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PEER-REVIEWED ARTICLE

Effect of Floor Malting on Novel Barley Germplasm Derived from a Cross with Maris Otter®

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ABSTRACT

Malting barley (*Hordeum vulgare* L.) is typically assessed using standard malting protocols that are likely to ensure acceptance by the majority of users in the contemporary supply chain. Craft maltsters often utilize malting techniques and barley varieties that are outside of this pipeline and have an interest in investigating barley lines that may be suitable for their production methods. The growing region targeted in this study, the Klamath Basin of northern California and southern Oregon, is in a multiyear period of drought, and there is interest in a shift to winter barley. This study assesses a winter-habit barley line derived from a cross with the heirloom variety Maris Otter® and a CDC Copeland control in an experimental mini-scale floor-malting protocol. Experimental malts were evaluated against the industry collaborator's commercial malt and a pneumatic-type malt that was also made with the novel line. Malts and beers were analyzed by trained sensory panels to determine whether there were detectable differences between barley genotype, whether descriptors similar to the heirloom parent were present, and whether the novel barley line produced a more preferable beer relative to the control. While the experimental malts were found to be indistinguishable by the panel, there were significant differences between the beers, and there was a slight, but not significant, preference for the beer made with the control variety (CDC Copeland). The experimental floor-malting protocol was successful but needs further development for regular deployment in the industry.

Keywords: barley, flavor, floor malt, hot steep, malt, Maris Otter

Introduction

Breeding for malting barley (*Hordeum vulgare* L.) in the United States has been influenced by established malt quality guidelines outlined by the American Malting Barley Association (AMBA), which represents the interests of member maltsters, brewers, and distillers (1). Experimental lines from private and public breeding programs are evaluated for agronomic adequacy and malt quality; those that ascend through the assessment pipeline receive an AMBA recommendation and, thus, are more likely to be adopted and promoted by all sectors of the supply chain. Lines in the AMBA pipeline are initially evaluated for malt quality using micro-scale malting equipment (<1 kg/batch) at universities, breeding companies, and maltsters and at a central malting facility at the USDA-ARS Cereal Crop Research Unit in Madison, WI (2). Micro-scale malting is a useful tool for evaluating large numbers of lines, but experimental germplasm is typically subjected to standard malting protocols. If the results are poor, lines are removed from the selection pipeline. This culling procedure is necessary to identify lines suitable for most maltsters but potentially ignores lines that may malt satisfactorily using a bespoke protocol. Further, there is no established sensory assessment within this pipeline other than guidance that, "malted barley must provide desired beer and spirit flavor" (1).

In 2014, a white paper published by the Brewers Association trade group called for barley breeders to investigate lines that better meet the needs of craft brewers producing all-malt beer, as well as to identify barley lines that produce more flavorful beers (3). This led to a distinction within AMBA between malt quality guidelines for all-malt brewing and guidelines for adjunct brewing. Simultaneously, the nascent craft malting sector has formed a niche within the industry focusing on small-scale production; local, heirloom, and/or regionally adapted grains; and unique and/or historic malting techniques (4). To that end, the industry partner for this work, Admiral Maltings (Alameda, CA), solely produces floor malt with barley sourced within the state of California. Currently, there is no established assessment track for identifying barley lines that may fit these new goals but that may not succeed in the AMBA pipeline.

The recent interest in barley variety contribution to beer flavor has spurred a series of investigations. Briefly, Herb et al. (5) found that barley genotype and growing environment contribute to beer flavor. Work by Bettenhausen et al. (6,7) coupled metab-

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olomic profiling with beer sensory to further investigate the effect of barley variety. They first studied malt made with different genotypes and malted at different locations and then studied selections from Herb et al. (5) that were grown at the same location and malted at the same facility. Windes et al. (8) used a novel malt sensory method, the American Society of Brewing Chemists (ASBC) malt hot steep, as well as beer sensory and metabolomics, to better trace barley variety contributions to malt and beer flavor in two sets of barley germplasm—one with experimental spring habit lines and the other with contemporary winter malting varieties that did not include Maris Otter®. More recently, Craine et al. (9) found that a consumer sensory panel could detect differences among beers brewed with different experimental barley lines and preferred certain experimental lines to the CDC Copeland control variety. Finally, Morrissy et al. (10) examined four barley lines sharing Maris Otter parentage and a Wintmalt control and found that malts and beers had present, but nuanced, differences in sensory and chemical profiling. That said, despite the experimental lines receiving approximately half of their genetic makeup from the Maris Otter parent, research malts and beers did not present the flavors associated with the heirloom variety.

Heirloom barleys have a reputation for contributing unique flavors to malts and beers, and interest in these varieties has increased in recent years, with varieties such as Barke®, Chevalier®, Haná, and Plumage Archer being malted and marketed to a broad audience—sometimes for the first time in decades. Maris Otter, in particular, is widely advertised as "rich and moreish," "unique, rich, and malty," and "the Rolls Royce of malts." Specific work using heirloom parents to produce progeny that can contribute positively to beer flavor is an emerging area of research, and Herb et al. (5) and Morrissy et al. (10) utilized the British heirlooms Golden Promise® and Maris Otter, respectively, due to their toothsome reputations. Despite their notoriety, previous research on the effects of these two varieties on beer flavor is very limited. This research focused on Maris Otter; once a major variety grown in the United Kingdom but dropped from the Maltsters' Association of Great Britain's (MAGB) list of recommended varieties in 1989 (11). While no longer listed, it maintains a small, but notable, market share and, as of 2020, made up 1.9% (31,261 mt) of all UK malting barley purchases—the largest percentage of any variety not currently recommended by MAGB (12).

Maris Otter is typically used to produce British-style pale ale malt, which is darker in color (2.5–4°SRM) than North American pale malt (1.6–2.8°SRM), and contributes malty, biscuit, and nut-like flavors to beer (13,14). Historically it was floor malted, and some maltsters continue to malt it this way. Research on the effect of floor malting versus pneumatic malting on the volatile chemistry of Maris Otter revealed that malt produced in a floor-malting system has a different volatile profile than malt produced in a pneumatic system despite having similar malt quality profiles (15). It has been posited that floor malts have higher levels of melanoidin compounds relative to their pneumatic counterparts due to specific floor-malting processes at the end of germination that encourage green malt to sweat, thus promoting a certain level of "stewing" during the free-dry kilning phase (16). Other research comparing floor malting to pneumatic malting has found variation in quality outcomes and potential impacts on beer flavor. One study found β-glucanase activity was higher in a floor-malting operation and led to lower malt β-glucan (17). There is conflicting evidence suggesting that floor malting can produce malt with higher levels of dimethyl sulfide (DMS) and DMS precursors (DMS-P) (18,19), with Kishani et al. (19) contradicting older research and finding that the elevated temperatures of a floor-malting germination bed do not result in higher DMS-P compared with pneumatic malting. As floor malting has declined, contemporary malting barley varieties are not assessed for suitability in this type of system. An exception is the variety Butta-12 released by UC-Davis (Davis, CA) and contracted by the industry partner (20).

As part of this research group's breeding program, germplasm is regularly grown in the Klamath Basin at the University of California–Intermountain Research and Extension Center (IREC) in Tulelake, CA. This area is a major growing region for barley sourced by the industry collaborator, and they are interested in exploring winter-habit varieties as the region faces ongoing summer drought stress and limited water availability for irrigation. Winter barley has agronomic advantages, such as higher yields and lower irrigation requirements. Winter barley also utilizes water when it is abundant during spring snow melt (21,22), reducing the risk to the grower and maltster if drought conditions continue.

This research evaluates three hypotheses. First, that an experimental winter-habit line with heirloom parentage, when malted in a mini-scale floor-malting system, will meet the malt quality expectations of the CDC Copeland control and will meet established malting and brewing control points. Second, that a sensory panel will detect differences between similar malts made with the experimental line and the control and between different malts made with the experimental line. Third, beer produced with the experimental line will be detectably different from the control, and the flavors associated with the Maris Otter parentage will be present in beer brewed with the floor-malted experimental line.

Materials and Methods

Barley

The genotypes used in this study, their pedigrees, and their developers are listed in Table 1. DH142010 is a winter-habit, two-row line developed for malting by the Oregon State University–Barley Project (Corvallis, OR). It is a doubled haploid derived from a cross of Maris Otter and 04-028-036, a malting line from Ackermann Saatzucht GmbH & Co. This line was selected from the germplasm used by Morrissy et al. (10) based on agronomic and malt quality data collected between 2017 and 2020 (data not shown). CDC Copeland is a spring-habit, two-row, malting variety and has had an AMBA recommendation since 1999 (23,24). It is regularly contracted to be grown in the Tulelake Region by Admiral Maltings and is used for their British-style, Maiden Voyage pale ale malt.

DH142010 was grown at UC-Davis, IREC in Tulelake, planted in fall 2019, and harvested in summer 2020. Barley was grown under irrigated conditions, and field management followed the research station's standard protocol for malt-quality barley. CDC Copeland was grown at commercial scale at Cascade Farms in Tulelake, planted in spring 2020, and harvested in summer 2020. Grain was grown under organic conditions on winter-flooded land, it received summer irrigation, and field management followed the farm's standard protocol for malting barley. The same

Table 1. Barley genotypes used for the malting, brewing, and sensory research described in this report

Genotype	Pedigree	Developer
CDC Copeland	WM861-5/TR118	Crop Development Centre, University of Saskatchewan
DH142010	04-028-36/Maris Otter®	Oregon State University

lot of CDC Copeland grain was used for both the Maiden Voyage and the mini-scale Copeland malt.

Barley grain analysis was performed using *ASBC Methods of Analysis* (Methods Barley-2, Physical Tests; Barley-3, Germination). Protein and moisture were measured using an Infratec NOVA near-infrared grain analyzer (FOSS, Denmark).

It should be noted that Maris Otter is licensed solely to growers in the United Kingdom, and seed is not available for export. Due to this restriction, the variety was not grown or malted for this experiment.

Malting

For the purposes of this report, malting scale is defined by batch size: micro (<1 kg); mini (<150 kg); and plant. Malts are differentiated as CDC Copeland-floor (mini scale); DH142010-floor (mini scale); Maiden Voyage (plant scale); DH142010-pneumatic (micro scale).

Floor Malting. Mini-scale malting was performed at Admiral Maltings in August 2021. Samples (80 kg) of each line were steeped in 121-L polyethylene containers under the following protocol: 10:00 hr wet; 16:00 hr dry; 10:00 hr wet; 12:00 hr dry; and 0:15 hr wet. In lieu of aeration, steeped malt was stirred after immersion. The final steep time was adjusted based on grain moisture content at the end of the second steep. Steep temperature was maintained at 14.4°C. Steeped grain was spread onto a temperature-controlled germination floor alongside a 7,250-kg plant-scale batch of Maiden Voyage malt as shown in Figure 1. Germination proceeded for 96:00 hr, with grain-bed temperatures monitored every 12 hr. The top of bed temperature was maintained between 22 and 23°C, while the bottom of bed temperature was maintained between 13 and 16°C. Grain was turned twice a day using a shovel. The mini-scale malts were kilned within the plant-scale batch inside perforated steel cylinders (Fig. 2). The following protocol was used for kilning: 13:00 hr free dry (8:00 hr ramp from 49 to 60°C, 5:00 hr hold at 60°C); 7:00 hr force dry (5:00 hr ramp from 71 to 91°C, 2:00 hr hold at 91°C); and 5:00 hr cure (1:00 hr ramp from 91 to 96°C, 4:00 hr hold at 96°C). Malt was cleaned with a deculmer and screen cleaner using a 5/64-in. sift screen.

Plant-Scale Malting—Maiden Voyage. Plant-scale malting was performed at Admiral Maltings in August 2021. Samples (7,250 kg) of each line were steeped in conical bottom steep tanks under the following protocol: 10:00 hr wet; 16:00 hr dry; 10:00 hr wet; and 12:00 hr dry. Aeration was provided with cycles of 10 min on and 20 min off during the wet steeps. CO_2 extraction was provided with cycles of 5 min on and 15 min off during dry periods. Steep temperature was maintained at 14.4°C. Steeped grain was spread onto a temperature-controlled germination floor. Germination proceeded for 96:00 hr, with grain bed temperatures monitored every 12 hr. Grain was turned twice a day using a mechanical turner. The top of bed temperature was maintained between 20 and 23°C, while the bottom of bed temperature was maintained between 13 and 16°C. The grain was turned twice a day using a mechanical turner. The following protocol was used for kilning: 13:00 hr free dry (8:00 hr ramp from 49 to 60°C, 5:00 hr hold at 60°C); 7:00 hr force dry (5:00 hr ramp from 71 to 91°C, 2:00 hr hold at 91°C); and 5:00 hr cure (1:00 hr ramp from 91 to 96°C, 4:00 hr hold at 96°C). Malt was cleaned with a deculmer and screen cleaner using a 5/64-in. sift screen.

Pneumatic Malting. Micro-scale malting was performed at Oregon State University in a Custom Laboratory Products (Milton Keynes, UK) steep/germination vessel and kiln. Malting followed a standard research protocol using 500 g of grain. Steeping was performed as follows: 8:00 hr wet; 16:00 hr dry; 8:00 hr wet; 12:00 hr dry; and 2:00 hr wet, all at 14°C. Germination proceeded for 96:00 hr at 15°C, with automated turning and air flow.

Figure 1. Mini-malting germination bed (foreground) and plant-scale germination bed (background). (Photo courtesy of Admiral Maltings)

Figure 2. Kilning mini malts (inside perforated steel cylinders) within the plant-scale batch of Maiden Voyage. (Photo courtesy of Admiral Maltings)

The following protocol was used for kilning: 6:00 hr free dry at 55°C; 6:00 hr free dry at 65°C; 6:00 hr forced dry at 72°C; and 4:00 hr cure at 85°C. Malt was cleaned on an A/S Rationel Kornservice sample cleaner (Pfeuffer GmbH, Germany).

Malt Analysis

Steep-out moisture, chit percentage, growth count index, and size assortment (*ASBC Methods of Analysis* Method Barley-2, Physical Tests) were measured by malting operators at Admiral Maltings and Oregon State University. Steep-out moisture was measured with a moisture balance analyzer at each facility. Chit percentage is a count of kernels from a sample of 100 with a visible rootlet prior to germination. Growth count index is a measure of acrospires at the end of germination. The acrospires of 100 kernels are measured as a percentage of the kernel length. Acrospires <25% the length of the kernel were weighted at a coefficient of 0.25; 25–50% at 0.50; 50–75% at 0.75; 75–100% at 1.0; and >100% at 1.25. The counts were multiplied by their weight coefficient and summed for a cumulative growth count.

All other malt quality parameters were analyzed by Hartwick College Center for Craft Food & Beverage (Oneonta, NY) using *ASBC Methods of Analysis* (Methods Malt-4, Extract; Malt-6, Diastatic Power; Malt-7, Alpha-Amylase; Malt-8, Protein; Malt-12, Friability, Beer-31, Free Amino Nitrogen). A commercial sample of Crisp Maris Otter floor malt was provided by Brewers Supply Group (Shakopee, MN) and analyzed at Hartwick College using the same methods.

Brewing

Beers were brewed at Seismic Brewing Company (Santa Rosa, CA) in August 2021 on a custom 60-L pilot system. The recipe was designed to emphasize malt characteristics but also to produce a commercial-type beer with consumer acceptance. Malt (10.25 kg) was mashed with 30.75 L of water; 8 g of $CaCl_2$ and 10.5 mL of 88% lactic acid were added to achieve a mash pH of 5.20. The mash was held at 62.7°C for 10 min, ramped to 68.3°C and held for 10 min, and finally ramped to 75.5°C. Lautering proceeded at 1.5 L/min until wort gravity dropped below 4°P. Grains were sparged with 75.5°C acidified water. Boil kettle volume was corrected with 85°C water to achieve desired preboil gravity (8.8–9.0°P), and 4 g of $CaCl_2$ and antifoam were added. Wort was boiled for 60 min with three hop additions of Hallertau Record at boil start, 40 min, and 50 min to achieve 30 IBU and match a hop sensory profile similar to commercial beers in the brewer's portfolio. Wort was cooled to 12.8°C and oxygenated at 12.1 ppm. A German bock lager strain (L32 Magnitude, Imperial Yeast, Portland, OR) was pitched at 1.5 million/mL/°P. Fermentation was performed at 12.8°C for 3 days and then increased to 14.4°C until diacetyl negative. Maturation proceeded for 3 weeks at 0°C. After 3 weeks, beer was fined and racked to a packaging tank for carbonation (2.65 vol/vol) and kegging.

Beer Quality Analysis

Brewing and beer quality analysis was performed at Seismic Brewing Company (Sebastopol, CA), except for color and diacetyl, which were performed at pFriem Family Brewers (Hood River, OR). Analysis was performed using *ASBC Methods of Analysis* (Methods Beer-2, Specific Gravity; Beer-4, Alcohol; Beer-9, pH; Beer-10, Color; Beer-23a, Beer Bitterness; Beer-25b, Diacetyl).

Malt Hot Steep Sensory

Hot steep extractions were prepared following the *ASBC Methods of Analysis* (Sensory Analysis-14 Hot Steep Malt Sensory Evaluation Method). Sensory was performed on the malt hot steeps using the established sensory panels at pFriem Family Brewers (15 panelists: 13 male-identifying, 2 female-identifying; age range 25–44 years) and Admiral Maltings (9 panelists: 8 male-identifying, 1 female-identifying; age range 29–61). The pFriem panel evaluated all samples, while the Admiral Maltings panel did not evaluate the DH142010-pneumatic malt due to sample limitations. Both panels were trained and managed using a coordinated approach to ensure consistency of results.

Samples were assessed using descriptive analysis. Nine attributes were selected from the DraughtLab Base Malt Flavor Map (https://store.draughtlab.com/collections/flavor-maps/products/malt-flavor-map). Samples were presented to panelists using 3-digit blind codes. Panelists were presented with reference samples, as shown in Table 2, and were asked to rate each attribute on a scale of 0–5, with 0.5 increments, where 0 is not present and 5 is extremely present.

Beer Sensory

Beer sensory was performed at pFriem Family Brewers using their established sensory panel (same as described for hot steep sensory). Samples were presented to panelists using 3-digit blind codes. Samples were first assessed using descriptive analysis. Participants were asked to assess each sample using a 10-attribute lexicon similar to that used in hot steep sensory but with "dough" and "nutty" removed (based on preliminary evaluation; data not shown), and "butter," "fruity," and "hoppy" added as these are associated with hop- and yeast-derived aromas and flavors. Panelists were asked to rate each attribute on a scale of 0–5, with 0.5 increments, where 0 is not present and 5 is extremely present. Panelists were presented with reference samples, as shown in Table 2. They were then asked to select the sample they preferred. This was repeated over two sessions with new blind codes and sample order for each session.

Table 2. Predefined attributes applied for descriptive sensory evaluation of hot steeps and beers and the respective references for panel training

Attributes for Hot Steep Sensory	Reference	Attributes for Beer Sensory	Reference
Bread	Whole wheat bread	Bread	Whole wheat bread
Breakfast cereal	Grape-Nuts®	Breakfast cereal	Grape-Nuts®
Cracker	Oyster cracker	Butter	Butter flavor extract
Dough	Fresh wheat yeast dough	Cracker	Oyster cracker
Grainy	Barley flour	Fruity	Canned peaches
Grassy	Barley straw	Grainy	Barley flour
Nutty	Mixed roasted nuts	Grassy	Barley straw
Sweet aromatic	Caramel candy	Hoppy	Tettnanger hop pellets
Vegetal	Canned corn	Sweet aromatic	Caramel candy
		Vegetal	Canned corn

Statistical Analysis

Data collection and graphical demonstration of data were performed using Microsoft Excel (version 16.16.27). Statistical analysis was performed using the R environment for statistical computing (25).

Results and Discussion

Grain Agronomics and Quality

Both genotypes met AMBA grain quality guidelines for protein (≤12.0%) and germination (≥98%); however, only DH142010 met the standards for plump (≥90%) and thin (≤3%) kernels. CDC Copeland had a much lower test weight, lower percentage of plump kernels (retained on a 6/64-in. screen), and higher percentage of thin kernels (through a 5/64-in. screen), as shown in Table 3. Plump kernels and homogeneity are considered critical for even modification and can be an indicator of the total starch content of grain. The Klamath Basin region saw significant drought stress during the 2020 season, particularly during spring barley grain fill, which may have influenced the kernel size and bulk density of spring barley in the region despite irrigation, while winter barley was less impacted due to its earlier grain fill and harvest date (26). The two lines were not compared for other agronomic traits due to the nature of this work; however, Halstead et al. (27) found that while DH142010 yield was similar to other elite malting lines in a controlled experiment at UC-Davis IREC, it had a lower yield compared with the AMBA-recommended variety Thunder.

While the grain used was grown at two different farms—one a commercial operation and the other a university research station—they were both within the Tulelake growing region. Annual rainfall was only 48% of the 30-year average (2020: 231.2 mm; 30 year: 477.4 mm), with the summer months (June through September) receiving only 42% of the 30-year average. The exception was May, in which rainfall exceeded the 30-year average by 24%, which provided a positive contribution to winter barley yield and quality. Mean monthly temperatures and peak temperatures did not differ significantly from the 30-year average (28). Continued drought stress and water restrictions will result in reduced yield and out-of-specification grain quality of spring-habit malting barley, which could reduce growers' interest in the crop. Further exploration of winter lines could help the malting industry maintain a supply chain in the region.

Malting

Both genotypes performed similarly in the mini-scale malting protocol but malted differently than the plant-scale Maiden Voyage. Four measures of malting progression were taken during the process: steep-out moisture, steep-out chit, growth count, and plumps (Table 4). These metrics are used by maltsters to ensure batch to batch consistency and are useful for evaluating the mini-scale malting protocol. After the final steep, moisture contents were 49.8% for DH142010-floor; 49.2% for CDC Copeland-floor; and 47% for Maiden Voyage. This indicates that variation in water uptake may be associated more with the steeping equipment (mini scale versus plant scale) than with genotype. Steep-out chit was higher for the mini-scale malts and is an indicator of the vigor of the grain at end of steeping. Similar to steep-out chit, growth count index is a measure of vigor at the end of germination. The CDC Copeland-floor showed the most vigorous growth during germination, which may be an indicator of overmodification (29), while Maiden Voyage was more moderate. Interestingly, DH142010-floor was closer to Maiden Voyage, indicating that it may respond differently to steep-out moisture. Only Maiden Voyage met the AMBA specification for plump

Table 3. Barley grain quality results for lines used in this experiment[a]

Line	Protein (% db)	Moisture (%)	Test Weight (kg/hL)	Plump (>6/64 in.)	Thin (<5/64 in.)	GE (4 mL [%])
CDC Copeland	11.20	9.80	59.0	80.0*	3.8*	100
DH142010	10.53	10.07	68.2	94.9	0.5	99

[a] Plump: retained on a 6/64-in. screen; Thin: through a 5/64-in. screen; GE: germinative energy.
* Outside AMBA guidelines for all-malt brewing (1).

Table 4. Malting data for parameters measured during the malting process to monitor batch performance[a]

Malt Batch	Steep-Out Moisture (%)	Steep-Out Chit (%)	Growth Count	Plump (>6/64 in.)
Maiden Voyage	47.0	97.0	100.6	75.5
DH142010-floor	49.8	100.0	104.3	60.0*
CDC Copeland-floor	49.2	100.0	115.6	60.5*
DH142010-pneumatic	48.6	ND	106.0	ND

[a] Plump: retained on a 6/64-in. screen.
* Below AMBA guidelines for all-malt brewing (1).

Table 5. Malt quality data for the two mini-floor malts compared with plant-scale Maiden Voyage and a commercial Maris Otter floor malt[a]

Malt Batch	Moisture (%)	Friability (%)	Extract (FGDB%)	Color (°SRM)	β-Glucan (mg/L)	Protein (%)	Soluble (%)	S/T (%)	FAN (mg/L)	DP (°L)	α-Amylase (20°DU)
Maiden Voyage	3.5	92.1	79.4#	3.5	49	11.2	5.4	47.8*	197*	117	56.9
DH142010-floor	3.6	92.2	82.8	3.3	48	10.3	5.2	50.4*	194*	111	47.4
CDC Copeland-floor	3.5	94.5	79.1#	4.1	43	10.3	5.8	56.2*	219*	121	73.6*
Crisp Maris Otter-floor	5.4	ND	82.6	3.1	102	10.5	5.1	48.1*	215*	106#	48.9

[a] FGDB%: Fine grind, % dry basis; S/T: soluble/total protein ratio; FAN: free amino nitrogen; DP: diastatic power.
Below AMBA guidelines for all-malt brewing (1).
* Above AMBA guidelines for all-malt brewing (1).

(>75%), which may be a result of its less vigorous growth and rootlet production (30).

Malt Quality

DH142010 performed well in the mini-scale floor-malting protocol, and results were closer to those of Maiden Voyage than CDC Copeland-floor. Malt quality results for the floor-malted lines are shown in Table 5. All three malts had similar diastatic power but differed in α-amylase, with CDC Copeland-floor 16.7 units higher than Maiden Voyage and 26.2 units higher than DH142010-floor. Malt extract for DH142010-floor (82.8%) was 3.3% higher than Maiden Voyage and 3.7% higher than CDC Copeland-floor. DH142010-floor was also the only one of the three to meet the AMBA extract specification (>81.0%). While the higher extract is notable, this may be a result of excess husk damage or skinned grains (>33% lost husk) in DH142010-floor during postmalting cleaning as noted by the maltster. Looking at malt samples, 31.5% of kernels in DH142010-floor were skinned compared to 5.5% of CDC Copeland-floor and 6.0% of Maiden Voyage. There are no established standards for skinned malt, but skinned barley has long been considered detrimental to malting and brewing (31,32). However, recent work has shown that this effect is only realized with severely skinned grain (33).

The S/T (soluble/total protein) ratio and FAN (free amino nitrogen) levels of DH142010-floor (Table 5) were closer to Maiden Voyage than to CDC Copeland-floor; however, all were above the ranges specified by AMBA for all-malt brewing (38–45% and 140–190 mg/L, respectively) (1). DH142010-floor and Maiden Voyage were just above the AMBA upper limit for FAN, whereas CDC Copeland-floor was much higher. The color of DH142010-floor was also closer to Maiden Voyage, as the higher proteolytic modification of CDC Copeland-floor may have contributed to formation of more color during kilning. As both mini-scale malts had similar steep-out moistures, the malt quality results seem to confirm that DH142010-floor may be less susceptible to overmodification. The steep-out moisture for DH142010-floor was 2.2% greater than for Maiden Voyage, but the S/T ratio was only 1.8% greater, and FAN was 3 ppm lower. Comparatively, CDC Copeland-floor was 8.4% and 22 ppm higher than Maiden Voyage for each attribute, respectively. If steep-out moisture of DH142010 was reduced, it might temper modification and produce malt with a lower S/T ratio and lower FAN. These results could influence further development of this research floor-malting protocol for further germplasm evaluation.

Notably, all three malts were comparable to the commercially available Crisp Maris Otter floor-malt, as shown in Table 5. While malted in a different facility, the Crisp Maris Otter sample was analyzed in the same laboratory using the same methods. Extract (82.6%) was similar to DH142010-floor. Diastatic power was lower than for the other malts, but only 5 units lower than DH142010-floor and just below AMBA specification, while α-amylase was similar to DH142010-floor. β-Glucan was the outlier at over twice the level of the other malts. Perhaps most surprisingly was the similarly high level of protein modification compared with the other malts (S/T at 48.1%; FAN at 215 mg/L). All of the malts exceeded AMBA all-malt guidelines for those parameters despite the commercial products being advertised toward the all-malt, ale brewery. This comparison shows that the plant-scale malting procedure and the experimental procedure are capable of achieving malt quality comparable to a commercially available Maris Otter floor malt.

Comparing malt types with the same genotype, DH142010 performed well in both floor and pneumatic systems, as shown in Table 6. These malts were malted on different scales and under different protocols typical of the equipment and to malt type. The floor-malting procedure was designed to produce a British-type pale ale malt, while the pneumatic procedure was designed to produce a low color malt for research purposes. Both produced acceptable malt of these types for brewing, but some of the parameters were out of range of the AMBA guidelines for all-malt brewing. The floor-malting process did not produce malt closer to the guidelines, other than a reduced amylolytic enzyme package, which may have been due to the higher ale-malt kilning temperatures (85°C versus 96°C). The malts were similar in friability, β-glucan, and FAN. DH142010-pneumatic was notably higher in extract, but both were above the AMBA specification (>81.0%). DH142010-floor was higher in color, which was to be expected given the more aggressive kilning regime of that protocol compared with that used to produce the low-color malt. Further, the S/T ratio was lower in DH142010-pneumatic, and while the final FAN values were similar, it was likely that some FAN in DH142010-floor was consumed in the development of Maillard reaction products during kilning. Due to the small size of the micro-scale malting batch, further evaluation through brewing and beer sensory was not performed.

Brewing

The two mini-scale floor malts produced beers that met similar quality parameters throughout the brewing process, as shown in Table 7. The greater extract level of DH142010-floor (+3.7%) was only partially realized. The significant spread in malt extract resulted in greater recovered extract after mashing and lautering. This was evidenced by a greater mash efficiency (81.7% versus 79.1%) and increased yield, as the DH142010-floor brew required

Table 6. Malt quality data for floor-malted DH142010 compared to pneumatic-malted DH142010[a]

Malt Batch	Moisture (%)	Friability (%)	Extract (FGDB%)	Color (°SRM)	β-Glucan (mg/L)	Protein (%)	Soluble (%)	S/T (%)	FAN (mg/L)	DP (°L)	α-Amylase (20°DU)
DH142010-floor	3.6	92.2	82.8	3.3	48	10.3	5.2	50.4*	194*	111	47.4
DH142010-pneumatic	4.4	90.6	83.8	1.8	45	10.3	4.9	47.1*	190	137	59.3

[a] FGDB%: Fine grind, % dry basis; S/T: soluble/total protein ratio; FAN: free amino nitrogen; DP: diastatic power.
* Above AMBA guidelines for all-malt brewing (1).

Table 7. Brewing quality data for the beers made with the pilot floor malts[a]

Beer	OG (°P)	FG (°P)	ABV (%)	pH	Color (°SRM)	IBU (ppm)	VDK (ppb)
CDC Copeland-floor	10.0	2.2	4.1	4.50	5.4	28	33
DH142010-floor	9.9	2.4	3.9	4.47	3.8	24	28

[a] OG: original gravity; FG: final gravity; ABV: alcohol by volume; IBU: international bitterness units; VDK: total vicinal diketone.

additional brewing water to meet target extract (25.7 L versus 19.1 L). However, these differences were not as great as the laboratory malt extract would predict. The DH142010-floor brew may have been hindered by the higher percentage of skinned malt (as noted previously). Additionally, the elevated α-amylase levels of the CDC Copeland-floor brew may have aided in starch saccharification that overcame a deficiency in total extract (34). Lastly, Evans et al. (35) posited that the accepted laboratory mashing regime for malt analysis may not produce numbers reflective of the results seen in the brewery, and evaluation under different protocols may be warranted.

Fermentation proceeded similarly, with both beers reaching terminal gravity in 7 days and achieving similar final extract, pH, and alcohol by volume (Table 7). Final beer color was noticeably different but was comparable to the color of their respective malts. There were slight differences in bitterness (IBU), and diacetyl (VDK). The bitterness for DH142010-floor was lower than the target and likely a result of the extra water added to meet target extract, and the difference between the two may be perceived in sensory. Similarly, diacetyl for each was near the detectable threshold, but the difference between the two was not considered significant. These results show that the mini-scale malts were capable of producing similar beers despite the different barley genotypes, and DH142010-floor produced malt that was as suitable for brewing as CDC Copeland-floor.

Malt Sensory

Hot steep sensory is a rapid method for the evaluation of malt and is a useful tool for breeders, maltsters, and brewers (36). The method has proven to be able to discriminate malts based on genotype, malt type, and maltster (8,10,37), but the connection between hot steep sensory outcomes and final beer is still unclear. This tool was used in this experiment to determine whether trained sensory panelists could differentiate between malt produced in the same malthouse under the same floor-malting conditions, as well as between malt produced from the same genotype but under different conditions (floor malting versus pneumatic malting). Radar plots of the comparisons are shown in Figures 3–5 to overlay the respective comparisons.

Comparing Similar Malts Made with Different Genotypes. The trained panels at Admiral Maltings and pFriem Family Brewers were unable to distinguish differences in flavor between the two floor malts made from different barley genotypes. The radar plot in Figure 3 shows two similar plots with only slight differences for "cracker" and "nutty" attributes, with DH142010-floor being 0.39 and 0.52 points higher than CDC Copeland for these attributes, respectively. The remaining seven attributes were very similar (less than a 0.15-point difference in scoring), and lack of significant differences confirmed the graphical representation. The descriptors associated with Maillard reaction products (bread, nutty, and sweet aromatic) all scored highly, indicating the kilning

Figure 3. Radar plot comparing genotypes in hot steep sensory: floor malts made with two different genotypes (DH142010 and CDC Copeland).

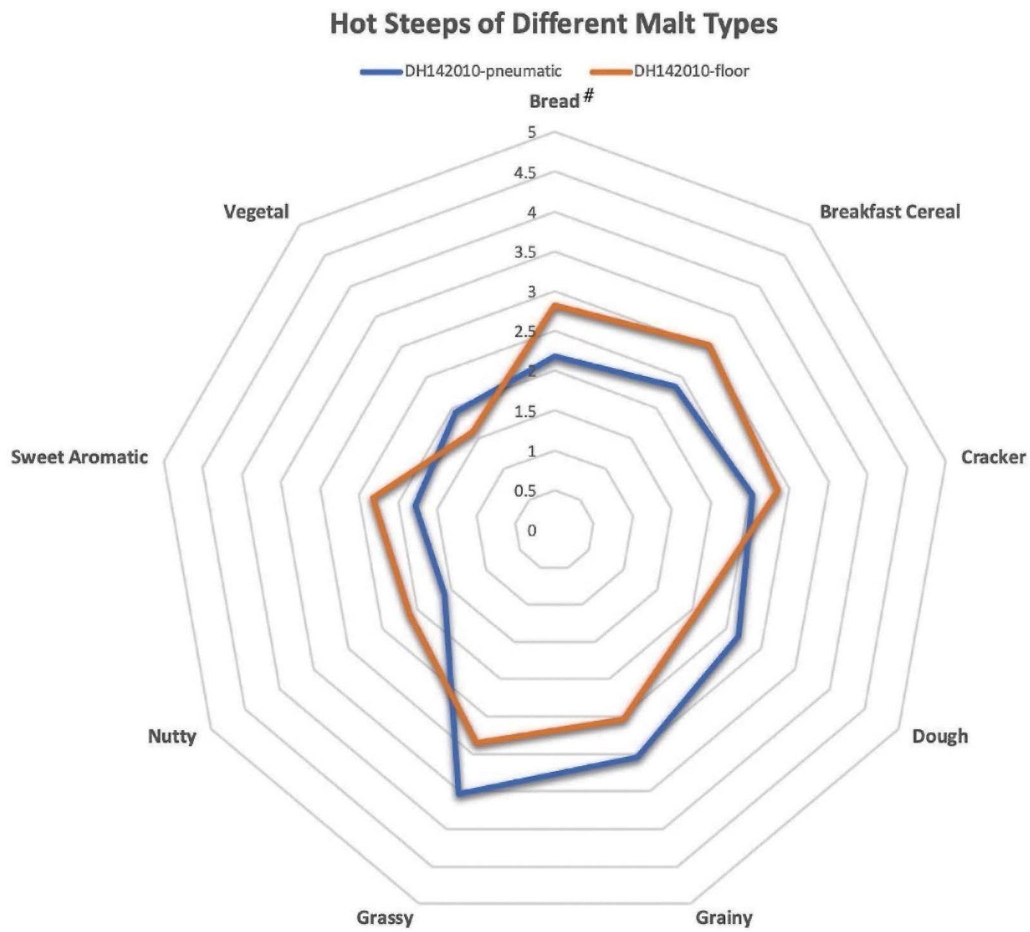

Figure 4. Radar plot comparing malt types in hot steep sensory: micro-pneumatic and mini-floor malts made with the same genotype (DH142010). #: Significant difference between samples at the 0.10 level.

procedure may be a major driver of malt flavor in this protocol. This suggests that the malting procedure is a greater source of variation of hot steep flavor than is genotype when using these two barley lines.

Comparing Different Malt Types Made with the Same Genotype. The trained panel at pFriem Family Brewers indicated the two malts made with DH142010 had different aroma and hot steep flavor profiles, as shown by distinct differences in the graphical representation in Figure 4. DH142010-pneumatic was characterized by "dough," "grainy," and "grassy" attributes, whereas DH142010-floor was characterized by "bread," "breakfast cereal," and "cracker." However, only one attribute was significant at the 90% level (bread; $P = 0.0828$), and none were significant at the 95% level, as determined by two-sided *t* tests. Strong conclusions based on these results are challenging due to the small sample size ($n = 14$) caused by a limited quantity of DH142010-pneumatic. However, distinct sensory outcomes between different malt types, regardless of barley genotype, are expected. While these results were not highly significant, the panel's ability to separate the samples is indicative of its ability to properly assess malt hot steep.

The floor-malted sample received higher scores on a scale of 0–5 than the new pneumatic-malted sample for "bread" (+0.58 points), "breakfast cereal" (+0.53 points), and "sweet aromatic" (+0.62 points). These are all descriptors associated with Maris Otter malts but may also be, at least partially, a result of the higher kilning temperatures used in the production of the floor-malt (Fig. 4). The floor-malted sample scored lower than the pneumatic-malted sample for "grassy" (–1.23 points), "dough" (–0.72 points), and "grainy" (–0.67 points), which may also be a result of the kilning process driving off volatiles (e.g., lipid oxidation products) associated with these sensory attributes. This lines up with the findings in the report by Griggs (15); while that study did not assess the sensory outcomes of the resulting malts, they found that floor-malted Maris Otter differed from pneumatic-malted samples in the volatiles associated with the "dough," "grassy," and "grainy" flavors. What is not clear, is whether this is simply a malting protocol effect or whether there is in fact a genotype by malting protocol interaction effect on flavor.

Comparing Mini-Scale Malt to Plant-Scale Malt. Sensory results for hot steeps of the two malts made with CDC Copeland are shown in Figure 5 and indicate that the mini-scale malting protocol produced malt similar to the plant-scale. Maiden Voyage was higher in "sweet aromatic" (+0.48) and lower in "grassy" (–0.52) attributes, with all other descriptors <0.30 points apart. Statistical analysis showed that no descriptor was significantly different between the malts. This is similar to the results comparing the two mini-scale malts made with different genotypes. This analysis shows that the mini-scale malting protocol was successful in producing malt with a sensory profile similar to the plant-scale version made with the same variety. Looking at both malt quality and hot steep sensory, this shows that the experimental protocol was sufficient but could be improved to better match all control points.

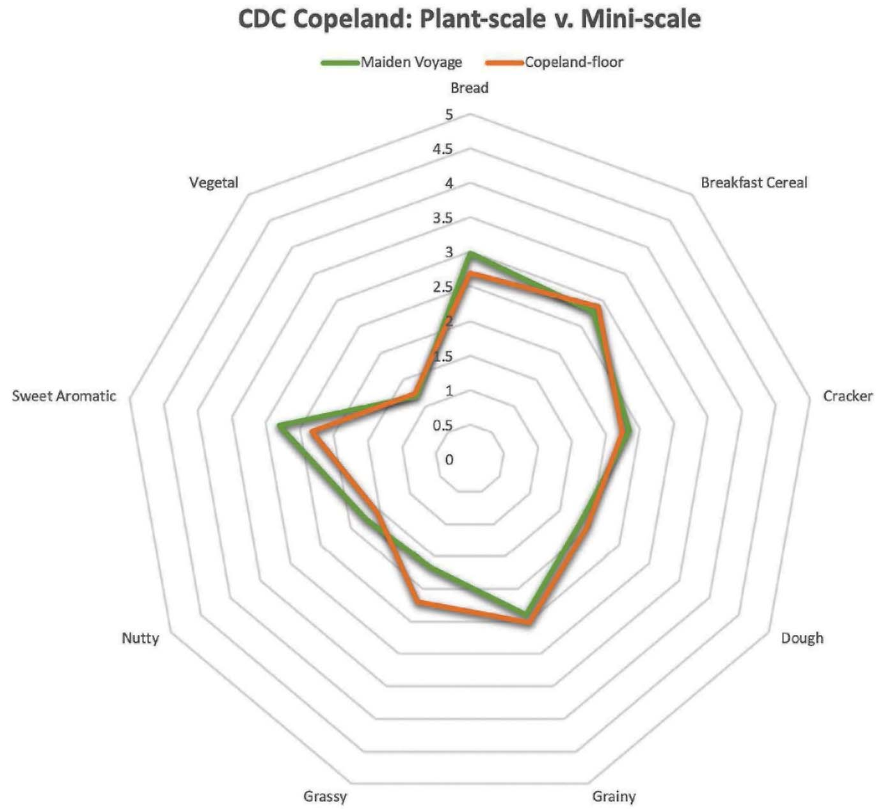

Figure 5. Radar plot comparing hot steep sensory of plant-scale Maiden Voyage malt (CDC Copeland) and mini-floor malt (CDC Copeland).

Beer Sensory

Beer sensory was performed on beers brewed with the two mini-scale malts to determine whether trained sensory panelists could differentiate between each genotype using descriptive analysis. Additionally, a preference test was used to determine whether one malt produced beer that was more appealing. The panel was able to detect differences between the beers, with "butter" (P = 0.0182) and "vegetal" (P = 0.0022) being significant descriptors. A graphic representation of the sensory scores is shown in Figure 6. Looking at response scores, the beer brewed with CDC Copeland-floor had the highest response rate for "fruity," "grassy," and "sweet aromatic," while the beer brewed with DH142010-floor was described as "cracker," "grainy," and "vegetal." Both "sweet aromatic" and "cracker "are descriptors associated with Maris Otter malt.

The significant difference in the "butter" descriptor was interesting, as this attribute is typically associated with high levels of diacetyl. However, the diacetyl levels for both beers (shown in Table 7) were both low and within 5 ppb of each other. Further, the beer with the higher "butter" scoring (DH142010) actually had the lower concentration. It is possible that flavor-active metabolites in DH142010-floor act in a synergistic effect with diacetyl to boost the overall perception of "butter" or, conversely that metabolites in the CDC Copeland-floor mask the effect of diacetyl. Regarding "vegetal," this study did not evaluate the compounds associated with this flavor: DMS, DMS-P, and S-methylmethionine (SMM). SMM and DMS-P are typically reduced in higher kilned base malts. Further, floor malts have recently been found to be lower in the precursors (19), so it is unlikely that the root cause of the "vegetal" flavor was DMS, although specific conclusions about the source cannot be made.

The panel did not indicate a significant preference between the two beers, as determined by a χ^2 test (P = 0.2393): 16 panelists preferred the beer brewed with CDC Copeland-floor, while 10 preferred the beer brewed with DH142010-floor. The slight preference for CDC Copeland-floor may be associated with the "sweet aromatic" descriptor, while the "vegetal" attribute may have contributed to the lower score for DH142010-floor. The overall similarity between the two beers may indicate that the genetic regions associated with the unique, heirloom flavors were absent in DH142010. Maris Otter was a major variety of its time, and many contemporary varieties can trace their genetic history to it (38). This includes lines that are also purported to provide unique contributions to beer flavor, such as Flagon, Halcyon, and Puffin, but also elite malting lines that are not considered by the industry to be drivers of flavor in beer, such as Violetta and Wintmalt. This spread of offspring is not surprising, and as shown in this study, flavor may depend on genetic introgression from specific regions of the genome. Recently Sayre-Chavez et al. (39) identified quantitative trait loci that are associated with beer flavor, via malt, using selections from Herb et al. (5). Further exploration of the genetic basis of beer flavor may be useful for breeders to effectively use heirloom varieties in their programs to potentially select for desirable flavors.

Conclusions

In this study, we observed that an experimental winter barley line, DH142010, with Maris Otter parentage performed acceptably in an experimental mini-scale floor-malting system. The line produced malt and beers that met most of the expectations established by the maltster's standard spring barley variety, the AMBA-listed CDC Copeland. Hot steep sensory found that floor

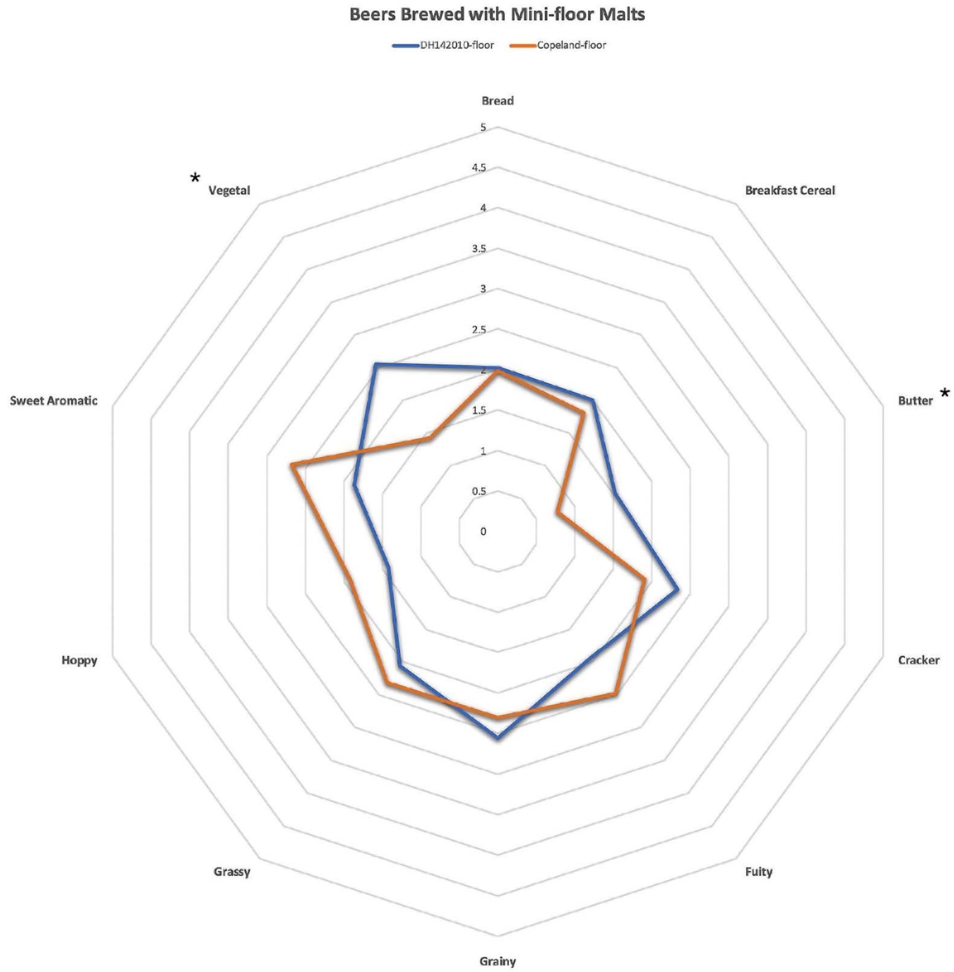

Figure 6. Radar plot comparing genotypes in beer sensory: floor malts made with DH142010 and CDC Copeland. *: Significant difference between samples at the 0.05 level.

malting with the experimental line produced malt with more characteristic flavors of Maris Otter compared with the pneumatic-malted sample but that it did not produce unique flavors compared with floor-malted CDC Copeland. Beers brewed with the mini-scale floor-malt beers with similar analytical profiles met brewhouse performance expectations. The sensory profiles of the beers had some differences, but both were characterized by certain attributes associated with Maris Otter, and there was no significant preference between the beers. Thus, while the experimental line did not bring forth its Maris Otter parentage with gusto, it did perform similarly to the AMBA-listed, commercially utilized variety. The higher ratings for "vegetal" in the DH142010 beer are a concern that will need to be addressed in future research, ideally with a larger sensory panel, and perhaps with different beer styles. Given the differing growth habits of the barleys used in this study, the results show the potential for using novel winter-habit lines grown in the Tulelake Region for floor malting at the industry collaborator. As climate change continues to put pressure on spring varieties in the region, winter barley may provide a more sustainable future. For future evaluation of experimental lines for their suitability for floor malting, the experimental procedure should be refined to temper steep-out moisture for better modification control. Further, smaller microscale malting trials should be performed to develop an assessment protocol optimized for higher throughput.

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CONFLICT OF INTEREST

The authors declare no competing financial interest.

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