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

# Researchers: Dr. Patrick Hayes, Mr. Scott Fisk, Ms. Laura Helgerson, Ms. Tanya Filichkin, Dr. Javier Hernandez, *Dr. Brigid Meints\*, and Dr. Daniela Carrijo\*\**

*\*Now at Pennsylvania State University; \*\*Focus on naked barley and dry beans for organic systems at OSU*

# Department: Crop and Soil Science

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**Executive Summary**

To assist AMBA in meeting its mission and objectives, the Oregon State University Barley Project develops winter and facultative doubled haploid 2-row covered malting barley varieties. Winter growth habit is a relatively straightforward target. Facultative growth habit is a multi-dimensional trait that we address through phenotyping and genotyping. Winter and facultative covered varieties will provide the malting and brewing industries with an abundant supply of high-quality malting barley meeting the quality specifications of AMBA members. We are developing these varieties for both adjunct and all-malt brewers, and for distillers. These varieties will have outstanding yield potential and broad-spectrum disease resistance, making them attractive alternatives to competing crops – such as corn and wheat. 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. We are assessing a limited number of naked winter types for malting under conventional cropping conditions – the attraction here is potentially high extract, a different flavor profile, and no GN. The major issue for the OSU program is ensuring rapid and responsive variety development: we 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 is on the AMBA-approved list and is in commercial production. Great Western Malting has been the principal driver behind the commercialization of the variety. Reports to date are favorable.
  + Lightning (tested as DH130910) is a facultative 2-row that we released in 2020. It is not on the AMBA recommended list – due in part to the challenges it can offer in the malthouse, due to dormancy and/or water sensitivity.
  + As shown in the accompanying tables, we have four submissions (besides DH120304, which was rated eligible for Plant Scale testing, but has yet to achieve granularity) in the AMBA Pilot program (2021 crop). Drill strips of these selections, and two new potential submissions, are in increase blocks at cooperating locations (2022 crop). Pedigrees and other data are provided in Table 1.
  + All AMBA Pilot scale entries have been, or are in, the Winter Malting Barley Trial.
* Develop new germplasm: We continue to generate new winter/facultative doubled haploids and advance them to preliminary, advanced, elite, and regional trials (trials are listed in Table 2). We have approximately 1,600 DH lines in the breeding pipeline. 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 expanded phenotyping of elite breeding material for facultative growth habit in spring-sown plantings and developed a set of allele-specific markers for vernalization and photoperiod genes.
* Develop germplasm meeting all-malt and adjunct brewer specifications: We have developed doubled haploids specifically to meet these contrasting quality specifications.
* Develop 0 GN germplasm meeting distillers needs: We have two 0 GN doubled haploids in advanced stages of testing (with the intention of submitting to the AMBA Pilot program, 2022 crop) and there are five additional 0 GN types at earlier stages in the breeding program (Elite and Preliminary Yield Trials).
* Doubled haploid collaborations: The DH production facility is now focused on simultaneously meeting the needs of the OSU Barley Project, the US Wheat and Barley Scab Initiative (USWBSI), and the Small Grains Genomics Initiative (SGGI).

*Most significant accomplishments:*

* Thunder, an AMBA-recommended variety, is in commercial production. To date, reports are favorable.
* DH120304 was approved for AMBA Plant Scale (2018 crop) and is available to interested maltsters/brewers. Initial interest in the selection, due to Maris Otter in the pedigree, was tempered by the finding that, according to 50K genotype data, Maris Otter was not a parent.
* Lightning (DH130910) was released as a variety in 2020 and is not on the AMBA recommended list. Despite an enticing agronomic and disease resistance profile, Lightning can be a challenge to malt due to dormancy and/or water sensitivity. Origin Malt continues testing, and LINC reports production of excellent malt – after some experiential learning during processing.
* DH141222 and DH141225 are second year submissions (2021 crop) to the AMBA Pilot Program. DH141222 was rated satisfactory in its first year of testing (2020) crop. DH141225 was rated unsatisfactory (2020 crop) but will be tested again (2021 crop).
* New entries in the AMBA Pilot program (2021 crop) are DH141917 and DH150683.
* DH162310 and DH170472 are 0 GN selections that will be entered into the AMBA Pilot program (2022 crop). Preliminary data are included in this report.
* Development of high yielding, lodging resistant winter/facultative 2-row malting barley germplasm with exciting malting quality profiles.
* Systematic introgression of novel alleles into U.S.-adapted germplasm 2-row malting 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. This development process 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. We initiated a small-scale effort on malting quality in naked barley for conventional cropping systems, in response to interest from Rahr Malting and in collaboration with the Virginia Tech program and the University of Lleida (Spain). Our other efforts in naked barley, under the direction of Brigid Meints, focus on multi-use naked barleys for organic systems.

***Methodology:***

* Accelerate generation time via doubled haploids and speed breeding.
* Corvallis, Oregon is our principal test site. As germplasm advances, it is tested regionally, nationally, and internationally. The 2021/2022 nurseries are summarized in Table 2.
* Malting quality assessments of most breeding material are conducted by the USDA/ARS CCRU. Great Western Malting provides support for, and on-farm testing of, our AMBA plant-scale submissions.
* The OSU Malt House plays an important role in generating malts on elite breeding lines and potential varieties. Malt analyses are conducted at the Hartwick Center for Craft Food and Beverage.
* Progress in our program depends on extensive collaboration. Kevin Smith at University of Minnesota is a key cooperator for providing winterhardiness data and coordinating the WMBT. Mark Sorrells, Cornell University, tests for winterhardiness and scab resistance. Gongshe Hu (USDA/ARS; Aberdeen, Idaho) provides data from Aberdeen and satellite locations in Idaho. Juliet Marshall includes our advanced lines in the University of Idaho Extension nurseries. We test for winterhardiness, malting quality and disease resistance with Wynse Brooks and Nicholas Santantonio at Virginia Tech, Eric Stockinger at Ohio State University, Lucia Gutierrez at the University of Wisconsin, Bob Brueggeman at Washington State University, and Katherine Frels at the University of Nebraska. Alicia del Blanco, at University of California, Davis, tests selections for stripe rust via the Barley Stripe Rust Screening Trial. Brian Steffenson provides TTKSK stem rust at the seedling stage and TTKSK surrogate testing of facultative accessions at the adult plant stage.

***Results:***

In the interest of space, in this report we provide only summary data on our AMBA Plant Scale prospects, Pilot Scale submissions, and potential AMBA Pilot Scale submissions.

**DH120304**

*Pluses:* Eligible for AMBA Plant Scale.

*Minuses*: Pedigree validation via 50K genotyping revealed that Maris Otter is not a parent of this selection.

*Overall Impression:* Perhaps best used as a parent in further breeding.

**DH141222**

*Pluses:* Yield much better than checks. Impressive test weight. Taller than average but good lodging resistance. Excellent stripe rust and scald resistance. Winter survival much better than Endeavor and a tad better (1%) than Wintmalt. Excellent plumps. Protein comparable to checks and malt extract higher than checks and Thunder (0.2%). Plenty of DP, modest alpha and FAN. Low beta glucan. Rated Satisfactory in first year of AMBA pilot (’20 crop)

*Minuses*: They will undoubtedly materialize, but all good for now.

*Overall Impression*: This one might just be a winner!

**DH141225**

*Pluses:* Yield better than checks (and DH141222). Impressive test weight. Taller than average but good lodging resistance. Excellent stripe rust and scald resistance. Winter survival much better than Endeavor and a tad better than Wintmalt; equal to DH141222. Excellent plumps. Protein and malt extract comparable to checks. Plenty of DP, modest alpha and FAN. Low beta glucan.

*Minuses*: Rated unsatisfactory in first year of AMBA Pilot testing (’20 crop): *“This first year selection had good plumpness; high protein and diastatic power; low extract, S/T, friability and FAN; and slightly high wort viscosity. Unbalanced modification.”*

*Overall Impression*: Might turn out to be crowd-pleaser, this half-sister of DH141222, but slipped up at the first showing.

**DH141917**

*Pluses:* Yield better than checks (a 25 bu/acre advantage over Thunder!). Impressive test weight. Taller than average but good lodging resistance. Excellent stripe rust and scald resistance. Winter survival fine to date in Oregon trials – to be determined in regional trials. Excellent plumps. Protein comparable to checks and malt extract edging out Thunder. Plenty of DP (following the sound of Thunder), modest alpha and FAN. Low beta glucan. A child of Thunder.

*Minuses*: Still looking.

*Overall Impression*: Oh my.

**DH150683**

*Pluses:* Yield – beats the checks! Impressive test weight. Taller than average but good lodging resistance. Excellent stripe rust and scald resistance. Winter survival fine to date in Oregon trials – to be determined in regional trials. Excellent plumps. Protein comparable to checks and malt extract higher than Thunder (almost 1%!). Plenty of DP, alpha and FAN. Low beta glucan.

*Minuses*: Waiting around the corner, for sure.

*Overall Impression*: Oh my x 2.

The next two selections, **both Zero GN**, will be submitted to the AMBA Pilot program (’22 crop). For now, just a heads up on what’s coming.

**DH162310**

*Pluses:* Yield – beats the checks! Impressive test weight. Taller than average but good lodging resistance. Excellent stripe rust and scald resistance. Winter survival fine to date in Oregon trials – to be determined in regional trials. Excellent plumps. Protein comparable to Thunder, and malt extract higher than Thunder (almost 3%). Plenty of DP, alpha and FAN for the adjunct distiller. Low beta glucan.

*Minuses*: Waiting for ‘em.

*Overall Impression*: Think whiskey!

**DH170472**

*Pluses:* Yield – beats the checks (and its GN partner by 1 bu/acre). Impressive test weight. Taller than average but good lodging resistance. Excellent stripe rust and scald resistance. Winter survival fine to date in Oregon trials – to be determined in regional trials. Excellent plumps. Protein lower than Thunder, and with malt extract higher than Thunder (2%). Plenty of DP, alpha and FAN but a bit more moderate than DH162310 – maybe some room for the all-malt distiller?

*Minuses*: Waiting for ‘em.

*Overall Impression*: Think whiskey, redux!

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

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

* Higher resolution analysis of the components of low temperature tolerance and facultative growth habit, including expanded phenotyping and genotyping.
* Testing the hypothesis that barley can contribute to beer flavor – witness the growing series of publications in JASBC and most recently in the Journal of Cereal Science.
* The Barley World Malt House producing ~ 200 lb. batches of malt from advanced lines and new varieties and smaller batches of experimental selections using the CLP.
* Multi-use naked barley.
* Genetic dissection of quantitative resistance to barley stripe, leaf, and stem rust (including TTKSK and the new nasty races from WA) 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, Assistant Professor, Senior Research (now at Pennsylvania State University)*
* *Brigid Meints, Assistant Professor, Senior Research (Focus on naked multi-use barley for organic systems, and dry beans for organic systems)*
* Javier Hernandez, Assistant Professor, Senior Research
* Tanya Filichkin, Senior Research Assistant
* Scott Fisk, Senior Research Assistant
* Laura Helgerson, Senior Research Assistant

**Graduate students**

* Campbell Morrissy, Graduate Research Assistant (PhD). Thesis research focuses on barley contributions to beer flavor (and some spirits on the side).
* Margaret Halstead, Graduate Research Assistant (MS). Thesis research focuses on environmental and management effects on barley contributions to beer flavor (and some hemp on the side).
* Cristiana Vallejos, Graduate Research Assistant (MS). Thesis research focuses on multi-use naked barley for organic systems.

**Publications (2021-2022)**

1. Windes, S., H.M. Bettenhausen, K.R. Van Simaeys, J. Clawson, S. Fisk, A.L. Heuberger, J. Lim, S.H. Queisser, T.H. Shellhammer, P.M. Hayes. 2021. Comprehensive analysis of different contemporary barley genotypes enhances and expands the scope of barley contributions to beer flavor. J. Amer. Soc. Brew. Chem*.* <https://doi.org/10.1080/03610470.2019.1706037>
2. Hagerty, C.H., L. Lutcher, K. McLaughlin, P. Hayes, K. Garland-Campbell, T. Paulitz, R.C. Graebner, and D. Kroese. 2021. Reaction of winter wheat and barley cultivars to *Fusarium pseudograminearum-*inoculated fields in the dryland Pacific Northwest, USA. Agrosyst. Geosci. Environ. <https://doi.org/10.1002/agg2.20173>
3. Morrissy, C., M. Fechir, H.M. Bettenhausen, K.R. Van Simayes, S. Fisk, J. Hernandez, K. Mathia, A. Benson, T.H. Shellhammer, and P.M. Hayes. 2021.Continued exploration of barley genotype contribution to base malt and beer flavor through the evaluation of lines sharing Maris Otter® parentage. J. Amer. Soc. Brew. Chem*.* <https://doi.org/10.1080/03610470.2021.1952509>
4. Meints, B., C. Vallejos, and P. Hayes. Multi-use naked barley: A new frontier. J. Cereal Sci. <https://doi.org/10.1016/j.jcs.2021.103370>
5. Massman, C., B. Meints, J. Hernandez, K. Kunze, P. Hayes, M. Sorrells, K. Smith, J. Dawson, and L. Gutierrez. 2021. Genetic characterization of agronomic traits and grain threshability for organic naked barley in the Northern U.S. Crop Sci. <https://doi.org/10.1002/csc2.20686>
6. Sayre-Chavez, B., Harmonie Bettenhausen, S. Windes, P. Aron, L. Cistué, S. Fisk, L. Helgerson, A. Heuberger, S. Tynan, P. Hayes, and M. Muñoz-Amatriaín. 2022. Genetic basis of barley contributions to beer flavor. J. Cereal Sci. <https://doi.org/10.1016/j.jcs.2022.103430>

**Table 1. Descriptors and status of OSU germplasm in the AMBA Pilot Program.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Selection** | **Pedigree** | **Growth Habit** | **EPH** | **AMBA Status** | **Regional Trial Submissions** |
| DH120304 | TC6W265-sib x Herz 29494/ 2991(35)-sib | Winter | Producer | Eligible for Plant Scale Testing | WMBT 2017-18, 2018-19 |
| DH141222 | 10.1044/Violetta | Winter | Producer | Pilot Submission 2021 Crop (Second Year) | WMBT 2020-21, 2021-22;  Idaho Extension 2020-21, 2021-22 |
| DH141225 | 10.1044/04\_028\_36 | Winter | Producer | Pilot Submission 2021 Crop (Second Year) | WMBT 2020-21, 2021-22;  Idaho Extension 2020-21, 2021-22 |
| DH141917 | 04-028-36/Thunder | Winter | Producer | Pilot Submission 2021 Crop (First Year) | WMBT 2021-22;  Idaho Extension 2021-22 |
| DH150683 | 04-028-36/DH131772 | Winter | Producer | Pilot Submission 2021 Crop (First Year) | WMBT 2021-22;  Idaho Extension 2021-22 |
| DH162310 | DH130939/Calypso | Winter | Non-producer | Potential Pilot Submission 2022 Crop | Idaho Extension 2021-22 |
| DH170472 | DH130939/Calypso | Facultative | Non-producer | Potential Pilot Submission 2022 Crop | Idaho Extension 2021-22 |

**Table 2. Oregon State University barley nurseries: 2021-22.** 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 only food.

**Malting Barley**

***Overview:***

***Number of advanced and fixed lines: 1679***

* 328 in yield trial plots
* 1351 in single rows or mini-plots (doubled haploids & F5s)

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

* 9 F3s
* 49 F2s
* 35 F1s

***Details:***

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

* Corvallis, OR Fall-planted 54 entries, 3 rep, RCBD
* Lebanon, OR Fall-planted 54 entries, unreplicated w/checks

***Oregon Malting Barley Preliminary Yield Trial (Cycle V)***

* Corvallis, OR Fall-planted 242 entries, unreplicated w/checks

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

* Corvallis, OR Fall-planted 32 entries, 3 rep, RCBD

***Malt Drill Strips***

* Corvallis, OR Fall-planted 13 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 4 entries

***Purification Head Rows***

* Corvallis, OR Fall-planted 8 entries, 108-120 rows each

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

* Corvallis, OR Fall-planted 903 entries, unreplicated w/checks

***Malt Doubled Haploid Single Rows***

* Corvallis, OR Fall-planted 276 entries, unreplicated w/checks

***Malt F5 Single Rows (MT x OR RIL Pop.)***

* Corvallis, OR Fall-planted 172 entries, unreplicated w/checks

***Malt F3 Bulk Plots***

* Corvallis, OR Fall-planted 9 entries, unreplicated

***Malt F2 Bulk Plots***

* Corvallis, OR Fall-planted 49 entries, unreplicated

***Malt F1 Head Rows***

* Corvallis, OR Fall-planted 35 entries, unreplicated

**Naked Barley**

***Overview:***

***Number of advanced and fixed lines: 157***

* 157 in yield trial plots

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

* 11 F4s
* 15 F3s
* 20 F2s

***Details:***

***Naked Malting Barley Yield Trial***

* Corvallis, OR Fall-planted 23 entries, 3 rep, RCBD
* Blacksburg, VA Fall-planted 23 entries, 2 rep, RCBD
* St. Paul, MN Fall-planted 23 entries, 3 rep, RCBD
* Madison, WI Fall-planted 23 entries, 3 rep, RCBD

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

* Corvallis, OR Fall-planted (Conv) 20 entries, unreplicated
* Corvallis, OR Fall-planted 20 entries, 3 rep, RCBD
* Lamberton, MN Fall-planted 20 entries, 3 rep, RCBD
* Freeville, NY Fall-planted 20 entries, 3 rep, RCBD
* Madison, WI Fall-planted 20 entries, 3 rep, RCBD
* Tulelake, CA Fall-planted 20 entries, 3 rep, RCBD

***Naked Preliminary Yield Trial (Organic)***

* Corvallis, OR Fall-planted (Conv) 8 entries, unreplicated
* Corvallis, OR Fall-planted 20 entries, 2 rep, RCBD

***Naked F6 Preliminary Yield Trial (Organic)***

* Corvallis, OR Fall-planted 60 entries, unreplicated

***Naked F2/F3 Bulk Plots (Organic)***

* Corvallis, OR Fall-planted 14 entries, unreplicated

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

* Corvallis, OR Fall-planted (Conv) 20 entries, unreplicated
* Corvallis, OR\* Spring-planted 20 entries, 3 rep, RCBD
* Lamberton, MN\* 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
* Davis, CA Fall-planted 20 entries, 3 rep, RCBD

***Spring Naked Preliminary Yield Trial (Organic)***

* Corvallis, OR\* Spring-planted 14 entries, 2 rep, RCBD

***Naked F3/F4 Bulk Plots (Organic)***

* Corvallis, OR\* Spring-planted 13 entries, unreplicated

***Naked F2 Bulk Plots (Organic)***

* Corvallis, OR\* Spring-planted 20 entries, unreplicated

***Purification Head Rows (Organic)***

* Corvallis, OR Spring-planted 2 entries, 48 rows each

\*Not yet planted as of 2/15/2022

**Genetics**

***Overview:***

***Number of advanced and fixed lines: 1119***

* 1119 in single rows

***Details:***

***Cycle V Germplasm Array***

* Davis, CA Fall-planted 267 entries, unreplicated
* Lincoln, NE Fall-planted 246 entries, unreplicated

***Barley Stripe Rust Screening Trial***

* Corvallis, OR Fall-planted 55 entries, 2 rep, RCBD

***TTKSK Resistant Lines***

* Corvallis, OR Fall-planted 53 entries, unreplicated

***KASP Array***

* Corvallis, OR Fall-planted 95 entries, unreplicated

***PVP Array***

* Corvallis, OR Fall-planted 96 entries, unreplicated

***Successor Population***

* Corvallis, OR Fall-planted 299 entries, unreplicated w/checks

***Vernalization Sensitivity Nursery (Corvallis, OR); Spring-planted***

* Cycle V DH Germplasm Array\* 242 entries, Augmented Design
* Naked Malting Barley Trial\* 23 entries, Augmented Design

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

* Corvallis, OR\* Spring-planted 254 entries, Type-2 Modified Aug. Design

\*Not yet planted as of 2/15/2022

Table 3. Agronomic data of OSU selections in the AMBA Pilot Program, compared to checks.

**DH120304.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Entry | Yield | Test Weight | Plant Height | Lodging | Stripe Rust (%) | Scald (%) |
| (bu/acre) | (lbs/bu) | (in) | (%) |
| *Station yrs.* | *9* | *10* | *10* | *10* | *5* | *10* |
| DH120304 | 148 | 52.6 | 44 | 21 | 19 | 1 |
| Endeavor | 121 | 51.6 | 39 | 21 | 6 | 67 |
| Wintmalt | 126 | 51.4 | 39 | 19 | 22 | 42 |
| Thunder | 124 | 51.6 | 38 | 31 | 21 | 54 |

Table 4. Agronomic data of OSU selections in the AMBA Pilot Program, compared to checks.

**DH141222.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Entry | Yield | Test Weight | Heading Date | Plant Height | Lodging (%) | Stripe Rust (%) | Scald (%) |
| (bu/acre) | (lbs/bu) | (DOY) | (in) |
| *Station yrs.* | 10 | 11 | 6 | 11 | 11 | 7 | 11 |
| DH141222 | 151 | 54.5 | 123 | 44 | 8 | 1 | 2 |
| Endeavor | 118 | 51.9 | 114 | 40 | 26 | 3 | 59 |
| Wintmalt | 125 | 51.2 | 121 | 39 | 21 | 17 | 38 |
| Thunder | 128 | 51.7 | 115 | 39 | 26 | 17 | 42 |

Table 5. Agronomic data of OSU selections in the AMBA Pilot Program, compared to checks.

**DH141225.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Entry | Yield | Test Weight | Heading Date | Plant Height | Lodging (%) | Stripe Rust (%) | Scald (%) |
| (bu/acre) | (lbs/bu) | (DOY) | (in) |
| *Station yrs.* | 10 | 11 | 6 | 11 | 11 | 7 | 11 |
| DH141225 | 162 | 54.1 | 119 | 45 | 15 | 2 | 6 |
| Endeavor | 118 | 51.9 | 114 | 40 | 26 | 3 | 59 |
| Wintmalt | 125 | 51.2 | 121 | 39 | 21 | 17 | 38 |
| Thunder | 128 | 51.7 | 115 | 39 | 26 | 17 | 42 |

Table 6. Agronomic data of OSU selections in the AMBA Pilot Program, compared to checks.

**DH141917.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Entry | Yield | Test Weight | Heading Date | Plant Height | Lodging (%) | Stripe Rust (%) | Scald (%) |
| (bu/acre) | (lbs/bu) | (DOY) | (in) |
| *Station yrs.* | 8 | 9 | 5 | 9 | 9 | 7 | 9 |
| DH141917 | 150 | 53.1 | 121 | 42 | 21 | 5 | 4 |
| Endeavor | 118 | 51.8 | 116 | 40 | 30 | 3 | 57 |
| Wintmalt | 125 | 50.9 | 123 | 39 | 25 | 17 | 35 |
| Thunder | 125 | 51.6 | 118 | 39 | 29 | 17 | 38 |

Table 7. Agronomic data of OSU selections in the AMBA Pilot Program, compared to checks.

**DH150683.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Entry | Yield | Test Weight | Heading Date | Plant Height | Lodging (%) | Stripe Rust (%) | Scald (%) |
| (bu/acre) | (lbs/bu) | (DOY) | (in) |
| *Station yrs.* | 8 | 9 | 5 | 9 | 9 | 7 | 9 |
| DH150683 | 168 | 53.0 | 115 | 42 | 20 | 0 | 1 |
| Endeavor | 118 | 51.8 | 116 | 40 | 30 | 3 | 57 |
| Wintmalt | 125 | 50.9 | 123 | 39 | 25 | 17 | 35 |
| Thunder | 125 | 51.6 | 118 | 39 | 29 | 17 | 38 |

Table 8. Agronomic data of OSU selections in the AMBA Pilot Program, compared to checks.

**DH162310.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Entry | Yield | Test Weight | Heading Date | Plant Height | Lodging (%) | Stripe Rust (%) | Scald (%) |
| (bu/acre) | (lbs/bu) | (DOY) | (in) |
| *Station yrs.* | 5 | 5 | 3 | 5 | 5 | 5 | 5 |
| DH162310 | 172 | 54.2 | 111 | 47 | 0 | 2 | 2 |
| Endeavor | 120 | 51.8 | 112 | 40 | 25 | 3 | 48 |
| Wintmalt | 120 | 49.3 | 119 | 39 | 16 | 11 | 39 |
| Thunder | 124 | 50.4 | 113 | 39 | 15 | 10 | 32 |

Table 9. Agronomic data of OSU selections in the AMBA Pilot Program, compared to checks.

**DH170472.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Entry | Yield | Test Weight | Heading Date | Plant Height | Lodging (%) | Stripe Rust (%) | Scald (%) |
| (bu/acre) | (lbs/bu) | (DOY) | (in) |
| *Station yrs.* | 5 | 5 | 3 | 5 | 5 | 5 | 5 |
| DH170472 | 173 | 53.7 | 118 | 46 | 0 | 2 | 2 |
| Endeavor | 120 | 51.8 | 112 | 40 | 25 | 3 | 48 |
| Wintmalt | 120 | 49.3 | 119 | 39 | 16 | 11 | 39 |
| Thunder | 124 | 50.4 | 113 | 39 | 15 | 10 | 32 |

Table 10. 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.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Entry | Winter survival | Entry | Winter survival | Entry | Winter survival |
| (%) | (%) | (%) |
| DH120304 | 63 | DH141222 | 93 | DH141225 | 93 |
| Endeavor | 53 | Endeavor | 84 | Endeavor | 84 |
| Wintmalt | 68 | Wintmalt | 92 | Wintmalt | 92 |
| *Station yrs. 8* | | *Station yrs. 4* | | *Station yrs. 4* | |

Table 11. Malting quality data of OSU selections in the AMBA Pilot Program, compared to checks. **DH120304.**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Entry | Plump kernels (%) | Malt extract (%) | Barley protein (%) | Wort protein (%) | S/T | DP | Alpha amylase | Beta glucan | FAN |
| (%) | (0ASBC) | (20°DU) | (ppm) | (ppm) |
| *Station yrs.* | *9* | *9* | *9* | *9* | *9* | *9* | *9* | *9* | *9* |
| DH120304 | 96.6 | 82.2 | 11.1 | 5.7 | 53.4 | 172 | 82 | 49 | 297 |
| Endeavor | 79.5 | 81.9 | 10.4 | 4.9 | 51.9 | 164 | 102 | 201 | 232 |
| Wintmalt | 96.1 | 81.4 | 10.2 | 4.1 | 43.5 | 140 | 56 | 64 | 169 |

Table 12. Malting quality data of OSU selections in the AMBA Pilot Program, compared to checks. **DH141222.**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Entry | Plump kernels (%) | Malt extract (%) | Barley protein (%) | Wort protein (%) | S/T | DP | Alpha amylase | Beta glucan | FAN |
| (%) | (0ASBC) | (20°DU) | (ppm) | (ppm) |
| *Station yrs.* | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| DH141222 | 97.8 | 83.1 | 10.3 | 5.0 | 51.4 | 198 | 60 | 49 | 208 |
| Endeavor | 83.5 | 82.2 | 10.2 | 5.1 | 53.9 | 161 | 104 | 224 | 236 |
| Wintmalt | 94.2 | 81.6 | 10.0 | 4.4 | 47.1 | 142 | 59 | 62 | 172 |
| Thunder | 95.2 | 82.9 | 10.4 | 5.4 | 56.1 | 155 | 123 | 61 | 268 |

Table 13. Malting quality data of OSU selections in the AMBA Pilot Program, compared to checks. **DH141225.**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Entry | Plump kernels (%) | Malt extract (%) | Barley protein (%) | Wort protein (%) | S/T | DP | Alpha amylase | Beta glucan | FAN |
| (%) | (0ASBC) | (20°DU) | (ppm) | (ppm) |
| *Station yrs.* | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| DH141225 | 98.1 | 83.0 | 10.5 | 5.0 | 51.0 | 214 | 60 | 49 | 204 |
| Endeavor | 83.5 | 82.0 | 10.5 | 5.1 | 53.4 | 162 | 101 | 220 | 235 |
| Wintmalt | 94.2 | 81.5 | 10.1 | 4.4 | 47.4 | 142 | 59 | 59 | 171 |
| Thunder | 94.7 | 82.8 | 10.6 | 5.5 | 56.0 | 159 | 122 | 57 | 271 |

Table 14. Malting quality data of OSU selections in the AMBA Pilot Program, compared to checks. **DH141917.**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Entry | Plump kernels (%) | Malt extract (%) | Barley protein (%) | Wort protein (%) | S/T | DP | Alpha amylase | Beta glucan | FAN |
| (%) | (0ASBC) | (20°DU) | (ppm) | (ppm) |
| *Station yrs.* | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| DH141917 | 98.2 | 82.9 | 10.9 | 5.1 | 49.7 | 164 | 53 | 46 | 199 |
| Endeavor | 85.8 | 82.1 | 10.4 | 5.2 | 55.0 | 153 | 99 | 216 | 231 |
| Wintmalt | 93.7 | 81.4 | 10.0 | 4.5 | 48.3 | 141 | 59 | 53 | 170 |
| Thunder | 95.0 | 82.7 | 10.7 | 5.6 | 56.9 | 163 | 124 | 57 | 271 |

Table 15. Malting quality data of OSU selections in the AMBA Pilot Program, compared to checks. **DH150683.**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Entry | Plump kernels (%) | Malt extract (%) | Barley protein (%) | Wort protein (%) | S/T | DP | Alpha amylase | Beta glucan | FAN |
| (%) | (0ASBC) | (20°DU) | (ppm) | (ppm) |
| *Station yrs.* | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| DH150683 | 97.6 | 83.5 | 10.6 | 5.5 | 54.6 | 191 | 90 | 45 | 271 |
| Endeavor | 85.8 | 82.1 | 10.4 | 5.2 | 55.0 | 153 | 99 | 216 | 231 |
| Wintmalt | 93.7 | 81.4 | 10.0 | 4.5 | 48.3 | 141 | 59 | 53 | 170 |
| Thunder | 95.0 | 82.7 | 10.7 | 5.6 | 56.9 | 163 | 124 | 57 | 271 |

Table 16. Malting quality data of OSU selections in the AMBA Pilot Program, compared to checks. **DH162310.**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Entry | Plump kernels (%) | Malt extract (%) | Barley protein (%) | Wort protein (%) | S/T | DP | Alpha amylase | Beta glucan | FAN |
| (%) | (0ASBC) | (20°DU) | (ppm) | (ppm) |
| *Station yrs.* | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| DH162310 | 98.5 | 84.3 | 11.1 | 5.5 | 51.1 | 225 | 116 | 73 | 289 |
| Endeavor | 84.0 | 81.7 | 10.2 | 5.3 | 54.9 | 166 | 105 | 234 | 248 |
| Wintmalt | 88.7 | 79.9 | 10.6 | 4.6 | 46.3 | 156 | 63 | 75 | 176 |
| Thunder | 92.9 | 81.6 | 11.3 | 5.8 | 56.1 | 184 | 137 | 99 | 301 |

Table 17. Malting quality data of OSU selections in the AMBA Pilot Program, compared to checks. **DH170472.**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Entry | Plump kernels (%) | Malt extract (%) | Barley protein (%) | Wort protein (%) | S/T | DP | Alpha amylase | Beta glucan | FAN |
| (%) | (0ASBC) | (20°DU) | (ppm) | (ppm) |
| *Station yrs.* | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| DH170472 | 99.0 | 83.3 | 10.0 | 4.7 | 48.7 | 176 | 99 | 39 | 240 |
| Endeavor | 84.0 | 81.7 | 10.2 | 5.3 | 54.9 | 166 | 105 | 234 | 248 |
| Wintmalt | 88.7 | 79.9 | 10.6 | 4.6 | 46.3 | 156 | 63 | 75 | 176 |
| Thunder | 92.9 | 81.6 | 11.3 | 5.8 | 56.1 | 184 | 137 | 99 | 301 |