KENTUCKY SMALL GRAINS GROWER ASSOCIATION
PROJECT SUMMARY

TITLE: Improvement and Development of Barley for Use in Feed, Malt, and Food

Project Summary

Purpose: The proposed research is designed to assess and enhance the yield potential, disease resistance and quality of barley lines for use in multiple end-use markets with emphasis on malt and feed. Ultimately, the goal is to enhance the competitiveness of barley with wheat and corn and also enhance the profitability of barley for producers.

Specific Objectives: The objectives of this project are to: 1) assess and improve yield potential and other desirable traits such as disease resistance, grain composition and quality of barley having diverse end uses; 2) develop barley cultivars comparable to or better than current high yielding cultivars Atlantic, Secretariat, SB255, and Thoroughbred using both conventional and marker assisted breeding methods and; 3) implement a program to develop barley varieties with greater marketability in both domestic and foreign markets and, thereby, make barley an economical cash crop.

Research Methods: The Virginia Tech breeding program will continue to accelerate development of high yielding, improved and higher quality barley cultivars for use as animal feed, malting, and human consumption. We deploy a combination of top-cross, backcross, and Marker Assisted Selection breeding methods. Starting in the F_2 generation, each population is planted, evaluated and heads selected from superior populations on the basis of desirable agronomic type and other traits of interest. Seed from heads harvested from each population are bulked each generation to advance the populations. In the F_4 generation, heads from desirable plants are harvested and threshed individually, planted in headrows and evaluated to derive desirable pure lines. Breeding populations derived from crosses with barley lines introduced from various sources also are being evaluated and advanced in the program, including lines from the Winter Malt Barley Trial (WMBT), Eastern Malt Barley Trial (EMBT) and the Barley Coordinated Agricultural Project (Barley CAP). New barley lines derived from crosses made between superior barley breeding lines from our program with elite breeding lines from other programs are being developed and evaluated in the Virginia Tech breeding program. In the spring of 2019, we made nearly 500 crosses in the greenhouse comprised of hulled (feed and malt) and hulless elite barley parents. This fall (2020), we planted F_1 progeny (320) from 497 crosses made in 2019, and F_2 progeny (305) from 520 crosses made in 2018. We also evaluated nearly 600 pure lines in replicated yield tests at multiple locations in Virginia, in order to identify potential high yielding varieties. Approximately 100 advance barley lines were evaluated in replicated yield tests at locations in Virginia, North Carolina, and Kentucky.

Increased interest in local and regional production of winter malt barley by producers and the malting industry has prompted the program to expand efforts to develop malt barley cultivars adapted to the mid-Atlantic and south eastern United States. As a result, we are currently involved in a cooperative national winter malt barley research project that includes collaborative trials at one to two locations in 23 states (NC, PA, GA, MD, MI, AR, KY, VA, OH, VT, NY, WI, TX, NE, MN, ND, MT, ID, UT, OR, MA, NM, and WA). The Virginia Tech breeding program will continue to work with interested parties in evaluating the potential of barley for these and other diverse purposes. Through these efforts, the quality and value of winter barley has increased greatly during the past few years.

1.0 PROJECT DESCRIPTION:

1.1 Introduction:

Barley is a short-season, early maturing crop with high yield potential and a wide range of adaptation. Winter barley is an integral component of the cropping system in the eastern United States. However, production of feed barley declined dramatically during the last decade due to low prices and competition from other crops (corn and wheat). Barley cultivar development efforts and related research are essential in making barley an attractive and competitive crop option for growers. Production of two winter annual crops allows producers to extend the time available for both harvesting barley and wheat and planting of soybeans, and also provides an alternate crop to reduce the buildup of crop-specific pathogens.

In 1996, the Virginia Tech breeding program generated considerable interest in alternative end uses for barley. This work initially was targeted at local animal feed industries in the region, but cultivars grown in the eastern United States were traditionally low in test weight and had poor feed quality. Recent demands for the following barley end uses include 1) low beta-glucan feed types for monogastric animals, 2) high starch and protein types for ruminant feed and increasingly, 3) production of high quality winter barley for the malt, brewing and distilling industries have generated new interest in barley. Our latest efforts have focused on development of malt barley lines that can double as feed, allowing flexibility in end use while incorporating better disease resistance. In this regard, we have focused our interest primarily on high yield potential along with malting quality traits. Yield potential and other value-added traits will continue to be incorporated, evaluated, and selected for in the breeding program. Improving disease resistance in barley, while also retaining Secretariat and Thoroughbred-like grain yield and quality, is critical for restoring confidence and increasing barley production in the region.

1.2 Objectives:

The primary objective of this project is to develop high yielding, disease resistant barley cultivars having optimal quality designed for specific end uses, thereby, making winter barley a more cost competitive crop in the eastern United States. We will accomplish this objective by increasing evaluation of improved cultivars, and enhancing yield potential and other value-added traits. The proposed research is designed to assess and improve yields, quality and disease resistance of barley through a combination of traditional and genome-enabled plant breeding technologies.

1.3 Justification for research:

The Virginia Tech barley-breeding program is the largest public program in the eastern United States with a major focus on value-added traits geared towards development of new and emerging markets. The rise of craft brewing and lack of locally adapted malting varieties to the eastern United States has helped ignite increased interest in the production and commercialization of winter malt barley for the region. An increased demand for locally produced malting barley, and the products derived therefrom will demand higher availability of locally grown barley. Producers who have been reluctant to grow feed barley due to low prices can profit from these new markets, if economically viable varieties adapted to the region can be made available. The short growing season of winter barley allows double cropping with soybeans, further enhancing economic returns. Our breeding program is currently part of a national winter malt barley breeding effort that includes cooperators in 23 states. This cooperative effort aims to develop malt barley cultivars adapted to large and diverse production areas to provide a uniform supply of winter barley for the malting and brewing industries. However, if barley is to regain its historical position, it must be competitive with other traditional crops (corn and wheat). Significant progress

continues to be made in the development of high value winter barley lines. We have developed elite barley lines having the potential for use in multiple end-use markets. The development of barley cultivars for use in the production of feed, malt and food having desirable quality traits including, but not limited to, high starch, high or low protein, and beta-glucan depending on targeted end uses is an overall goal. Focus on improving yield potential, disease resistance and end use quality of barley will have several practical benefits to producers and end users, by making barley an important contributor to a healthy and productive agronomic system.

The beneficiaries of this research project include farmers all over the mid-Atlantic, southeastern U.S. and in winter barley growing regions. This includes farmer coops and investors in corn deficit regions near malting and brewing markets, the American consumers who want high quality beer, feeders of poultry, swine, and cattle, and all Americans who want locally produced craft malts and beers.

Barley genetics research has taken a huge leap forward via implementation of the USDA-CSREES Barley Coordinated Agricultural Project (Barley CAP). This cooperative project involved 10 barley breeding programs around the country and was initiated to genetically characterized and map over 40 targeted traits in barley breeding lines. Four years of phenotypic data collected by the Virginia Tech barley-breeding program was analyzed along with data collected by collaborators in an effort to identify DNA markers associated with traits of interest (See table below). Of particular interest are markers associated with disease resistance, agronomic traits, and quality traits. Association analysis of the Virginia Tech data identified markers for agronomic traits including yield, test weight and heading date; markers for disease resistance including leaf rust and powdery mildew; and markers for kernel brightness. Additionally, other programs have successfully identified markers for Fusarium Head Blight (FHB) resistance, spot blotch resistance, and other agronomic and quality traits. The Virginia Tech barley breeding program is unique from other participants as it is the only program in the eastern U.S. that collaborated on this research. The funding we are requesting is an important complement to support the limited funding we receive from other local and regional sources. Focus has been placed on successful implementation of marker-assisted and genome-enabled selection to enhance effectiveness and efficiency of the breeding program. This coordinated effort to revitalize barley production and improve yield potential is appropriate for this study and within the technical capacity of our breeding and research program. Through this research, yield potential and other value-added traits will be evaluated and desirable traits will be incorporated into the breeding program. Focus will be placed on developing agronomically desirable cultivars of barley to make it a viable crop for area producers. A well-focused and integrated breeding program is essential for developing, maintaining, and expanding barley markets in the region.

Marker-assisted and genome enabled selection is being deployed in the program for the following barley traits: Malt quality, resistance to Leaf rust, Fusarium Head Blight (FHB), Powdery mildew, and Net Blotch.

1.4 Review of literature:

In the United States, the primary use of barley continues to be in the malt industry and also as a competitive feed stock. The divergence between cultivars targeted for use in the feed market and the more lucrative malting market continue to converge. However, barley is a versatile grain that is only now beginning to demonstrate its potential beyond these traditional applications. Compared to wheat, barley grain has typically been used on a limited basis in food production, with the exception of barley malt. Wheat generally has a greater market demand than barley due to its primary use for flour

production. Barley potentially has two avenues to enhance both its value and competitive position via the application of breeding techniques to address market demands. Barley needs to out yield or offer significant production advantages in cropping systems and/or, the value of barley can be enhanced by identification of unique end uses or through the application of technological advancements facilitating extraction of value-added derivatives. Barley having high protein and digestible energy has the potential for use in swine diets (Bhatty, 1999). Barley has approximately 3% higher protein content and a higher proportion of total digestible amino acids, particularly lysine, than corn (Bhatty et al., 1979). Elucidation of genetic factors for yield and other traits of interest in current barley lines will allow for improvement of yield along with other desirable chemical and nutritional components. Barley containing such high value components will greatly benefit and provide new marketing venues for producers and end users. Development of unique feed, malt, and food products will provide new opportunities for these industries. High yield potential in combination with high value traits will improve the competitiveness of winter barley and will improve farm revenues.

2.0 MATERIALS AND METHODS:

2.1 Experiment 1: Evaluation of yield potential and disease resistance of barley lines

We will continue to assess and improve yield potential of barley lines derived from crosses made between superior hulled breeding lines and cultivars, such as Secretariat, Atlantic, SB255, and Thoroughbred. Emphasis will be placed on improving grain yields, end use quality, and resistance to Fusarium Head Blight (FHB), net blotch, leaf rust, and powdery mildew. Our winter barley advance and preliminary lines are evaluated in diverse environments in replicated field tests. Last season (2018-2019) we evaluate nearly 600 pure lines in replicated yield tests at two to six locations in Virginia in order to identify potential high yielding cultivars. Approximately 100 advance barley lines were evaluated in replicated yield tests at locations in North Carolina, Kentucky, Pennsylvania, and Virginia. During winter 2017-2018, seedling tests of over 800 advanced barley lines were conducted for reaction to three races of leaf rust in the greenhouse. In field tests, disease reaction data were also collected for all prevalent diseases (leaf rust, net blotch, *Barley Yellow Dwarf Virus* (BYDV), powdery mildew, and FHB). Other traits will be evaluated in field trials including, winter hardiness, heading date, plant height, straw strength, grain yield, test weight, starch and protein content.

2.2 Experiment 2: Development of winter barley cultivars for the Malting Industry and Craft Breweries in Virginia and the Eastern United States

This experiment compliments current breeding activities, and the primary goal is to develop winter malt barley cultivars adapted to Virginia and the eastern U.S. Commercial winter malt barley cultivars and promising advanced malt barley lines from our program will be evaluated in replicated tests conducted at two to four locations in Virginia and in the Eastern Malt Barley Trial (EMBT) at one or two locations in cooperating states (Maryland, Kentucky, Pennsylvania, and North Carolina). In addition, we will also evaluate our advance and elite winter malt barley lines in the Winter Malt Barley Trial in 23 other states. Colleagues and other breeding programs including those in North Carolina, Kentucky, Ohio, Texas and Pennsylvania are also collaborating in this uniform nursery. Expected impacts include: 1) development of winter malt barley cultivars that are broadly adapted and grown in diverse production areas; and 2) expanded production of malt barley in under-utilized cropping systems in the northern and southeastern U.S. In addition, current crop management protocols are being evaluated by Dr. Wade Thomason's research team and will be modified as necessary to facilitate high yields and desirable quality in production of the best current malt barley cultivars. These tests will assess the use of plant growth

regulators to reduce lodging, fertilizer impacts on grain yield and quality, and strategies for controlling foliar and head diseases.

2.3 Experiment 3: Grain compositional analyses

Knowledge of grain quality attributes of barley, with specific focus on starch and protein content for feed, malt, and food end uses is of critical importance to the breeding program. Grain samples of our advance barley lines will be evaluated with a Perten Instruments DA 7250 Near-Infrared machine at Blacksburg, VA, which facilitates rapid analysis of key grain components of all potential lines in early generations. Data on grain quality and functionality will become an integral criterion to aid with the selection process in the breeding program. We also will continue to collaborate with the Cereal Crops Research Unit in Madison, WI and with Dr. Aaron MacLeod at Hartwick College's Center for Craft Food and Beverage Research in Oneonta, NY to obtain grain composition and malting quality data, respectively, on promising barley lines.

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Budget for $7,500 Funding Request from Kentucky Small Grains Grower Association

NAME/POSITION	% Effort	Year 1
Undergraduate Wage		$6,123
TOTAL PERSONNEL SALARIES		$
FRINGE BENEFITS		
Undergraduate Wage		$124
TOTAL SALARIES & FRINGES		$
MATERIALS & SUPPLIES		$1,253
TOTAL DIRECT COSTS		$7,500
INDIRECT COSTS @ 0%		$0
TOTAL COSTS		$7,500

Budget Justification

Funding ($6,247) is requested to cover undergraduate wages to aid research scientists, other personnel, and graduate students with barley research activities in the program. Funding ($1,253) also is requested for materials and supplies that are required in conducting lab, greenhouse and field research including items such as glycine bags, paper tags, labels, envelopes, and bags for crossing, planting, and harvest; flats, pots, and potting media for greenhouse tests; stakes, fertilizer, insecticides and fungicides for greenhouse and field tests. This project also requires the purchase of PCR kits, SSR and STS primers, DNA polymerase, polymer, primers, plates, pipette tips, micro-centrifuge tubes and other molecular biology reagents used for MAS and mapping.

Progress Report for 2020

Kentucky Small Grains Association
Improvement and Development of Barley for ese in Feed, Malt, and Food

Wynse S. Brooks, Joshua Fitzgerald, Carl Griffey, Mark Vaughn and Nicholas Santantonio
Virginia Polytechnic Institute and State University

The Virginia Tech barley breeding program is devoted to the development of barley cultivars that will result in the restoration and expansion of barley production throughout the mid-Atlantic and southeastern U.S. We utilize the best available genetic and agronomic technologies to accomplish this objective.

This project is designed to assess the yield potential and quality of elite barley lines to determine genetic factors contributing to their improvement. The specific objectives of this project are: 1) to assess and improve yield potential, quality, and other desirable traits such as resistance to diseases (leaf rust, powdery mildew, net blotch and Fusarium Head Blight-FHB); 2) to develop barley cultivars that are superior to current high yielding cultivars Secretariat, Atlantic, SB255, and Thoroughbred using both conventional and marker assisted breeding methods; and 3) to develop and deploy DNA markers associated with yield, quality and disease resistance.

The main activities and accomplishments of the Virginia Tech Barley Breeding Program during the 2019-2020 crop season are as follows. Breeding efforts were focused on development and improvement of yield potential of winter barley cultivars and a focus on incorporation of value-added traits geared towards the development of new markets. Significant progress continues to be made in the development of high value winter barley lines.

We are pleased to report the release of one malt barley 'Avalon' (tested as VA16M-81 2R) and one hulless barley VA15H-73 2R, released in March 2020 as the first two-rowed winter malt barley and hulless feed barley cultivars, respectively, developed by the Virginia Tech barley breeding program. Cultivar VA15H-73 has better resistance to scab than previous cultivars. One other advanced malt line VA16M-84 2R is also being considered for potential release in 2021. We will continue to develop and evaluate new barley lines derived from crosses made between hulled cultivars and breeding lines with a number of our outstanding malt barley lines.

Progress is also being made in improving resistance to diseases in the program. Of particular interest are markers associated with disease resistance, agronomic traits and quality traits. A resistance QTL region in Eve associated with scab severity, DON toxin, and Fusarium damaged kernels (FDK) has been identified on chromosome 6H with flanking markers SCRI_RS_147342 and Bmag0613 that are 10.1 cM apart by our program. We are currently using marker-assisted selection to incorporate this FHB QTL region into elite materials. Other breeding populations, derived from crosses with barley lines introduced from various programs including sources of FHB resistance and winter malting barley lines, are being advanced in the program. Many lines have improved yield and quality, straw strength, grain plumpness and have better resistance to diseases (e.g. leaf rust, powdery mildew, net blotch and FHB). The size of our winter malt barley project has increased dramatically. For the first time since 2011, all breeding generations are represented in the project. We are now in a position to increase our selection intensity since we have a large number of populations and breeding lines to select from, including Double Haploid (DH) pure lines. We will continue to evaluate new winter barley lines for potential release from crosses made between the two-rowed winter malt barley varieties Violetta, Flavia KWS Scala and elite Virginia

barley cultivars/lines. DH lines from crosses between Endeavor/ VA09B-34, Violetta/Nomini, Violetta/VA09B-34, KWS Scala/VA11B-102, VA15H-73/Flavia, and VA15H-73/Violetta are being evaluated in the program. Last spring (2020), 42 elite malt barley lines were evaluated in the EMBT at three locations in Virginia, and at one to two sites in North Carolina, and Kentucky. Approximately, 110 advanced malt barley lines were evaluated in replicated yield tests (Advance and Preliminary) at three locations in Virginia (Blacksburg, Warsaw and Painter). Thirty-three entries of DH lines were also planted and evaluated in an observation test at two locations in Blacksburg and Warsaw, VA last season (2019-2020). Pure lines possessing good agronomic characteristics and malt quality were selected and are being advanced in yield tests in our program.

Our breeding strategy is to select and use superior germplasm from the Winter Malt Barley Trial (WMBT) and the Eastern Malt Barley Trial (EMBT) as parents in crosses with elite material from our program. We made extensive crosses between elite winter malting barley lines from our program with elite two and six-rowed winter malting barley lines and cultivars from the WMBT and the EMBT having favorable malt and brewing quality. We will develop winter malt barley cultivars that are valuable to local producers and the malting and brewing industries. In the interim, cultivars from the WMBT possessing good agronomic characteristics and malt quality will be identified and evaluated in yield tests in our breeding program. Malt barley cultivars with superior malt quality, improved grain yield, and excellent disease resistance will be recommended for production in the eastern U.S. Our breeding program continues to play a major role in recommending the production of elite winter malting barley varieties (such as Violetta, Calypso and Flavia) evaluated in the WMBT which are currently grown in the mid-Atlantic and southeastern United States. Violetta and Calypso were developed and are marketed by Limagrain Cereal Seed. Flavia, developed by Ackermann Saatzucht in Germany and tested in our program, is marketed by the Virginia Crop Improvement Association (VCIA) foundation seed farm.

Performance data for hulled barley entries in the Virginia Tech State Barley Trials conducted at six locations in 2020 are presented in Table 1. The overall grain yield of Secretariat was 107 bushels per acre with an average test weight of 48.5 pounds per bushel compared to the mean yield of 99 bushels per acre and a test weight of 48.8 pounds per bushel for the mean of all cultivars tested. Average grain yield of Secretariat (107 bushels per acre) was 8 bushels per acre higher than Thoroughbred (99 bushels per acre), 4 bushels per acre higher than Atlantic (103 bushels per acre), 10 bushels per acre higher than SB255 (VA11B-141 LA and Callao (97 bushels per acre). However, the six rowed barley cultivar KWS Faro had the highest average overall grain yield (118 bushel per acre) that was 11 bushel per acre higher than Secretariat, 19 bushel per acre more than Thoroughbred and the overall test mean. In addition, two other cultivars (Hirondella and Flavia) ranked 2nd and 3rd respectively in average grain yield (112 and 110 bushels per acre) that were 5 and 3 bushels per acre higher than that of Secretariat; 13 and 11 bushels per acre higher than Thoroughbred.

Three year (2018, 2019 and 2020) average performance data of hulled barley entries evaluated in the Virginia Tech State Barley Trial are shown in Table 2. The experimental line VA16B-264 LA had the highest three-year average grain yield (97 Bu/ac) that was 1 Bu/ac higher than Secretariat, 5 bushels per acre higher than SB255, 6 bushels per acre more than Atlantic, 7 bushels per acre higher than Thoroughbred, 15 bushels per acre higher than Callao and 9 bushels per acre above the overall test average. Two other newly developed experimental lines (VA16B-213 LA, and VA14B-63)) ranked 2nd and 3rd respectively in average grain yield, that were higher than the check varieties.

Agronomic performance data for entries in the Eastern Malt Barley Trial conducted at locations in Blacksburg, Blackstone and Warsaw, VA in 2020 are presented in Table 3. One six rowed Virginia

winter malt barley doubled-haploid (DH) experimental line VA17M-13DH1720 LX ranked 1st in average grain yield (122 bu/ac) and was 10 bushel per acre higher than the cultivar Thoroughbred, 3 bushel per acre higher than the two rowed malt barley cultivar Flavia (119 bu/ac), 22 bushel per acre higher than Violetta, 7 to 13 bu/ac higher than the American Malting Barley Association (AMBA) winter malt barley check cultivars Wintmalt and Endeavor (115 bu/ac, and 109 bu/ac) respectively, 10 bushels per acre more than Calypso (112 bu/ac), and 25 bushels per acre higher than the overall test average. The two-row winter malt barley cultivar Flavia ranked 2nd in grain yield (119 Bu/ac) that was 6 bushel per acre higher than Thoroughbred and 4 to 22 bushel per acre higher than the two row winter check cultivars Wintmalt (115 bu/ac), Calypso (112 bu/ac), Endeavor (109 bu /ac) and Violetta (97 bu/ac). The two-row recently released Virginia malt barley cultivar Avalon (tested as VA16M-81 2R) had average grain yield that was 6 bushel per acre higher than Violetta, but lower than the check cultivars Flavia, Wintmalt, Calypso and Endeavor. Results for these new malt barley lines are encouraging and indicate that significant progress is being made by the breeding program in developing barley cultivars with high yield and improved disease resistance.

Two year (2018 and 2019) average summary of quality analysis of malt barley lines in the EMBT conducted by the Hartwick College, Center for Craft, Food and Beverage in Oneonta, NY are presented in Table 4. Malting quality data among malt barley indicates that the Virginia malt barley cultivar Avalon released in 2020 meets or exceeds the desired AMBA target ranges for all of the important malting characteristics including protein (11.0 %), plump kernels >6/64" (95 %), germination energy 8mL (88 %), malt extract (83 %), beta-glucan (45 ppm), soluble /total protein (46 %), diastatic power (157 °ASBC), alpha-amylase (69 D.U.), and FAN (208 ppm). Malt extract for VA16M-81 2R is 2% higher than Violetta (81 %), beta-glucan content of VA16M-81 2R is 50 ppm lower than Violetta (85 ppm). Overall, malt quality for three elite Virginia malt barley lines (VA16M-81 (2R), VA16M-82 (2R), and VA16M-84 (2R)) are all within the desirable range set by the AMBA for all malt two-row barley. Feedback from Aaron Macleod, Director of the Center for Craft, Food and Beverage, Hartwick College, NY indicates that VA16M-81 2R has unique functional profile for malting quality.

Our breeding program plans to continue to build on the data collected on these varieties and evaluate and select superior malt barley lines each year from the EMBT and the WMBT, to determine which lines are best suited to provide the yields and quality sought by craft maltsters and brewers in the eastern U.S.

Table 1. Summary of performance of barley entries in the Virginia Tech Barley Test, 2020 harvest.

Barley Lines	Yield (Bu/a @ 48 lb/bu)	Test Weight (Lb/bu)	Date Headed (Julian)	Mature Height (In)	Plant Lodging (0-9)	Net Blotch (0-9)
	(5)	(5)	(2)	(3)	(3)	(2)
KWS Faro	118.0	48.4	112	34	0.4	2.3
Hirondella	111.8	47.2	114	34	0.9	2.0
Flavia	110.2	48.9	116	31	0.4	2.0
Calypso	109.7	48.3	115	38	0.8	2.9
Fay	109.3	47.5	110	33	0.8	2.1
KWS Somerset	107.9	48.9	114	34	0.9	2.1
Br11864pl	107.4	48.8	108	30	0.3	2.4
Secretariat	107.0	48.5	107	33	2.3	2.6
VA18B-52 LA (Dec.)	106.8	49.6	107	35	0.7	2.0
VA18B-43 LA	106.1	48.5	110	36	0.3	1.6
Casanova	104.5	49.3	116	33	0.4	1.8
VA18B-39	104.4	48.7	108	34	2.0	2.4
VA18B-50 LA	103.1	50.1	107	34	1.4	2.3
Atlantic	103.0	48.5	105	34	2.4	2.1
VA18B-5 LA	102.7	49.7	112	38	1.2	2.9
VA16BFHB-279 NA	102.4	47.0	105	38	0.9	2.9
VA18B-33 LA	102.2	49.4	108	35	1.8	1.8
VA17B-163 LA	101.7	50.0	107	35	1.5	1.4
VA16B-264 LA	101.3	49.6	104	36	0.6	2.0
VA18B-23 LA	101.2	49.6	111	37	1.8	1.9
VA16M-81	101.1	50.5	114	37	1.0	1.8
VA13B-25 LA	101.0	48.2	103	35	0.8	1.6
VA17B-177 LA	100.9	49.1	107	34	1.3	2.4
VA14B-63	100.2	48.3	109	35	1.7	1.8
Nomini	100.0	45.7	103	38	1.8	2.0
Violetta	99.8	49.0	109	32	0.7	2.1
VA18B-34	99.6	49.2	109	35	2.3	1.4
Thoroughbred	99.1	49.5	111	38	0.7	3.0
VA18B-35	98.8	48.8	105	34	2.3	2.3
VA17B-166 LA	97.8	50.0	107	35	1.1	1.1
VA18BFHB-80 LA	97.5	49.0	109	37	0.9	2.0
VA18BFHB-160 LA	97.3	48.2	106	37	0.8	2.5
SB255 (VA11B-141 LA)	97.1	49.4	108	37	0.6	2.3
VA16B-213 LA	97.1	48.3	109	38	0.4	1.8
Callao	97.0	47.3	104	32	3.2	2.1
VA18B-44 LA (Dec.)	96.5	50.1	106	36	0.8	1.6
KWS Scala	96.2	47.3	109	30	0.6	2.8
Wysor	95.9	46.1	107	39	2.8	3.6
Average	98.6	48.8	108	35	1	2
LSD (0.05)	5.9	0.7	1	2	0.6	0.7
C.V.	8.8	2.0	1	7	---	---

Table 2. Three-year average summary of performance of hulled entries in the Virginia Tech Barley Tests, 2018, 2019 and 2020 harvests.

Barley Lines	Yield (Bu/a @ 48 lb/bu)	Test Weight (Lb/bu)	Date Headed (Julian)	Mature Height (In)	Plant Lodging (0-9)	Leaf Rust (0-9)	Net Blotch (0-9)	Powdery Mildew (0-9)
	(16)	(15)	(6)	(9)	(14)	(1)	(7)	(1)
VA16B-264 LA	97.2	48.2	109	34	2.3	2.3	1.8	0.0
VA16B-213 LA	95.8	47.0	113	36	2.2	1.8	2.3	0.0
VA14B-63	95.7	46.9	113	33	3.7	1.8	1.5	0.0
Secretariat	95.5	47.2	111	31	4.4	1.0	3.1	0.0
VA13B-25 LA	93.2	47.0	108	33	3.4	2.8	2.3	0.0
SB255 (VA11B-141 LA)	92.0	47.6	112	35	3.2	2.8	2.3	0.5
Atlantic	91.4	46.3	109	31	4.5	4.0	4.0	0.0
Calypso	90.8	44.3	118	33	2.7	1.5	3.7	0.0
Thoroughbred	90.4	45.8	114	34	2.5	3.3	5.3	0.0
Violetta	88.8	47.2	113	30	2.0	2.0	3.0	0.5
Barsoy	83.5	46.6	108	32	4.5	5.5	4.0	0.0
Callao	82.3	45.6	108	29	6.0	3.5	3.4	0.0
Nomini	80.3	44.6	108	37	3.1	3.8	2.3	0.0
Wysor	74.4	44.0	111	37	4.7	5.8	5.0	0.0
VA92-42-46	71.5	44.2	111	37	4.2	1.0	5.9	0.0
Average	88.2	46.2	111	33	3.6	2.8	3.3	0.1
LSD (0.05)	4.1	0.6	0	1	0.6	0.8	0.5	0.5
C.V.	12.6	3.3	1	9	---	---	---	---

Released cultivars are shown in bold print.

Varieties are ordered by descending yield averages.

The 0-9 ratings indicate a genotype's response to disease or lodging where 0 = highly resistant and 9 = highly susceptible.

The number in parentheses below column headings indicates the number of location-years on which data are based.

Table 3. Summary of agronomic performance of ten commonly assessed data of entries in the Eastern Malt Barley Trial (EMBT) at Blacksburg, Blackstone and Warsaw, VA, 2020 harvest.

Line	Yield (Bu/a)	Test Weight (Lb/bu)	Heading Date (Julian)	Height (In)	Lodging (0-9)	Net Blotch (0-9)	Source
	(3)	(3)	(2)	(2)	(1)	(2)	
VA17M-13DH1720 (LX)	121.5	48.2	114.2	34.8	4.0	2.2	Virginia Tech
Flavia	118.7	49.4	115.2	30.2	0.3	1.7	Germany
VA17M-14DH1476 (LX)	116.9	47.9	112.2	36.0	3.7	2.3	Virginia Tech
VA17M-14DH1801 (LX)	115.3	47.9	107.8	33.3	2.3	2.3	Virginia Tech
VA17M-14DH1840	115.0	50.1	112.2	33.5	2.0	1.2	Virginia Tech
Wintmalt	115.0	49.7	116.5	32.3	0.7	2.0	USDA-ARS
Thoroughbred	112.9	51.3	110.3	37.8	2.0	3.5	Virginia Tech
12W587-n-28	112.9	51.2	118.8	33.3	1.7	3.0	USDA-ARS-NC
Hirondella	111.8	47.6	114.3	33.5	2.3	1.7	Germany
Calypso	111.6	47.9	115.8	35.5	2.7	2.2	Limagrain
Endeavor	108.9	50.7	107.2	35.8	0.7	2.8	USDA-ARS Idaho
ARS15B12	108.1	50.6	109.8	35.5	0.3	1.3	USDA-ARS-NC
VA17M-14DH1815 (LX)	104.8	49.7	108.2	37.3	1.0	1.3	Virginia Tech
12W589-n-07	102.9	47.0	114.7	34.0	3.3	4.0	USDA-ARS-NC
VA16M-14DH1312 (2R)	102.9	50.4	108.2	33.2	0.0	0.8	Virginia Tech
Avalon (VA16M-81 (2R)	102.1	51.7	114.5	36.2	1.7	2.2	Virginia Tech
12W587-n-23	100.2	49.9	117.8	33.3	2.0	3.2	USDA-ARS-NC
12W595-n-16	100.1	48.6	114.3	34.8	4.0	5.0	USDA-ARS-NC
Violetta	97.4	49.2	109.8	29.8	1.3	2.0	Limagrain
VA16M-84 (2R)	95.4	52.4	114.5	39.7	0.7	1.8	Virginia Tech
VA18M-75 LA	93.9	50.8	106.7	33.7	1.0	0.5	Virginia Tech
VA17M-14DH1836	93.8	50.7	104.3	31.2	2.0	2.7	Virginia Tech
12W595-n-74	93.4	47.9	114.7	34.3	6.0	6.0	USDA-ARS-NC
12W595-n-02	93.4	48.2	115.0	32.2	4.7	4.2	USDA-ARS-NC
12W595-n-96	93.2	47.2	114.3	34.8	5.7	5.2	USDA-ARS-NC
VA16M-82 (2R)	93.0	52.3	109.8	41.3	2.3	2.0	Virginia Tech
12W595-n-83	92.7	46.1	114.5	32.7	5.0	6.0	USDA-ARS-NC
VA17M-189 (2R)	92.4	49.8	106.7	37.3	3.0	1.7	Virginia Tech
12W595-n-71	90.4	45.5	114.3	33.7	7.0	4.2	USDA-ARS-NC
12W595-n-05	89.9	46.8	114.7	33.0	6.0	5.7	USDA-ARS-NC
VA17M-15DH0272	89.7	52.4	110.8	35.2	2.0	1.0	Virginia Tech
12W595-n-04	89.5	46.9	115.2	33.2	4.7	5.2	USDA-ARS-NC
12W595-n-66	86.6	46.8	114.5	33.2	6.7	5.3	USDA-ARS-NC
ARS15B19	85.3	49.2	108.3	40.3	0.0	1.2	USDA-ARS-NC
VA17M-128 (2R)	84.7	49.1	109.0	37.7	4.7	4.2	Virginia Tech
VA17M-187 (2R)	82.0	49.8	107.5	38.2	1.3	1.5	Virginia Tech
VA16M-115 (2R)	81.9	50.1	105.8	31.8	1.3	2.8	Virginia Tech
12W586-n-28	80.8	44.9	116.2	28.3	2.3	5.5	USDA-ARS-NC
12W586-n-50	80.5	46.9	115.2	28.2	1.7	5.3	USDA-ARS-NC
12W586-n-56	80.0	45.9	115.5	27.8	3.3	6.0	USDA-ARS-NC
12W581-n-13	79.2	45.0	112.0	32.0	5.0	7.0	USDA-ARS-NC
12W581-n-42	55.6	43.7	113.7	28.7	4.7	7.5	USDA-ARS-NC
Average (n=42)	97.1	48.8	112.3	34.0	2.8	3.3	
LSD (0.05)	11.1	1.4	2.0	2.5	1.8	1.3	
C.V.	12.1	3.0	1.1	6.4	40.8	36.2	

Note: The number in parentheses below column headings indicates the number of locations on which data are based.

Note: Released cultivars are shown in bold print.

Note: The 0-9 ratings indicate a genotype's response to disease or lodging where 0 = highly resistant and 9 = highly susceptible.

Table 4. Two-year average summary of Malt Quality analysis of entries in the Eastern Malt Barley Trial, 2018 and 2019 harvest*.

Line	Plump >6/64" %	Germin. Energy 8mL (%)	Malt Extract (%)	Barley Protein (%)	S/T (%)	Diastatic Power (°L)	Alpha Amylase (D.U.)	β-glucan (ppm)	FAN (ppm)
AMBA Quality Target:	> 90%	>70%	>81%	≤ 13%	40-47%	> 140%	>50%	< 100%	>210%
Calypso	96.2	77.0	82.0	9.9	46.1	149.0	53.6	67.0	184.5
KWS Joy	93.4	74.0	81.8	10.4	46.3	122.5	57.0	102.5	196.0
KWS Scala	93.7	83.0	82.6	10.8	50.8	158.0	66.1	44.5	223.0
SU-Mateo	91.9	87.0	80.4	9.8	48.9	135.0	59.7	97.0	192.0
Violetta	92.4	71.0	81.0	10.9	48.1	182.0	65.2	85.0	211.5
Avalon (VA16M-81 2R)	94.7	87.5	82.6	10.5	46.3	156.5	68.8	44.5	207.5
VA16M-82 (2R)	93.9	96.0	81.7	11.3	40.5	127.5	53.8	154.5	185.0
VA16M-83 (2R)	97.8	82.5	82.4	10.8	42.5	133.0	56.1	149.0	181.5
VA16M-84 (2R)	96.4	87.0	82.1	11.5	42.5	135.5	58.2	149.5	187.0
ARS14B12	94.1	90.5	80.1	12.0	44.6	**111**	53.8	156.0	219.5
ARS14B14	92.7	95.0	82.4	11.6	46.1	107.5	50.3	151.0	218.0
ARS14B15	94.7	94.5	79.4	11.4	45.0	111.5	50.7	120.5	211.0
ARS15B12	90.5	72.0	79.6	11.0	45.4	105.5	58.4	278.5	208.5
ARS15B19	98.4	66.0	80.4	11.6	48.0	93.5	55.6	385.5	243.0
ARS15B24	67.6	46.0	78.9	11.0	50.5	127.0	84.0	174.5	261.5
ARS15B32	98.6	73.0	80.7	11.5	48.5	95.0	59.5	358.5	241.5
VA16M-14DH1272 (2R)	93.0	84.0	80.2	11.2	40.4	105.0	59.2	416.5	177.0
VA16M-14DH1285	82.6	73.5	80.8	11.5	53.4	177.5	86.9	206.5	283.0
VA16M-14DH1294 (2R)	95.6	72.5	82.1	11.5	54.9	135.0	68.0	149.5	292.0
VA16M-14DH1310	89.3	85.5	80.0	11.6	39.2	137.0	48.0	344.0	171.5
VA16M-14DH1312 (2R)	92.3	69.5	81.4	11.2	54.5	129.0	79.6	82.5	283.0
Mean (N=21)	92.3	79.4	81.0	11.1	46.8	130.2	61.5	177.0	218.0
C.V.	3.9	12.0	1.5	3.4	4.5	9.9	7.8	30.6	6.3
L.S.D.	7.6	19.9	2.5	0.8	4.4	26.9	10.0	113.1	28.6

* Malt analyses performed by Hartwick College Center for Craft, food and Beverage, Oneonta, NY.