Research Article

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Effects of plant growth regulator application on the malting quality of barley

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Abstract

BACKGROUND: Lodging can negatively affect yield and quality of barley grain. Synthetic plant growth regulators (PGRs) reduce lodging by producing shorter, thicker, and stronger stems. However, the impact of applying PGRs on malting performance of barley is not known. The objective of this work was to assess the effect of application of three PGRs (ethephon, chlormequat chloride, and trinexapac-ethyl) in combination with different seeding rates on the malting quality of barley grown in several locations and years in western Canada.

RESULTS: The kernel weight in PGR-treated barley was reduced by 1.7% to 6.5% compared with the nontreated grain. Application of PGRs had no effect on the concentration of proteins and germination energy. Seeding rates significantly affected kernel weight, protein content, and germination index (GI), but no interactions between PGRs and seeding rates were observed. The smaller kernels of ethephon- and trinexapac-treated barley showed good hydration and grain modification during malting, as indicated by high levels of starch-converting enzymes, high Kolbach indices, and low levels of wort β-glucans. Overall, the fine extract of malt from PGR-treated barley was slightly lower than that of the control malt; however, the extract reduction was statistically significant only for chlormequat- and trinexapac-treated barley.

CONCLUSIONS: The application of PGRs had significant effects on kernel plumpness and kernel weight, but the effects of PGR application on the malting quality were generally small and insignificant. The decision of PGRs application on malting barley needs to be considered in combination with potential benefits of PGRs in mitigating lodging and their effects on the agronomic performance of barley.

Keywords: plant growth regulators (PGRs); barley; malting quality

INTRODUCTION

Barley (*Hordeum vulgare* L.) is a versatile crop used in animal feed, human food, and in the production of malt and beer. A short growing season and hot and dry climate on the Canadian Prairies create favorable conditions for cultivating barley, and Canada is the fourth largest producer of barley in the world, with an average yearly production of 9×10^6 t (2008–2017). Malting varieties make up approximately 60% of the barley seeded in Canada and are potentially the most profitable commodities for producers. However, barley selected for malting purposes has to meet the most stringent quality requirements, and cultivation of malting barley is challenging. Many aspects influence the quality and suitability of barley grain for malting and brewing purposes, including genetics, agronomic practices, and environmental factors. Discerning breeding practices resulted in the development of distinctive barley genotypes capable of producing high levels of various hydrolytic enzymes to efficiently hydrolyze/degrade the cell walls and proteins in barley endosperm during malting and completely convert starch into fermentable sugars during subsequent steps of the brewing process. In addition to genetic predisposition, barley selected for malting has to exhibit an appropriate level of grain protein (11–12.5%), adequate plumpness and kernel weight, a high germination potential (≥95%), and be free of microbial infestation and weathering.[1]

Even though it is possible to cultivate barley in a wide range of environments, adverse climatic conditions and abiotic stresses (e.g. drought, salt, precipitation, cold, and heat) may negatively affect the productivity and quality of the barley crop. For example, heavy rainfalls and strong winds during storm events are known to cause lodging in plant cereals, including barley. Lodging may lead to leaning or completely horizontal lying of plants on the ground,[2] causing substantial loss in yield depending on duration and time of lodging.[3] Jedel and Helm[2] reported higher yield loss

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when lodging occurred at the milk stage of barley grain development compared to lodging occurring at the hard-dough stage. Further, lodging may lead to problems in mechanical harvesting of the crop.[4] Several studies have reported that grain quality can also be degraded by negative effects of lodging on grain size and specific weight.[5,6] Jedel and Helm[2] further reported some reduction in kernel weight and an increased number of thin kernels for a tall barley (cv Johnson) when subjected to lodging treatment. Bending of cereals during lodging may also result in a higher susceptibility of grain to fungal attack, and consequently a higher level of mycotoxins.[7,8] Lodging, therefore, is an important factor that can negatively affect yield and quality of barley grain and lower its potential for being selected for malting. Accordingly, various strategies to prevent lodging or minimize its negative effects have been investigated. As numerous morphological, anatomical, and biochemical traits (e.g. plant height, stem diameter, stem wall thickness, and composition) are associated with lodging susceptibility of cereal grains, plant breeders integrate these traits in development of lodging-resistant cereal varieties. In addition, different agronomic approaches, such as tillage system, sowing time, seeding rate, nutrient application, and use of plant growth regulators (PGRs), have been shown to reduce lodging.[4]

PGRs are synthetic compounds that can modify plant growth and development. They can reduce lodging by producing shorter, thicker, and stronger stems. Ethephon (an active ingredient in the brand-name product Ethrel) is one of the oldest PGRs on the market. After absorption, it decomposes into ethylene in plants, which inhibits the movement of auxin in stem tissues, thereby reducing the auxin's ability to promote stem elongation.[9] Application of ethephon is time sensitive, as it needs to be applied at a particular crop stage to avoid yield losses. Chlormequat chloride and trinexapac-ethyl have a wider window of application. Both compounds are inhibitors of gibberellins; chlormequat chloride inhibits gibberellin biosynthesis in the early stages, whereas trinexapac-ethyl does so at later stages of gibberellin metabolism.[10] Chlormequat chloride (present in the brand-name product Manipulator) was introduced in Canada in 2013 and is used commonly by wheat growers. Trinexapac-ethyl (trade name Moddus) is commonly used in many countries, and its maximum residue limits are established in EU, USA, and Japan, and are currently undergoing registration review in Canada. The use of PGRs is standard practice in many western European countries. In the high yield potential environments of western Canada, PGR use is expected to increase once certain marketing and registration issues and application guidelines have been resolved and established. We have recently undertaken a study to determine if PGR application can mitigate lodging and possibly affect yield and quality of malting barley in western Canada.[11] The specific objective of this work was to assess the effect of PGR application in combination with different seeding rates on the malting quality of barley grown in several locations in western Canada regardless of occurrence of lodging.

MATERIALS AND METHODS

Plant materials and treatments

Field trials were conducted at three locations across the Canadian Prairies: Lacombe, AB (52° 28′ N, 113° 44′ W), Lethbridge, AB (49° 41′ N, 112° 46′ W), and Indian Head, SK (50° 32′ N, 103° 40′ W). In 2014, barley was grown in Lacombe, in 2015 in Lethbridge and Indian Head, and in 2016 in Lacombe and Lethbridge (Table 1). The effect of three PGRs (ethephon, chlormequat, and trinexapac) on barley, cv. CDC Copeland, at three seeding rates (200, 300, 400 m^{-2}) was assessed using a factorial randomized complete block design with four replicates. Ethephon was applied at early flag leaf emergence to swollen-boot stage (Zadoks scale 37–45). Chlormequat and trinexapac were applied before third node detectable stage (Zadoks scale 30). In each treatment, 120 kg ha^{-1} of nitrogen was applied, with other nutrients (potassium, phosphorus, and sulfur) supplied as per soil test recommendations at each site.

Barley grain analyses

Barley grown in all environments was tested according to the American Society of Brewing Chemists (ASBC) *Methods of Analysis* for protein content (ASBC Barley-7B), 1000 kernel weight (ASBC Barley-2D), plumpness (ASBC Barley-2C), and germinative energy (ASBC Barley-3A).[12] Germination index (GI) was calculated from germinative energy results according to Riis and Bang-Olsen.[13]

Micromalting and malt analyses

Barley was malted in a Phoenix Automated Micromalting machine (Phoenix Biosystems, Edwardstown, SA, Australia). Steep-out moisture was calculated from the difference in weight between dry matter barley and steeped barley.

Malt analysis was performed according to the procedures outlined in the ASBC methods. Malt samples were analyzed for moisture content (ASBC Malt-3) and malt modification by friability with a Pfeuffer friabilimeter (ASBC Malt12). Wort viscosity was determined with an Anton Paar Lovis ME rolling-ball viscometer (Anton Paar GmbH, Graz, Austria) (ASBC Wort-13B). Wort free amino-nitrogen concentration was determined by segmented flow analysis (ASBC Wort-12B). The content of β-glucan in wort was determined by measuring increased fluorescence from calcofluor binding with β-glucan polymers by segmented flow analysis (Skalar Analytical B.V., Breda, The Netherlands) (ASBC Wort-18B). Protein in unhopped wort (soluble protein) was determined by spectrophotometry based on the

Table 1. Soil classification and total precipitation for five environments (location–year combination) used for investigating the effects of plant growth regulators on the quality of malting barley (cv CDC Copeland)

Environment #	Year	Location	Province	Soil classification	Total precipitation (mm)
1	2014	Lacombe	Alberta	Black chernozem	286.8
2	2015	Lethbridge	Alberta	Dark brown	188.5
3	2015	Indian Head	Saskatchewan	Black chernozem	284.2
4	2016	Lacombe	Alberta	Black chernozem	365.6
5	2016	Lethbridge	Alberta	Black chernozem	275.2

Table 2. *P* values from the analysis of variance for the effects (fixed) of environment (E: location–year combination), plant growth regulator (PGR), seeding rate (SR), and interactions of E × PGR and PGR × SR on barley quality parameters. Replicates within each environment were considered random

	P-value[a]				
Dependent variable	E	PGR	SR	E × PGR	PGR × SR[a]
Plumpness (%)	**<0.0001**	**<0.0001**	0.0870	**<0.0001**	0.4920
1000-kernel weight (g)	**<0.0001**	**<0.00001**	**<0.0001**	**0.0092**	0.4912
Barley protein (%)	**<0.0001**	0.0768	**<0.0001**	**0.0119**	0.4474
Germination (4 mL, %)	**<0.0001**	0.0606	0.1833	0.0532	0.1748
Germination index	**<0.0001**	0.0721	**0.0001**	0.0982	0.6871

Significant effects ($P < 0.05$) are in bold.
[a] *P*-values in bold for treatment effects are statistically significant $P < 0.05$.

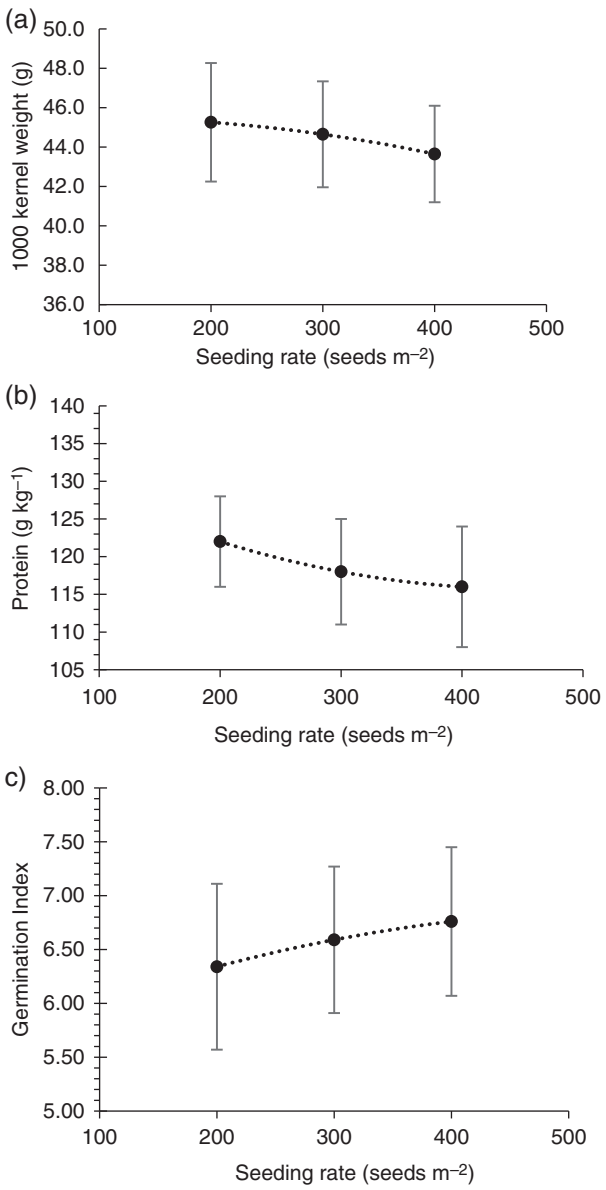

Figure 1. Effects of increasing seeding rates on (a) 1000 kernel weight, (b) grain protein concentration, and (c) germination index. Values averaged across the five environments tested in this study.

differing ultraviolet absorption of protein at 215 and 225 nm (ASBC Wort-17). Malt protein content was measured by nitrogen combustion with a LECO protein analyzer (F628, Leco Corporation, St. Joseph, Michigan, USA) (ASBC Malt-8B).

Statistical analyses

Statistical analyses were conducted in SAS Enterprise Guide Version 7.15. Analysis of variance (ANOVA) and Tukey–Kramer multiple comparison tests were used to determine all pairwise differences in mean values among treatments. For barley and malt quality parameters, PROC MIXED ANOVA was conducted for each control–treatment pair across environments and within each environment. For across-environment (E) analyses, environment (location by year combination), PGR, seeding rate (SR), and interactions of E × PGR and PGR × SR were treated as fixed effects and replicates were set as random effects. For within-environment analyses, PGR, SR, PGR × SR were treated as fixed effects, whereas replicates were treated as random effects. From the PROC MIXED ANOVA results, the consistency of the response across environments was evaluated by comparing the response observed between each control–treatment pair at individual environment to the control–treatment pair response averaged across all environments.

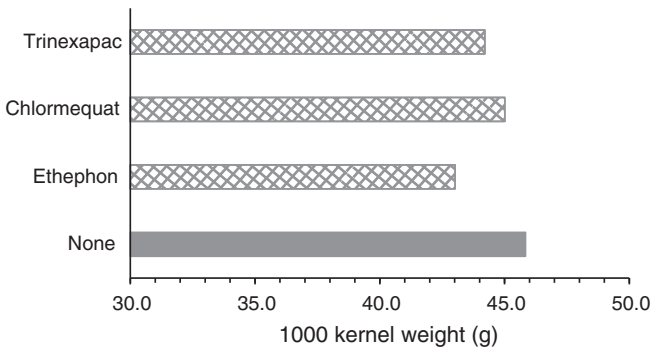

Figure 2. The effect of plant growth regulator application on mean kernel weight (averaged across all five environments). Crossed bars indicate the treatment means that are significantly different ($P < 0.05$) from the control as determined by treatment–control comparisons using PROC MIXED ANOVA.

Table 3. Effects of different plant growth regulator (PGR) application on barley quality parameters

PGR treatment	Plumpness (%)	1000 kernel weight (g)	Protein (g kg^{-1} db)[a]	GE[b] (%)	GI[c]
None	93.0c	45.8d	118a	97a	6.42a
Ethephon	90.0a	43.0a	119a	97a	6.62a
Chlormequat	92.5c	45.0c	117a	98a	6.69a
Trinexapac	91.2b	44.2b	120a	97a	6.52a

Values represent means from five environments used in this study. Means in the same column followed by a different letter are significantly different ($P < 0.05$), as determined by Tukey–Kramer multiple comparison test.
[a] db: dry basis.
[b] GE: germination energy.
[c] GI: germination index.

Table 4. *P* values from the analysis of variance for the effects (fixed) of environment (E: location–year combination), plant growth regulator (PGR), seeding rate (SR), and interactions of E × PGR and PGR × SR on malt and wort quality parameters. Replicates within each environment were considered random

	P-value				
Quality parameter	E	PGR	SR	E × PGR	PGR × SR
Malt					
Steep-out moisture	**<0.0001**	**<0.0001**	0.5203	0.3641	0.6684
Malt yield	**<0.0001**	**<0.0001**	0.5690	0.3225	0.7639
Malt protein	**<0.0001**	0.1183	**<0.0001**	**0.0011**	0.6358
Friability	0.0851	0.1908	**<0.0001**	**0.0298**	0.4006
Diastatic power	**<0.0001**	**<0.0001**	0.3627	0.4116	0.9725
α-Amylase	**<0.0001**	**<0.0001**	0.7574	0.1052	0.6579
Wort					
Fine extract	**<0.0001**	**0.0001**	**0.0044**	0.3069	0.7501
Wort soluble protein	**<0.0001**	**<0.0001**	0.1638	0.6423	0.5127
Kolbach index	**<0.0001**	**0.0007**	0.1624	0.8823	0.2384
Wort free amino-nitrogen	**<0.0001**	**<0.0001**	0.3118	0.9024	0.7874
Wort color	**<0.0001**	**0.0025**	0.2402	0.8628	0.5979
Wort β-glucan	**<0.0001**	**0.0004**	**0.0016**	**0.0140**	0.1558
Wort viscosity	**<0.0001**	**<0.0001**	**0.0024**	**<0.0001**	0.0727

Significant effects ($P < 0.05$) are in bold.

Table 5. Effects of seeding rate on malt and wort quality parameters

	Malt							Wort					
Seeding rate (m^{-2})	Steep-out moisture (g kg^{-1})	Yield (g kg^{-1})	Protein (g kg^{-1} db)[a]	Friability (%)	DP[b] (°)	α-Amylase (DU)[c]	Extract (g kg^{-1} db)	Soluble protein (g kg^{-1} db)	KI[d] (%)	FAN[e] (mg L^{-1})	Color (ASBC[f] units)	β-Glucan (mg L^{-1})	Viscosity (cP)
200	459a	906a	122b	73.1a	159a	71.0a	801a	491a	40.1a	221a	2.16a	100.6b	1.45a
300	458a	906a	119a	75.9b	158a	71.2a	803a	482a	40.4a	219a	2.10a	88.8b	1.45a
400	460a	905a	118a	77.7b	156a	71.7a	803a	483a	41.0a	222a	2.16a	85.2a	1.45a

Values represent means from five environments used in this study. Means in the same column followed by a different letter are significantly different ($P < 0.05$) as determined by Tukey–Kramer multiple comparison test.
[a] db: dry basis.
[b] DP: diastatic power.
[c] DU: dextrinizing units.
[d] KI: Kolbach index.
[e] FAN: free amino-nitrogen.
[f] ASBC: American Society of Brewing Chemists.

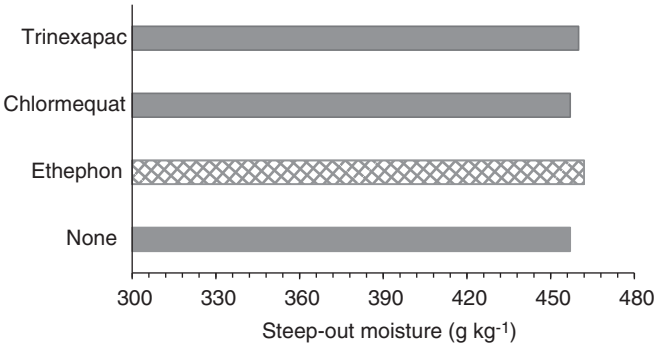

Figure 3. The effect of plant growth regulator application on mean malt steep-out moisture (averaged across all five environments). Crossed bar indicates the treatment mean that is significantly different ($P < 0.05$) from the control as determined by treatment–control comparisons using PROC MIXED ANOVA.

RESULTS AND DISCUSSION

Effects of PGRs on barley quality

'CDC Copeland', the most common malting barley variety in western Canada, was grown in three locations in the Prairies over three growing seasons (2014–2016), generating results from a total of five different environments (location–year combinations), as shown in Table 1. Ethephon was applied between the Zadoks stages 37 and 45, whereas chlormequat and trinexapac were applied before the Zadoks stage 30 of barley plant development. In addition to testing the effects of three different PGRs, the field trials also included three different seeding rates (200, 300, and 400 m^{-2}) to determine any possible interactions between the application of PGR and seeding rates. The environment had a significant effect on all barley quality characteristics tested in this study; namely, kernel plumpness and kernel weight, protein content, germination energy, and GI (Table 2). Overall, the application of PGRs had significant effects on kernel plumpness and kernel weight. In agreement with earlier studies,[14,15] seeding rates significantly affected kernel weight, protein concentration in the grain, and GI. Further, as previously observed, kernel weight and protein concentration decreased, whereas the GI increased as seeding rate increased (Fig. 1). However, no significant interactive effects between PGRs and seeding rates on any of the barley quality parameters were observed (Table 2), and the following sections of this manuscript will focus on the effects of PGRs when averaged across seeding rates.

The effect of an individual PGR on the mean kernel weight when averaged across all five environments is shown in Fig. 2 and Table 3. A statistically significant ($P < 0.05$) reduction in the mean kernel weight compared with the control was observed for all three PGRs (Fig. 2). Ethephon exhibited the greatest lowering effect, resulting in an overall 6.5% reduction of kernel weight compared with the control. The effect of ethephon was consistent, with all five environments showing a significant reduction in kernel weight, in agreement with the overall response observed across all environments. When averaged across all environments, trinexapac reduced the kernel weight by about 3.5%, and in three out of five environments the reduction was statistically significant compared with the control. The smallest reduction in kernel weight was observed with application of chlormeqaut (1.7%), and only in two out of five environments tested was the reduction statistically significant compared with the control (Fig. 2). It has been shown previously that timely application of chlormequat increased barley yield by 10–20% through increasing grain number without any compensatory decrease in grain size.[16–18]

When averaged across all environments, a small decrease in kernel plumpness was observed for each of the PGRs applied (Table 3). However, only for trinexapac- and ethephon-treated barley was the reduction in plumpness statistically significant ($P < 0.05$). Evaluation of results in individual environments revealed that a statistically significant ($P < 0.05$) lowering effect on kernel plumpness was observed in only two out of five environments for both compounds. The decreased kernel weight and plumpness may be a concern from a malting quality perspective, because maltsters place a large emphasis on plump kernels, which result in greater malt extract potential.[19] However, the PGRs-treated grain exhibited grain plumpness ranging from 90 to 92.5%, thus exceeding the required limit of 80% (Brewing and Malting Barley Research Institute).[1] The application of any of the PGRs tested did not have a negative impact on the germination energy of grain (Table 3). A small increase in GI (germination vigor) was observed for all three

Table 6. Effects of different plant growth regulator (PGR) application on malt and wort quality parameters

	Malt							Wort					
PGR treatment	Steep-out moisture (g kg^{-1})	Yield (g kg^{-1})	Protein (g kg^{-1} db)[a]	Friability (%)	DP[b] (°)	α-Amylase (DU)[c]	Extract (g kg^{-1} db)	Soluble protein (g kg^{-1} db)	KI[d] (%)	FAN[e] (mg L^{-1})	Colour (ASBC[f] units)	β-Glucan (mg L^{-1})	Viscosity (cP)
None	457a	906b	120a	75.2a	155ab	70.5ab	804b	481ab	40.1a	219b	2.10a	95b	1.46c
Ethephon	463b	901a	120a	76.8b	163c	72.3bc	803b	498c	41.4b	228c	2.24b	79a	1.45ab
Chlormequat	457a	907b	118a	75.6a	151a	68.6a	802ab	467a	39.4a	211a	2.07a	100b	1.45bc
Trinexapac	460ab	908b	121a	74.7a	161bc	73.6c	800a	495bc	41.0b	225bc	2.15ab	91ab	1.44a

Values represent means from five environments used in this study. Means in the same column followed by a different letter are significantly different ($P < 0.05$) as determined by Tukey–Kramer multiple comparison test.
[a] db: dry basis.
[b] DP: diastatic power.
[c] DU: dextrinizing units.
[d] KI: Kolbach index.
[e] FAN: free amino-nitrogen.
[f] ASBC: American Society of Brewing Chemists.

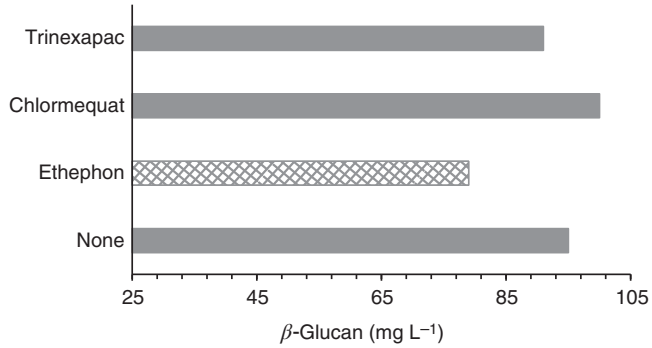

Figure 4. The effect of plant growth regulator application on mean wort β-glucan level averaged across all five environments. Crossed bar indicates the treatment mean that is significantly different ($P < 0.05$) from the control as determined by treatment–control comparisons using PROC MIXED ANOVA.

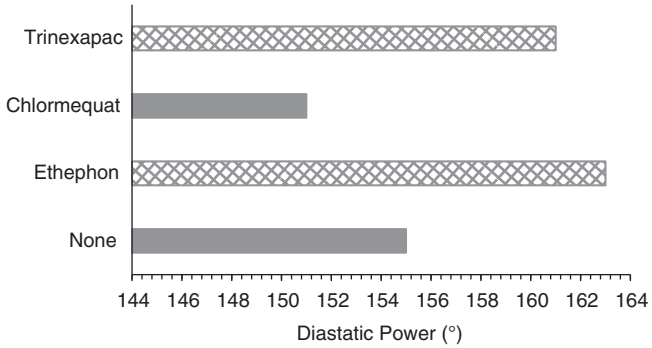

Figure 6. The effect of plant growth regulator application on mean diastatic power in malts averaged across all five environments. Crossed bars indicate the treatment means that are significantly different ($P < 0.05$) from the control as determined by treatment–control comparisons using PROC MIXED ANOVA.

PGR treatments when compared with the control (Table 3). This slight increase in vigor could be related to the reduced kernel size of PGR-treated barley compared with the control. It has been shown that smaller kernels tend to absorb water faster, and consequently initiate germination faster than larger kernels do. The application of PGRs had no significant effect, nor did it show any consistent pattern on the level of proteins in the grain (Table 3).

Effects of PGRs on malt quality

To assess the effects of PGRs treatments on quality of malt, barley was micro-malted using a Phoenix Automated Micromalting System and the resulting malt was analyzed for a variety of quality parameters. Not surprisingly, environment affected virtually all of the malting parameters (Table 4), reflecting the significance of locations and year-to-year variances on barley and malt characteristics. However, the objective of this study was to determine whether and how PGRs and seeding rate affect malt quality, and not to investigate the effects of environment on quality, which has been previously reported.[20,21] Seeding rate affected several aspects of malt quality (Table 4). Malt produced from high-seeding rate (400 m^{-2}) *versus* low-seeding rate (200 m^{-2}) had better endosperm modification, as reflected by lower levels of wort β-glucans (85.2 mg L^{-1} *versus* 100.6 mg L^{-1} respectively) and higher friability values (77.7% *versus* 73.1% respectively) (Table 5). The differences in extract between malts made from high- and low-seeding-rate barley (803 g kg^{-1} *versus* 801 g kg^{-1}, dry matter, respectively) were not statistically significant. These observations are in agreements with previous studies.[14] Application of PGRs on barley also affected several aspects of malt quality, but no significant interactions effects between PGRs and seeding rates on any of the malt quality parameters were observed (Table 4). Therefore, in the following we will focus on the effects of PGRs on malt quality when averaged across seeding rates.

On average, at the end of the steeping stage of the malting process, barley treated with ethephon exhibited higher steep-out moistures than the control (Fig. 3). This significant effect was observed in four out of five environments tested and can be related to the smaller size of kernels of ethephon-treated barley. The increased hydration of ethephon-treated grains during steeping contributed to improved modification of grain, as indicated by higher friability values (Table 6). Steep-out moistures for chlormequat- and trinexapac-treated barley did not differ significantly from the control and on average were lower than for barley treated with ethephon.

Malts produced from ethephon- and trinexapac-treated barley exhibited slightly better endosperm modification than the control, as indicated by lower levels of wort β-glucans, lower wort viscosity values, and higher Kolbach indices (Table 6). When averaged across all environments, wort produced from ethephon-treated barley showed significantly lower levels of

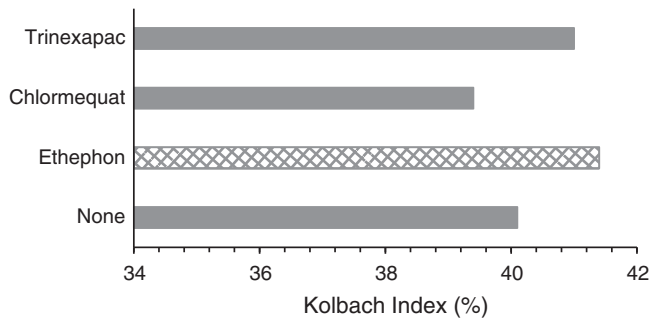

Figure 5. The effect of plant growth regulator application on mean wort Kolbach indices (ratio of soluble to total malt proteins × 100) averaged across all five environments. Crossed bar indicates the treatment mean that is significantly different ($P < 0.05$) from the control as determined by treatment–control comparisons using PROC MIXED ANOVA.

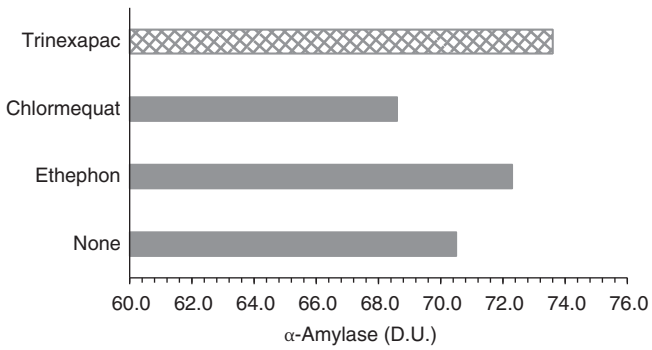

Figure 7. The effect of plant growth regulator application on mean α-amylase level in malts averaged across all five environments; DU: dextrinizing unit. Crossed bar indicates the treatment mean that is significantly different ($P < 0.05$) from the control as determined by treatment–control comparisons using PROC MIXED ANOVA.

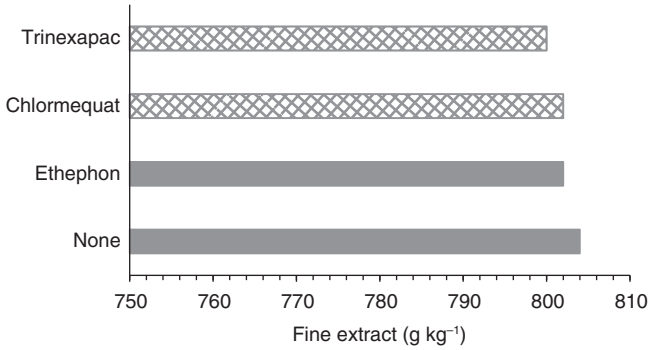

Figure 8. The effect of plant growth regulator application on mean malt extract level produced by differently treated barley averaged across all five environments. Crossed bars indicate the treatment means that are significantly different ($P < 0.05$) from the control as determined by treatment–control comparison using PROC MIXED ANOVA.

β-glucans compared with the control (Fig. 4). Significantly lower β-glucan levels were observed in worts from ethephon-treated barley from three out of five environments. On average, ethephon-treated barley produced worts with Kolbach indices higher than the control barley (Fig. 5). The levels of diastase enzymes (diastatic power) in malts from ethephon- and trinexapac-treated barley were generally higher than in the control malts (Fig. 6). The levels of α-amylase in malts from trinexapac-treated barley were significantly higher than in the control malts (Fig. 7).

Malts produced from chlormequat-treated barley showed lower levels of diastatic power and α-amylase than the other PGR-treated grain did (Table 6). Generally, malts produced from chlormequat-treated barley were less modified than other PGR-treated barleys were, as indicated by higher levels of wort β-glucans and lower Kolbach indices, but not significantly different from the control malt from untreated grain (Table 6, Figs 4 and 5).

In general, malts from each of the three PGR-treated barleys produced slightly lower extract than malt from untreated barley (Table 6). The extract reduction ranged from 1 to 4 g kg^{-1}, and the differences were found to be statistically significant ($P < 0.05$) for chlormequat- and trinexapac-treated barley (Fig. 8). Interestingly, despite having the smallest kernels, the ethephon-treated barley produced malt extract that was slightly higher than extracts from other PGR-treated barley and not significantly different from the control barley (Fig. 8). Most likely, the high levels of enzymes and good endosperm modification in malts of ethephon-treated barley compensated for the lower extract potential usually associated with smaller barley kernels.

CONCLUSIONS

The results of this study showed that application of any of the three PGRs investigated (ethephon, chlormequat chloride, and trinexapac-ethyl) reduced the kernel weight of barley. The kernel weight in PGR-treated barley was reduced by 1.7% to 6.5% compared with the nontreated grain, with ethephon instigating the greatest effects, observed consistently in all five environments tested (combination of years and locations), and chlormequat the smallest. Application of PGRs did not negatively affect other quality parameters of barley grain, including protein content, germination energy, and germination vigor. The effects of PGR application on the malting quality of barley were generally small. Overall, the fine extract of malt from PGR-treated barley was slightly lower than that of the control malt; however, the extract reduction was statistically significant only for chlormequat- and trinexapac-treated barley. The smaller kernels of specifically ethephon- and trinexapac-treated barley showed good hydration during steeping, good germination vigor, and good grain modification during malting, as indicated by high levels of starch-converting enzymes (diastase and α-amylase), high Kolbach indices, and low levels of wort β-glucans. The chlormequat-treated barley produced malt with somewhat reduced levels of enzymes and poorer endosperm modification than the ethephon- and trinexapac-treated barley did, indicating possibly a different mode of action of chlormequat chloride compared with the other two PGRs tested in this study. The increasing seeding rates produced barley with smaller kernels, but improved endosperm modification and the overall malting quality, in agreement with previous studies.[14] However, no significant interactive effects between PGRs and seeding rates on any of the barley or malt quality parameters were observed.

It is prudent to recommend that the decision of PGRs application for western Canadian malting barley needs to be considered in combination with potential benefits of PGRs in mitigating lodging and their effects on the agronomic performance of barley. Since PGRs are most useful in environments with abundant moisture, high levels of fertility, and in climatic conditions prone to intense precipitation and storm events, it might, however, be challenging to accurately predict the economic benefits of PGRs given the wide variety and unpredictability of climatic conditions in western Canada.

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