Identifying Spring Malting Barley Varieties for the Craft Brewing Industries
2017 Final Report

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Executive Summary

Funding from the Brewers Association in 2017 was used to support the evaluation of 25 barley varieties in the Eastern Spring Barley Nursery (ESBN) that was grown in eight states in the eastern US (MI, MA, NJ, OH, PA, NY, VT, and ME) and North Dakota. The overall goal of our work is to identify varieties developed outside the region that are adapted for local production.

Entries in the 2017 ESBN included 20 named varieties and five experimental lines from the North Dakota State University (NDSU) breeding program. The named varieties included two from Canada, five from the U.S., four from France, and eight from Germany. The experimental NDSU lines were selected because of their moderate resistance to pre-harvest sprouting (PHS) and improved resistance to Fusarium Head Blight (FHB). In general, the varieties from Europe show some promise because of their superior resistance to PHS as compared to the varieties developed in North America. Additionally, the yield of the varieties developed in Europe is competitive with the varieties developed in North America.

In general, the malt quality of the European varieties was superior to that of the six-rowed varieties and many of the North American varieties/lines. The European varieties typically had higher malt extract and friability, and lower wort ß-glucan levels.

Research on determining malt flavor attributes of selected varieties began in 2017 using the varieties AAC Synergy, Explorer, ND Genesis, Newdale, and Quest. The malt for evaluation was produced in Dr. Schwarz's lab and the malt flavor evaluation was overseen by Lindsay Barr, an employee of New Belgium Brewing. In this initial evaluation, we could not determine if one variety had a "better" or "unfavorable" flavor as compared to other varieties; however, growing location did appear to have an effect.

Based on results combined across 2015-2017, we believe discussions should start in summer 2018 to identify farmers, craft maltsters, and craft brewers that are interested in conducting evaluations of locally grown barley. Suggested varietal candidates for evaluation, based on two or more years of testing in ESBN trials, are Explorer, LCS Genie, LCS Odyssey, and KWS Beckie. These varieties each have greater PHS resistance and malt extract, and low wort ß-glucan levels. A weakness of these verities is their greater susceptibility to FHB and higher levels of mycotoxin accumulation. Additional research is needed to identify varieties/lines that have the competitive yield, greater PHS resistance, and lower ß-glucan similar to the European varieties and the higher levels of FHB resistance similar to the two-rowed variety and lines from NDSU.

Introduction
The craft malting and brewing industries across the US have an increased desire to use locally produced grains for making their products. The most widely used grain in brewing is barley, which is predominantly produced in Idaho, Montana, and North Dakota in the US; and Alberta, Manitoba, and Saskatchewan in Canada. Each of these areas has large barley-breeding programs developing varieties adapted to their specific growing regions, which are quite different from those in the eastern US. Cornell University, Ohio State University, and Virginia Tech are the only programs specifically developing barley for the eastern US; however, most of their efforts are on winter barley.

Barley used for malting and brewing must meet specific requirements on nearly 20 different end-use quality traits. Barley grown outside of its area of adaptation often fails to meet the specifications needed for malting and brewing, which include grain free of pre-harvest sprouting, grain protein less than 12%, plump kernels > 80%, and germination ≥ 95%. Additionally, unadapted varieties often have lower yields and are susceptible to local diseases that are not present in the area where they were developed.

Funding from the Brewers Association in 2017 was used to support the evaluation of 25 barley varieties in the Eastern Spring Barley Nursery (ESBN) that was grown in eight states in the eastern US (MI, MA, NJ, OH, PA, NY, VT, and ME) and North Dakota (Table 1). Researchers at Rutgers University grew the trial using their own funds to support their work. The overall goal of our work is to identify varieties developed outside the region that are adapted for local production. The work to be done, including research sites, is described below.

The ESBN trial was sown and managed locally by a university or extension person with experience conducting research on small grains. Data collected included days to heading, plant height, foliar diseases, lodging, and yield. Following harvest, a sample of each entry from each location was sent to NDSU where kernel plumpness, grain protein, test weight, pre-harvest sprouting (PHS), and deoxynivalenol (DON) content were determined. Grain from trials at Chatham, MI, Hickory Corners, MI, University Park, PA, and Orono, ME were malted at NDSU. Data collected were malt extract, wort color, wort protein, Kolbach Index, wort ß-glucan, diastatic power, α-amylase activity, and free amino nitrogen concentration.

All data from the trial were compiled into a final report that could be used by local university/extension personnel to educate their growers and other stakeholders on which varieties perform best in their region. The data also can be used by barley breeding programs to identify other varieties or advanced breeding lines that may be candidates for production in the region.
Results
Results from individual locations are available upon request. Results presented in this report include the means for agronomic performance, and barley and malt quality averaged across locations; and best linear unbiased predictors (BLUPs) across locations and years for ESBN entries that have been tested for a minimum of two years. An explanation of BLUPs will explained later in this report.

2017 Agronomic Performance, and Barley and Malt Quality

Entries in the 2017 ESBN included 20 named varieties and five experimental lines from the NDSU breeding program. The named varieties included two from Canada, five from the U.S., four from France, and eight from Germany. The experimental NDSU lines were selected because of their moderate resistance to pre-harvest sprouting (PHS). Mean agronomic performance across locations is presented in Table 2. In general, the varieties from Europe show some promise because of their superior resistance to PHS as compared to the two-rowed Canadian varieties AAC Synergy and Newdale; and the two-rowed NDSU varieties Conlon, Pinnacle, and ND Genesis. In general, the yield of the varieties developed in Europe varieties is competitive with the varieties developed in North America. The experimental lines 2ND33757 and 2ND33760 had yields comparable to AAC Synergy and ND Genesis.

Mean barley quality of the entries averaged across environments is presented in Table 3. As in previous years, a wide variation in resistance to PHS resistance was observed. Damage due to PHS is determined using the stirring number obtained from the Rapid Viscoanalyzer (RVA). Stirring number values less than 120 indicate that there is damage due to PHS. Resistance to PHS is going to be a major criterion on deciding which varieties to recommend for planting in the eastern U.S. Varieties with the best PHS resistance included the European varieties LCS Genie, KWS Fantex, Manta, and Acorn; and the six-rowed varieties Tradition and Quest. The varieties showing the most damage due to PHS included AAC Synergy, Conlon, ND Genesis, KWS Tinka, Bettina, and Newdale.

Mean malt quality of the entries averaged across environments is presented in Table 4. In general, the malt quality of the European varieties was superior to that of the six-rowed varieties and the NDSU varieties and experimental lines. The European varieties typically had higher malt extract and friability, and lower wort ß-glucan levels. Varieties showing promising malt quality included Sangria, Esma, and Bettina. However, Esma and Bettina also had greater damage to the barley due to PHS.

Malt Flavor Evaluation

Research on determining malt flavor attributes of selected varieties began in 2017 using the varieties AAC Synergy, Explorer, ND Genesis, Newdale, and Quest (Table 5). The samples were obtained from trials grown in Orono, ME in 2015-2017 and the Kellogg Biological Station (KBS) in Hickory Corners, MI in 2017. The goals of this initial malt flavor evaluation was done to determine: 1) if there were flavor differences between varieties grown at the same location and 2) if there were flavor differences for the same variety grown at different environments. The malt for evaluation was produced in Dr. Schwarz's lab and the malt flavor evaluation was overseen by Lindsay Barr, an employee of New Belgium Brewing. Flavor samples were prepared using the ASBC Hot Steep Method and evaluated on an individual basis using the *DraughtLab Malt Sensory Software* program. Results from this initial evaluation should be considered preliminary and much more data are needed to draw more solid conclusions. In this initial evaluation, there did not appear to be consistent flavor profiles for individual varieties. We could not determine if one variety had a "better" or "unfavorable" flavor as compared to other varieties. Within the three years of testing using samples from Maine, there appeared to be

a year effect on flavor. In 2017, we evaluated samples from Maine and Michigan. There appeared to be differences in flavor between the two locations

Combined Results from 2015-2017

Now that we have three years of data from the ESBN (2015-2017), we can begin to draw preliminary conclusions on varieties that may be adapted for production in the east. An analysis was conducted across years using varieties that were grown in at least two years. There were 24 varieties that met this criteria; seven from Canada, four from NDSU, two from Busch Ag Resources, three from the University of Minnesota, and eight from Europe. Because of the unbalanced nature of the data (i.e. not all varieties being grown together in all years) analysis of variance was conducted using a mixed model that allowed for calculation of the values presented in Tables 6 and 8. These predictive values, which are called (BLUPs) are routinely used by private breeding companies.

To help in visualizing the varieties that had similar agronomic performance or quality, hierarchical cluster analysis was performed and the results are presented as constellation plots (Figures 1 and 2). Additionally, the means across lines within each cluster were calculated (Tables 7 and 9). Distinguishing traits related to agronomic performance that differentiated varieties into clusters included heading date, plant height, yield, and stirring number (Figure 1 and Table 7). Cluster four was comprised of all eight European varieties, Cerveza, and Newdale. The European varieties in this cluster tended to have later heading dates, shorter height, moderate yields, and high stirring numbers. Cerveza and Newdale fall into a subcluster with Cluster 4. These two varieties were similar to the European varieties except in height and stirring number. Cerveza and Newdale were taller and had lower stirring numbers than the European varieties. Distinguishing traits related to barley and malt quality that differentiated varieties into clusters included S/T and wort ß-glucan content (Figure 2 and Table 9). All European varieties and AAC Synergy were in cluster two. The varieties in this cluster had moderate S/T and low wort ß-glucan values.

Recommendation for Plant Scale Evaluation of Selected Varieties in 2019 or 2020.

Discussions should start in summer 2018 to identify farmers, craft maltsters, and craft brewers that are interested in conducting evaluations of locally grown barley. Varietal candidates for evaluation, based on two or more years of testing in ESBN trials, are Explorer, LCS Genie, LCS Odyssey, and KWS Beckie. These varieties each have high stirring number values and malt extract, and low wort ß-glucan levels. We need to determine demand so we can obtain the needed seed for planting.

Table 1. Variety/lines evaluated in the 2017 Eastern Spring Barley Nursery.

Entry	Entry name	Row type	Origin	Years tested previously
1	AAC Synergy	2-row	Agriculture and Agri-Food Canada (Brandon)	2
2	Newdale	2-row	Agriculture and Agri-Food Canada (Brandon)	2
3	Conlon	2-row	North Dakota State University	2
4	ND Genesis	2-row	North Dakota State University	2
5	Pinnacle	2-row	North Dakota State University	2
6	Tradition	6-row	Busch Agricultural Resources, LLC	2
7	Quest	6-row	University of Minnesota	2
8	LCS Genie	2-row	Limagrain Cereal Seeds (France)	1
9	LCS Odyssey	2-row	Limagrain Cereal Seeds (France)	1
10	2ND28065	2-row	North Dakota State University	1
11	Sirish	2-row	Syngenta	1
12	Explorer	2-row	Secobra (France)	1
13	Acorn	2-row	Ackermann (Germany)	1
14	KWS Fantex	2-row	KWS (Germany)	1
15	KWS Beckie	2-row	KWS (Germany)	1
16	Manta	2-row	Ackermann (Germany)	0
17	Sangria	2-row	Ackermann (Germany)	0
18	Esma	2-row	Ackermann (Germany)	0
19	KWS Tinka	2-row	KWS (Germany)	0
20	KWS Josie	2-row	KWS (Germany)	0
21	Bettina	2-row	Secobra (France)	0
22	2ND33710	2-row	North Dakota State University	0
23	2ND33757	2-row	North Dakota State University	0
24	2ND33760	2-row	North Dakota State University	0
25	2ND33821	2-row	North Dakota State University	0

Table 2. Means agronomic performance across environments for entries grown in the 2017 ESBN.

Entry	Variety	Heading date (days to 5/31)	Height (cm)	Foliar disease (1-9†)	Lodging (1-9)	Stem breakage (1-5‡)	Yield (bu/ac)	Moisture (%)
Number of locations		13	13	12	9	5	15	12
1	AAC Synergy	25.3	70.8	2.7	1.6	2.1	70.7	12.8
2	Newdale	26.4	67.6	2.9	2.1	2.4	65.8	12.5
3	Conlon	21.2	67.4	3.6	3.9	3.9	59.2	12.5
4	ND Genesis	23.3	70.5	2.8	1.6	2.2	68.6	12.9
5	Pinnacle	23.1	65.1	6.5	5.1	4.1	44.7	12.9
6	Tradition	22.6	68.3	3.8	2.6	2.5	59.3	12.6
7	Quest	22.2	72.5	4.0	2.8	3.0	64.2	12.4
8	LCS Genie	28.1	62.6	3.5	2.6	2.4	55.7	13.0
9	LCS Odyssey	28.2	61.4	3.9	3.7	2.5	58.2	12.6
10	2ND28065	23.1	68.8	3.8	2.6	3.5	63.7	13.1
11	Sirish	26.6	60.5	3.4	3.4	2.8	62.2	12.3
12	Explorer	25.1	59.6	3.0	2.8	2.4	68.3	12.7
13	Acorn	27.7	63.2	2.8	3.0	3.5	65.8	12.5
14	KWS Fantex	26.1	58.3	2.9	3.0	3.2	69.4	12.5
15	KWS Beckie	26.7	56.4	3.8	2.6	2.6	63.4	12.3
16	Manta	25.7	62.3	3.6	2.1	2.0	65.7	12.9
17	Sangria	25.0	62.3	3.3	2.5	2.4	69.0	12.9
18	Esma	24.7	62.2	2.7	2.3	2.5	74.3	12.7
19	KWS Tinka	25.5	66.2	2.6	1.9	2.3	71.4	13.0
20	KWS Josie	26.0	59.6	3.2	2.9	2.9	67.4	12.6
21	Bettina	26.2	66.7	3.2	3.6	3.1	58.5	13.1
22	2ND33710	22.1	68.5	3.7	3.1	3.0	60.4	13.0
23	2ND33757	24.4	69.4	4.0	2.3	3.3	67.1	13.1
24	2ND33760	23.0	70.1	3.7	1.8	3.2	69.1	12.7
25	2ND33821	21.0	69.7	3.6	2.6	2.4	60.5	13.4

†A 1-9 scale was used to rate general resistance to foliar diseases and resistance to lodging. Scores of 1 = no disease or lodging and a score of 9 = severe disease or lodging.
‡A 1-5 scale was used to rate resistance to stem breakage prior to harvest. A score of 1 = no stem breakage and a score of 5 = severe stem breakage.

Table 3. Mean barley quality across environments for entries grown in the 2017 ESBN.

Entry	Variety	Test weight (lbs/bu)	Barley DON (ppm)	Barley protein (%)	Plump kernels (%)	Thin kernels (%)	Barley color (L)	Stirring number (SN†)	Germinative energy (%)
Number of locations		12	12	12	12	12	12	8	10
1	AAC Synergy	47.1	0.6	11.0	91.6	1.1	50.3	51	88
2	Newdale	46.7	0.4	11.4	80.2	3.1	50.3	83	91
3	Conlon	48.4	0.7	11.7	94.1	0.7	50.4	74	88
4	ND Genesis	47.7	0.8	10.5	91.8	0.8	49.9	74	85
5	Pinnacle	45.8	0.4	11.1	81.3	2.9	49.6	115	81
6	Tradition	47.0	0.6	12.0	82.7	1.7	50.7	119	87
7	Quest	47.8	0.4	12.0	81.9	1.9	50.1	135	83
8	LCS Genie	47.1	0.6	11.8	88.5	1.6	49.4	135	83
9	LCS Odyssey	44.5	0.3	10.6	87.1	1.5	49.4	109	79
10	2ND28065	48.3	0.3	11.0	81.3	3.0	50.3	104	87
11	Sirish	46.3	0.5	11.0	89.4	1.0	50.0	112	86
12	Explorer	47.0	0.5	11.0	88.6	1.4	49.5	105	83
13	Acorn	45.8	0.4	10.9	90.1	1.1	49.8	120	77
14	KWS Fantex	46.2	0.3	10.6	88.4	1.6	49.6	127	85
15	KWS Beckie	44.2	0.3	10.7	87.5	1.4	49.2	113	85
16	Manta	47.5	0.6	11.2	85.8	1.5	49.2	128	84
17	Sangria	47.4	0.5	10.8	88.1	1.2	49.2	102	82
18	Esma	47.4	0.3	10.8	88.3	1.3	49.5	85	83
19	KWS Tinka	46.0	0.8	11.2	90.3	1.1	49.5	67	81
20	KWS Josie	46.6	0.2	10.9	87.1	1.9	49.3	107	86
21	Bettina	46.7	0.3	10.8	86.8	1.7	49.6	75	84
22	2ND33710	48.1	0.2	11.2	83.4	2.8	50.2	110	87
23	2ND33757	48.2	0.5	10.6	83.4	2.7	50.3	98	94
24	2ND33760	47.8	0.5	10.9	84.1	2.5	50.5	96	91
25	2ND33821	46.5	0.6	10.6	92.6	1.0	50.7	76	80

†Stirring number (SN) was determined using a Rapid Viscoanalyzer (RVA). SN values < 120 are indicative of samples that have damage from pre-harvest sprouting. The lower the number the greater the damage.

Table 4. Mean malt quality across environments for entries grown in the 2017 ESBN.

Variety	Extract (%)	Friability (%)	Wort protein (%)	S/T (%)	Wort color	DP (°ASBC)	Alpha-amylase (20° DU)	Wort ß-glucan (ppm)	Wort viscosity (mPa.s)	FAN (ppm)
# Locations	5	5	5	5	5	5	5	5	5	5
AAC Synergy	82.6	88.1	5.64	57.0	2.9	103	85.8	154	1.44	253
Newdale	81.3	83.0	5.69	55.5	2.8	113	85.7	196	1.43	243
Conlon	81.8	74.6	4.94	46.6	2.3	106	75.3	386	1.49	216
ND Genesis	83.0	85.3	4.99	52.1	2.7	85	69.4	296	1.48	215
Pinnacle	80.7	73.3	4.89	48.1	2.4	92	63.2	370	1.51	204
Tradition	80.7	77.7	4.87	45.7	2.1	133	61.3	365	1.52	213
Quest	81.2	81.9	5.31	48.8	2.3	121	67.2	335	1.48	240
LCS Genie	82.7	85.4	5.58	54.1	2.9	117	66.7	161	1.47	245
LCS Odyssey	82.8	90.0	5.13	55.8	3.0	90	75.9	148	1.44	222
2ND28065	82.1	82.7	5.18	52.8	2.2	91	65.2	238	1.47	216
Sirish	82.0	90.7	5.19	54.1	2.6	97	69.0	102	1.42	233
Explorer	81.7	94.3	4.86	51.5	2.6	93	76.6	52	1.43	222
Acorn	83.2	88.7	4.85	50.8	2.6	91	68.5	172	1.46	211
KWS Fantex	83.2	89.8	4.96	53.7	2.9	91	66.7	200	1.49	219
KWS Beckie	82.5	90.0	4.89	52.1	2.8	92	63.3	140	1.44	210
Manta	82.8	86.0	4.82	50.0	2.6	91	64.2	153	1.47	214
Sangria	82.6	92.5	5.09	53.8	2.8	98	62.9	81	1.45	231
Esma	83.1	95.8	5.11	55.8	2.8	95	67.5	53	1.42	229
KWS Tinka	82.5	86.7	5.40	55.5	3.2	90	66.0	198	1.46	239
KWS Josie	81.9	86.5	4.77	48.7	2.5	90	66.9	189	1.45	204
Bettina	82.3	93.1	5.41	55.7	3.1	99	74.3	82	1.47	228
2ND33710	82.7	81.5	5.03	50.2	2.2	103	65.3	209	1.45	207
2ND33757	82.4	82.4	5.12	52.7	2.5	89	66.4	166	1.47	219
2ND33760	83.1	83.1	5.37	54.5	2.5	96	67.1	205	1.46	226
2ND33821	82.1	77.4	4.76	49.4	2.4	76	57.3	352	1.54	203

Table 5. Barley varieties and location from where grain was obtained for malt flavor evaluation.

Environment	AAC Synergy	Explorer	ND Genesis	Newdale	Quest
2015 Maine	X		X	X	X
2016 Maine	X			X	X
2017 Maine	X		X	X	X
2017 KBS	X	X	X	X	X

Table 6. Best linear unbiased predictors for agronomic performance and barley quality for ESBN entries tested in two or more years, 2015-2017.

Variety	Heading date (days after 5/31)	Height (cm)	Lodging (1-9†)	Foliar disease (1-9)	Stem breakage (1-5)	Yield (bu/ac)	Moisture (%)	Test weight (lb/bu)	Protein (%)	Stirring number (SN‡)	DON (ppm)
2ND28065	23.0	69.8	1.8	4.5	2.3	64.8	14.0	48.6	10.9	106.3	0.5
AAC Synergy	26.1	70.0	1.6	3.3	1.7	68.3	14.0	47.4	11.0	60.1	0.6
AC Metcalfe	26.3	70.7	2.2	4.1	2.2	57.6	14.0	47.2	11.8	69.5	0.5
Acorn	28.6	63.3	2.3	4.1	2.4	64.0	13.9	46.5	10.8	126.1	0.5
Bentley	26.1	71.3	2.1	4.0	2.3	61.4	14.0	46.6	11.3	87.4	0.6
CDC Copeland	28.2	69.3	2.5	4.7	2.4	53.5	13.9	45.9	11.2	77.4	0.5
CDC Meredith	28.1	64.6	2.7	3.9	2.5	55.2	14.0	45.7	11.2	64.4	0.5
Cerveza	27.2	62.6	1.9	3.6	1.9	64.8	13.9	46.3	10.9	57.3	0.5
Conlon	21.2	66.2	2.6	4.2	2.6	56.9	13.9	48.3	11.8	81.8	0.5
Explorer	25.9	59.6	2.0	3.9	1.9	66.2	14.0	47.3	11.0	113.5	0.5
Innovation	20.6	66.5	1.7	4.6	2.1	60.6	13.9	47.1	12.1	96.1	0.5
KWS Beckie	27.7	55.7	1.8	4.3	1.9	64.5	13.9	45.5	10.8	128.6	0.5
KWS Fantex	27.1	56.9	2.1	4.0	2.2	68.2	13.9	46.3	10.8	130.6	0.5
Lacey	20.8	69.4	1.9	4.6	1.9	63.7	14.0	47.8	11.9	108.0	0.5
LCS Genie	28.6	62.0	1.9	4.3	1.8	58.6	14.0	47.5	11.4	137.9	0.5
LCS Odyssey	28.8	61.3	2.5	4.3	2.2	61.6	14.0	46.1	10.6	121.1	0.5
ND Genesis	23.8	70.2	1.4	3.7	1.7	65.0	14.0	47.5	10.4	83.8	0.6
Newdale	27.7	64.3	1.6	3.6	1.7	63.2	13.9	46.9	11.3	83.0	0.5
Pinnacle	23.1	66.9	3.0	6.0	2.9	52.2	14.0	46.9	10.7	122.2	0.6
Pioneer	28.1	59.6	1.9	4.2	2.0	61.0	13.9	47.2	11.0	123.2	0.5
Quest	21.8	73.3	2.1	4.4	2.6	63.3	13.9	47.4	11.8	135.4	0.5
Robust	21.7	73.7	2.0	5.6	2.3	60.6	13.9	47.4	12.2	128.6	0.5
Sirish	27.6	60.3	2.2	4.1	2.1	64.4	13.9	47.1	11.1	124.7	0.5
Tradition	21.9	68.2	1.8	4.5	1.9	61.7	13.9	47.3	11.9	129.8	0.5

†Low scores for lodging, foliar disease, and stem breakage are desired.
‡Stirring numbers <120 indicate there is damage to the kernel due to pre-harvest spouting.
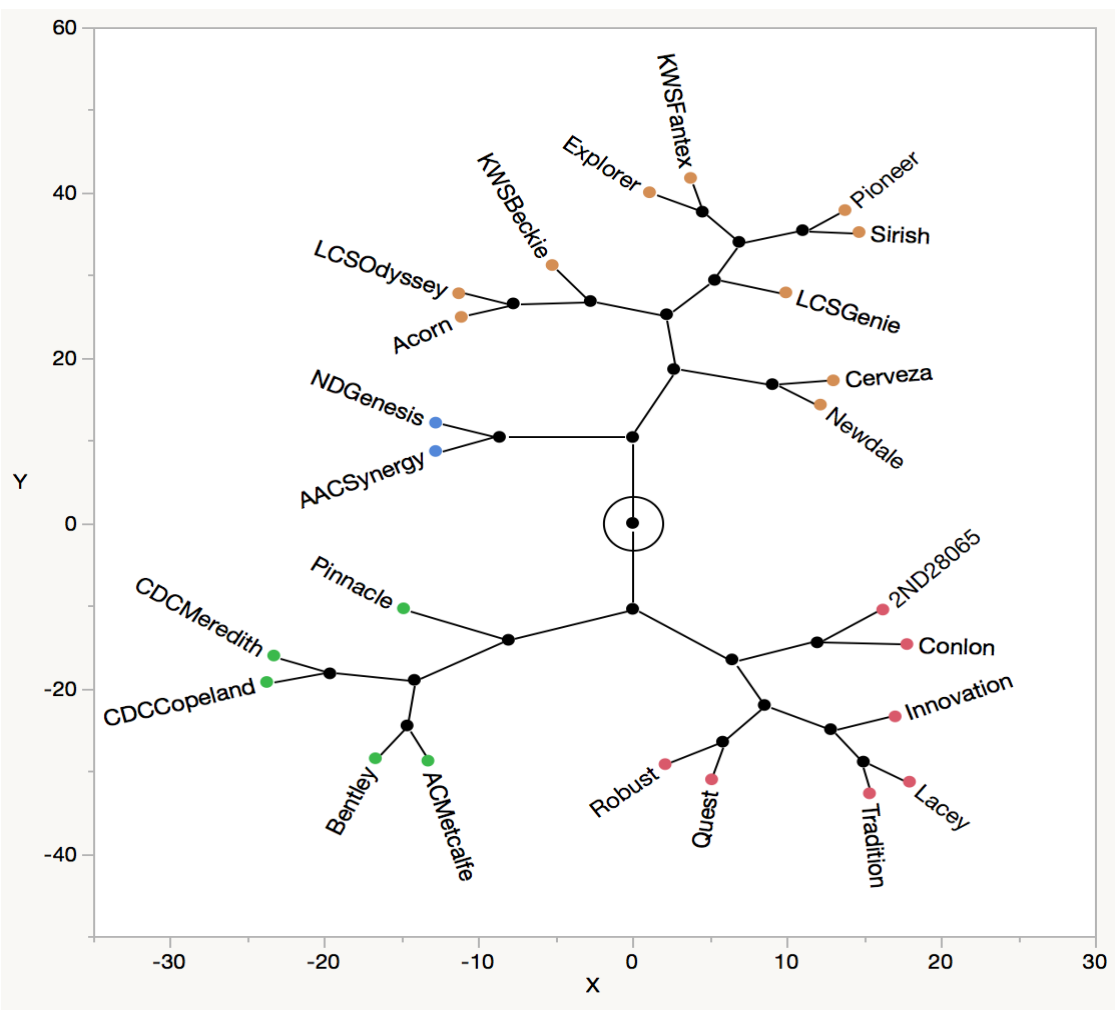
Figure 1. Constellation plot from the hierarchical clustering of agronomic and barley quality data obtained from barley lines evaluated for two or more years in the Eastern Spring Barley Nursery (2015-2017). The Ward method was used for the cluster analysis. Four clusters were identified and lines falling within a similar cluster are the same color. Cluster 1 begins in the bottom right hand corners and the numbering of clusters proceeds counter clockwise. Cluster 1 = 2ND28065, Conlon, Innovation, Lacey, Tradition, Quest, and Robust; Cluster 2 = AC Metcalfe, Bentley, CDC Copeland, and CDC Meredith; Cluster 3 = AAC Synergy and ND Genesis; and Cluster 4 = Acorn, LCS Odyssey, KWS Beckie, Explorer, KWS Fantex, Pioneer, Sirish, LCS Genie, Cerveza, and Newdale.

Table 7. Mean agronomic performance and barley quality across barley lines within a cluster†.

Cluster‡	Count	Heading date (days after 5/31)		Height (cm)		Lodging (1-9)¶		Foliar disease (1-9)		Stem breakage (1-5)		Yield (bu/ac)		Moisture (%)		Test weight (lb/bu)		Protein (%)		Stirring number SN§		DON (ppm)	
1	7	21.6	b††	69.6	a	2.0	ab	4.6	a	2.2	a	61.7	b	13.9	a	47.7	a	11.8	a	112	a	0.53	a
2	5	26.4	a	68.6	a	2.5	a	4.5	a	2.5	a	56.0	c	14.0	a	46.5	a	11.3	ab	84	b	0.55	a
3	2	24.9	a	70.1	a	1.5	b	3.5	b	1.7	a	66.6	a	14.0	a	47.5	a	10.7	b	72	b	0.60	a
4	10	27.7	a	60.6	b	2.0	ab	4.0	ab	2.0	a	63.6	ab	13.9	a	46.7	a	11.0	ab	115	a	0.52	a

† Hierarchical clustering of barley lines evaluated for two or more years in the Eastern Spring Barley Nursery was done using the Ward method.
‡Cluster 1 =2 ND28065, Conlon, Innovation, Lacey, Tradition, Quest, and Robust; Cluster 2 = AC Metcalfe, Bentley, CDC Copeland, and CDC Meredith; Cluster 3 = AAC Synergy and ND Genesis; and Cluster 4 = Acorn, LCS Odyssey, KWS Beckie, Explorer, KWS Fantex, Pioneer, Sirish, LCS Genie, Cerveza, and Newdale.
¶Scores of 1 for lodging or foliar disease score = no lodging or disease, and scores of 9 = severe lodging or disease. Score of 1 for stem breakage = no stem breakage at harvest and 5 = severe stem breakage at harvest.
§Stirring numbers (SN) <120 indicate there is damage to the kernel due to pre-harvest spouting.
††Means within a column followed by the same letter are not significantly different at $P \leq 0.05$.

Table 8. Best linear unbiased predictors for malt quality for ESBN entries tested in two or more years, 2015-2017.

| Variety	Plump kernels	Barley protein	Extract	Friability	Wort protein	S/T	Wort color	DP	Alpha-amylase	Wort ß-glucan	FAN	Wort Viscosity
	(%)	(%)	(%)	(%)	(%)	(%)		(°ASBC)	(20° DU)	(ppm)	(ppm)	(mPa.s)
2ND28065	88.3	10.4	81.7	78.9	5.25	50.9	2.3	92	67.7	303	220	1.50
AAC Synergy	93.8	10.4	82.0	84.3	5.62	55.0	3.0	96	80.1	181	244	1.48
AC Metcalfe	87.9	11.2	81.0	73.0	5.63	51.2	3.0	111	78.9	209	246	1.48
Acorn	92.5	9.9	82.7	85.4	4.81	49.0	2.7	91	70.4	220	211	1.49
Bentley	89.7	10.7	81.7	77.1	5.72	54.1	2.9	95	76.0	229	251	1.49
CDC Copeland	87.6	10.5	81.3	81.9	5.95	57.8	3.2	101	73.9	148	247	1.46
CDC Meredith	84.8	10.6	80.8	73.8	5.68	55.0	3.4	101	71.7	252	237	1.48
Cerveza	85.2	10.4	82.4	78.8	5.47	53.4	2.9	101	78.1	265	225	1.51
Conlon	94.6	11.2	81.0	70.5	5.17	46.4	2.4	111	70.5	460	218	1.55
Explorer	92.9	10.2	81.0	88.9	5.13	50.7	2.7	92	76.5	105	228	1.46
Innovation	90.6	11.4	80.9	78.1	5.51	48.4	2.4	125	68.8	335	242	1.52
KWS Beckie	90.8	10.1	82.1	85.7	5.10	51.5	2.9	91	66.1	186	217	1.48
KWS Fantex	91.8	9.9	82.3	86.3	4.99	51.5	2.9	90	68.6	238	217	1.50
Lacey	90.3	11.4	80.7	81.0	5.38	46.9	2.3	119	65.3	240	234	1.48
LCS Genie	92.1	10.6	82.2	83.1	5.49	52.8	2.9	110	67.8	175	235	1.48
LCS Odyssey	92.9	9.8	82.3	86.4	5.14	53.4	2.9	92	74.0	195	220	1.47
ND Genesis	92.2	9.9	82.0	81.5	5.00	50.9	2.7	93	70.2	359	210	1.53
Newdale	83.8	10.8	80.9	80.1	5.56	52.6	2.9	104	80.6	237	232	1.47
Pinnacle	87.4	10.1	81.1	72.4	4.84	48.4	2.6	88	60.8	422	203	1.55
Quest	86.0	11.3	80.7	79.4	5.36	47.4	2.3	121	68.5	353	237	1.52
Robust	88.7	11.6	80.6	78.1	5.71	48.8	2.4	132	57.8	308	240	1.50
Sirish	92.8	10.3	81.7	87.1	5.30	52.9	2.7	97	70.9	149	231	1.46
Tradition	89.0	11.2	80.7	74.7	5.12	45.6	2.1	134	65.2	386	223	1.55
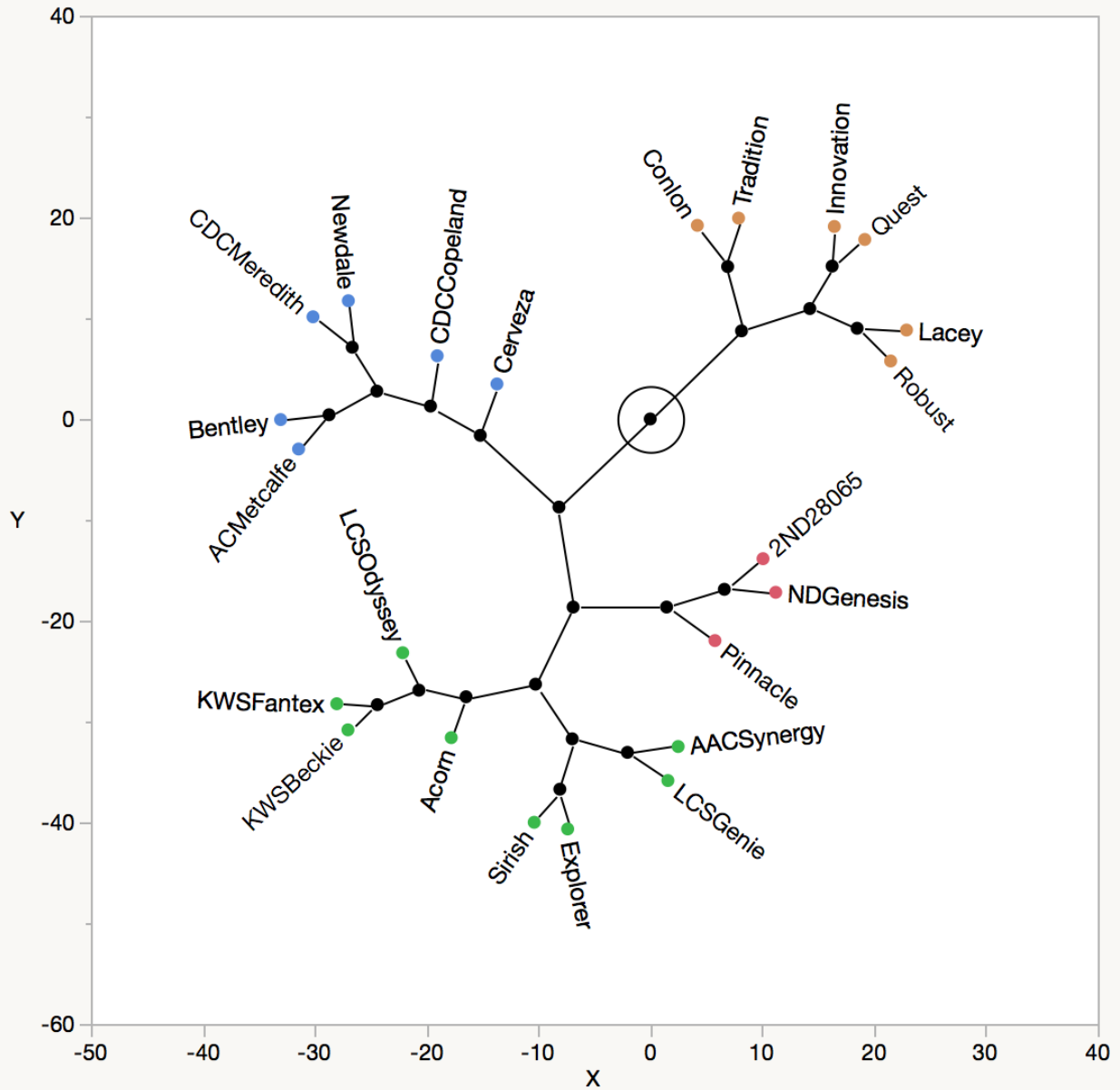
Figure 2. Constellation plot from the hierarchical clustering of barley and malt quality data obtained from barley lines evaluated for two or more years in the Eastern Spring Barley Nursery (2015-2017). The Ward method was used for the cluster analysis. Four clusters were identified and lines falling within a similar cluster are the same color.

Cluster 1 begins in the bottom right hand corners and the numbering of clusters proceeds counter clockwise. Cluster 1 = 2ND28065, ND Genesis, and Pinnacle; Cluster 2 = AAC Synergy LCS Genie, Explorer, Sirish, Acorn, KWS Beckie, KWS Fantex, and LCS Odyssey; Cluster 3 = AC Metcalfe, Bentley, CDC Meredith, Newdale, CDC Copeland, and Cerveza; and Cluster 4 = Conlon, Tradition, Innovation, Quest,, Lacey, and Robust.

Table 9. Mean barley and malt quality across lines within a cluster†.

Cluster‡	Count	Plump kernels (%)		Barley protein (%)		Extract (%)%		Friability (%)		Wort protein (%)		S/T (%)		Wort color		DP (°ASBC)		Alpha-amylase (20° DU)		Wort ß-glucan (ppm)		FAN (ppm)		Wort Viscosity (mPa.s)	
1	3	89.3	a¶	10.1	b	81.6	ab	77.6	a	5.03	b	50.1	ab	2.5	ab	91	b	66.2	b	361	a	211	b	1.53	a
2	8	92.4	a	10.1	b	82.0	a	85.9	a	5.20	b	52.1	a	2.8	a	95	b	71.8	ab	181	b	225	ab	1.48	b
3	6	86.5	a	10.7	ab	81.3	b	77.5	a	5.67	a	54.0	a	3.0	a	102	b	76.6	a	223	b	240	a	1.48	b
4	6	89.9	a	11.4	a	80.8	b	76.9	a	5.38	ab	47.2	b	2.3	b	124	a	66.0	b	347	a	232	a	1.52	ab

† Hierarchical clustering of barley lines evaluated for two or more years in the Eastern Spring Barley Nursery was done using the Ward method.

‡Cluster 1=2ND28065, ND Genesis, and Pinnacle; Cluster 2=AAC Synergy, LCS Genie, Explorer, Sirish, Acorn, KWS Beckie, KWS Fantex, and LCS Odyssey; Cluster 3=AC Metcalfe, Bentley, CDC Meredith, Newdale, CDC Copeland, and Cerveza; and Cluster 4=Conlon, Tradition, Innovation, Quest, Lacey, and Robust.

¶Means within a column followed by the same letter are not significantly different at $P \leq 0.05$.