plantings.
* Develop germplasm meeting all-malt brewer specifications: Developed doubled haploids specifically to meet these quality specifications.
* Doubled haploid collaborations: The DH production facility has focused on our own needs and those of collaborators. We have met the objectives of the two AMBA-funded collaborative germplasm projects.

*Most significant accomplishments:*

* Moving OR-W1 and/or OR-W2 towards release as varieties.
* Five doubled haploids (all facultative) submitted for AMBA evaluation and assessment in regional nurseries.
* Development of lodging resistant and semi-dwarf growth habit facultative/winter 2-row malting barleys.
* 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 based on an understanding of the genetic basis of target traits. In facultative/winter barley, our primary traits of interest are: malting quality, productivity, winter hardiness and disease resistance. All our efforts are directed at facultative/winter 2-row. 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 2016/2017 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. Great Western Malting, Canada Malting, and Rahr Malting provides additional malting quality data on special projects and selections.
* Progress in our program depends on extensive collaboration. Dr. Kevin Smith, University of Minnesota is a key cooperator. 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. Dr. David Hole, Utah State, screens varying numbers of lines at Logan, Utah. We exchange germplasm with European companies.

***Results:***

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 submissions and new germplasm with potential for all-malt brewers.

Table 1 shows agronomic data on the five OSU AMBA Pilot submissions compared to the standard checks. Being averages, these data are confounded by the environments sampled. For example, Charles and Endeavor will do relatively better in South Idaho and relatively worse in western Oregon. Over the six station years of data, the Pilot Scale Submissions (all of which are facultative) have a considerable yield advantage over Charles and Endeavor and are competitive with Wintmalt. The five Pilot Scale candidates, with the exception DH 120228, have excellent lodging resistance; the lodging susceptibility of DH 120228 may be attributable to its taller stature. Winter survival values are superior to Endeavor, generally better than Charles, and DH130004 is superior to Wintmalt.

In terms of malting quality (Table 2) over five station years, the selections are all plumper than Charles and Endeavor and greater than or equal to Wintmalt. Proteins are within AMBA specifications and malt extracts are equal to, or better than, all checks. There are plenty of enzymes, making these selections most attractive to adjunct brewers. Table 3 shows the malting quality data from 2 locations, 2016 crop to make the point that these are not “high protein” selections per se. With proper management, grain proteins can be kept moderate and malt extract increased. The enzyme and FAN levels are, however, high even with more modest proteins – these are intrinsic genetic attributes of the selections.

Brewers interested in all-malt prospects may be more attracted to the data in Table 4. These are a subset of “next-generation” doubled haploid selections. These were selected for lower FAN, alpha amylase and diastatic power. Overall, the malt extract and beta glucan values are superior to the checks. These selections are entering more advanced testing and more data will be available from the 2017 crop.

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

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

* Higher resolution analysis of the components of 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 and new varieties.
* Multi-use naked barley.
* 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

* Tanya Filichkin, Senior Research Assistant
* Scott Fisk, Research Assistant
* Laura Helgerson, Research Assistant

**Graduate students**

* Dustin Herb, Graduate Research Assistant (PhD). Thesis research focuses on GWAS for low temperature tolerance-related traits and barley contributions to beer flavor.
* Javier Hernandez, Graduate Research Assistant (PhD). Thesis research focuses on facultative growth habit and resistance to multiple rusts.

**Publications (2016-2017)**

1. Brouwer, B., P. Barr, P.M. Hayes, S. Jones, K. Murphy, and P. Schwarz. 2016. Evaluating barley for the emerging craft malting industry in western Washington. 2016. Agron. J. 108:939-949.
2. Cuesta-Marcos A., Kling J.G., Belcher A.R., Filichkin T., Fisk S.P., Graebner R., Helgerson L., Herb D., Meints B., Ross A.S., Hayes P.M. and Ulrich S.E. 2016 Barley: Genetics and Breeding. In:Wrigley, C., Corke, H., and Seetharaman, K., Faubion, J., (eds.) *Encyclopedia of Food Grains, 2nd Edition,* pp. 287-295. Oxford: Academic Press.
3. Esvelt-Klos, K., T. Gordon, P. Bregitzer, P. Hayes, X. M. Chen, I. A. del Blanco, S. Fisk and J. M. Bonman. 2016. Barley stripe rust resistance QTL: Development and validation of SNP markers for resistance to *Puccinia striiformis* f. sp. *hordei.* Phytopathology. 106: 1344-1351.
4. Lau, R. M. Cluskey, E. Howes, P. Hayes, and A. Ross. 2016. Sensory acceptance and satiation potential of barley flakes as a breakfast cereal replacement for oatmeal. Cereal Foods World. 61: 204-210.
5. Hisano, H., B. Meints, M.J. Moscou, L.Cistue, B.Echávarri, K.Sato and P. M. Hayes. 2017. Selection of transformation efficient barley genotypes based on *TFA* (transformation amenability)haplotype and higher resolution mapping of the *TFA* loci. Plant Cell Reports. DOI 10.1007/s00299-017-2107-2

**Table 1. Oregon State University barley nurseries: 2016-2017.** The summary is divided into “Malting”, “Naked” and “Genetics”. In reality, these areas of endeavor are tightly integrated. This is especially true for naked barley as we are viewing naked types for multi-use (malt, food, and feed) rather than for just food.

**Malting Barley**

***Overview:***

***Number of advanced and fixed lines: 802***

* 274 in yield trial plots
* 463 in single rows or mini-plots (doubled haploids)
* 65 in double rows (intro lines)

***Details:***

***Oregon Winter/Facultative Barley Elite Yield Trial***

* Corvallis, OR Fall-planted 30 entries, 3 rep, RCBD
* Lebanon, OR Fall-planted 30 entries, un-replicated w/checks
* Logan, UT Fall-planted 30 entries
* Aberdeen, ID Fall-planted 30 entries
* Wooster, OH Fall-planted 30 entries
* Rupert, ID Fall-planted 30 entries
* Ithaca, NY Fall-planted 30 entries
* West Lafayette, IN Fall-planted 30 entries
* Blacksburg, VA 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, un-replicated w/checks

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

* Corvallis, OR Fall-planted 75 entries, un-replicated w/checks

***Romp of Otters Yield Trial***

* Corvallis, OR Fall-planted 47 entries, un-replicated w/checks
* Lebanon, OR Fall-planted 47 entries, un-replicated w/checks

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

* Corvallis, OR Fall-planted 30 entries, 3 rep, RCBD

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

* Corvallis, OR Fall-planted 22 entries, 3 rep, RCBD

***AMBA Drill Strips***

* Corvallis, OR Fall-planted 15 entries (OSU & USDA-ARS)
* Lebanon, OR Fall-planted 13 entries (OSU & USDA-ARS)
* Aberdeen, ID Fall-planted 13 entries (OSU & USDA-ARS)
* Filer, ID Fall-planted 13 entries (OSU & USDA-ARS)
* Rupert, ID Fall-planted 6 entries

***Purification Head Rows***

* Corvallis, OR Fall-planted 12 entries

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

* Corvallis, OR Fall-planted 182 entries, un-replicated w/checks

***Malt Doubled Haploid Single Rows***

* Corvallis, OR Fall-planted 281 entries, un-replicated w/checks

***European Intro Nursery***

* Corvallis, OR Fall-planted 65 entries, un-replicated

***Flavor Fields Forever Yield Trial***

* Lebanon, OR\* Spring-planted 30 entries, 2 rep, RCBD
* Madras, OR\* Spring-planted 30 entries, 2 rep, RCBD
* La Grande, OR\* Spring-planted 30 entries, 2 rep, RCBD
* Mount Vernon, WA\* Spring-planted 20 entries, 3 rep, RCBD
* St. Paul, MN\* Spring-planted 20 entries, 2 rep
* Wooster, OH\* Spring-planted 20 entries, 2 rep
* Madison, WI\* Spring-planted 20 entries, 2 rep
* Ithaca, NY\* Spring-planted 20 entries, 2 rep
* Pullman, WA\* Spring-planted 20 entries, 2 rep
* Chatham(?), MI\* Spring-planted 20 entries, 2 rep

***Oregon Promise Drill Strips***

* Lebanon, OR\* Spring-planted 4 entries
* Madras, OR\* Spring-planted 4 entries
* La Grande, OR\* Spring-planted 4 entries

\*Not yet planted as of 2/22/17

**Naked Barley**

***Overview:***

***Number of advanced and fixed lines: 32***

* 32 in yield trial plots

***Details:***

***Oregon Naked Barley Elite Yield Trial***

* Corvallis, OR Fall-planted 20 entries, 3 rep, RCBD
* Lebanon, OR Fall-planted 20 entries, Un-replicated w/checks
* St. Paul, MN Fall-planted 20 entries
* Aberdeen, ID Fall-planted 20 entries
* Ithaca, NY Fall-planted 20 entries
* Logan, UT Fall-planted 20 entries
* West Lafayette, IN Fall-planted 20 entries
* Blacksburg, VA Fall-planted 20 entries

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

* Corvallis, OR Fall-planted 1 entry

***Purification Head Rows***

* Corvallis, OR Fall-planted 14 entries

***Black Beaut Yield Trial***

* Lebanon, OR\* Spring-planted 12 entries, 2 rep, RCBD

\*Not yet planted as of 2/22/17

**Genetics**

***Overview:***

***Number of advanced and fixed lines: 1528***

* 1528 in single, double or mini-plots

***Details:***

***BARI Scald Nursery***

* Corvallis, OR Fall-planted 120 entries, un-replicated w/checks

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

* Barley Stripe Rust Screening Trial 46 entries, 2 reps, RCBD
* UG99 Germplasm Array 127 entries, 2 reps, RCBD
* 95SR316A/GZ Population 164 entries, 2 reps, RCBD
* Uniform Barley Winter-hardiness Nursery 25 entries, 2 reps, RCBD
* BARI BSR Nursery 152 entries, 2 reps, RCBD
* Bison 1H x Baronesse 42 entries, 2 reps, RCBD

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

* Corvallis, OR Winter-planted 482 entries, un-replicated w/checks

***Multi-Rust Cycle 2 Doubled Haploid Germplasm Array***

* Corvallis, OR Winter-planted 370 entries, un-replicated w/checks

**Other**

***Adaptive Symbiotic Technologies Drill Strips***

* Corvallis, OR Fall-planted 2 entries, 2 treatments, 4 reps

Table 1. Agronomic Data of OSU AMBA Pilot Scale Candidates vs. Checks Across Years and Locations.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  | Plant |  |
| Variety/ | Yield | Lodging | Height | Survival |
| Selection | (bu/acre\*) | (1-9†) | (Inches) | (%) |
| DH130718 | 164 | 1 | 37 | 75 |
| DH120412 | 150 | 2 | 41 | 76 |
| DH130004 | 126 | 1 | 32 | 87 |
| DH120228 | 142 | 5 | 42 | 65 |
| DH130939 | 141 | 1 | 40 | 74 |
| *Charles* | 85 | 3 | 38 | 72 |
| *Endeavor* | 95 | 3 | 38 | 65 |
| *Wintmalt* | 106 | 2 | 38 | 84 |
| STA.YRS. | 6 | 6 | 6 | 5 |

\*calculated using 48 lbs/bu

Table 2. Malting Quality of OSU AMBA Pilot Scale Candidates vs. Checks Across Years and Locations.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Kernel | Grain | Malt | Wort |  | Diastatic | Alpha | Beta- |  |
| Variety/ | Plumpness | Protein | Extract | Protein | S/T | Power | Amylase | Glucan | FAN |
| Selection | (on 6/64") | (%) | (%) | (%) | (%) | (°L) | (20° DU) | (ppm) | (ppm) |
| DH130718 | 98.1 | 12.4 | 81.3 | 5.26 | 44.9 | 172 | 86.0 | 74 | 264.0 |
| DH120412 | 96.4 | 11.9 | 80.6 | 5.20 | 46.4 | 217 | 76.0 | 74 | 269.8 |
| DH130004 | 94.0 | 12.1 | 80.9 | 5.48 | 47.8 | 170 | 74.4 | 58 | 296.5 |
| DH120228 | 94.3 | 11.3 | 82.6 | 5.30 | 50.0 | 187 | 114.2 | 50 | 268.8 |
| DH130939 | 96.4 | 11.6 | 82.0 | 5.13 | 47.1 | 162 | 104.3 | 149 | 267.9 |
| *Charles* | 87.5 | 11.3 | 80.3 | 5.09 | 48.1 | 155 | 95.5 | 198 | 251.8 |
| *Endeavor* | 70.1 | 10.8 | 81.1 | 5.03 | 49.6 | 182 | 100.4 | 215 | 247.8 |
| *Wintmalt* | 94.2 | 10.7 | 80.4 | 4.03 | 40.4 | 147 | 54.6 | 84 | 174.3 |
| STA.YRS. | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |

Table 3. Malting Quality of OSU AMBA Pilot Scale Candidates from Corvallis & Lebanon, OR 2016.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Variety/  Selection | Kernel  Plumpness  (on 6/64") | Grain  Protein  (%) | Malt  Extract  (%) | Wort  Protein  (%) | S/T  (%) | Diastatic  Power  (°L) | Alpha  Amylase  (20° DU) | Beta-  Glucan  (ppm) | FAN  (ppm) |
| DH130718 | 97.6 | 11.7 | 83.3 | 5.14 | 46.6 | 179 | 92.1 | 69 | 277 |
| DH120412 | 97.1 | 11.6 | 81.7 | 5.09 | 47.2 | 217 | 80.4 | 101 | 284 |
| DH130004 | 98.5 | 11.3 | 83.2 | 5.02 | 48.4 | 154 | 73.8 | 68 | 291 |
| DH120228 | 94.6 | 11.5 | 83.6 | 5.32 | 50.3 | 187 | 118.6 | 66 | 299 |
| DH130939 | 98.0 | 10.9 | 84.2 | 5.01 | 49.3 | 158 | 108.0 | 159 | 282 |
| *Charles* | 82.3 | 11.4 | 80.8 | 5.10 | 47.9 | 164 | 98.1 | 227 | 279 |
| *Endeavor* | 65.5 | 11.0 | 81.8 | 4.98 | 47.6 | 200 | 102.3 | 271 | 268 |
| *Wintmalt* | 95.6 | 9.8 | 82.2 | 4.02 | 44.8 | 136 | 56.0 | 93 | 181 |

Table 4. Malting Quality of OSU Potential All Malt Selections from Corvallis, OR 2016.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Kernel | Grain | Malt | Wort |  | Diastatic | Alpha | Beta- |  |
| Variety/ | Plumpness | Protein | Extract | Protein | S/T | Power | Amylase | Glucan | FAN |
| Selection | (on 6/64") | (%) | (%) | (%) | (%) | (°L) | (20° DU) | (ppm) | (ppm) |
| DH140963 | 97.1 | 10.8 | 82.0 | 3.90 | 39.3 | 124 | 38.3 | 139 | 152 |
| DH141117 | 95.1 | 10.6 | 83.0 | 4.66 | 47.5 | 135 | 71.9 | 99 | 190 |
| DH141170 | 93.6 | 10.2 | 82.1 | 4.28 | 43.9 | 173 | 55.2 | 81 | 174 |
| DH141944 | 98.5 | 9.5 | 83.0 | 4.14 | 45.9 | 158 | 49.9 | 14 | 163 |
| DH142000 | 98.2 | 9.8 | 82.7 | 4.51 | 48.2 | 141 | 56.7 | 83 | 166 |
| DH150101 | 94.4 | 9.9 | 82.7 | 4.62 | 49.0 | 150 | 61.5 | 53 | 175 |
| DH150115 | 95.0 | 10.1 | 82.9 | 4.79 | 51.9 | 122 | 65.1 | 43 | 188 |
| *Wintmalt* | 93.5 | 10.2 | 81.9 | 4.48 | 48.1 | 146 | 53.7 | 116 | 201 |
| *Charles* | 80.4 | 12.0 | 80.4 | 5.38 | 48.1 | 162 | 84.3 | 388 | 286 |
| *Endeavor* | 62.9 | 11.8 | 81.1 | 5.45 | 47.4 | 222 | 100.9 | 357 | 294 |