TITLE: FROM GROUND TO GLASS: EVALUATION OF UNIQUE BARLEY VARIETIES FOR WESTERN WASHINGTON CRAFT MALTING, BREWING AND DISTILLING

PRINCIPAL INVESTIGATOR(S) AND COOPERATOR(S): STEPHEN BRAMWELL (PI), DR. KEVIN MURPHY (CO-PI), DR. THOMAS COLLINS (CO-PI)

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ABSTRACT

This research project was initiated to provide regional agronomic and end-use data for specialty barley producers and end-users in western Washington, and to evaluate for the impact of barley variety on distillate and beer flavor compounds. The long-term aim of the project is to cultivate high-value markets for grain based on distinctive end-use qualities such as taste, aroma, and mouth feel. This study utilized a breeder-extension-farmer-craft brewer/distiller-food science collaboration to evaluate barley varieties for organic production and value-added processing. We hypothesized that unique flavors exist among the germplasm in the WSU barley breeding program that would be of interest to craft maltsters, brewers, and distillers. Nine barley breeding lines and/or varieties were evaluated for valuable agronomic and end-use characteristics. In 2017 and 2018, three replicates of breeding lines (nine in 2017, four advanced to 2018) were grown on field-scale plots in Southwest Washington. Grain from both years was evaluated for grain and malt quality. Micro-malting for malt analysis was completed utilizing two different steep regimes to evaluate the impact of malt regime on malt quality. Barley from 2017 and 2018 trials was distilled by Sandstone Distillery and unaged distillate was analyzed for flavor compounds using Gas Chromatography Mass Spectrometry (GC/MS) and Liquid Chromatography Quadrupole Time of Flight Mass Spectrometry (LC/QTOF-MS) at the WSU Wine Science Center. Hot barley steeps were evaluated using LC/QTOF-MS for the same varieties grown in Western and Eastern Washington. Malt from 2018 trials was brewed into beer, and mean acceptance ratings for aroma, appearance, taste/flavor, sweetness, bitterness and overall likings along a 9-point scale were obtained from trained sensory panelists for hot barley steeps and beer, in collaboration with the WSU Food Science program. A community sensory evaluation was undertaken at the Tumwater Brewfest. Barley lines showed difference in malt quality within lines and in comparison with Copeland as an industry standard malt variety. Several lines were competitive with Copeland regarding grain yield, fine extract (alcohol yield potential), and water sensitivity (need for altered steep regimes in the malt house), with generally higher levels in breeding lines as compared to Copeland of beta glucan. Altered steep regimes improved overall malt performance when adjusting for water sensitivity. Differences in new make whiskey flavor compounds were detected based on breeding line, trial location, and distillation conditions. Flavor compounds in new make whiskey, as well as their relative incidence and flavor character (spiciness, fruity), could be assigned by breeding line. Preliminary sensory evaluation of fresh-make (i.e., not barrel-aged) whiskies distilled from the barleys from the 2017 harvest found sufficient differences in the aromas of undiluted and diluted (2:1) samples to justify conducting a descriptive analysis of the samples upon approval of the IRB. Approval of the IRB is anticipated for early September 2019. The descriptive analysis will be conducted to evaluate the differences in aroma and flavor intensity across the samples in this set of whiskies, followed by evaluation of correlations if any between the previously obtained chemical composition and the sensory perception of the whiskies. Trained panelists detected various significant differences in end-use qualities in hot malt steeps and beer regarding appearance, aroma, taste/flavor, sweetness, and for overall liking. For evaluating aroma, sample 12WA-120.14 was liked the most and sample Copeland the least. Aged whiskey from Sandstone Distillery will be evaluated at the 2020 Cascadia Grains Conference, and into in the future, to track modification of end-use characteristics over time.

PROJECT DESCRIPTION

Expansion of grain production in minor growing regions has been promoted to give farmers biological tools for managing pests and disease when grain is rotated with other crops such as vegetables or vegetable seed and to develop marketing relationships among farmers, craft brewers and craft distillers (1, 2, 3). Western Washington has been shown to be a unique agro-ecosystem for the union of regional grain production and end-use product development (4, 5). However, expansion of specialty grain production appears to depend on development and successful marketing of novel attributes, as well establishment of new infrastructure. This project addressed specific literature gaps regarding 1) identification of suitable barley cultivars for production and craft brewing and distilling in western Washington, and 2) the impact of barley cultivar on novel flavor attributes in craft beverages.

This project extended WSU breeding efforts into local westside communities through field-scale evaluation of barley cultivars for craft brewing and distilling, as well as community sensory evaluation. Breeding work in recent years at WSU has identified several barley lines apparently well-suited to grain production in western Washington while also exhibiting good malting, brewing, and distilling characteristics. Breeding for malting cultivars has historically focused on lines suitable for adjunct brewing, in which malted barley is supplemented by rice or corn. These breeding programs serving large-scale adjunct brewing have emphasized high diastatic power (DP), high free amino nitrogen (FAN) cultivars (6). Breeding programs for adjunct brewing emphasize high DP barley because malted barley drives enzymatic conversion of carbohydrate to alcohol.

In contrast, the current study is evaluating barley for all-malt (all barley) brewing typically employed by craft brewers. In this study, we sought lines that:

1. Exhibited traditional grain and malt quality performance such as high potential alcohol conversion (fine extract), low protein, and suitable (>90%) friability,
2. Separated from industry malt through lower diastatic power, lower free amino nitrogen, and
3. Demonstrated distinct end-use characteristics such as taste and aroma compounds.

Characteristics evaluated by the WSU breeding program, and important to craft brewers, include malt quality, percent malt extract, DP and FAN, beta glucan content, germination energy, water sensitivity and falling number. Breeding work utilizing these evaluation criteria identified promising lines that, grown out for field-scale evaluation for this project, allowed for sensory evaluation of distilling and brewing characteristics using analytical tools and sensory panels.

OUTPUTS

OVERVIEW OF WORK COMPLETED AND IN PROGRESS

Growing Trials

- In 2017, three reps of nine barley varieties were grown out in one-sixth acre plots at Hidden River Farms in Montesano, WA, totaling twenty seven plots and 4.5 acres. Breeding lines (numbered) and varieties (named) selected for this evaluation included two hulless types (Havener, 10WA-107.8) and seven hulled types (Muir, 10WA-117.24, 10WA-117.17, 11WA-107.43, 11WA-107.58, 12WA-120.14, 12WA-120.17. Approximately 1,200 lbs per variety was harvested (data below) for distillation and analysis in 2017.
- Approximately 6,000 lbs of grain was needed from a second trial in 2018 to provide a full-size batch (1500 lbs) per variety to Sandstone Distillery for a second year run, and 4,000 lbs of each variety for malting (to ensure sufficient grain for brewer-cooperators). In 2018, three breeding lines (12WA-120.17, 12WS-1240.14, and 10WA-117.17) were advanced to a second trial in Adna, WA. Each variety was grown in triplicate on one-half acre plots amounting to 1.5 acres per breeding line and 6 acres total including Copeland as a replicated check. Larger plots were established in 2018 to provide more barley for malting, brewing and end-use evaluation. The Adna trial site had lower weed pressure and improved soil fertility, and received higher N application rates to meet yield objectives.

Agronomic data

- Agronomic data regarding breeding lines was collected including yield, height, rust incidence, and percent lodging in the Montesano trial, while and only yield data was collected in the Adna trial (2018) as no significant differences in agronomic performance beyond yield and height were detected. This was due to absence of rust pressure, and conditions conducive to lodging. Neither were detected in the Adna trial.

Malting, grain and malt quality analysis

- Micro-malting, and grain and malt quality analysis were completed on raw barley samples for 2017 and 2018. Analyses of all breeding lines and replications were conducted by the USDA ARS Cereal Crops Research laboratory in Madison, WI. Triplicate samples of 2018 lines have been sent to Wisconsin to allow for malt quality comparisons from the same laboratory.
- Grain samples were also micro-malted and analyzed for grain and malt quality at the Hartwick College Center for Craft Food and Beverage in Oneonta, NY for more rapid turnaround, and to utilize this laboratory that is well-known in the craft malting industry. In 2018, replicated samples were analyzed by the Hartwick Center.
- Mini-malting of 20 pound samples of selected 2017 lines was completed at the OSU Barley World Laboratory for small-batch brewing and sensory evaluation work that occured spring 2019.
- Roughly 4,000 lbs of three 2018 trial breeding lines and a check was malted by Gold Rush Malt in Baker City Oregon, allowing quantity for full-scale brewing and sensory evaluation in summer 2019. An agritourism event featuring beer sensory evaluation was completed in August 2019 at the Tumwater Brewfest, but reporting on results was not in the original proposal and analysis fell outside the reporting timeframe. One-hundred sixty attendees participated in the evaluation.

Distillation and distillate analysis

- All breeding lines from 2017 and 2018 trials were distilled by Sandstone Distillery, with intermediate distillation products (low wines) and final unaged product packaged and transported

to the WSU Wine Science Center. Flavor compounds were analyzed at the WSU Wine Science Center using GC/MS and LC/QTOF-MS analysis of unaged whiskey from 2017 trials. Results are summarized below. All of the 2017 crop less 2018 seed was required to complete this distillation and analysis.

- Fifteen hundred pounds of barley from 2018 trials was distilled by Sandstone Distillery in winter 2018/19. Compound analysis of unaged and aged whiskey from 2018 barley will be analyzed using GC/MS and LS/Q-TOF/MS at the Wine Science Center. A second and future years of flavor compound analysis will result from this study, but go beyond deliverables identified for this grant and fell outside the reporting timeframe.

Sensory Evaluation

- Protocol for a sensory panel to evaluate unaged and one-year aged whiskey from 2017 trials has been developed by Dr. Collins, Dr. Scott Frost, and Layton Ashmore. The same protocol will be utilized to evaluate whiskey samples from 2018 trials as well but results are not reported in this final summary.
- Distillate sensory evaluation will use a trained tasting panel at the WSU Wine Science Center to conduct a descriptive sensory analysis of the whiskies, based on a consensus set of descriptive developed by the panel. Once completed, the sensory data will be evaluated for correlation with specific chemical compounds, such as ethyl esters which are known to impart “fruity” odors (10), among other attribute-compound associations.
- The 20 pound samples of 2017 barley micro-malted by OSU was provided to Dr. Murphy and his graduate student in Pullman, WA. Sensory evaluation was conducted by a Evan Craine in collaboration with Dr. Murphy and Dr. Caroline Ross in spring semester 2019.
- Malted barley from 2018 trials was provided to five cooperating breweries in Olympia, WA. A brewer at one brewery produce the same beer from all four varieties for a IRB-approved sensory evaluation at the Tumwater Artesian Brewfest.
- Aged whiskey evaluation from 2017 trials (>2-year aged) is intended for sensory evaluation at the 2020 Cascadia Grains Conference.
- Aged whiskey from 2017 and 2018 trials will be made available for WSU sensory evaluation/fundraising events, to generate revenue for craft brewing and distilling flavor evaluations in the future.

METHODS

Field Preparation, Seeding and Harvest

Barley breeding lines were grown in randomized complete block designs in 2017 and 2018 trials at two farms in Southwestern, WA (Montesano, WA and Adna, WA respectively). Breeding lines (numbered) and varieties (named) grown in 2017 were Havener, 10WA-107.8, Muir, 10WA-117.24, 10WA-117.17, 11WA-107.43, 11WA-107.58, 12WA-120.14, and 12WA-120.17; and in 2018 were 10WA-117.17, 12WA-120.14, 12WA-120.17, and Copeland as a control. The named cultivars were used as 1) check cultivars and 2) to demonstrate an immediate product available for growers. Selected barley varieties were 2-row types with low to moderate beta glucan and protein content, and possessed quality traits which suggest them as excellent candidates for malting. Wheat was grown the year prior to field trials at both sites. Uniform fertility application and management practices were employed.

Soil at the trial sites consisted of uniform Chehalis silt-loam (fine-silty, mixed, superactive, mesic Cumulic Ultic Haploxeroll, NRCS 2016) at Montesano, and Chehalis silt loam as well as Newberg fine sandy loam (Coarse-loamy, mixed, superactive, mesic Fluventic Haploxeroll, NRCS 2016) at Adna.

Figure 1. Rolling in seeded barley with a cultipacker in 2018.

Field operations and timing in 2017 and 2018 are summarized in Table 1. In 2017, fields received primary tillage using an off-set disk and secondary tillage consisting of four passes with a finishing disk. In 2018, fields received primary and secondary tillage with a vibra-shank harrow followed by spike tooth harrowing. Plot fertility was evaluated prior to planting in both years, and soil samples analyzed by A&L Laboratory in Portland, OR. In Montesano, Stutzman's (4-3-2) organic chicken manure was applied at a rate of 0.7 tons per acre (56 lbs N per acre), and the fields were limed at a rate of 2 tons per acre on. At Adna, 230 lbs per acre of ureasul purchased from Valley Agronomics in Chehalis, WA, was applied at a rate of 75 lbs N per acre. Fertilizer was worked into the ground prior to seeding, and lime was not applied at the Adna trial.

Table 1. Summary of field operations in 2017 and 2018

	Tillage	Fertilizer application	Secondary Tillage	Seeding	Emergence	Tine harrowing	Harvest
2017	4/17	5/8	n/a	5/10	5/17-5/19	5/22	9/6
						5/27	9/7
2018	4/10	4/23	4/25	4/27	5/5 – 5/7	5/4*	8/10
		4/24	4/26			5/10**	8/13

* *Pre-emergence tine harrowing*

***Post-emergence tine harrowing*

Figure 2. Cleaning grain with Clipper 47B.

Barley was seeded at approximately 95 lbs per acre with a McCormick-Deering 8-ft seed drill in 2017, and at 110 lbs per acre with a John Deer 8-foot grain drill in 2018. In Montesano, field plots were harrowed twice after grain emergence while in the Adna trials fields received one pre-emergence and two post-emergence passes, both sites with an Einboch tine weeder with 7 mm tines designed for post-emergence cultivation.

The fields were harvested September 6th and 7th, 2017 in Montesano, and August 10th and 13th, 2018 in Adna. Harvested grain was cleaned with a Clipper 47B to remove weed seed both years. Moisture content was evaluated at harvest in 2017 and three times in 2018 (at ten days before harvest, on the day of harvest, and in storage 50 days after harvest). Moisture readings were collected with an AgraTronix MT-16 Grain Moisture Test.

Malting, and Grain and Malt Quality Analysis

Grain and malt quality analysis was completed at the USDA Grains Research Program in Madison, WI and the Hartwick College Center for Craft Food and Beverage in Oneonta, NY. Grain quality analysis consisted of grain moisture (%), protein (%), test weight (lbs/bu), plump (% retained on 6/64" screen), thins (5/64"), germination energy (4 ml and 8 ml), RVA and DON. Samples were micro-malted in a Custom Laboratory Products (Milton Keynes, UK) capable of processing sixteen 500g samples per batch. Malted barley was analyzed for malt moisture (%), friability (%), fine extract (% DB), wort color (SRM), beta glucan (ppm), soluble protein (%), protein modification or S/T (%), free amino nitrogen (ppm), diastatic power (L), alpha amylase (D.U.), and pH. Grain and malt quality analyses were conducted using official methods of the American Society of Brewing Chemists (http://methods.asbcnet.org/toc.aspx).

Mini-malting of larger, 20 lb samples of selected 2017 lines was completed at the Oregon State University Barley World Laboratory using a Curio Malting (Milton Keynes, UK) MMSG Steep and Germinator and MMK Kiln.

All 2017 and 2018, varieties micro-malted at Hartwick Center utilized a standard steeping regime most adapted to grain with no water sensitivity (Table XY). Water sensitivity is a dormancy mechanism, associated with moisture levels at harvest as well as a genetic component (Aaron Macloed, Personal

Communication), which when addressed with altered steeping regimes can improve malt performance. Several 2017 barley varieties malted at OSU exhibited mild to moderate water sensitivity, and received a modified steeping regime (Table XY).

Table 2. Standard and modified steeping regimes for 2017 Montesano trial used at the Hartwick Center and OSU Barley World.

	Entry	Steep	Germ	Kiln
Hartwick Center (standard)	All entries	8 hrs wet (16 hrs air) 6 hrs Wet (14 hrs air) 2 hrs wet @ 14°	96 Hours @ 15°C	6 hrs @ 55°C, 6 hrs @ 65°C, 6 hrs @ 72°C, 4 hrs @ 85°C
OSU (modified, minimally)	Copeland	8 hrs Wet (16 hrs Air) 8 hrs Wet (12 hrs Air) 2 hrs Wet @ 14° C	96 Hours @ 15°C	5 hrs @ 50°C, 5 hrs @ 55°C, ΔT = 9 @ 60°C, 6 hrs @ 72°C, 4 hrs @ 85°C
OSU (modified)	12WA 120.14 & 12WA 120.17	8 hrs Wet (16 hrs Air) 8 hrs Wet (12 hrs Air) 2 hrs Wet @ 14° C	120 Hours @ 15°C	5 hrs @ 50°C, 5 hrs @ 55°C, ΔT = 9 @ 60°C, 6 hrs @ 72°C, 4 hrs @ 85°C
OSU (modified)	10WA 117.17 & 10WA 107.43	5 hrs Wet (19 hrs Air) 5 hrs Wet (15 hrs Air) 2 hrs Wet @ 18°	120 Hours @ 15°C	5 hrs @ 50°C, 5 hrs @ 55°C, ΔT = 9 @ 60°C, 6 hrs @ 72°C, 4 hrs @ 85°C

Agronomic performance of the selected varieties was evaluated for production potential in western Washington based on plant height (cm), barley stripe rust (% leaf infected), lodging (percent of plot area), and yield (lbs per acre clean grain on basis of harvested plot area). Upon harvest, all nine varieties were cleaned through a Clipper 47B to eliminate weed seed. Cleaned grain was transported to craft distilling cooperator Sandstone Distillery for micro-distillation into new make whiskey.

Unmalted barley was distilled from the Montesano trial by distiller-cooperator Sandstone Distillery in Tenino, WA between October 2017 and January 2018. Starch was converted to fermentable sugars through the addition of added enzymes rather than relying on the addition of malted barley as is done more traditionally. This reduced variation associated with the malting procedure, potentially allowing for greater expression of grain variations. One thousand pounds of each line was ground and deposited as two 500 lb reps into separate reactors utilized both for cooking and fermenting. Mash production consisted of combining grain, enzymes and water, and heating to 180 degrees F over the course of approximately one hour. An iodine test was administered to evaluate for presence unconverted starch and hence completion of fermentation. Temperatures cooled from 180 to 120 at which point 202 HY and 250 g of GW yeast were pitched. Fermentation was complete with very little activity after two days.

Figure 3. Cooker-fermenter reactors used also as a pot still at Sandstone Distillery.

Fermented mash was distilled directly from the cooker-fermenter reactors by utilizing the reactor as a pot still (Figure 1). The reactors were heated, and alcohol vapor was channeled to a copper Lyne arm and through a water jacket manufactured from a central column wrapped in copper coil through which cold water was circulated. Low wines distillate product was collected in a 100 gallon stainless steel drum. Product was further distilled through two subsequent distillation stripping runs, each with the addition of 100 gallons of water, from which was obtained mid wines and high wines. Each run was completed in approximately five to six hours over the course of three days (one per distillation), with samples collected at each step and recordings taking of alcohol yield in gallons and proof.

Subsamples of the replicates were collected after the second distillation, resulting in 375 ml "low wines" samples. Subsequently, low wines were combined for a third distillation run and one 375 ml subsample of this final product was collected prior to barreling. All samples were sent to the WSU Wine Science Center in Richland, WA along with 50 ml samples of pre-fermentation mash for each variety. Samples were analyzed for differences among flavor compounds and flavor compound identification by GC/MS and LC/QTOF-MS, the former for volatile compounds and the latter to evaluate flavor precursors and compounds associated with mouth feel. The remainder (unsampled) distillate product was transferred to oak barrels (type & size, retrieving info) at Sandstone Distillery for aging.

Sensory evaluation of fresh make (un-aged) whiskies

Informal evaluation of the aromas of the fresh-make whiskies was conducted by a panel of students and staff (3 male, 2 female) at the WSU Wine Science Center on August 23, 2019. Undiluted (~60% v/v ethanol) 20 mL samples of eight whiskies from the 2017 barley harvest were presented in standard wine tasting glasses (Riedel) were evaluated for their aroma characteristics. After the undiluted samples were evaluated, 40 mL of deionized water was added to each sample and the aromas were evaluated for the diluted samples (~20 v/v ethanol).

Brewing

Figure 4. Initial evaluation of aged whiskey. Full evaluation of aged product will occur on whiskey aged two years (winter 2020 Cascadia Grains Conference).

Approximately 6-7 kg of five varieties of barley mini-malted by the OSU Barley World program was brewed by Moscow Brewing Company, and were utilized by the WSU Barley Breeding and Food Science programs for sensory evaluation in spring 2019.

Untrained Panelist Sensory Evaluation

Beers were received in to the Food Science program April 25, 2019. Samples were placed in 35°F (4° C) storage at the WSU School of Food Science. The sensory evaluation study was conducted in the WSU School of Food Science Sensory Facility in Pullman, WA on April 26, 2019. Materials including unsalted-top crackers and grapes were purchased from a local Safeway grocery (Pullman WA). Purified deionized water was used for palate rinse during the sensory evaluations. Deionized water was filtered over a Milli-Q Reagent Water System containing carbon, deionizing, and trace organic filters (Millipore, Bedford, MA). Wine glasses with aroma caps (i.e. lids) were provided for samples.

The test sample beer bottles were held on ice to maintain a sample temperature of ~43° F (6°C). When the consumers were prepared to receive the first flight of samples, 30mL aliquots of the beers were poured into clear wine glasses. Glasses were covered with aroma caps to preserve the carbonation and aroma. Each glass was labeled with a 3-digit blinding code, and the samples were presented under white light.

The sensory panel for acceptance of Hot Steep Malt was conducted over one day. The panel was composed of 95 untrained participants, 54 females and 40 males. The age range was from 21 to 71 years. Before the test, screening criteria were applied to all participants. Specifically, all consumers were screened to confirm (1) they were age 21 or older, (2) they purchase/consume craft beer at least once or twice a month. Additionally, the screening criteria before the product test included questions to capture data related to demographics, consumption pattern, and consumer behavior. Consumers were recruited from the Washington State University community, as well as the broader Moscow-Pullman community. The project was approved by the Washington State University Institutional Review Board (IRB).

Acceptance test

Consumers rated the attributes for aroma, appearance, taste/flavor, sweetness, bitterness and overall liking using a 9-point hedonic acceptance scale. Acceptance ratings were labeled 'dislike extremely' (i.e. "1"), 'dislike very much', 'dislike moderately', 'dislike slightly', 'neither like or dislike', 'like slightly', 'like moderately', 'like very much', 'like extremely' (i.e. "9"). Consumers selected main attributes that they perceived in each sample from a randomly ordered attribute table to generate check-all-that-apply scores. Attributes were selected from the Base Malt Flavor and Beer Flavor Maps, and were chosen based on there potential to best differentiate the samples (DraughtLab). The hot steep malt attributes included "bready", "breakfast cereal", "earthy", "floral", "fruity", "grainy", "grassy", "honey", "nutty", stale", and "other"; the beer attributes included "butter", "cereal", "chemical", "citrus", "earthy", "floral", "fruity", "grassy", "nutty", "stale", "sweet aromatic", "yeasty", and "other. Comments for liking or disliking of each sample were collected. Statistical analysis was performed in Compusense Cloud. Level of significance for treatment differences was established at $p \leq 0.05$.

Community Sensory Evaluation

A sensory evaluation was held at the Tumwater Brewfest on August 17th, 2019 in collaboration with Top Rung Brewery. The same beer recipe from all four of the 2018 malting barley varieties was produced for the activity. The Tumwater Brewfest typically attracts between 5,000 and 6,000 attendees. The research team sought a minimum of 80 and a maximum of 160 panelists for the evaluation.

On the day of the event, a bank of eight tasting booths with privacy panels were constructed using two 8 ft tables. Panelists self-identified from among the crowd, signed a consent form, completed a short questionnaire, and were provided with 30 ml each of the four beers in randomized order. A cup of distilled water and two saltine crackers were provided as palate cleansers. Each participant received a questionnaire to fill out to capture demographic data, and a ballot to guide the sensory evaluation

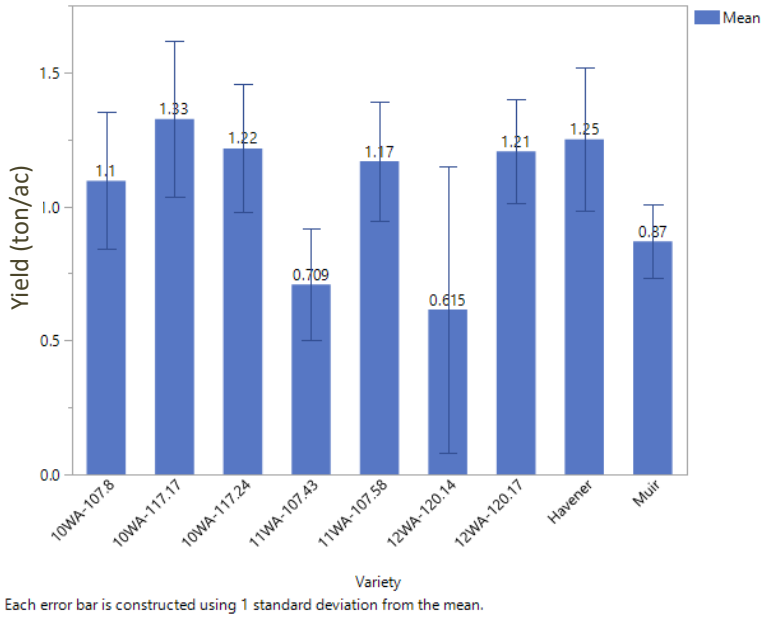
In the tasting booth, panelists completed a IRB-approved sensory evaluation ballot to record overall liking, provide an open-ended description of each beer, and complete a Check-All-That-Apply for each as well. In the latter, participants selected taste, aroma and mouthfeel flavor attributes from a provided Beer Flavor map developed by the Flavor Lab LLC (https://www.draughtlab.com/flavormaps). One-hundred sixty panelists completed the sensory evaluation.

RESULTS

Yield Data

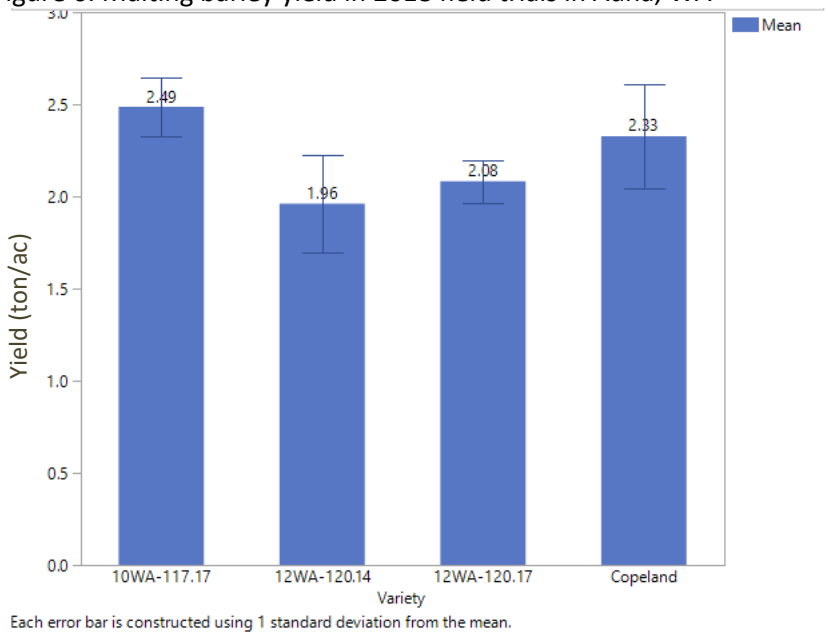
Barley varieties overall did not differ significantly in yield due largely to in-field variation in both years (Figures 5 and 6). Random effects of replication obscured variety differences. Generally, year two yields were much higher than year one, owing likely to weed pressure, soil preparation, and soil fertility differences. Yields in 2018 of all test varieties were not significantly different from the industry standard malting barley control (Copeland), indicating good yield potential.

Figure 5. Malting barley yield in 2017 field trials in Montesano, WA



**No significant differences were detected between varieties*

Figure 6. Malting barley yield in 2018 field trials in Adna, WA

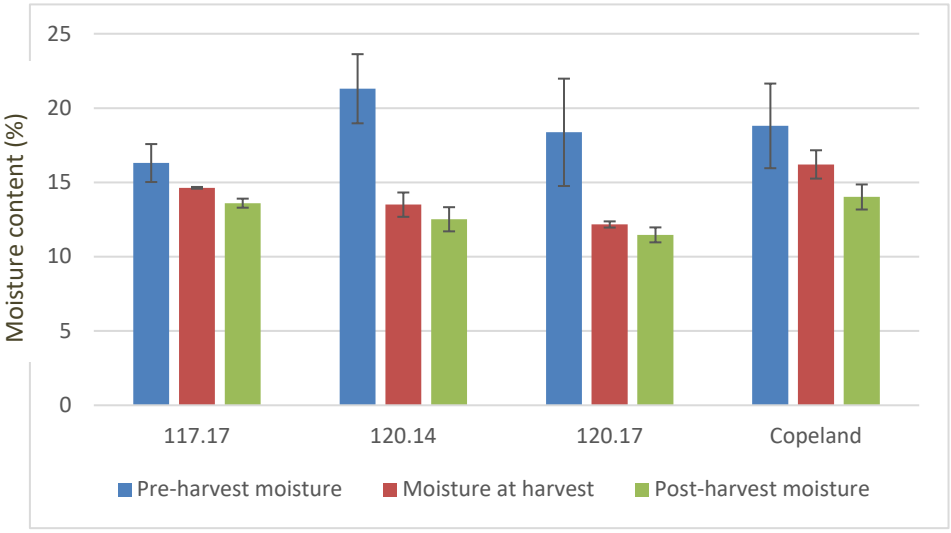


*No significant differences were detected between varieties

Barley Moisture

Barley varieties showed some differences in moisture content before, at, and harvest (Figure 7). Day and sequence of harvest, and moisture content at harvest appeared to be the primary determining factor of post-harvest moisture content. The driest variety after harvest was 120.17, which was harvested at 12.2% moisture prior to a small rain event. The rest of the barley was harvested three days later (August 13th), starting with Copeland and followed by 117.17 and then 120.14. Post-harvest moisture content was significantly different between 120.17, and Copeland and 117.17. There was no difference between 120.17 and 120.14.

Figure 7. Barley moisture levels before, at and after harvest in 2018



*Error bars constructed using 1 standard deviation from the mean.

Malt and Grain Quality Data

Given the approach in these trials of employing field-scale barley plots, and full-scale malt production for industry evaluation, not all grain and malt quality data could be replicated. In some instances, that would require 2 to 3 ton replications depending on minimum quantities required by cooperating malt facilities.

General trends and significant differences in grain and malt quality parameters were observed across many varieties in both years (Figs 3, 4, 5, 6, 7, 8). Grain quality differences were minimal across varieties in 2018, whereas wider variation was observed in 2017 varieties, some of which were dropped from the 2018 trials.

The altered steep regime improved malt performance of water sensitive breeding lines by reducing Beta glucan levels. Overall malt quality scoring in 2017 identified preferred varieties for all-malt brewing, and informed release of Palmer (107.43) in 2018, and which lines to advance to 2018. In 2018 trials, varieties showed no difference in characteristics generally required for brewing and distilling, and separation from industry standard in ratio of soluble to total protein, preferred by craft brewers.

Table 3. Grain Quality Analysis for 2017 Trial

Entry	Yield (t/ac)	Protein (%)	Moist. (%)	Test weight (lbs/bu)	Plump (>6/64%)	Thin (<5/64%)	Germ. (Energy, 4mL %)	Germ. (Energy, 8mL %)	RVA
Copeland	n/a	9.8	14.9	51.8	99.1	0.1	100	90	202
Havener* (hulless)	0.615	10.8	15.6	53.2	98.1	0.1	85	61	169
Muir	1.096	9.2	15.0	58.4	92.1	0.4	100	83	128
10WA-107.8* (hulless)	0.709	9.9	14.9	50.1	98.4	0.3	100	82	200
10WA-117.17	1.326	10.0	14.6	50.7	99.0	0.1	96	60	165
10WA-117.24	1.168	10.0	15.0	52.9	99.1	0.1	97	80	160
11WA-107.43	1.206	10.6	15.5	52.4	98.9	0.1	97	71	201

11WA-107.58	0.870	10.1	15.4	50.6	98.7	0.3	96	90	180
12WA-120.14	1.216	10.3	16.9	49.7	99.1	0.1	97	87	176
12WA-120.17	1.251	10.3	13.4	48.9	99.6	0.0	100	91	140

*Grain quality data for 2017 was obtained from the Hartwick College Center for Craft Food and Beverages, and did not include replicated evaluation within the project budget. *Hulless varieties*

Table 4. Grain Quality Analysis for 2018 Trial

	Protein (%)	Plump (6/64" %)	Thin (<5/64" %)	Germination (4 ml)	Germination (8 ml)	RVA
Copeland	11.4 a	93.6 a	0.80 a	98.0 a	93.0 a	155 b
12WA-120.14	12.6 a	94.8 a	0.73 a	99.7 a	93.7 a	188 a
12WA-120.17	12.4 a	93.5 a	1.20 a	97.0 a	88.7 a	190 a
10WA-117.17	11.5 a	89.2 a	1.53 a	98.0 a	91.7 a	207 a

Means comparisons using Tukey pairwise comparisons reported for treatment differences at $p \leq 0.05$.

Table 5. Malt quality analysis for Montesano trials (2017) utilizing a generalized steeping regime developed for the industry standard Copeland (for steeping regime see Table Q.)

	Fine extract (% DB)	Friability (%)	B-Glucan (ppm)	S/T (%)	FAN (mg/L)	DP (°L.)
BA* Targets	>80.0	>85	<140	<45	<150	<150
Copeland	81.9	92	75	49.9	232	131
107.43	82.4	89.2	471	40.8	157	86
120.14	81.7	88.8	195	47.5	217	98
120.17	81.1	89	228	45	202	98
117.17	80.6	92.4	340	40.7	156	94
117.24	78.8	70.9	730	37.5	138	90
107.58	80.3	69.8	483	39.2	164	87
107.8	83.6	70.1	622	41.4	171	76
Havener	89.1	63.8	726	41.9	149	67
Muir	80.3	82.0	216	41.3	153	101

**BA Targets refers to Brewers Association targets set for optimal malt quality for the craft brewing industry. These targets serve as a good benchmark to evaluate malt quality. Means comparisons using Tukey pairwise comparisons reported for treatment differences at $p \leq 0.05$.*

Table 6. Malt quality analysis for Montesano trials (2017) utilizing a modified steeping regime developed by variety (for steeping regime see Table Q.)

	Fine extract (% DB)	Friability (%)	B-Glucan (ppm)	S/T (%)	FAN (mg/L)	DP (°L.)
BA* Targets	>80.0	>85	<140	<45	<150	<150
Copeland	81.3	87.5	85	44.4	193	122
107.43	81.5	87.9	95	37.7	155	101
120.14	81.5	86.1	127	44.7	208	102
120.17	80.9	84.4	130	42.4	190	100

117.17	79.5	89.1	99	40.9	151	106

**BA Targets refers to Brewers Association targets set for optimal malt quality for the craft brewing industry. These targets serve as a good benchmark to evaluate malt quality. Means comparisons using Tukey pairwise comparisons reported for treatment differences at p≤0.05.*

Table 7. Malt Quality Analysis for 2017 Barley Trial

	All Malt Quality Score	Adjunct Score	Fine extract (% DB)	B-Glucan (ppm)	S/T (%)	FAN (mg/L)	DP (°L.)
11WA-107.43	42.0 a	44.7 ab	82.4 b	391.6 bc	53.4 cd	174.7 bc	82.5 ab
Muir	34.0 ab	44.3 a	80.0 e	126.5 d	54.9 bcd	182.0 b	91.2 a
12WA-120.14	33.3 ab	43.3 a	81.9 bc	288.3 c	63.4 a	220.5 a	64.9 bc
10WA-107.8	32.7 ab	44.3 a	82.3 b	660.6 a	54.2 bcd	158.1 cd	71.9 abc
10WA-117.17	30.7 b	38.0 b	80.5 de	462.1 b	55.4 bcd	151.9 cde	77.6 abc
12WA-120.17	30.0 b	44.0 a	81.1 cd	300.5 c	60.5 ab	193.3 b	78.8 bc
11WA-107.58	28.3 b	44.0 a	81.1 cd	406.8 bc	56.7 bc	186.9 b	66.8 bc
Havener	28.3 b	38.0 b	87.8 a	725.4 a	60.3 ab	148.5 de	58.5 c
10WA-117.24	26.0 b	31.0 b	79.7 e	700.6 a	49.0 d	129.4 e	78.8 ab

Means comparisons using Tukey pairwise comparisons reported for treatment differences at p≤0.05.

Table 8. Malt Quality Analysis for 2018 Barley Trial

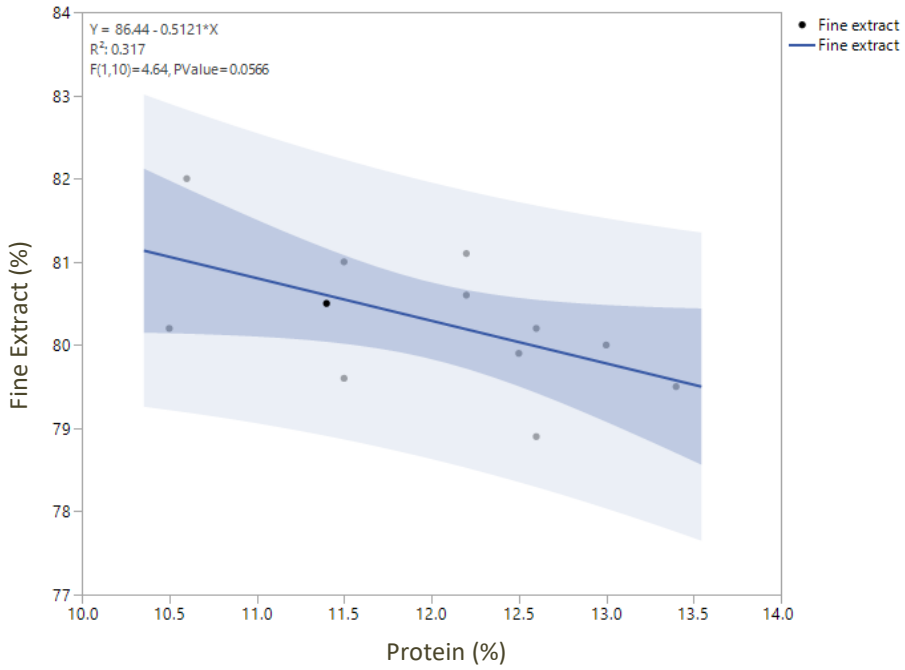
	Fine extract (% DB)	Friability (%)	Beta glucan (ppm)	Soluble protein (%)	S/T (%)	FAN (mg/L)	DP (°L.)	Alpha Amylase (D.U.)
Copeland	82.2 a	85.9 a	155.3 b	5.9 a	51.8 a	266.3 a	115.0 ab	71.3 a
12WA-120.14	80.4 ab	77.4 a	202.7 ab	5.7 a	45.6 b	257.7 a	123.3 ab	76.5 a
12WA-120.17	80.0 ab	82.9 a	133.3 b	5.7 a	46.1 b	260.3 a	130.7 a	73.5 a
10WA-117.17	79.6 b	82.7 a	254.7 a	4.4 b	38.4 c	172.3 b	104.7 b	57.2 b

Means comparisons using Tukey pairwise comparisons reported for treatment differences at p≤0.05.

Impact of protein on malt quality

Grain protein impacted grain quality as measured by fine extract, or alcohol yield potential of malting barleys. Fine extract generally declined as protein levels increased. Differences in grain protein level was likely a replication effect, as one of the replications exhibited higher protein levels generally than the other two replications.

Figure 8. Impact of Protein Levels on Malt Quality in 2018 Trials



Chemical Composition of Whiskies from Select Lines

Lines 120.14 and 107.43 diverged in terms of flavor compounds, with higher α-farnesene and β-bisabolene levels in 120 lines associated with woodiness, green "vegetativeness", floral, and herbal citrus aroma and flavor. Terpene levels were generally highest in 120 lines. Line 117.17 showed higher trans-2nonenal levels associated with 'cardboard' in beer, but which are potentially important flavor precursors in whiskey, indicating the potential need for different approaches in evaluating beer and whiskey varietals.

A summary of the key differences in volatile chemical composition are displayed in Figure 9, Figure 10, and Table 9. Breeding lines 107.58 and 107.8 were excluded due to being distilled on a separate system, causing an abnormal increase in variance in the data.

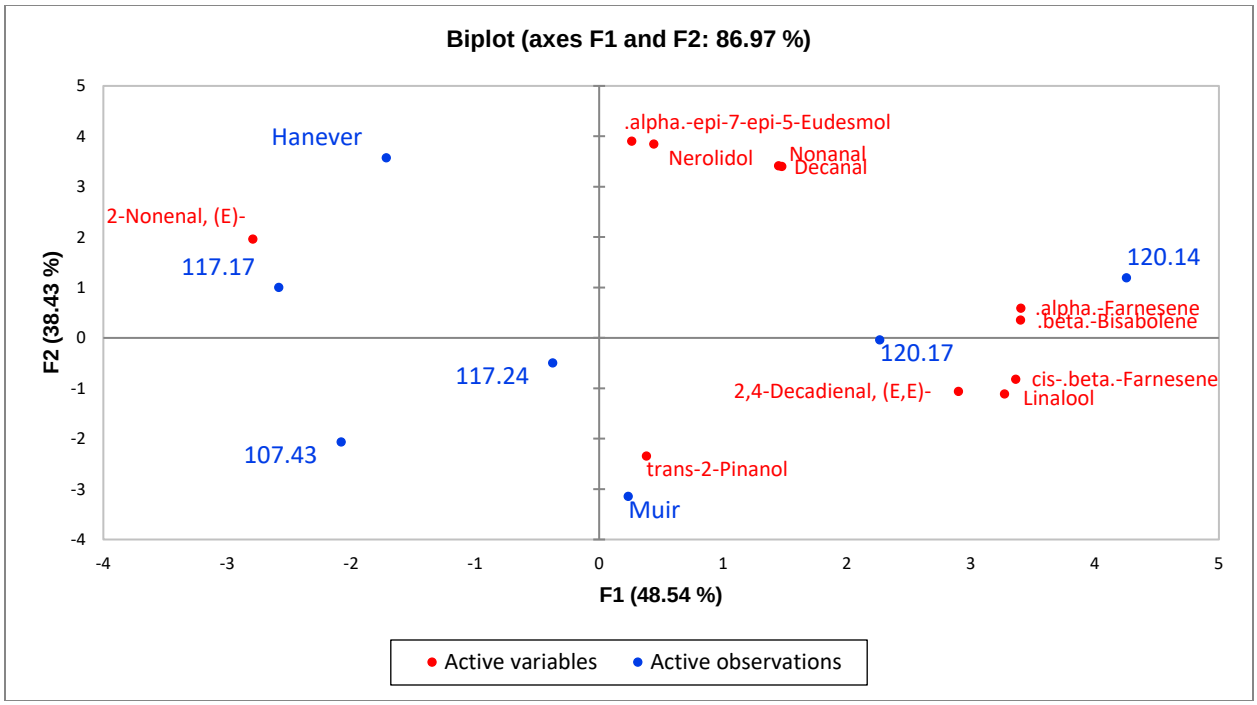


Figure 9. A biplot of volatile whiskey compounds from 2017 trial strains, measured by GC-MS. The amount of trans-2-nonenal and some terpenes appear to account for the majority of separation between breeding lines. The 120.xx strains were similar in volatile composition, as were the 117.xx strains, suggesting they perform similarly in a distillery setting.

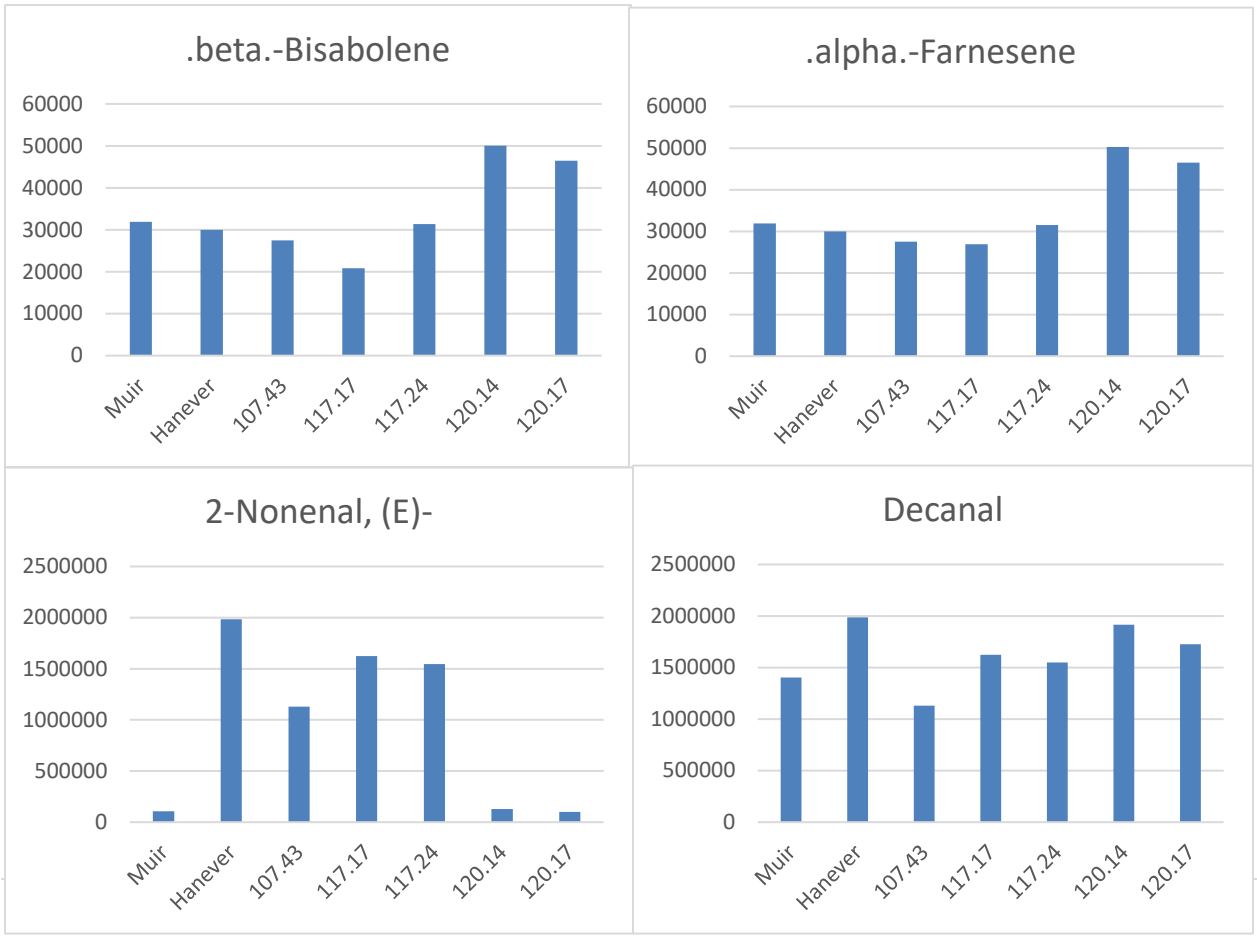


Figure 10. Difference in key volatiles in whiskies made from 2017 barley breeding trials. β-Bisabolene and α-farnesene represent prevalent terpenes which were elevated in 120.xx strains, and trans-2-nonenal and decanal represent oxidation products which were elevated in 117.xx strains.

Table 9. Summary of key volatile compounds from 2017 whiskey trials, as identified by NIST14 library lookup.

Compound	RT (min)	Parent Ion (m/z)
Linalool	4.1522	71
Nonanal	4.1802	57
Trans-2-nonenal	4.5997	70
Trans-2-pinanol	5.0235	43
Decanal	5.1687	57
2,4-Decadienal	5.9761	81
α-Farnesene	7.5130	69
β-Farnesene	7.7053	69
Nerolidol	9.6156	69
α-Eudesmol	10.148	59
β-Bisabolene	12.536	69

To investigate potential flavor precursors, unmalted barleys grown in both Pullman and Olympia were ground, steeped in hot water, and analyzed by LC-QToF-MS. Due to lack of supply, not all barleys grown at each location were analyzed, and the vast majority of variance was described by growing location. A discriminant analysis of the results, including 95% confidence intervals, can be found in Figure 11. A second discriminant analysis (Figure 12) was performed without taking location in to account, to see differences due to just the breeding lines. The 120 and 117 lines showed similar nonvolatile composition, and were significantly different from the 107 lines.

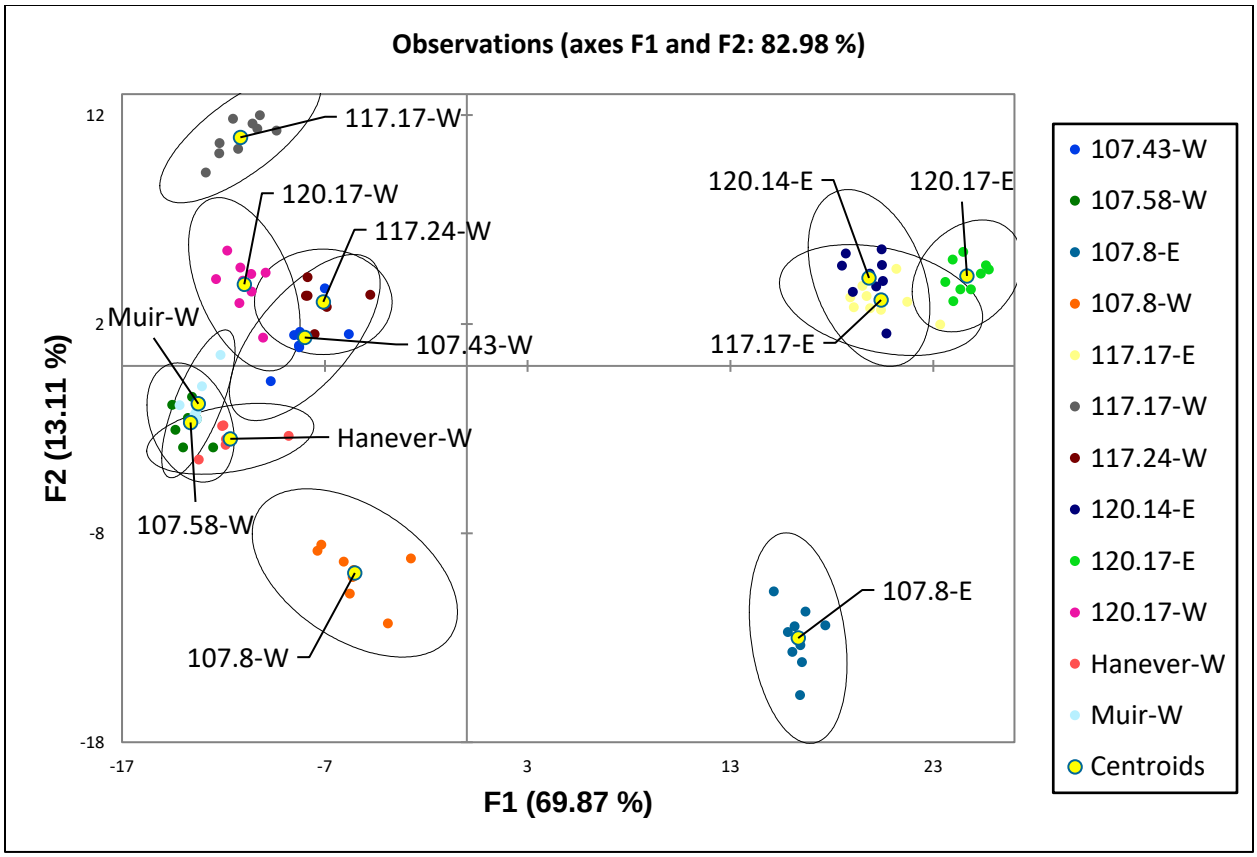


Figure 11. DA of LC-QToF data from unmalted barley steeps according to strain/location. Steeps and measurements were performed in triplicate. PC1 represents almost 70% of the variance in samples and indicates growing location (East vs West of the Cascades). Ellipses represent 95% confidence intervals about the centroid.

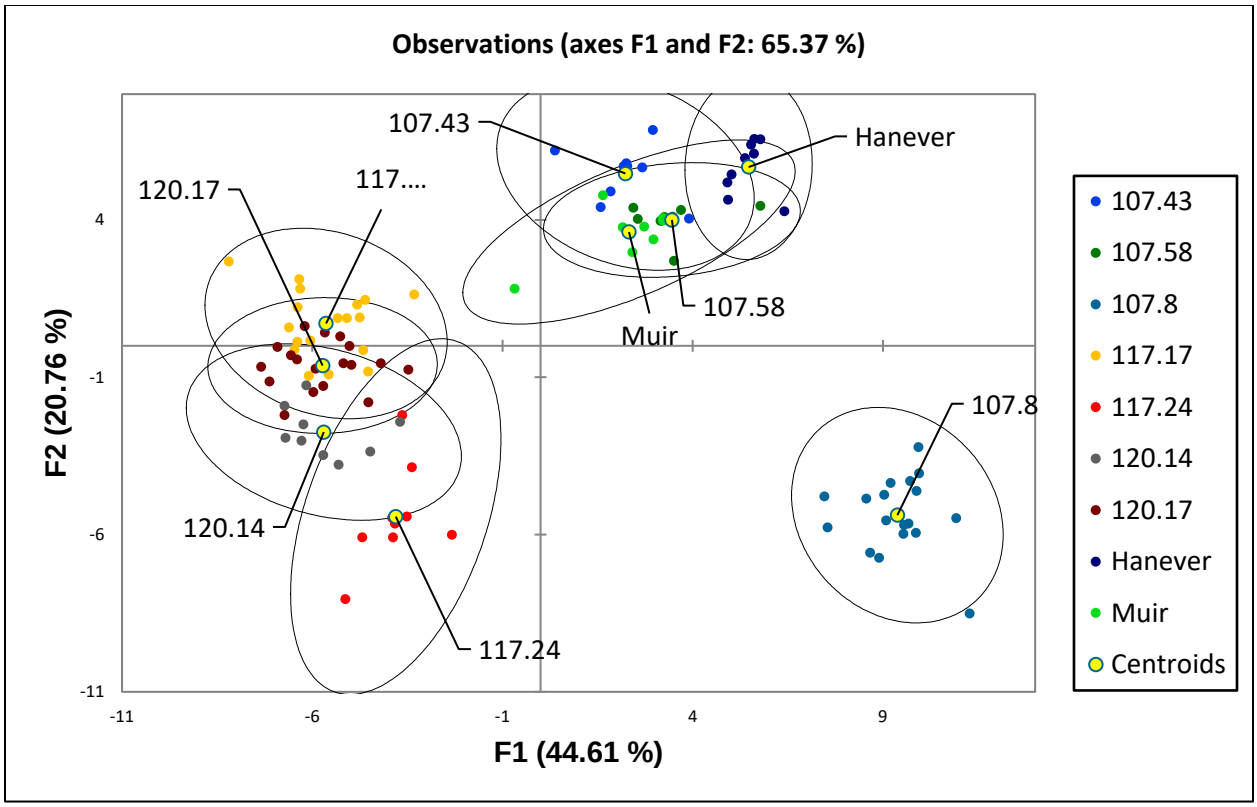


Figure 12. DA plot of LC-QToF data from barley hot water steeps according to strain. Steeps were performed in triplicate, as were measurements. Data from strains 107.8, 117.17, and 120.17 represent barley grown in both eastern and western Washington state. Ellipses represent 95% confidence intervals about the centroid.

Preliminary Evaluation of aromas of Whiskies from Select Lines (2017 harvest)

Informal preliminary evaluation of diluted and undiluted samples of fresh-make whiskies from the 2017 harvest found sufficient differences across the sample set to justify conducting a full descriptive analysis of the whiskies without first conducting a set of difference tests. The evaluators noted differences in fruity aromas, grassy/herbal/vegetal character and in acetaldehyde/ethyl acetate aromas that were large enough that a trained sensory panel would likely judge the samples to be significantly different. As with the chemical composition, 120.14 and 107.43 stood out as being notably different from the other samples. The 120.14 sample was described as more "floral", which aligns with the increased terpene content shown in the GC data. Other descriptors such as "cardboard", "green apple", and "grassy" were given, which also align with notable compounds found in the volatile profiling.

Beer Flavor of Select Lines

Due to limited supplies of malt from barley grown and harvested in 2017, a small-scale brewing regime was used to produce the beers for untrained panelist sensory evaluation via the consumer panel. Ideally, wort produced from each malt sample would have been separated following the boil and fermented in duplicate or triplicate. Following fermentation, difference testing of replicates within each treatment (i.e. barley varietal) would be completed to ensure that considerable variation was not produced during the fermentation process. Given the limitations of the raw material available for beer production, 3 gallon batches were fermented under homogenous fermentation conditions. Replicate fermentation was considered at this scale. However, this was avoided due to the risk of oxidation of the small liquid volume

during bench testing and subsequent combination of the replicates for sensory evaluation, which could have produced more variation from off-flavors created via oxidation. However, the primary attributes for some of the samples seem to indicate the presence of off-flavors, which may be an artifact of the small-scale, “home brew” style brewing process.

Figure 13. Beer samples shown in the sample presentation glasses with aroma caps. The three digit binding code for sample 120.14 is 705.

Sensory profiles for the beer samples support the conclusion of distinct sensory profiles. This may be a result of the influence of the barley varietal, an interaction between the barley varietal, hops and yeast, or off-flavors produced during fermentation as mentioned. Sensory profiles may drive the differences seen in overall liking, and liking based on aroma, appearance, taste/flavor, and sweetness. Sample 120.14 had significantly higher liking than the other samples, and was primarily characterized as having a “sweet aromatic” character. Sample 120.14 was also visibly darker than the other beer samples (Figure 13). This difference in color may have biased consumers to perceive more flavor in this sample, since the beers were evaluated under white light. Evaluation under red light would mask color differences, and perhaps provide a more unbiased evaluation. Futhermore, darker color is likely a result of darker malt color, potentially from a more extensive Maillard reaction contributing to the development of more complex flavor compounds.

The only significant difference among hot steep malt samples, based on hedonic liking scores, was found for appearance. The “sister lines” (120.14 and 120.17) were visibly darker than the other samples, which may be one reason why these samples were more preferred (Figure 14).

Check-all-apply-scores illustrate that the primary attributes selected for the samples reflect desirable attributes in base malt, or the type of malt that makes up the majority a beer recipe grain bill. These characteristics (grassy, grainy, honey) provide a strong malt backbone that complements the addition of specialty malts and hops. However, these results challenge the space given to “bready” on the base malt flavor map. During the development of the flavor map maltsters, brewers, and sensory scientist sampled a wide array of commercially available base malts and aggregated attribute data. The subcategories present for bready represent the strong presence of this attribute found in base malts. It’s possible that the sensory profiles of these malt samples are distinct from the majority of commercially available malts, and could provide novel flavors and aromas to the craft brewing industry. These results also indicate that

untrained panelists (i.e. consumers) may not be able to perceive and report more nuanced differences present in malt samples; hot steep malt may be an unfamiliar product

Figure 14. Hot steep malt samples shown in the sample presentation glasses with aroma caps. The three digit blinding codes 407 and 246 correspond to sample 120.14 and 120.17, respectively.

to consumers compared to maltsters and brewers, who regularly perform sensory as part of their business procedures.

Untrained Panelist Sensory Evaluation, Pullman, WA

Screening Questionnaire. Results of the screening test are reported as a percentage for panelists who qualified to participate in the sensory evaluation study (n = 95). On average, panelists had 1 child. Screening test results are not reported here.

Acceptance Test. The mean acceptance ratings for aroma, appearance, taste/flavor, sweetness, bitterness and overall likings along a 9-point scale for of Steep Malt are shown in Table 10**.** Differences at the p≤0.05 levels are indicated. In evaluation of Hot Steep Malt, panelists significantly liked sample 120.14 and sample 120.17 for appearance. There were no other significant differences across other attributes. The mean acceptance ratings for Beer are shown in Table 11**.** For evaluating aroma, sample 120.14 was liked the most and sample Copeland the least. Regarding appearance, taste/flavor, sweetness and overall liking, sample 120.14 was significantly different from sample Copeland. No significant differences were observed for bitterness across all samples.

Table 10. Mean hedonic scale values (9-point scale) for the sensory attribute of aroma, appearance, taste/flavor, sweetness, bitterness and overall liking of the hot steep malt. Each value is mean of 95 responses.

Attributes	107.43	117.17	120.14	120.17	Copeland
Aroma	5.13 a	5.09 a	5.13 a	5.08 a	4.97 a
Appearance	6.13 c	6.13 c	6.62 a	6.55 ab	6.25 bc
Taste/Flavor	5.79 a	5.79 a	5.83 a	5.85 a	5.89 a
Sweetness	5.92 a	5.92 a	5.79 a	6.03 a	6.09 a

Bitterness	5.61 a	5.40 a	5.37 a	5.71 a	5.55 a
Overall liking	5.71 a	5.61 a	5.74 a	5.85 a	5.83 a

Table 11. Mean hedonic scale values (9-point scale) for the sensory attribute of aroma, appearance, taste/flavor, sweetness, bitterness and overall liking of the beer. Each value is mean of 95 responses.

Attributes	107.43	117.17	120.14	120.17	Copeland
Aroma	6.61 ab	6.96 a	6.93 a	6.33 bc	5.89 c
Appearance	6.89 ab	6.91 ab	7.08 a	7.04 a	6.67 b
Taste/Flavor	6.02 ab	6.01 ab	6.31 a	6.24 a	5.53 b
Sweetness	5.85 ab	5.69 ab	6.06 a	5.82 ab	5.53 b
Bitterness	5.40 a	5.20 a	5.59 a	5.37 a	5.15 a
Overall liking	5.89 ab	5.68 ab	6.18 a	6.05 ab	5.52 b

Sensory Profiles. The check-all-that-apply scores for the hot steep malt samples are shown in Table 12. Overall, hot steep malt samples were primarily comprised of “Grainy”, “Grassy”, and “Honey”. The check-all-that-apply scores for the beer samples are shown in Table 13. “Citrus” and “yeasty” were the main attributes selected for sample 107.43. “Chemical” and “yeasty” were the main attributes selected for sample 117.17. “Sweet aromatic” and “yeasty” were the main attributes selected for sample 120.14. “Yeasty” and “chemical” were the main attributes selected for sample 120.17. “Earthy” and “Yeasty” were the main attributes selected for Copeland.

Table 12. Check All That Apply (CATA) scores for main attributes describing hot steep malt samples (n=95)

Attributes	107.43	117.17	120.14	120.17	Copeland
Bready	28.42%	33.68%	30.53%	32.63%	28.42%
Breakfast Cereal	37.89%	29.47%	37.89%	30.53%	31.58%
Earthy	42.11%	40.00%	31.58%	35.79%	34.74%
Floral	15.79%	20.00%	18.95%	26.32%	15.79%
Fruity	12.62%	13.68%	5.26%	15.79%	20.00%
Grainy	60.00%	60.00%	68.42%	57.89%	57.89%
Grassy	50.53%	55.79%	60.00%	52.63%	52.63%
Honey	46.32%	41.05%	41.05%	42.11%	49.47%
Nutty	23.16%	26.32%	25.26%	32.63%	32.63%
Stale	16.84%	22.11%	12.63%	17.89%	13.68%
Other	1.05%	2.11%	7.37%	2.11%	1.05%

Table 13. Check All That Apply (CATA) scores for main attributes describing beer samples (n=95)

Attributes	107.43	117.17	120.14	120.17	Copeland
Butter	11.58%	17.89%	14.74%	13.68%	7.37%
Cereal	27.37%	21.05%	31.58%	28.42%	26.32%
Chemical	28.42%	40.00%	22.11%	37.89%	32.63%
Citrus	36.84%	22.11%	21.05%	23.16%	24.21%
Earthy	21.05%	21.05%	26.32%	29.47%	42.11%
Floral	23.16%	28.42%	27.37%	24.21%	22.11%
Fruity	24.21%	27.37%	30.53%	16.84%	14.74%

Grassy	23.16%	20.00%	14.74%	17.98%	30.53%
Nutty	18.95%	12.63%	15.79%	15.79%	18.95%
Stale	13.68%	8.42%	11.58%	14.74%	22.11%
Sweet aromatic	22.11%	33.68%	41.05%	24.21%	16.84%
Yeasty	36.84%	34.74%	35.7%9	43.16%	34.74%
Other	3.16%	10.53%	6.32%	4.21%	8.42%

Brewer Evaluations

Malt from this project was distributed for full-scale evaluation by brewers in Olympia, Tumwater, and Lacey, WA, and Moscow, ID (Table 14). A standardized brewer feedback form (Appendix I) was used to obtain responses from cooperating breweries. Feedback form data from brewers is being collected at the time of final reporting. Three of five brewers have provided feedback forms which will be used to evaluate the potential for commercial release of one or more of the 2018 varieties.

Table 14. Research Malt Distributed to Local Breweries for Flavor Evaluation

Business	Quantity (50 lb bags)	Weight (lbs)	Notes
Packwood Brewing Co	4	200	One of each variety
Well 80	10	500	12WA-120.14
Well 80	8	400	12WA-120.14
Fishtale	4	200	Copeland
Three Magnets	20	1000	12WA-120.17
Three Magnets	22	1100	(12) 120.17, (10) Copeland
Singing Hops	4	200	(2) 120.17, (2) 120.14
Total	72	3,600	

DISCUSSION

Barley breeding lines suitable for release as craft brewing, malting and distilling varieties should:

- Exhibit traditional grain and malt quality performance such as high potential alcohol conversion (fine extract), low protein, and suitable (>90%) friability;
- Separate from industry malt in ways identified by craft brewers and distillers. Craft brewers have identified such desired differences as lower diastatic power, lower free amino (FAN) nitrogen, lower soluble to total protein levels (S/T) and;
- Demonstrate distinct end-use characteristics such as flavor compounds, which may or may not differ between the brewing and distilling communities.

Agronomic, Grain and Malt Quality

Four breeding lines (107.43, 120.14, 117.17, and 120.17) emerged as candidates for variety release for craft brewing and distilling. One line (107.43) was released in 2018 as Palmer. This variety consistently exhibited very good grain and malting quality parameters.

Lines 107.43 and 120.14 exhibited very good potential alcohol yield (fine extract), lower FAN sought by craft brewers, but somewhat higher total protein levels than 120.17 and 117.17. Line 107.43 had lowest S/T and diastatic power sought by the craft beverage industry. All four lines exhibited competitive yield potential, with 107.43 showing the somewhat lower yields among the group in the 2017 trial.

Steep Regime Considerations

The altered steep regime improved malt performance of water sensitive breeding lines, and facilitated the evaluation of steep regime impacts on grain malt quality.

CONCLUSIONS

Germplasm in the WSU barley breeding program did exhibit differences in malt and grain quality, as well as in flavor compounds. Evaluated lines exhibited sufficiently good performance in standard agronomic, malt and grain quality characteristics to warrant release of at least one new spring malting barley variety (107.43). Both 120.14 and 120.17 are being considered for release due to good performance in these areas, as well as very good reception among brewers who used the malt for the Tumwater Brewfest. Brewers were eager to buy more of the malt.

Lines evaluated specifically for craft brewing and distilling exhibited some separation from the industry standard in qualities sought by craft brewers and distillers. In this trial, these differences were limited to the soluble-total nitrogen ratio, with lower levels of soluble as related to total protein being of interest in the craft beverage industry.

Relatively fewer differences than would potentially be desired by craft brewers and distillers were observed in enzymatic activity (diastatic power and alpha amylase), free amino nitrogen, and soluble protein. Nevertheless, the breeding program was successful in establishing initial separation in craft brewing parameters, while maintaining critical performance in other agronomic, malt and grain quality parameters such as yield, fine extract, friability, and Beta glucan levels.

Most significantly, this project demonstrated enormous interest among the craft malting and distilling industries, as well as the general public. Locally produced, experimental malting barley varieties were met with initial skepticism among brewers, but eventually great enthusiasm. The general public indicated overwhelming interest at the sensory evaluation held at the Tumwater Brewfest in August 2019. The research team exceeded its minimum participant quota of eighty within three hours of the seven hour event, and met its maximum participant load of 160 two hours before the event was over. Additionally, well established craft distillers in Seattle, WA and elsewhere are eager to be involved in and support additional WSU varietal and flavor evaluation research that could supply the industry with regionally distinctive malt.

Brewers voiced their interest in locally produced malting barley by purchasing over 3,500 lbs of malt to experiment with, and had placed orders for more malting barley at the completion of the final report.

Regionally, this project touched a vein of interest among farmers and economic development partners. A grain grower and grain buyer survey conducted as part of this research helped secure funding of $800,000 for a grain storage facility at the Port of Chehalis, and established the foundation for potential Port investment in a malt receiving facility at the Craft District established by the City of Tumwater at the old Olympia Brewery site. If constructed, the facility would improve the chances of establishing lasting connections between the regions farmers, brewers, and distillers, and initially allow for approximately 30 tons annually of locally-grown malting barley to be sold into urban markets in Tumwater, Olympia and Lacey.

Future legislative budget allocations and other funding requests will be sought by regional development partners to build out large-scale (three to five 1,000 ton silos) grain storage in Lewis County. This would facility grain production of several thousand acres, and support local sales as well as regional sales to Great Western malting, Excel Feed and other accounts. Grain is of great interest among regional growers as a marketable crop itself, as well as it’s role in crop rotation such as with vegetable seed.

PUBLICATIONS, HANDOUTS, OTHER TEXT AND WEB PRODUCTS

- Tilth Producers Presentation. November 2019. upcoming
- National Association of County Agricultural Agents. Poster presentation, 2019 Conference, Fort Wayne, IN.
- State winner applied research. Poster presentation, Spring 2019 Washington Extension Agents and Specialists Association.
- BIOAg Symposium, Spring 2019Poster presentation.
- A field day hand-out developed for the Montesano (2017) event.
- A field day hand-out was developed for the Adna (2018) event.
- Thurston Talk Coverage:
    - The Thurston Economic Development Council Facilitates Growth in Our Region, and It's Not Just Beer. https://www.thurstontalk.com/2019/08/07/the-thurston-economic-development-council-facilitates-growth-in-our-region-and-its-not-just-beer/
    - WSU Extension Partners with Port of Olympia, Local Brewers, and Land Trust to Create Local Beer from Local Barley. https://www.thurstontalk.com/2019/08/06/wsu-extension-partners-with-port-of-olympia-local-brewers-and-land-trust-to-create-local-beer-from-local-barley/.
    - The Port of Olympia Partners with Local Agencies to Grow Local Grain for Craft Brewing and Distilling. https://www.thurstontalk.com/2019/08/02/the-port-of-olympia-partners-with-local-agencies-to-grow-local-grain-for-craft-brewing-and-distilling/.
    - Well 80 Artesian Brewing with Paul Knight to Brew Leopold Schmidt's First Lager. https://www.thurstontalk.com/2019/07/10/well-80-artesian-brewing-with-paul-knight-to-brew-leopold-schmidts-first-lager/
    - WSU Barley Breeding, Craft Malting, Brewing and Distilling Field Walk. http://www.thurstontalk.com/2017/08/11/wsu-barley-breeding-craft-malting-brewing-distilling-field-walk/
    -
- NPR Stories
    - Where's the Wheat; Farmers, Foodies Want to Bring Grain Back to the Westside. https://www.nwnewsnetwork.org/post/wheres-wheat-farmers-foodies-want-bring-grains-back-west-side
    - A 'farm-to-bottle' movement takes off in the Pacific Northwest. https://www.knkx.org/post/farm-bottle-movement-takes-pacific-northwest
- Other press coverage:
    - https://www.theolympian.com/living/food-drink/article233374067.html
    - http://www.washingtonbeerblog.com/history-and-innovation-tumwater-artesian-brewfest-on-august-17th/
    - https://olywip.org/how-the-people-of-thurston-county-support-local-food-local-farming-and-local-heritage/
    - https://brewdad.com/2019/07/10/3-magnets-brewing-summertime-sippin/
- Notice and coverage of the variety trials were featured in the July and August 2017, and May and July 2018 Thurston County Extension *Ag Sounder* Newsletter: https://extension.wsu.edu/thurston/agriculture/farming-news-resources/ag-sounder-newsletter/
- Project webpage: https://extension.wsu.edu/thurston/specialty-grain/.
- Related findings from grain infrastructure field trip to Port of Skagit partially funded by this project: https://s3.wp.wsu.edu/uploads/sites/2056/2018/10/Skagit-Tour-2018_Notes-1.pdf

- Grain grower survey funded in combined trials-infrastructure project ($10,500) by Port of Olympia for this project, and supported by WSU undergraduate internship funding: https://s3.wp.wsu.edu/uploads/sites/2056/2018/10/Grain-grower-survey-results-1.pdf
- Grain buyer survey funded in combined trials-infrastructure project ($10,500) by Port of Olympia for this project, and supported by WSU undergraduate internship funding: https://s3.wp.wsu.edu/uploads/sites/2056/2018/10/Grain-buyer-survey-results.pdf.
- Washington State University, Food Systems Team Cascadia Grains Conference. January 2019 presentation.

Outreach & Education Activities

- A field day was held July 18th, 2017 at Hidden River Farms and July 19th 2018 at Reisinger Farm, and was attended, respectively, by 25 and 20 farmers, brewers, distillers, agronomy professionals and students. Evaluations of the field day were collected:
    - In 2017, among 45 attendees and 23 evaluations, 78 percent reported moderate increase to greatly increased knowledge of topics (agronomic performance, brewing/distilling performance, opportunity to grow barley, opportunity to buy, using local barley for craft beverages) and 70 percent report they will use information from field day. The 2018 evaluations have not been analyzed.
- Trials and proposal for funding a grain handling facility presented to Port of Olympia Commissioners in 2017 and was funded ($10,500) in 2018.
- A successful proposal was presented to Thurston County in 2018 for Lodging Tax funds ($5,000) to host a community tasting evaluation of beer from Thurston County barley (event flyer below)
- Presentation to South Sound Community Farmland Trust. April 2019
- Untrained panelist sensory evaluation. Spring 2019
- Tumwater Brewfest. August 2019. 160 participants

IMPACTS

Short-term

Description	Metric	Complete
30 growers attend field days and are aware of opportunity to grow barley in western WA	25 20	x
10 local government decision-makers more aware of brewing/distilling using local grain	12 of 10	x
Growers have agronomic information about performance of available barley varieties	2017, 18 field days, 2019 summary	x
Growers and craft brewers, distillers have end-use data on available barley varieties	2018 field day hand-out	x
Research results used in ongoing grain mill feasibility study with local land trust	2018 survey work, WSU intern & Port Olympia and Port Chehalis	x
Farmer are interested in grain network, want to experiment with integrating grain-veg-livestock*	20+ farmers	In progress

- Local officials with increased knowledge:
- *This work dovetailed with 2018 survey work focused on establishing a grain network and grain handling facility in south Puget Sound. Over 20 grain farmers completed the survey, as well as 15 local grain buyers.

- A team of local food system representatives toured Port of Skagit grain handling facilities and businesses in July 2018. Visited The Bread Lab, Skagit Valley Malting, met with Port of Skagit executives, Cairnspring Mill, Skagit Valley Brewing Academy
- Established a non-binding Letter of Intent with two Ports, two EDCs, two Conservation Districts, WSU Thurston and Lewis Counties, Cities of Tumwater, Tenino, Chehalis, Olympia on "collaboration for planning and development of regional grain and food system infrastructure".
    - Facilitated a meeting of some 30 of these Letter signatories August 26th, 2019 at Centralia College to discuss coordinated regional development efforts, including for grain storage and handling facilities.
- Worked with Port of Chehalis on 2019 funding for grain storage facility planning and design project. Facilitated $800,000 Distressed County Funds allocation to Port of Chehalis.

Medium term

15 Local brewers/distillers/feed purchasers are provided research result publications	Working on summary for local circulation, 2019
Brew/distillate from local barley featured in three regional agri-tourism marketing materials.	Complete. Tumwater Artesian Brewfest
160+ community members attend events, increase awareness brewing/distilling with local grain	Complete. Tumwater Brewfest tasting event
Local craft brewing and distilling initiative in City of Tumwater uses information to promote development of Craft Brewing and Distilling Center	Complete. Materials social media for City Tumwater support on Brewfest event
Consumers are willing to pay a small premium for local craft beer, spirits	TBD. Data analysis yet to complete from Brewfest
One local distillery regularly sources organic barley	1 sources barley, no organic available
Local agri-tourism organizations (VCB) and jurisdictions (City of Tumwater) are interested in matching funds to support community sensory panel agri-tourism event	Compete. Thurston County matched, VCB in-kind support, Tumwater in-kind support

Long term

Ed material on organic barley for Craft Brewing-Distilling available through WSU	In progress
Integrating grain into crop rotation including in cultivating success advanced course	In progress
Small-scale (and large-scale) grain mill, handling is established for mixing feed, brokering sales	In progress at local Thurston farm, and Port of Chehalis
A local grain equipment cooperative is established to farms to integrate grain production	In progress
Barley is used in intensive vegetable crop rotation for feed and brewing-distilling to close nutrient loops, integrate crops-livestock, and break pest and disease cycles	Not at this time

A field trial is established to evaluate the impact of grain-vegetable crop rotation on specific pest and/or disease severity or population	Not at this time

ADDITIONAL FUNDING APPLIED FOR / SECURED

- Port of Olympia - $10,500
- Thurston County Lodging Tax - $5,000
- WSU Barley Breeding program (contribution) - $5,000
- Lewis County Distressed County funds for grain facility in Lewis County with Port of Chehalis - $800,000
- Legislative bid (unsuccessful) for 2019/2020 biennium for a large-scale grain storage facility at Port of Chehalis - $1.5 million. A supplemental budget request will be submitted by Northwest Agriculture Business Center (project partner) in 2020 for this grain handling facility

GRADUATE STUDENTS FUNDED

Graduate student at WSU Wine Science Center led whiskey compound analysis and sensory evaluation
Graduate student at WSU Sustainable Seed System lab organized sensory evaluation
WSU Undergraduate intern secured in 2018 for grower-buyer survey work – $2,500

RECOMMENDATIONS FOR FUTURE RESEARCH

Short-medium term project continuation:

Continued support of craft spirits industry

Several products from this research are yet to be analyzed:

- Year 2018 flavor compound analysis of unaged whiskey
- Year 2017 and 2018 flavor compound analysis of aged whiskey
- Sensory evaluation over multiple trial and aging years of aged and unaged whiskey

Additional variety grow-out and evaluation are possible harnessing infrastructure and relationships established for this project.

Support craft brewing industry in search for novel flavor attributes from malt

There are remaining products available for evaluation that could be analyzed, including compound analysis of

- Barley steeps (unmalted)
- Malted barley steeps
- WORT compound analysis
- Beer compound analysis

Malting barley variety trials

- Winter varieties are of particular interest to growers, interest among craft brewers
- Trials for high-volume production and sale to Great Western

Infrastructure for barley product, malting and malt storage in Southwestern, WA

- Large-scale grain storage is under consideration at Port of Chehalis, (3) 1,000 ton silos
- A proposal is submitted to Port of Olympia for malt receiving storage at Tumwater Craft District. Economic analysis is needed to determine feasibility of local product, contract malting, and local malt sales to craft brewers and distillers.
- Malting facility:
    - Small-scale research malting and malt storage facility in Southwestern, WA partnering with South Puget Sound Community College and the City of Tumwater Craft District. Collaborators include WSU Barley Breeding Program, County Extension, The Bread Lab, and the WSU Food Systems Team.

Coordinated malting barley research team

- A Westside Cropping Systems Team (networked with state-wide partners) has been established to combine research and extension personnel involved in Cascadia Grains Conference, The Bread Lab, County Extension, The Wine Science Center, craft beverage industry partners, malting industry partners, education partners (SPSCC and SVC), and farmer partners.
- With public partnerships at Ports, Counties and Cities
- Research priorities are under development to guide this Team

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