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SCREENING OF BARLEY CULTIVARS FOR POTENTIAL ETHANOL PRODUCTION IN MARYLAND

FINAL GRANT REPORT

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EXECUTIVE SUMMARY

To investigate the potential of barley as a potential stock for fuel ethanol production, advanced lines and varieties of hulled and hulless barleys were tested during the 2002 and 2004 harvest years in Maryland for grain yield, test weight, heading date, plant height, resistance to lodging, grain protein content, grain starch content, and grain beta-glucan content. Hulless barleys are a potentially superior raw material for the production of ethanol because they have a higher starch content than hulled barleys. Hull-less barleys had 2 to 3 % points higher starch content than the hulled varieties traditionally grown in the mid-Atlantic. Hulled varieties with high test weight and plump seed, such as the variety Thoroughbred, consistently had a higher starch content compared to other hulled varieties such as Nomini (the variety most commonly grown in the region). Protein and Beta-glucan content were similar for both hulled and hulless barleys. An additional advantage of hulless barley is that it does not have the abrasive hulls of hulled barley that damages grain handling and grinding equipment. The current drawback for growers of hulless varieties is that grain yields are significantly lower than those of hulled varieties. Current breeding of hulless barley for the mid-Atlantic will likely close this gap in productivity in the near future.

Hulless barley seed germ is subject to significant damage when the same aggressive at-harvest combine settings that are used for hulled barley are used. In order to produce quality hulless barley seed, seed growers will have to use gentler combine settings. In this research, it was shown that seed with 85% germination was attained with a cylinder speed of 700 rpm and a concave opening of 12 mm.

Improved varieties of hulless barley are only one of the keys to successful production of hulless barley. Profitable and sound nitrogen management will also be an important factor. Although only one year and one location of information have been collected to date, the limited results indicate that financially and environmentally sound nitrogen management practices will be identified for producing hulless barley. A hulless barley yield of 85 bu acre^{-1} was obtained with 20 lb N acre^{-1} applied in the fall and with a spring split application of 40 lb N acre^{-1} at greenup and another 40 lb N acre^{-1} at the jointing growth stage of the crop. Additional research over years and locations will be necessary to fine-tune these nitrogen recommendations. Based in part on continuing this research, an ethanol plant may be built in Maryland using mostly barley grain.

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BACKGROUND AND OBJECTIVES

Starchy grains, such as those of barley, contain fermentable sugars that can be efficiently used to produce fuel ethanol. There are several reasons for producing and using ethanol instead of gasoline. Ethanol is an environmentally friendly fuel that can be mixed with gasoline, as an oxygenating agent replacing the toxic compound MTBE, or used directly to replace gasoline.

Winter barley is an important crop in the state of Maryland. Barley acreage is currently approximately 45,000 acres with an average yield of 75 bushels/acre for the period of 1999-2003. This acreage is much lower than the acreage planted in the 1980's when barley occupied between 80,000 and 100,000 acres (USDA National Agricultural Statistics Services: http://www.usda.gov/nass/). The current limited market for barley grain has kept prices at very low levels. The low price of barley has had a major impact in the reduction of the cultivated area with barley. Cereal grains such as corn, wheat, barley, sorghum, triticale, oats and rye have a large proportion of starch. Corn has generally the highest percentage of starch that can be easily used for ethanol production. In Maryland, there is a corn deficit (corn is imported from other states) because of the demand from the chicken industry. Rather than compete with the chicken industry for corn, ethanol production could be based on other cereal grains that also contain starch but have a lower price. Ethanol producers could offer a significant premium for barley, especially hull-less cultivars that have a higher starch percentage and can produce yields of ethanol comparable to those of corn.

Barley, additionally, has an important agronomic advantage over other small grains in Maryland. Barley is harvested earlier than wheat allowing for an earlier planting of the following soybean crop (double-crop). The earlier a double-cropped soybean is planted, the higher its yield potential. New barley lines and varieties with no hulls (hull-less) on the grain are becoming available. Currently, only hulled barley varieties are grown in Maryland. Hulless barley has the potential for higher ethanol yields as well as new food uses. Starch is the main fermentable component of barley grain. In addition to starch, protein and other complex carbohydrates called beta-glucans are present. There is limited information on the levels of these grain components in barley currently grown in the mid-Atlantic. To investigate the levels of these different grain components in currently grown varieties and lines of barley, studies were established in Maryland during two growing seasons.

Breeding for yield improvement in hulless barley will no doubt result in hulless barley varieties that will yield better than the only one currently available, `Doyce'. In order to attract the estimated 100,000 to 200,000 acres of hulless barley necessary to provide enough feedstock for a fuel ethanol plant, farmers will also want information about sound agronomic production practices. The second two objectives of this project were established to address production-related issues.

Objective two was designed to evaluate the impact that at-harvest combine settings would have on seed quality. Field observations have indicated that seedling emergence for hulless barley is not comparable to hulled barley varieties at similar seeding rates and seed germination percentages. In a seeding rate study (not part of this funded initiative) conducted at two locations in Maryland during fall 2004, the seedling emergence for hulless and hulled barley were compared across the same seeding rate treatments. Three-week post planting seedling counts were taken and resulted in seedlings for only 47% of the viable seeds planted for 'Doyce' hulless barley while 'Thoroughbred' hulled barley had 77% of planted seed resulting in emerged seedlings. This failure to establish the same number of plants per acre immediately places the hulless barley at a disadvantage for yield potential compared to hulled barley since plant population is a critical yield component. The difficulty in seedling establishment is attributed to the inherent trait of the hulless kernels, i.e. they do not have the protective outer seed coat that hulled barley has. Unlike wheat, a grain species that also has the hulls thresh free, the germ portion of a hulless barley kernel is not recessed into the caryopsis. This kernel characteristic allows the germ to be more easily damaged when the kernels are threshed particularly at the aggressive combine settings that farmers have become accustomed to using for hulled barley.

Objective three is designed to help answer questions about suitable nitrogen fertilization rates and timing of applications for both profitable and environmentally sound management of hulless barley. This objective actually has two goals. The first goal is to provide much needed fertility management information for hulless barley. The second goal is to investigate nitrogen management strategies for a dual purpose crop i.e. cover crop in the fall and grain crop the following spring. Maryland has established a goal of 600,000 acres of cover crop use by 2010,therefore, there is increased interest in the capability of fall-planted cereal grains that are normally produced for grain production to be used as a dual-purpose crop, It is believed that with specific nitrogen management practices this could become a viable practice for Maryland farmers. The addition of 100,000 to 200,000 acres of hulless barley for an ethanol plant would contribute significantly toward the 600,000 acre goal. This research is designed to allow a number of comparisons to be made using nitrogen management strategies that would complement a dual-purpose use of the crop.

METHODOLOGY

Objective One

Advanced lines and varieties of hulled and new hull-less barleys were tested during the 2002 and 2004 harvest years in Maryland for grain yield, test weight, heading date, plant height, resistance to lodging, grain protein content, grain starch content, and grain beta-glucan content. A sample of grain (1000 grams) was used to determine test weight using a Seedburo GMA-128. A sub-sample of 100 grams was used for further tests. β-glucan levels were determined using an enzymatic assay. Protein content and starch content were assayed with an Infratec Model 1255 Food and Feed analyzer. Starch, β-glucan and protein content of the grain were expressed as percentage of grain corrected to 13.5 moisture content. The data were entered into an Excel worksheet. These data were converted to a file format that was analyzed with the statistical package Statistical Analysis System (SAS) for Windows Release 6.12 (SAS Institute, 1985). An analysis of variance of the data was conducted using the procedure PROC GLM and means were calculated for each location and growing season. A Fisher Protected LSD (0.05) was used to separate means.

Objective Two

During late June 2004, barley samples were collected from a 'Doyce' hulless barley production field on the Boyle Bros. Farm. A number of different combine cylinder speeds and concave space settings were evaluated. Each setting was established prior to harvesting a 50-foot section of the field using a Massey Ferguson 8-XP plot combine. Representative samples of the harvested barley were collected for each treatment. The combine settings evaluated were cylinder speeds of 150 rpm increments ranging from 700 rpm to 1300 rpm. The concave settings were 10 and 12 mm across the five cylinder speed treatments. Barley samples were submitted to the Maryland Department of Agriculture Seed Laboratory for germination analysis. Data were analyzed using the SAS PROC MIXED procedure. Barley seed samples were again collected from research plots during 2005 but have not yet been analyzed by the lab.

Objective Three

During 2004-2005 production season, 'Doyce' hulless barley was grown in replicated plots (3 replications) at Wye Research and Education Center (WREC) and CMREC (Central Maryland Research and Education Center)-Beltsville (4 replications) to evaluate different nitrogen application rates and timing of applications. The treatments were arranged in a split plot experimental design with whole plots consisting of a factorial arrangement of fall nitrogen application (0 and 20 lb/acre) and Feekes growth stage 2/3 (spring greenup) nitrogen (0, 40, 60, and 80 lb/acre) and the split plots consisting of nitrogen rates of 0, 40, 60, and 80 lb/acre applied at Feekes growth stage 5 (jointing). Plots at CMREC were abandoned during early spring because of lack of uniformity in barley stands. Plots at WREC received all treatments and were harvested 25 June 2005. Yield data were analyzed using the SAS PROC MIXED procedure. A Fisher's Protected LSD (p=0.05) was used to identify mean differences.

RESULTS

Objective One

The detailed performance data of the barley advanced lines and varieties in the Virginia State Variety Trial grown in Maryland are presented in Table 1 (2002), Table 2 (Clarksville, 2004), Table 3 (Queenstown, 2004) and Table 4 (average performance, 2004). The 2002 season was warmer than average with early heading and harvest dates. Grain yields and test weights in 2002 were higher than historical averages (Table 1). The 2004 harvest season was cooler than average with lower grain yields and test weights. Overall performance data of hulled and hulless genotypes are presented in Table 5 (2002), Table 6 (Clarksville, 2004), Table 7 (Queenstown, 2004) and Table 8 (average performance, 2004). The hulless genotypes had lower grain yields, higher test weights, and higher grain starch than hulled cultivars across years and locations. There were no significant differences for grain protein content, grain beta glucan content, heading date, plant height, lodging or aphid damage (which was significant in 2002 but was absent in 2004).

Table 1. **Performance of hulled and hulless barley entries in 2002 test grown in Maryland (Queenstown).**

Barley Entry	Yield (Bu/A)	Test Weight (Lbs/Bu)	Heading (April)	Height (in)	Lodging (0-10)	Aphids (0-9)	Protein (%)	Starch (%)	Beta Glucan (%)	Hulls
VA97B-176	112.4	53.3	15.0	29.5	1.5	3.0	9.5	59.3	4.6	Hulled
VA98B-221	111.5	51.4	16.5	27.5	0.5	2.5	10.7	59.0	4.4	Hulled
VA98B-199	105.9	50.7	17.5	28.5	0.5	2.0	9.7	59.0	4.3	Hulled
VA98B-524	105.5	49.1	18.0	29.5	2.0	3.5	9.9	57.6	5.3	Hulled
VA99B-161	103.1	49.2	16.0	28.5	1.5	2.0	8.8	57.9	4.8	Hulled
Thoroughbred	102.1	50.8	18.0	32.5	1.5	4.5	8.6	60.6	4.5	Hulled
VA00B-7	100.7	49.3	15.0	29.5	2.0	2.5	9.2	56.8	5.2	Hulled
VA00B-182	100.0	51.1	13.0	30.5	3.0	2.0	8.4	62.6	6.1	Hulled
Nomini	99.7	48.0	17.5	35.5	0.5	4.0	9.9	57.1	5.1	Hulled
VA99B-206	99.3	51.2	15.5	32.5	1.5	3.5	9.9	60.1	5.7	Hulled
VA99B-125	96.2	49.7	16.5	28.0	2.5	3.0	10.3	59.4	5.0	Hulled
VA00B-9	95.1	50.5	15.0	29.0	1.0	2.0	9.5	60.5	5.2	Hulled
Callao	93.9	50.1	14.5	28.0	3.0	3.0	9.5	60.0	5.9	Hulled
VA92-42-46	93.3	48.0	14.5	39.0	2.0	4.5	10.8	59.2	5.5	Hulled
Wysor	91.4	47.2	17.0	36.5	2.0	3.0	10.6	58.4	5.4	Hulled
VA00B-11	90.0	49.6	15.5	29.5	2.0	2.5	8.7	61.0	5.5	Hulled
VA97B-142	89.3	49.6	12.5	30.0	1.5	2.0	8.8	58.8	4.5	Hulled
Catchpenny	87.3	46.2	14.5	33.5	1.0	2.0	10.6	57.0	5.2	Hulled
VA00H-74	82.6	61.4	16.5	30.0	1.0	2.5	9.1	63.0	5.1	Hulless
VA99B-162	82.0	49.7	16.0	29.0	1.5	4.0	9.1	62.0	5.1	Hulled
VA00H-70	79.5	62.0	16.0	29.0	0.0	2.5	9.6	62.4	5.2	Hulless
VA00H-211	79.0	61.9	15.0	32.0	1.5	3.0	10.6	58.7	5.4	Hulless
VA00H-88	76.6	60.9	15.5	29.5	1.5	2.5	8.6	63.1	5.1	Hulless
VA00H-65	75.5	62.5	15.5	29.0	0.5	3.0	9.7	62.5	4.8	Hulless
Doyce	75.3	60.5	16.0	30.0	2.5	3.5	8.1	65.5	5.4	Hulless
VA00H-99	69.5	61.8	16.5	29.5	0.0	3.0	9.8	62.2	5.2	Hulless
VA00H-134	68.7	59.5	16.0	26.5	1.5	1.5	10.6	60.0	5.7	Hulless
Barsoy	67.6	51.8	13.5	32.5	4.0	2.5	10.3	61.9	5.3	Hulled
VA00H-93	67.5	62.2	16.0	28.0	0.5	4.0	8.9	63.1	5.8	Hulless
VA00H-10	59.4	60.8	15.5	29.0	0.5	3.5	9.6	62.7	4.9	Hulless
VA00H-218	59.0	62.3	14.0	23.0	0.5	4.5	11.0	60.2	5.7	Hulless
VA00H-243	57.6	60.0	15.5	29.0	3.5	5.0	11.9	59.2	5.3	Hulless
VA00H-24	57.1	61.5	15.0	28.0	3.0	4.5	12.2	60.8	5.1	Hulless
SC890585	56.0	59.5	14.0	31.0	3.5	4.0	10.3	60.7	4.7	Hulless
SC880248	53.7	60.4	16.0	30.0	4.0	5.0	9.6	62.1	5.2	Hulless
VA00H-15	44.5	59.7	15.5	31.0	3.0	6.0	11.0	62.3	4.4	Hulless
VA00H-32	43.3	60.3	15.5	26.5	1.0	6.0	11.6	59.5	5.1	Hulless
VA00H-12	26.3	56.3	16.5	28.5	1.0	7.5	12.0	61.1	5.4	Hulless
Means	84.4	54.1	15.6	29.8	1.6	3.2	9.9	61.4	5.1	-

Table 2. Performance of hulled and hulless barley entries in 2004 test grown in Clarksville, Maryland.

Entry	Yield (Bu/A)	Test Weight (Lbs/Bu)	Heading (days*)	Height (inches)	Lodging (0-9)	Net Blotch (%)	Protein (%)	Starch (%)	Beta Glucan	Hulls
Barsoy	76.9	49.2	25	38	3.5	55.0	13.1	61.3	4.8	Hulled
Wysor	85.5	42.6	30	40	4.0	50.0	11.3	60.4	4.9	Hulled
Nomini	93.8	44.4	28	42	3.5	20.0	11.9	61.1	5.0	Hulled
Callao	78.1	48.0	27	33	8.5	55.0	12.6	60.4	5.3	Hulled
VA92-42-46	77.5	44.8	28	44	7.0	30.0	12.1	61.0	5.2	Hulled
Thoroughbred	96.8	49.5	31	38	2.0	65.0	10.9	64.1	4.7	Hulled
VA96-44-304	93.8	45.3	27	36	6.5	50.0	12.7	59.0	4.6	Hulled
Price	95.6	46.6	29	37	3.5	70.0	11.4	60.6	4.4	Hulled
VA98B-208	98.9	45.7	30	32	3.5	45.0	11.6	60.7	5.1	Hulled
VA98B-213	93.0	44.1	29	36	5.0	80.0	11.7	60.4	5.0	Hulled
VA97B-175	99.6	47.6	27	35	7.0	32.5	12.6	60.9	4.8	Hulled
VA97B-176	80.1	47.5	27	35	5.0	55.0	11.1	61.6	4.5	Hulled
VA99B-161	95.7	47.6	28	35	4.5	35.0	11.1	61.4	4.7	Hulled
VA99B-125	93.6	46.8	29	34	7.0	20.0	12.2	60.6	4.8	Hulled
VA00B-91	83.6	44.9	31	37	4.5	20.0	12.2	60.6	4.6	Hulled
VA00B-279	101.1	46.7	31	38	0.0	10.0	11.8	59.7	4.7	Hulled
VA01B-26	92.1	46.4	28	39	3.0	30.0	12.5	60.3	4.5	Hulled
VA99B-327	101.8	42.1	27	37	0.5	15.0	11.3	60.2	5.1	Hulled
VA01B-87	87.2	48.2	29	36	5.5	17.5	12.5	61.0	5.0	Hulled
VA01B-8	88.0	46.5	28	30	7.5	12.5	10.8	61.2	5.3	Hulled
VA01B-50	78.0	46.3	29	37	5.0	40.0	13.8	59.9	4.7	Hulled
VA01B-62	94.7	46.6	27	39	7.0	65.0	12.0	61.8	4.6	Hulled
SC880248	65.9	57.1	28	39	6.5	90.0	12.9	63.0	5.0	Hulless
VA00H-10	78.9	58.0	28	36	3.0	25.0	12.6	63.2	4.7	Hulless
VA00H-65	62.5	58.0	28	37	8.0	80.0	12.6	62.8	4.5	Hulless
VA00H-70	58.6	56.1	28	37	9.0	85.0	13.6	62.3	4.9	Hulless
VA00H-72	60.4	57.0	28	37	8.0	95.0	13.2	62.7	5.5	Hulless
VA00H-74	61.5	56.8	28	36	6.5	75.0	13.0	62.3	4.8	Hulless
VA00H-88	68.0	56.1	28	37	8.5	75.0	13.2	62.1	5.1	Hulless
VA00H-89	63.5	56.1	30	37	7.0	85.0	13.9	60.9	4.6	Hulless
VA00H-97	57.7	56.1	29	36	8.0	85.0	12.7	62.4	4.8	Hulless
VA00H-99	59.0	56.1	30	37	7.0	100.0	13.4	61.5	5.0	Hulless
Doyce	61.7	56.6	28	36	6.0	40.0	11.3	66.0	5.1	Hulless
VA01H-13	62.8	56.7	29	37	8.5	95.0	11.8	65.4	4.8	Hulless
VA01H-26	66.5	58.1	31	35	5.0	50.0	12.4	64.9	4.6	Hulless
VA01H-37	74.0	56.6	29	36	7.5	30.0	10.7	65.8	5.2	Hulless
VA01H-44	68.6	56.8	28	36	7.0	60.0	10.3	66.6	4.4	Hulless
VA01H-122	52.5	60.3	29	41	6.0	55.0	14.5	64.2	4.5	Hulless
VA01H-124	67.5	57.0	26	30	8.5	100.0	13.1	63.2	4.6	Hulless
VA01H-125	55.1	55.5	26	31	7.5	95.0	12.7	62.8	4.7	Hulless
VA01H-68	69.3	60.1	27	35	3.5	70.0	12.6	65.4	5.0	Hulless
H-585	63.3	58.0	26	39	7.5	90.0	13.3	62.4	4.8	Hulless
Means	77.7	51.4	28	36	5.8	56.0	12.3	62.1	4.8	
LSD (0.05)	18.4	2.0	3	3	3.7	35.4	1.2	1.2	NS	
CV (%)	11.7	1.9	4.5	4.0	31.8	31.3	5.0	1.0	3.2	

Table 3. Performance of hulled and hulless barley entries in 2004 test grown at Queenstown, Maryland.

Entry	Yield (Bu/A)	Test Weight (Lbs/Bu)	Heading (days*)	Height (inches)	Lodging (0-9)	Protein (%)	Starch (%)	Beta Glucan (%)	Hulls
Barsoy	76.1	49.4	24	32	1.0	12.7	61.2	5.1	Hulled
Wysor	66.2	44.0	31	37	1.5	11.1	60.4	5.0	Hulled
Nomini	56.0	43.2	29	36	1.0	11.6	60.3	4.9	Hulled
Callao	77.5	49.5	27	25	4.5	12.0	61.4	5.2	Hulled
VA92-42-46	45.3	45.5	30	36	1.0	12.6	60.2	4.8	Hulled
Thoroughbred	89.6	46.4	31	32	0.0	10.9	62.7	4.5	Hulled
VA96-44-304	64.1	47.5	26	28	4.5	12.0	59.9	4.8	Hulled
Price	63.7	48.3	31	25	2.5	11.6	60.6	4.8	Hulled
VA98B-208	76.4	47.3	30	26	2.5	12.4	59.7	5.0	Hulled
VA98B-213	64.2	49.0	30	25	1.0	12.5	60.1	4.8	Hulled
VA97B-175	75.0	48.4	27	26	1.5	11.3	62.0	4.6	Hulled
VA97B-176	66.8	48.7	29	26	3.5	12.4	60.7	4.7	Hulled
VA99B-161	81.1	47.7	30	28	1.0	11.9	60.7	4.8	Hulled
VA99B-125	64.7	48.2	30	25	3.0	12.3	60.5	4.8	Hulled
VA00B-91	50.8	46.0	36	23	1.0	12.1	61.2	4.5	Hulled
VA00B-279	67.7	42.0	26	35	1.5	11.5	59.6	4.6	Hulled
VA01B-26	62.8	46.8	31	31	1.5	12.9	59.9	4.6	Hulled
VA99B-327	73.1	42.6	28	34	2.0	11.3	59.9	5.0	Hulled
VA01B-87	72.6	48.3	30	25	1.0	12.2	60.9	4.8	Hulled
VA01B-8	91.5	45.0	27	25	4.0	10.8	60.4	5.2	Hulled
VA01B-50	63.1	46.1	29	32	2.5	12.9	65.0	4.8	Hulled
VA01B-62	84.9	49.9	26	29	3.5	11.6	61.9	4.7	Hulled
SC880248	52.3	57.3	30	29	1.0	13.1	62.3	5.0	Hulless
VA00H-10	50.5	52.5	31	28	1.0	12.4	62.7	4.9	Hulless
VA00H-65	59.4	56.1	28	31	1.0	12.4	63.1	4.7	Hulless
VA00H-70	51.1	56.5	31	26	2.0	13.2	62.0	4.8	Hulless
VA00H-72	45.8	57.5	31	27	1.5	12.8	62.7	5.1	Hulless
VA00H-74	46.8	57.7	30	28	1.0	13.0	62.7	4.6	Hulless
VA00H-88	37.1	59.1	32	25	1.0	13.4	62.2	4.6	Hulless
VA00H-89	54.8	59.1	30	30	1.5	12.7	63.6	4.5	Hulless
VA00H-97	53.7	57.9	31	29	1.5	12.9	63.1	4.7	Hulless
VA00H-99	53.4	55.2	30	29	3.0	12.3	62.9	5.1	Hulless
Doyce	62.1	53.7	28	31	4.5	10.7	66.2	5.2	Hulless
VA01H-13	53.4	56.0	30	30	2.5	12.7	64.0	4.9	Hulless
VA01H-26	61.9	56.7	30	27	1.5	11.8	64.2	4.7	Hulless
VA01H-37	53.2	55.4	30	26	2.0	11.8	64.4	5.0	Hulless
VA01H-44	37.1	56.0	32	24	2.5	12.3	63.7	4.8	Hulless
VA01H-122	42.2	59.5	30	33	1.5	14.1	62.6	4.6	Hulless
VA01H-124	62.7	56.6	25	25	4.0	12.4	63.3	4.5	Hulless
VA01H-125	42.4	53.5	27	23	5.0	13.0	61.8	4.6	Hulless
VA01H-68	54.0	56.9	29	31	1.0	12.8	64.7	4.8	Hulless
H-585	51.9	58.6	26	32	1.0	13.4	63.1	4.8	Hulless
Means	60.9	51.4	29	28	2.0	12.3	62.0	4.8	
LSD (0.05)	22.6	2.3	3	4	2.1	1.2	2.6	NS	
CV (%)	18.4	2.4	5.4	7.2	51.6	4.9	2.1	3.1	

Table 4. Average performance of hulled and hulless barley entries in 2004 test grown at 2 locations in Maryland.

Entry	Yield (Bu/A)	Test Weight (Lbs/Bu)	Heading (days*)	Height (inches)	Lodging (0-9)	Protein (%)	Starch (%)	Beta Glucan (%)	Hulls
Barsoy	76.5	49.3	24.3	34.8	2.3	12.9	61.2	5.0	Hulled
Wysor	75.8	43.3	30.0	38.3	2.8	11.2	60.4	5.0	Hulled
Nomini	74.9	43.8	28.3	38.5	2.3	11.8	60.7	5.0	Hulled
Callao	77.8	48.7	26.8	28.5	6.5	12.3	60.9	5.3	Hulled
VA92-42-46	61.4	45.1	28.5	39.8	4.0	12.4	60.6	5.0	Hulled
Thoroughbred	93.2	47.9	30.5	34.8	1.0	10.9	63.4	4.6	Hulled
VA96-44-304	78.9	46.4	26.5	32.0	5.5	12.3	59.5	4.7	Hulled
Price	79.6	47.4	29.8	30.8	3.0	11.5	60.6	4.6	Hulled
VA98B-208	87.6	46.5	30.0	28.8	3.0	12.0	60.2	5.1	Hulled
VA98B-213	78.6	46.5	29.0	30.3	3.0	12.1	60.2	4.9	Hulled
VA97B-175	87.3	48.0	27.0	30.3	4.3	12.1	61.2	4.7	Hulled
VA97B-176	73.5	48.1	28.0	30.5	4.3	11.8	61.1	4.6	Hulled
VA99B-161	88.4	47.6	28.8	31.3	2.8	11.5	61.0	4.8	Hulled
VA99B-125	79.2	47.5	29.3	29.3	5.0	12.2	60.5	4.8	Hulled
VA00B-91	67.2	45.5	33.0	29.8	2.8	12.2	60.9	4.6	Hulled
VA00B-279	84.4	44.3	28.5	36.3	0.8	11.6	59.7	4.7	Hulled
VA01B-26	77.4	46.6	29.3	34.8	2.3	12.7	60.1	4.6	Hulled
VA99B-327	87.5	42.3	27.3	35.5	1.3	11.3	60.1	5.1	Hulled
VA01B-87	79.9	48.2	29.3	30.0	3.3	12.3	61.0	4.9	Hulled
VA01B-8	89.8	45.7	27.3	27.0	5.8	10.8	60.8	5.3	Hulled
VA01B-50	70.5	46.2	28.8	34.3	3.8	13.3	62.4	4.8	Hulled
VA01B-62	89.8	48.3	26.0	33.8	5.3	11.8	61.9	4.7	Hulled
SC880248	59.1	57.2	28.8	33.8	3.8	13.0	62.7	5.0	Hulless
VA00H-10	64.7	55.2	29.3	31.8	2.0	12.5	63.0	4.8	Hulless
VA00H-65	61.0	57.0	28.0	33.5	4.5	12.5	62.9	4.6	Hulless
VA00H-70	54.9	56.3	29.3	31.0	5.5	13.4	62.2	4.9	Hulless
VA00H-72	53.1	57.2	29.5	31.8	4.8	13.0	62.7	5.3	Hulless
VA00H-74	54.1	57.2	29.0	31.8	3.8	13.0	62.5	4.7	Hulless
VA00H-88	52.5	57.0	30.0	31.0	4.8	13.3	62.1	4.9	Hulless
VA00H-89	59.2	57.6	29.8	33.5	4.3	13.3	62.3	4.6	Hulless
VA00H-97	55.7	57.0	29.5	32.3	4.8	12.8	62.8	4.8	Hulless
VA00H-99	56.2	55.6	29.8	32.8	5.0	12.9	62.2	5.1	Hulless
Doyce	61.9	55.1	28.0	33.5	5.3	11.0	66.1	5.2	Hulless
VA01H-13	58.1	56.3	29.3	33.3	5.5	12.3	64.7	4.9	Hulless
VA01H-26	64.2	57.4	30.0	30.5	3.3	11.9	64.5	4.7	Hulless
VA01H-37	63.6	56.0	29.3	30.5	4.8	11.3	65.1	5.1	Hulless
VA01H-44	52.8	56.4	30.0	29.8	4.8	11.3	65.1	4.6	Hulless
VA01H-122	47.4	59.9	29.3	36.5	3.8	14.3	63.4	4.6	Hulless
VA01H-124	65.1	56.8	25.3	27.0	6.3	12.8	63.2	4.6	Hulless
VA01H-125	48.8	54.5	26.3	26.5	6.3	12.9	62.3	4.7	Hulless
VA01H-68	61.7	58.5	28.0	32.5	2.3	12.7	65.0	4.9	Hulless
H-585	57.6	58.3	26.0	35.3	4.3	13.3	62.8	4.8	Hulless
Means	69.3	51.4	28.6	32.3	3.9	12.3	62.0	4.8	
LSD (0.05)	14.8	2.4	2.2	3.0	2.5	1.3	2.2	NS	
CV (%)	15.3	2.9	5.4	6.7	44.9	5.3	1.8	5.2	

Table 5. Overall performance of hulled and hulless barley entries grown in Maryland in 2002.

Barley Type	Yield (bu/A)	Test Weight (lbs/bu)	Beta Glucan (%)	Starch (%)	Protein (%)	Heading Date (April)	Height (in)	Lodging (0-10)	Aphid Damage (0-9)
Hulled	98.4	50.1	5.1	59.3	9.7	16	30.3	1.5	2.7
Hulless	63.1	60.7	5.2	61.6	10.2	16	28.9	1.6	4.1
"t" test	**	**	NS	**	NS	NS	NS	NS	*

Table 6. Overall performance of hulled and hulless barley entries grown at Clarksville in 2004.

Barley Type	Yield (bu/A)	Test Weight (lbs/bu)	Beta Glucan (%)	Starch (%)	Protein (%)	Heading Date (April)	Height (in)	Lodging (0-10)
Hulled	90.2	46.2	4.8	60.8	11.9	28	36	4.7
Hulless	63.9	57.1	4.8	63.5	12.7	28	36	6.9
"t" test	**	**	NS	**	*	NS	NS	*

Table 7. Overall performance of hulled and hulless barley entries grown at Queenstown in 2004.

Barley Type	Yield (bu/A)	Test Weight (lbs/bu)	Beta Glucan (%)	Starch (%)	Protein (%)	Heading Date (April)	Height (in)	Lodging (0-10)
Hulled	69.7	46.8	4.8	60.9	11.9	29	28	2.1
Hulless	51.3	56.6	4.8	63.3	12.7	29	28	2.1
"t" test	**	**	NS	**	*	NS	NS	*

Table 8. Overall performance of hulled and hulless barley entries grown in Maryland in 2004.

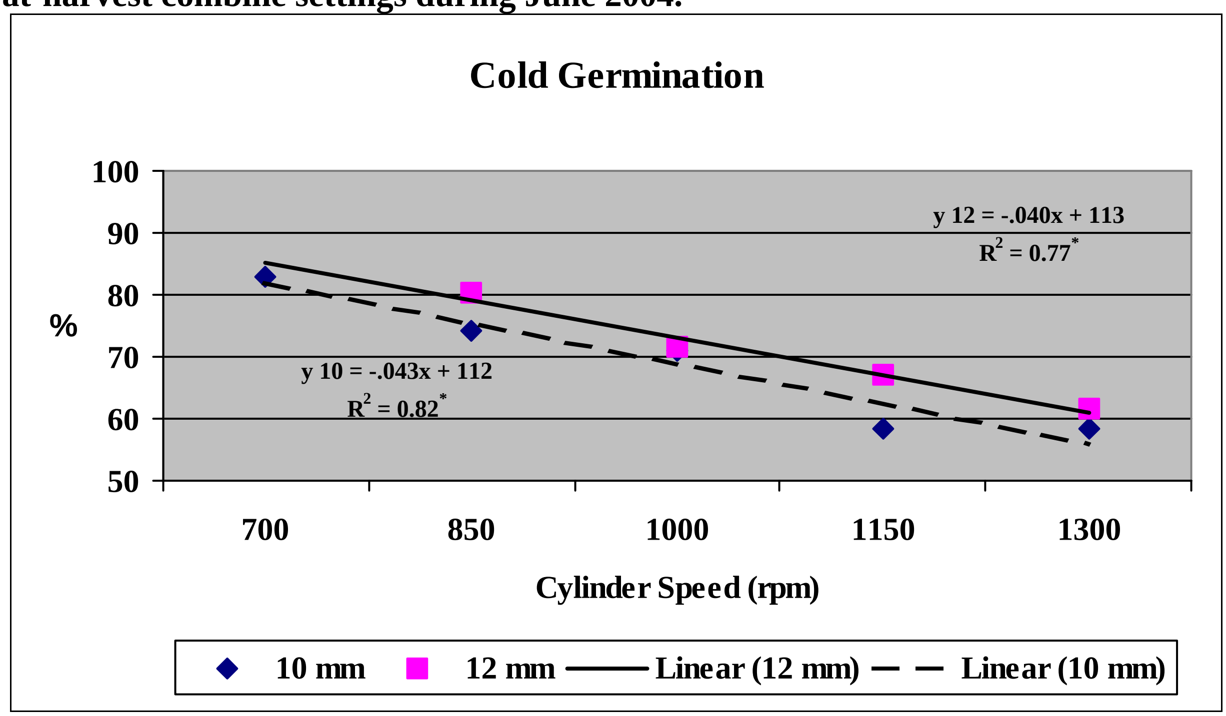
Barley Type	Yield (bu/A)	Test Weight (lbs/bu)	Beta Glucan (%)	Starch (%)	Protein (%)	Heading Date (April)	Height (in)	Lodging (0-10)
Hulled	80.1	46.5	4.8	60.8	12.1	29	33	3.4
Hulless	57.6	56.8	4.8	63.4	12.7	29	32	4.5
"t" test	**	**	NS	**	*	NS	NS	*

Results – Objective Two

Laboratory analyses conducted on the samples of hulless barley obtained from the combine setting study provided information about the germination percentage and number of abnormal sprouts. Percent germination is probably the most important seed quality characteristic to farmers since it directly determines how much seed will be required for planting their acreage. In this study, it also indicated if the seed had received varying amounts of damage across the different combine setting treatments that were used for harvesting the grain. Since the cylinder speed settings were quantitative, a simple linear regression analysis was conducted for each concave setting. A highly significant negative linear response was observed for percent seed germinated as combine cylinder speed increased from 700 rpm to 1300 rpm (Figure 1). Additionally, percent germination observed when the concave opening was 10 mm was less than was observed for the 12 mm concave setting.

The other seed quality characteristic that indicated if seed was damaged during harvest was number of abnormal sprouts (i.e. seeds that germinate but do not produce normal, healthy looking sprouts). For this characteristic there was no significant linear or quadratic response observed, however, an unacceptable number of abnormal sprouts (ranging from 9 to 15 percent) were produced across the combine cylinder speed treatments for both combine concave settings. Abnormal sprouts indicate that the germ area of the seed was damaged. The germination and abnormal sprouts results indicated that the hulless barley seed was damaged by the at-harvest combine settings and that a seed producer will want to set the combine for gentle threshing of hulless barley to minimize damage.

Figure 1. Germination response for `Doyce' hulless barley subjected to a range of at-harvest combine settings during June 2004.



Results-Objective Three

Even though barley is a commonly grown cereal grain in Maryland, hulless barley is considered a new crop sinceit has not been grown here prior to the past 3-4 years except in research plots. Using the nitrogen management recommendations for hulled barley, the objective of this study was to identify suitable nitrogen rates and timings of application for hulless barley. Since one of two locations where this study was conducted was abandoned during the spring of 2005, there is currently only data from one location that is available for establishing nitrogen recommendations. It is also important that these results were obtained on a silt loam soil type that retains nitrogen better than many of the sandier soil types that exist on the Delmarva peninsula. This study will be repeated during 2005-2006 and 2006-2007 crop years at two locations each year to obtain additional data.

For 2005, the use of 20 lb N acre^{-1} at fall planting increased yield 17 bu acre^{-1} (83 bu acre^{-1} compared to 66 bu acre^{-1}) compared to no fall nitrogen use when averaged over all greenup and jointing stage nitrogen treatments (Table 9). And, a fall application of 20 lb N acre^{-1} coupled with greenup applications or either 40, 60, or 80 lb acre^{-1} produced better yield than the same greenup applications that received no fall nitrogen (Table 9). A greenup nitrogen application of 40 lb N acre^{-1} following a fall application of 20 lb N acre^{-1} appeared to be near the optimum rate since 85 bu acre^{-1} was realized at that rate compared to 89 and 87 bu acre^{-1} respectively when either 60 or 80 lb N acre^{-1} was used in addition to the fall nitrogen application. No yield benefit was observed with jointing stage nitrogen applications that exceeded the 40 lb N acre^{-1} rate (Table 9).

Considerable interest has been expressed regarding the response that hulless barley will have if no fall nitrogen is used. For this one year, one location set of data, there was a definite yield advantage when 20 lb acre^{-1} of nitrogen was applied in the fall. When no fall nitrogen was applied, the nitrogen management strategy that used no nitrogen at greenup and 40 lb acre^{-1} at the jointing stage produced a yield comparable to what was observed when higher rates of nitrogen were applied at those two growth stages. This indicates that hulless barley may function as a dual-purpose crop, i.e. serving as a cover crop during fall and winter, and then serving as a grain crop in the spring under strict nitrogen management criteria. However, until additional data is obtained regarding this dual-purpose strategy, it appears that it would only be successful if financial incentives, such as currently exist for the cover crop program, were made available to farmers.

Table 9. Yield for `Doyce' hulless barley for different nitrogen fertilizer rates applied at fall planting, at spring greenup, and at jointing growth stages at Wye Research and Education Center during 2004-2005 crop year.

	Fall Nitrogen Rate ---------------Lb N acre^{-1}---------------									
	0					20				
	Greenup Stage Nitrogen Rate ----------------------Lb N acre^{-1}---------------------									
Joint Stage Nitrogen Rate	0	40	60	80	Mean	0	40	60	80	Mean
Lb N acre^{-1}	---------------------------------Bu acre^{-1}-------------------------------									
0	35b[1]	47b	49c	43c	**44**	46b	70b	88a	79b	**70**
40	76a	66a	64b	61b	**67**	73a	88a	88a	88ab	**84**
60	81a	69a	76ab	76a	**76**	77a	86a	87a	96a	**87**
80	78a	69a	86a	76a	**77**	85a	95a	92a	84ab	**89**
LSD	**12.4**					**12.4**				
Mean	**68**	**63**	**69**	**64**	**66**	**70b**	**85a**	**89a**	**87a**	**83**
LSD	**ND**					**5.3**				

[1]Means within each column that are followed by the same letter are not significantly different at p=0.05.

CONCLUSIONS

Hulless barleys are a potentially superior raw material for the production of ethanol because they have a higher starch content than hulled barleys. Over 2 years in Maryland trials, hulless barleys had 2 to 3 % points higher starch content than the hulled varieties traditionally grown in the mid-Atlantic. It should be pointed out that the hulled variety Thoroughbred consistently had a higher starch content compared to other hulled varieties such as Nomini (the variety most commonly grown in the region). This difference can be explained by the higher test weight and plumpness of the grain of Thoroughbred. Protein and Beta-glucan content were similar for both hulled and hulless barleys. An additional advantage of hulless barley is that it does not have the abrasive hulls of hulled barley that damages grain handling and grinding equipment. Grain yields of hull-less lines were lower than those of hulled lines. Current breeding of hulless barley at Virginia Tech and other breeding programs for the mid-Atlantic will likely close this gap in grain yield in the near future.

Continued screening of new varieties and lines of barley is important because it will provide useful information to both growers and users of barley about the performance of current and new cultivars of hulled and hulless barley that will soon be available to Maryland farmers.

With possible construction of an ethanol plant in Maryland using hulless barley as its primary feedstock, seed production necessary to plant the 100,000 to 200,000 acres of the crop will be needed. It is estimated that 3500 to 7000 acres of seed production will be required annually to meet the feedstock production requirements. Hulless barley seed growers must be particularly careful when harvesting the crop in order to minimize the damage to the seed. Much less aggressive at-harvest combine settings than are commonly used for hulled barley seed (i.e. cylinder speed of > 1000 rpm and concave opening of 10 mm or less) will be required to minimize the amount of damage to the kernels and maximizing the germination potential of the harvested seed. In this study, a cylinder speed of 700 rpm coupled with a concave opening of 12 mm safely and adequately threshed the hulless barley seed, producing seed that had 85% germination when tested.

Profitable and sound nitrogen management practices will also be a key criterion for hulless barley production. Only limited information is available at this time with data from one year and one location used for this evaluation. Research for nitrogen management strategies will continue in succeeding years on different soil types to fine-tune the nitrogen management recommendations for this crop. During 2005, a significant yield response was observed with the use of 20 lb N acre^{-1} in the fall. This was likely due to the better than average preceding corn crop that used nearly all the nitrogen it was supplied, and to the wet fall that was experienced following corn harvest and preceding barley planting that leached any residual nitrogen beyond the root zone for the barley seedlings. In this one location study, 40 lb N acre^{-1} at spring greenup followed by another 40 lb N acre^{-1} at jointing growth stage coupled with the 20 lb N acre^{-1} fall application was determined to be adequate to attain optimum yield.