Optimum seeding rates for hulless barley production in eastern Canada

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Abstract

Hulless barley is a relatively new crop in eastern Canada. Best cultural practices must be developed for hulless barley to achieve its maximum yield potential. A study was carried out to identify the optimum seeding rates for hulless barley in eastern Canada. Six barley lines consisting of two-row and six-row covered and hulless varieties (AAC Azimuth, AAC Starbuck, CDC Ascent, AAC Bloomfield, AAC Ling, and CH2720-1) were seeded in six different seeding rates (250, 350, 450, 550, 650, and 750 seeds m\(^{-2}\)) in a factorial experiment with four replications at seven sites across eastern Canada. The results showed that the optimum seeding rate for covered barley was 250–350 seeds m\(^{-2}\), but those for hulless barley higher yield potentials were achieved at seeding rate from 450 to 550 seeds m\(^{-2}\). Two-row varieties were higher yielding and had higher protein concentration than six-row varieties. The results of this study show that there is potential for further development of high-yielding two-row cultivars for eastern Canada.

Key words: seeding rate, hulless, yield

Introduction

Hulless barley contains high protein and high digestible energy and is increasingly popular for use in swine diets in western Canada (Bhatty 1999). It also contains high \(\beta\)-glucan, which, in turn, can lower the blood cholesterol level, enhance lipid metabolism, lower glycemic index, and reduce the threat of colon cancer (Shaveta and Kaur 2019). Hulless barley varieties with malting quality have been registered in Canada (Edney et al. 2014). Therefore, hulless barley can be used for multiple purposes: feed, food, and malt. In addition, hulless barley is less susceptible to mycotoxin contamination because dehulling during harvest eliminates a major portion of mycotoxins, if present, from barley grain (Clear et al. 1997). It provides a means to reduce mycotoxin contaminations, a common production problem of barley in eastern Canada (Campbell et al. 2000). Several hulless barley varieties have now been developed for eastern Canada. AC Alberte (Choo et al. 2001a, 2004), AAC Azimuth (Choo et al. 2013), and AAC Starbuck (Choo et al. 2015) are all low in deoxynivalenol (DON) content. Furthermore, both AAC Azimuth and AAC Starbuck contain an average amount of \(\beta\)-glucan, high levels of starch and protein, and reasonable levels of total antioxidant phenols, and they can be promoted for food use (Abdel-Aal and Choo 2014; Choo et al. 2015).
Growing hulless barley is a new venture in eastern Canada. Best cultural practices must be developed for hulless barley to achieve its maximum yield potential. Currently, the recommended seeding rates for barley in Ontario is 250–350 seeds m⁻² (OMAFRA 2017). Without protection from the hull, the embryo of hulless barley can be damaged mechanically by threshing, cleaning, and seeding and consequently fail to germinate or is not strong enough to emerge from the ground. Choo et al. (2001b) found that plant density was lower in hulless barley genotypes compared with covered genotypes at Charlottetown, PE. Therefore, a study was needed to determine the optimum seeding rates for hulless barley in eastern Canada. Previously, Thomason et al. (2009) reported that the seeding rates in VA, USA, should be at least 400 seeds m⁻² for winter hulless barley to approach optimum yields and that seeding at 480–520 seeds m⁻² is appropriate for sites with high yield potential. The objective of this study was to assess the effect of seeding rate on hulless barley grain yield and other agronomic and quality traits under the environmental conditions of eastern Canada.

Materials and methods

Plant material and experimental design

The experiment was conducted across four sites in eastern Canada, New Liskeard and Ottawa, ON; Normandin, QC; Charlottetown, PE, in 2018, and at all sites except New Liskeard in 2019 (Table 1). All crop management inputs were applied in accordance with local recommended practices for spring barley production in the region.

Six barley varieties were selected for this study and included three hulless varieties, AAC Azimuth (six rows), AAC Starbuck (two rows), CDC Ascent (two rows), and three covered varieties, AAC Bloomfield (six rows), AAC Ling (two rows), and CH2720-1 (two rows). AAC Azimuth, AAC Starbuck, AAC Bloomfield (Khanal et al. 2018), AAC Ling (Khanal et al. 2019), and CH2720-1 were developed by the Ottawa Research and Development Centre, Agriculture and Agri-Food Canada. The advanced breeding lines CH2720-1 and AAC Ling are sister lines from the Leader/Pasadena cross. CDC Ascent is a waxy, high β-glucan variety developed by the University of Saskatchewan.

These six varieties were planted at each site at six seeding rates (250, 350, 450, 550, 650, and 750 seeds m⁻²) arranged in 6 x 6 factorial experiment with four replications. To assure consistent plant populations, the number of seeds m⁻² was adjusted for germination rate of each seed lot. Plots were four, six, and eight rows, spaced 18 cm apart, and plot length ranged from 5 to 7 m, depending on the site-year (Table 1). Soybean was the previous crop at all site-years.

Plant height was measured after stem elongation and was the distance from the soil surface to the tip of spike, excluding awns. Heading days were recorded when 50% of the heads emerged. Grain was harvested from entire plot area using a plot combine, and the yield from each plot was adjusted to

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Fig. 1. Effect of seeding rate on barley grain yield (kg ha\(^{-1}\)) across seven environments in eastern Canada. Two-row varieties are represented by a solid circle; 6-row varieties are represented by a solid inverted triangle. Standard errors of the means are represented by solid squares. Waffle squares and circles represent group values for covered vs. hulless factors.

Table 3. Effect of seeding rate on grain yield, heading date, plant height, 1000 kernel weight, test weight, and protein across seven environments.

| Seeding rate | Type | Grain yield (kg ha\(^{-1}\)) | Heading days (days) | Plant height (cm) | 1000 kernel weight (g) | Test weight (kg L\(^{-1}\)) | Protein (%) |
|--------------|------|-----------------------------|--------------------|-------------------|------------------------|----------------------------|------------|
| Seed rate 250 | covered | 4108                        | 56                 | 71                | 49                     | 66                        | 12.5       |
|              | hulless | 3270                        | 58                 | 68                | 40                     | 76                        | 13.0       |
| Seed rate 350 | covered | 4274                        | 56                 | 70                | 48                     | 66                        | 12.4       |
|              | hulless | 3502                        | 57                 | 68                | 39                     | 76                        | 12.5       |
| Seed rate 450 | covered | 4143                        | 56                 | 70                | 47                     | 66                        | 12.4       |
|              | hulless | 3671                        | 57                 | 66                | 39                     | 76                        | 12.5       |
| Seed rate 550 | covered | 4212                        | 55                 | 69                | 46                     | 66                        | 12.2       |
|              | hulless | 3556                        | 57                 | 66                | 38                     | 75                        | 12.4       |
| Seed rate 650 | covered | 4145                        | 55                 | 67                | 46                     | 65                        | 12.1       |
|              | hulless | 3533                        | 57                 | 66                | 38                     | 75                        | 12.4       |
| Seed rate 750 | covered | 4211                        | 55                 | 68                | 45                     | 65                        | 12.1       |
|              | hulless | 3515                        | 57                 | 65                | 37                     | 75                        | 12.3       |
| Mean         |       | 3847                        | 56                 | 68                | 43                     | 71                        | 12.4       |
| Standard error |     | 85                          | 0.43               | 0.84              | 0.33                   | 0.35                      | 0.21       |

13.5% moisture content. A 1 kg sub-sample of grain was taken from each plot to determine test weight, 1000 kernel weight, and protein content. Protein content was measured by near infrared transmittance using an Infratec 1241 Grain Analyzer (FOSS Tecator, Hoganas, Sweden).

Statistical analysis

All statistical analyses were performed using GENSTAT version 19.1 (VSN International 2019). Mixed models were used to measure the influence of treatment main factors, variety, and seeding rate and their interactions on agronomic metrics. Site and year were included as random effects in the model. Output from reduced maximum likelihood mixed-models analysis was used to create a correlation matrix to perform principal components analysis (PCA). Subsequently, a PCA biplot was created by plotting scores from the first axis against scores from the second axis. Line graphs were prepared using the ggpubr version 0.4.0 (Kassambara and Kassambara 2020) and ggplot 2 version 3.3.5 (Wickham 2009) packages under R version 4.1.1.

Results

Analysis of variance

The combined Analysis of variance (ANOVA) for grain yield and related traits showed that both variety and seeding rate had highly significant main effects on all measured traits—grain yield, heading date, plant height, test weight, 1000 kernel weight, and grain protein (Table 2). When using the polynomial contrasts as a means of comparison to further evaluate the elements of each factor, there were highly
significant differences between covered and hulless varieties for all measured factors except 1000 kernel weight. Similarly, there were highly significant differences between two-row and six-row varieties for all factors except grain protein. For seeding rate, linear mixed models showed that there were highly significant or significant differences between all measured factors, and the quadratic model was highly significant \((p < 0.001)\) for grain yield. There were relatively few statistically significant variety \(\times\) seeding rate interactions, but at the \(p < 0.05\) level, plant height, 1000 kernel weight, and test weight were significant. Polynomial contrasts of the interaction term variety \(\times\) seeding rate showed significant differences between covered and hulless varieties in grain yield, 1000 kernel weight, test weight, two rows and six rows for plant heights, and two-row and six-row quadratic models for grain yield (Table 2).

Effect of seeding rate on barley varieties

Covered varieties had consistently higher yields than hulless barley varieties (Fig. 1); within those classes, two-row varieties showed higher yields than six-row varieties. AAC Ling had the highest average yield \((4254 \text{ kg ha}^{-1})\) of the two-row varieties tested. Hulless varieties showed increasing yield response with increasing seeding rates with peak at 500 seeds m\(^{-2}\) (Fig. 1). On average, hulless barley grain yield increased up to 500 seeds m\(^{-2}\) and then tended to level off and decline (Table 3; Fig. 1). A quadratic trend shows a decrease in yield at seeding rates above 500 or 550 seeds m\(^{-2}\), suggesting that there may be a risk in terms of yield loss to seeding at higher seed rates. However, covered barley grain yield did not show significant increase with increasing seeding rate (Fig. 1). On average, covered barley varieties produced 671 \text{ kg ha}^{-1} more grain than hulless varieties so that grain

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**Fig. 2.** Effect of seeding rate on barley days to heading (days) across seven environments in eastern Canada. Two-row varieties are represented by a solid circle; 6-row varieties are represented by a solid inverted triangle. Standard errors of the means are represented by solid squares. Waffle squares and circles represent group values for covered vs. hulless factors.

**Fig. 3.** Effect of seeding rate on barley test weight \((\text{kg} \text{ hl}^{-1})\) across seven environments in eastern Canada. Two-row varieties are represented by a solid circle; 6-row varieties are represented by a solid inverted triangle. Standard errors of the means are represented by solid squares. Waffle squares and circles represent group values for covered vs. hulless factors.
Fig. 4. Effect of seeding rate on barley 1000 kernel weight (g) across seven environments in eastern Canada. Two-row varieties are represented by a solid circle; 6-row varieties are represented by a solid inverted triangle. Standard errors of the means are represented by solid squares. Waffle squares and circles represent group values for covered vs. hulless factors.  

Fig. 5. Effect of seeding rate on barley plant height (cm) across seven environments in eastern Canada. Two-row varieties are represented by a solid circle; 6-row varieties are represented by a solid inverted triangle. Standard errors of the means are represented by solid squares. Waffle squares and circles represent group values for covered vs. hulless factors.

yield of hulless barley was, overall, 19% less than covered barley.

Seeding rates had similar response for plant height between covered and hulless varieties, with increasing seeding rate negatively affecting average plant height (Fig. 2). Covered barley varieties were on average taller than hulless varieties as one of the hulless varieties (CDC Ascent) was much shorter and did not respond to seeding rate. Analysis shows that seeding rate had a significant effect on days to heading, with increasing seeding rates reducing the days to heading for both types of barley (Table 3; Fig. 3). Polynomial contrasts for both linear and quadratic trends for test weight were significant for both barley types (Fig. 4; Table 3). Hulless barley produced an average test weight of 76 kg ha$^{-1}$, while average test weight of covered barley was 66 kg ha$^{-1}$, a difference of 13%. The 1000 kernel weight decreased linearly with increasing seeding rate for both covered and hulless lines (Fig. 5). Interestingly, hulless barley AAC Starbuck showed a similar or higher 1000 kernel weight than the covered AAC Bloomfield. Response to seeding rate on protein content was similar in both covered varieties, with decrease in protein content with increasing seeding rate (Fig. 6). The decrease in protein content was most pronounced at 550 seeds m$^{-2}$. CDC Ascent produced the highest concentration of protein, while AAC Boomfield produced the similar protein concentration at different seeding rates.

Multivariate analysis

PCA was performed to establish a global perspective on the differences between varieties, seeding rates, and their interaction (Fig. 7). In the PCA biplot, the first axis accounted for
Fig. 6. Effect of seeding rate on barley grain protein (%) across seven environments in eastern Canada. Two-row varieties are represented by a solid circle; 6-row varieties are represented by a solid inverted triangle. Standard errors of the means are represented by solid squares. Waffle squares and circles represent group values for covered vs. hulless factors.

Fig. 7. Biplot of principal component analysis (PCA) based on six traits (TW, test weight; HD, heading date; protein; TKW, 1000 kernel weight; GY, grain yield, and PHT, plant height) measured in six barley varieties at six different seeding rates; different colors correspond to the different barley varieties with corresponding seeding rates. 58% of the variability in the dataset. This axis was loaded positively by 1000 kernel weight, grain yield, and plant height and negatively by protein, heading date, and test weight. The biplot showed positive correlations among 1000 kernel weight, grain yield, and plant height. These factors were correlated with lower seeding rates in AAC Ling and CH2720-1. At higher seeding rates, these varieties were associated with earlier maturity, lower protein, and taller plants but also with a lower overall test weight and grain protein content. Higher test weight was correlated with earlier heading date and was associated primarily with lower seeding rates in CDC Ascent.

Discussion

This study showed that the optimum seeding rates for covered barley were 250–350 seeds m\(^{-2}\). Where seeding rate exceeded 350 seeds m\(^{-2}\), grain yield of AAC Bloomfield started to decrease. This finding supported the recommended seeding rate for barley in ON (OMAFRA 2017). More importantly, this study also showed that the optimum seeding rates for hulless barley ranged from 450 to 550 seeds m\(^{-2}\). The results agreed with Thomason et al. (2009), who reported that seeding winter hulless barley of 480–520 seeds m\(^{-2}\) is
appropriate for sites with high yield in VA. With a seeding rate of 450 seed m$^{-2}$, the average yield of hulless barley (3671 kg ha$^{-1}$) was 89% of the average yield of covered barley (4143 kg ha$^{-1}$). This yield difference was encouraging, given that the hulless class included the waxy hulless CDC Ascent that is not well-adapted to eastern Canada and that the hull itself accounts for approximately 15% of the kernel weight. The results of this study suggested that the barley production guides in eastern Canada should provide two recommended seeding rates, one for covered and the other for hulless barley.

The results also have implications for current testing procedures of performance trials or recommendation tests in eastern Canada. Currently, ON uses the seeding rates of 250–350 seeds m$^{-2}$ for spring barley in its performance trials. QC adopted the seeding rates of 350–400 seeds m$^{-2}$ for both two-row and six-row barley in its recommendation tests. Atlantic Canada specified a seeding rate of 350 seeds m$^{-2}$ for barley in its recommendation tests. These seeding rates are appropriate for covered barley but not for hulless barley because they underestimate the yield potential of hulless barley. To correctly compare the performance of hulless barley with that of covered barley cultivars, a higher seeding rate for hulless barley cultivars is more appropriate, given that their emergence rates are lower.

It has previously been shown that under the growing conditions in eastern Canada, two-row genotypes on average yield less than six-row genotypes (Jui et al. 1997). This study, however, showed that it is possible to develop high-yielding two-row barley for eastern Canada. AAC Ling (two-row covered) yielded as well as AAC Bloomfield (six-row covered), and it yielded even higher where seeding rates were low. Similarly, AAC Starbuck (two-row hulless) yielded higher than AAC Azimuth (six-row hulless) where seeding rates were low. Furthermore, both AAC Ling and AAC Starbuck contained more protein than six-row cultivars where seeding rates were low. Frégeau-Reid et al. (2001) also reported that two-row genotypes on average contain more protein than six-row genotypes under the growing conditions in eastern Canada. Another desirable characteristic of two-row barley is that two-row varieties are more resistant to DON accumulation than six-row varieties (Choo et al. 2004).

In conclusion, the results of this study confirm that the optimum seeding rate varies between covered and hulless barley varieties. The optimum seeding rate is 350 seeds m$^{-2}$ for covered barley and 500 seeds m$^{-2}$ for hulless barley. The findings suggest that to achieve the optimum yield, hulless barley seeding rate should be increased about 40% higher than recommended seeding rate for feed barley in eastern Canada.

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Data availability
Data are available from the corresponding author upon request.

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Competing interests
No competing interests exist among authors.

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