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Effect of preceding crop and nitrogen application on malting barley quality

Short title: Crop and nitrogen effects on malting barley

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As legume crops fix nitrogen (N) from the atmosphere, there is concern that soil residual N from legumes grown in rotation with malting barley may result in unacceptably high protein and negative effects on quality. However, little research has been conducted to investigate this. Field pea, lentil, faba bean [for seed or as a green manure crop (GM)], canola, and wheat were grown in 2009, canola in 2010 and malting barley in 2011. The objective was to determine the effects of crops grown in 2009 on quality of barley grown in 2011. Crops were direct-seeded at Lacombe, AB, Swift Current, SK, and Brandon, MB. Fertilizer N (urea) was applied in 2010 and 2011 at 0, 30, 60, 90, and 120 kg ha⁻¹. The legumes had few negative effects on barley quality compared to canola or wheat. Exceptions occurred at Lacombe where lentil and faba bean GM crops increased protein and decreased kernel plumpness. This was not evident at other locations. Increasing N fertilizer rate negatively affected almost all malt quality parameters at all locations. The results indicate that growing legume crops prior to malting barley is less likely to reduce malting barley quality than applying fertilizer N.

Key words: Legumes in rotation, barley germination, β -glucan, α -amylase, endosperm modification.

Barley (*Hordeum vulgare* L.) growers in western Canada often have difficulty achieving malting grade.. Annually, only about 20% of barley produced is acceptable for malting and the rest is sold as livestock feed. This can result in reduced revenues for growers (Smith et al. 2012). Relatively low protein concentration (110 to 125 mg g⁻¹) and plump (>800 mg kg⁻¹) uniform kernels are major acceptance criteria for malting grade. This derives largely from the perception that plump kernels contain higher starch levels, and to the inverse relationship between protein and starch (Weston et al. 1993). High protein is often associated with reduced malt extract levels, poorer endosperm modification, and problems with beer stability and viscosity (Mather et al. 1997; Edney et al. 2012).

Many factors influence barley protein concentration and overall malt quality in western Canada. The short growing season and adverse climatic conditions such as inadequate precipitation and high temperatures, can be a major factor in reducing quality (Edney et al. 2012). This can result in situations where growers may be limited in their management options when striving for optimum malting quality (Therrien et al. 1994). Recent research conducted in the Northern Great Plains indicated that optimal agronomic practices can improve malting barley yield and quality when conditions are favourable. These practices included strategic N fertilizer application (McKenzie et al. 2005; O'Donovan et al. 2011; Edney et al. 2012), proper cultivar selection (O'Donovan et al. 2011; Edney et al. 2012; O'Donovan et al. 2015), optimal seeding dates and rates (McKenzie et al. 2005; O'Donovan et al. 2012; O'Donovan et al. 2016), and appropriate crop rotations and tillage practices (Turkington et al. 2012; Sainju et al. 2013; Carr et al. 2014).

The effect of crop rotation on malting barley quality has received less attention when compared to other agronomic practices such as nitrogen application, seeding rate and seeding date. This is particularly true for sequences involving legume crops. Legume crops can achieve high levels of symbiotic N₂ fixation, producing a significant portion of

their own N needs and contributing to the N supply of non-legume crops grown in rotation with the legumes (Beckie et al. 1997; Miller et al. 2006; Walley et al., 2007; Gan et al. 2015). However, growers are often reluctant to grow legume crops prior to malting barley because of the perception that the practice may lead to unacceptably high seed protein content and rejection for malting grade. In a study in western Canada, planting barley directly on field pea (*Pisum sativum* L.) residue did not consistently result in an increase in grain protein (Turkington et al. 2012). Fertilizer N application was more likely to result in unacceptable protein concentration. It is unclear if the situation would change if legumes other than field pea were grown in rotation with malting barley, or if the barley was sown two years after the legume when decomposition of legume residues may be more complete.

A study was conducted at seven locations in western Canada (2009 to 2011) to determine the effects of several legume and non-legume crops grown in 2009, as well as fertilizer N application on yield and yield components of canola (*Brassica napus* L.) grown in 2010 and malting barley grown in 2011 (O'Donovan et al. 2014). In most cases the legume crops resulted in higher canola and barley yields compared to when wheat (*Triticum aestivum* L.) was the preceding crop. In addition, the legumes had little negative effects on canola oil or malting barley protein concentration.

Barley management studies rarely determine malting quality parameters other than protein concentration or kernel plumpness largely due to the high cost and time requirements associated with malt quality analysis (Edney et al. 2012). In addition, appropriate kernel germination, and maximum fine extract production are very important to maltsters and brewers. Two important features of barley kernel germination during the malting process are the synthesis of hydrolytic enzymes and the breakdown of barley endosperm structure (Enari and Sopanen 1986). When these processes have reached the desired stage, the germination process is interrupted by drying. Thus efficient and

rapid germination is a very important first step in the malting barley process. The amount of fine extract derived from the malting process is of high economic importance to maltsters and brewers since this is the material that determines the amount of beer produced. If the amount of extract is reduced, the amount of malt must be increased thus increasing the cost of production. Thus any crop management practice that results in a reduction in fine extract would be viewed with concern. The present study was an extension of the study of O'Donovan et al. (2014). The objective was to directly determine the effects of legume and non-legume preceding crops grown two years before malting barley, and fertilizer N rate and its interaction with preceding crops on several malting barley grain and quality parameters.

MATERIALS AND METHODS

Field Operations

A no-tillage field experiment was conducted at seven rain-fed locations in western Canada (Beaverlodge, Lacombe and Lethbridge, AB; Indian Head, Scott and Swift Current, SK; and Brandon, MB) between 2009 and 2011. In 2009, CDC Golden field pea, CDC Imperial lentil (*Lens culinaris* Medik), Snowbird faba bean (*Vicia faba* L.), imidazolinone-resistant 45H73 canola and CDC Imagine wheat were sown for seed production. Faba bean was also seeded as a green manure (GM) treatment. Legume seed was inoculated at each location. Canola and wheat only were fertilized with urea (46-0-0) at seeding time according to the soil test recommendation for N. Mono-ammonium phosphate (12-51-0) was applied to all crops according to the soil test recommendation for phosphorus. Thus the legume crops received a small amount of N.

The faba bean GM was sprayed at the flat pod leaf stage with glyphosate and clopyralid, and mowed in the fall and the entire plant returned to the soil surface.

After harvest, the straw of each crop was chopped and spread on the surface of the plots. These crops, seeded in 2009, provided the six preceding crop treatments for the canola and barley experiments conducted in 2010 and 2011, respectively.

In 2010 and 2011, glyphosate-resistant 7255 canola and AC Metcalfe malting barley were sown across the entire experimental area, respectively. The experiment in 2010 and 2011 was designed as a split-plot with the six crop residues established in 2009 as main plots. The subplots each year consisted of five N rates (0, 30, 60, 90, and 120 kg ha⁻¹) randomized within the main plots. Each treatment was replicated four times. Canola and barley were swathed at maturity and subsequently harvested with a small plot combine. Soil types, seeding dates and rates, soil nitrate nitrogen, and other agronomic management practices at the various locations are described in detail by O'Donovan et al. (2014).

Grain Germination, Kernel Plumpness and Malt Analysis

Constraints on capacity for micro-malting quality analysis limited the number of locations that could be malted and analysed. Of the seven experimental locations, samples for germination and malt analysis were selected from three replicates at Lacombe, AB, Swift Current, SK and Brandon, MB thus representing the three western Canadian Prairie provinces.

The proportion of plump kernels was determined by estimating the amount of seed retained on a sieve with 2.38 by 19.05 mm slots (Canadian Grains Commission 2016). Germination energy, protein concentration and micro-malting analysis were determined according to the standard methods of the American Society of Brewing Chemists (2004). Germination index, an indicator of the potential for rapid germination, was calculated from the germination energy results according to the method of Riis and Bang-Olsen (1991). Samples were malted in a Phoenix Automated Micromalting machine (Adelaide,

SA, Australia) using the following malting schedule: steeping (8 h wet, 16 h air, 8 h wet, 12 h air at 13 °C), germination (96 h at 15 °C) and kilning (12 h at 55 °C, 6 h at 65 °C, 2 h at 75 °C, 4 h at 85 °C – 24 h total). Malt analyses included: fine grind malt extract, which is a measure of a malt's beer production potential; Kolbach index, the ratio of soluble to total malt protein which is an indicator of the extent of protein modification; wort β -glucan which indicates the extent to which cell walls were degraded during malting; diastatic power (collective measurement of α - and β -amylase and β -glucanase activity) and α -amylase, enzymes that produce fermentable sugars from malt during mashing; and friability modification, an indicator of how well the endosperm was broken down during malting.

Data Analysis

Data from each of the three locations were analyzed for a split-plot design using PROC MIXED of SAS (Littell et al. 2006). Preceding crop and N rate were considered as fixed effects, and replicates as random effects. Mean separation (preceding crops only) was determined using Fishers protected least significant difference (LSD) test. Contrast statements were used to test for linear and quadratic responses to N rate. P values in Table 1 indicate the significance of the linear and quadratic responses to N rate as determined by PROC MIXED. Where responses were significant, regression equations were fitted to describe the relationship between the dependent variables and N rate. Differences were deemed significant at $P < 0.05$.

RESULTS AND DISCUSSION

There was a significant treatment by location interaction for the variables measured. Thus data are presented for each location. Preceding crops had few significant effects on grain or malting barley quality parameters and with the exception of kernel plumpness at Lacombe and β -glucan at Swift Current, there were no significant preceding crop by N

rate interactions (Table 1). Exceptions occurred mainly at Lacombe where preceding crops significantly affected kernel plumpness, protein concentration and friability modification.

Grain Quality Parameters

At Lacombe and Swift Current, kernel plumpness was greater than 800 mg kg^{-1} with all preceding crops (Table 2). However, at Lacombe, faba bean GM resulted in slight reductions in barley kernel plumpness compared to both wheat and canola, while lentil resulted in reduced kernel plumpness compared to canola. Overall kernel plumpness at Brandon was considerably lower ($<700 \text{ mg kg}^{-1}$) than at Lacombe or Swift Current, and tended to be slightly higher with canola than with the other preceding crops (Table 2). Overall, however, this study indicated few negative effects on kernel plumpness when legume crops were grown two years before malting barley. This is in general agreement with previous studies. Turkington et al. (2012) found an increase in kernel plumpness when barley was grown directly on field pea compared to barley residue. Similarly, increased kernel plumpness was reported when barley was seeded the year after field pea, lentil or faba bean (Wright 1990).

Barley protein concentration averaged across preceding crops and N rates was highest at Brandon (124 mg g^{-1}), intermediate at Lacombe (119 mg g^{-1}) and lowest at Swift Current (104 mg g^{-1}). Protein concentration did not differ among preceding crops at Brandon and Swift Current (Table 2). However, at Lacombe, protein concentration was significantly higher with lentil (126 mg kg^{-1}) and faba bean GM (123 mg kg^{-1}) than with the other preceding crops (Table 2). These concentrations at Lacombe would have made the samples marginally acceptable for malting grade since barley is often rejected for malting if the protein concentration exceeds 125 mg g^{-1} . This indicates that there may

be a higher risk of unacceptable protein levels with lentil grown for seed or faba bean GM. However, in the original study (O'Donovan et al. 2014) these preceding crops caused significant increases in barley protein only at three of the seven locations and the concentrations approached unacceptable levels (125 mg g^{-1}) only at Lacombe. This suggests that the overall risk may be relatively low. These results are in general agreement with previous studies which showed that legume crops are less likely to increase barley protein compared to crops fertilized with N when the barley is grown either one (Turkington et al. 2012; Williams et al. 2014) or two (Wright 1990; Ross et al. 2015) years after the legumes.

In contrast to preceding crops, N rate significantly affected all barley grain quality parameters except germination energy (Table 1). The effect of N rate on kernel plumpness was variable among the locations and there was a significant preceding crop by N rate interaction at Lacombe (Table 1; Fig. 1). The interaction was largely related to the lack of a significant response to N rate when wheat was the preceding crop whereas all other preceding crops resulted in a decrease in kernel plumpness as N rate increased (Fig. 1A). In addition, at high N rates the decrease in kernel plumpness tended to be more pronounced with lentil and faba bean GM than with the other preceding crops, again suggesting that there may be a slightly greater risk of rejection for malting grade with these preceding crops when protein concentration and kernel plumpness are used as criteria for selection. Slight decreases in kernel plumpness with increasing N rate also occurred at Swift Current but the opposite trend occurred at Brandon where kernel plumpness increased with increasing N rate (Fig. 1B). Previous studies have shown barley kernel plumpness usually decreased with increasing N rate but the results were sometimes inconsistent among locations and years (Zubriski et al. 1970; Lauer and Partridge 1990; McKenzie et al. 2005; O'Donovan et al. 2011).

As expected, protein concentration increased with increasing N rate at all locations (Fig. 1C). This is consistent with the results of previous studies (Lauer and Partridge 1990; McKenzie et al. 2005; O'Donovan et al. 2011; Turkington et al. 2012; Edney et al. 2012; O'Donovan et al. 2014), and is a major reason why malt barley growers are advised to limit N application.

The lower kernel plumpness at Brandon may have been associated with overall higher grain protein concentration at that location compared to Lacombe or Swift Current. The reason for the reduced kernel plumpness and high protein levels at Brandon relative to the other locations is unclear. Growing season precipitation was generally higher than average at all locations in 2011 and mean temperatures were close to normal (O'Donovan et al. 2014). Normally, protein content tends to increase under relatively dry conditions (Therrien et al. 1994).

Preceding crop had no effect on either germination energy or germination index while N rate had no effect on germination energy (Tables 1 and 2). However, the germination index was significantly affected by N rate (Table 1), and slightly decreased as N rate increased at both Brandon and Lacombe (Fig 2A). The decrease tended to be steeper at Lacombe than at Brandon. The results suggest that there may a higher risk of reduced potential for rapid germination at higher N rates but not when legumes are grown prior to malting barley. Edney et al. (2012) also showed a decrease in germination index with increasing N rate. In that study, the index tended to be higher with AC Metcalfe compared to CDC Copeland barley. In contrast to N rate, increasing the barley seeding rate was shown to increase the germination index (Edney et al. 2012; O'Donovan et al. 2016). This was possibly due to greater kernel uniformity at the higher seeding rates.

Malt Quality Parameters

The effects of agronomic practices on grain quality factors such as kernel plumpness and protein concentration have been used in many studies to indirectly indicate malting and brewing quality. However, endosperm modification during the malting process is complex. Thus effects on these factors are best determined directly if the impact of crop management on end use quality is to be clearly demonstrated and lead to reliable recommendations. To the best of our knowledge only a few studies (Weston et al. 1993; Li and Egi 2004; Edney et al. 2012; O'Donovan et al. 2016) have linked crop management practices directly to malt quality and none have investigated the effects of crop rotation or the interaction of crop rotation with N fertilization. In the present study, there were no effects of the preceding crops on any of the malting quality parameters including fine extract, kolbach index, β -glucan, diastatic power or α -amylase (Tables 1 and 2). There were slight differences in friability modification among the preceding crops at Lacombe, but reductions were not consistently associated with the legume or non-legume preceding crops (Table 2). Friability modification tended to be highest with field pea and lowest with wheat and lentil. The preceding crops had no effect on friability modification at Swift Current or Brandon (Tables 1 and 2).

In contrast to preceding crops, N rate significantly affected all malting barley quality parameters at one or more of the locations (Table 1), and, with the exception of diastatic power and α -amylase, the impact on quality was mostly negative. Endosperm modification was negatively impacted with increasing N rate as indicated by lower Kolbach indices (Fig. 2B), higher levels of wort β -glucan (Fig. 2C, Fig. 3A) and lower values for friability modification (Fig. 3B). There was a significant preceding crop by N rate interaction on β -glucan at Swift Current (Table 1; Fig. 2C) but not at Lacombe or Brandon (Table 1; Fig. 3A). This interaction is difficult to interpret but possibly reflects a higher β -glucan level at the highest N rate (120 kg ha^{-1}) with faba bean grown for seed

compared to the other preceding crops (Fig. 2C). These findings are generally consistent with previous studies where grain β -glucan content increased with increasing N rate (Guler 2003; Edney et al. 2012). However, in a Western Australian study, N had less of an effect on β -glucan content than cultivar or location (Paynter and Harasymow 2010).

The effect of N rate on enzyme levels was variable. As expected, diastatic power increased (Fig. 3C), which is consistent with higher protein concentrations, while α -amylase levels increased at Lacombe and Swift Current but not at Brandon (Fig. 4A). This may have been due to the lesser response of protein concentration to N rate at Brandon compared to the other two locations. Positive correlations between diastatic power, N rates and protein concentrations have been reported previously (Weston et al. 1993; Edney et al. 2012). Enzyme levels tend to increase with increases in protein concentration (Edney et al. 2012).

Overall, fine extract concentrations were highest at Swift Current (812 mg kg⁻¹) compared to Brandon (807 mg kg⁻¹) and Lacombe (805 mg kg⁻¹). The higher extract at Swift Current is consistent with the lower protein at that location. At all locations, fine extract levels decreased with increasing N rates (Fig. 4B). This is likely due to a reduction in starch content. Protein concentration increased with increasing N rate (Fig. 1C) and high protein is often associated with reduced starch content (Weston et al. 1993). Edney et al. (2012) also reported a reduction in fine extract with increasing N rate. However, in that study the response of fine extract to N differed between barley cultivars. AC Metcalfe had higher extract than CDC Copeland at low (<60 kg ha⁻¹) but not at high N rates.

The results of this study indicate few if any negative effects on barley grain or malting quality associated with growing legume crops two years prior to malting barley. There may be an elevated risk of higher protein or reduced kernel plumpness associated with lentil grown for seed or faba bean GM but this risk would likely be low. In contrast,

applying fertilizer N at relatively high rates negatively impacted many grain and malt quality parameters including a reduction in fine extract levels. In the original study (O'Donovan et al. 2014), malting barley yield increased by 6 and 7% when field pea or lentil, respectively, preceded the barley by two years compared to when wheat was the preceding crop. In addition, the study found that the amount of fertilizer N required to obtain a given barley yield could be reduced by 25% in a legume (field pea or lentil)/canola/barley rotation compared to the more common wheat/canola/barley rotation. This resulted in higher economic returns with the legume/canola/barley rotation (Khakbazan et al. 2014). This study also showed that faba bean grown for seed was less likely to increase yield and net return; and while faba bean GM resulted in the highest barley yield, net return was lowest due to a lack of crop revenue during the GM year (Khakbazan et al. 2014). It is unlikely, however, that legume green manure crops would be grown in rotation with malting barley. In conventional farming systems in western Canada, annual legume crops, especially field pea and lentil, would most likely be grown as cash seed crops. The results from this study would therefore be most relevant to these growers.

CONCLUSIONS

The results of this study and that of Turkington et al. (2012) suggest that malting barley growers in western Canada can grow legume crops in rotation with malting barley without compromising grain or malting quality, and thus accrue the economic and environmental benefits associated with rotating legumes with non-legumes. Significantly, legume crops preceding non-legume crops such as barley may allow for a reduction in fertilizer N which can have a major negative impact on grain and malting quality. Further studies may be necessary to determine the effect of growing legumes other than field pea [e.g. lentil, faba bean, soybean (*Glycine max* L.)] the year before barley on grain and

malting quality, and on the interactive effects of split-applications of N with the rotational crops.

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Fig.1. Effect of increasing N rate on (A) kernel plumpness at Lacombe, (B), kernel plumpness at Swift Current and Brandon, and (C) grain protein at Lacombe, Swift Current and Brandon. Regression equations were fitted when linear or quadratic responses were significant ($P < 0.05$) as determined by PROC MIXED (see Table 1). NS indicates non-significant linear or quadratic response.

Fig. 2. Effect of increasing N rate on (A) germination index and (B) kolbach index at Lacombe, Swift Current and Brandon, and (C) β -glucan at Swift Current. Regression equations were fitted when linear or quadratic responses were significant ($P < 0.05$) as determined by PROC MIXED (see Table 1).). NS indicates non-significant linear or quadratic response.

Fig. 3. Effect of increasing N rate on (A) β -glucan at Lacombe and Brandon, and (B) friability modification and (C) diastatic power at Lacombe, Swift Current and Brandon. Regression equations were fitted when linear or quadratic responses were significant ($P < 0.05$) as determined by PROC MIXED (see Table 1).

Fig. 4. Effect of increasing N rate on (A) α -amylase and (B) fine extract at Lacombe, Swift Current and Brandon. Regression equations were fitted when linear or quadratic responses were significant ($P < 0.05$) as determined by PROC MIXED (see Table 1). NS indicates non-significant linear or quadratic response.

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Table 1. P values from the ANOVA for the effects of preceding crop, nitrogen (N) rate and their interaction on malting barley grain and malt quality. Significant ($P < 0.05$) effects are indicated in bold type.

Location	Effect	Germination energy	Germination index	Kernel plumpness	Protein	Fine extract	Kolbach index	β -glucan	Diastatic power	α -amylase	Friability modification
Lacombe	Preceding crop (C)	0.602	0.335	0.039	0.009	0.154	0.157	0.4966	0.422	0.189	0.037
	N rate (N)	0.447	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.058	<0.001
	C x N	0.451	0.391	<0.001	0.545	0.457	0.731	0.211	0.100	0.791	0.964
	N linear ^a	0.365	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.034	<0.001
	N quadratic ^a	0.155	0.613	0.010	0.224	0.158	0.667	<0.001	0.147	0.582	0.412
Swift Current	Preceding crop (C)	0.454	0.112	0.894	0.555	0.715	0.243	0.980	0.395	0.215	0.874
	N rate (N)	0.583	0.958	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	C x N	0.865	0.304	0.359	0.166	0.264	0.403	0.008	0.715	0.967	0.355
	N linear ^a	0.165	0.741	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	N quadratic ^a	0.431	0.944	0.038	<0.001	<0.001	<0.001	0.006	0.001	0.186	<0.001
Brandon	Preceding crop (C)	0.510	0.369	0.042	0.751	0.970	0.129	0.917	0.665	0.102	0.742
	N rate (N)	0.448	<0.001	<0.001	<0.001	0.028	<0.001	<0.001	<0.001	0.894	<0.001
	C x N	0.992	0.639	0.233	0.254	0.868	0.451	0.612	0.468	0.902	0.474
	N linear ^a	0.181	<0.001	<0.001	<0.001	0.687	<0.001	<0.001	0.001	0.437	<0.001
	N quadratic ^a	0.595	0.253	0.060	<0.001	0.001	<0.001	<0.001	0.131	0.508	<0.001

^aP values indicate the significance of linear and quadratic responses to seeding rate as indicated by PROC MIXED.

Location	Preceding crop	Germination energy (mg g ⁻¹)	Germination index	Kernel plumpness (mg g ⁻¹)	Protein (mg g ⁻¹)	Fine extract (mg g ⁻¹)	Kolbach index (mg g ⁻¹)	β-glucan (mg l ⁻¹)	Diastatic power (°L)	α-amylase (DU)	Friability modification (mg g ⁻¹)
Lacombe	Field pea	973	7.0 a	850 abc	117 b	802 a	431 a	134 a	187 a	71 a	696 a
	Faba bean	989	7.0 a	856 ab	117 b	808 a	409 a	191 a	183 a	75 a	645 ab
	Lentil	981	6.6 a	821 bc	126 a	802 a	409 a	232 a	185 a	75 a	575 c
	Faba bean (GM)	975	6.6 a	805 c	123 a	804 a	401 a	204 a	186 a	76 a	617 bc
	Wheat	981	6.9 a	859 ab	117 b	806 a	415 a	160 a	175 a	75 a	575 c
	Canola	991	6.8 a	868 a	115 b	807 a	409 a	152 a	176 a	74 a	617 bc
	LSD _{0.05}	NS	NS	43.6	5.50	NS	NS	NS	NS	NS	69.8
Swift Current	Field pea	998	7.5 b	875 a	104 a	811 a	452 a	98 a	153 a	77 a	856 a
	Faba bean	996	7.9 ab	877 a	104 a	813 a	461 a	99 a	156 a	77 a	865 a
	Lentil	994	7.9 ab	872 a	103 a	813 a	467 a	91 a	163 a	79 a	865 a
	Faba bean (GM)	997	8.2 a	881 a	104 a	813 a	460 a	93 a	156 a	79 a	864 a
	Wheat	997	8.2 ab	872 a	104 a	811 a	446 a	94 a	157 a	77 a	878 a
	Canola	999	7.9 ab	875 a	105 a	812 a	449 a	96 a	160 a	78 a	858 a
	LSD _{0.05}	NS	0.558	NS	NS	NS	NS	NS	NS	NS	NS
Brandon	Field pea	991	8.9 a	630 b	123 a	808 a	430 a	131 a	171 a	82 a	675 a
	Faba bean	992	8.9 a	617 b	123 a	807 a	447 a	119 a	166 a	81 a	684 a
	Lentil	998	9.2 a	646 b	125 a	806 a	415 a	126 a	171 a	83 a	670 a
	Faba bean (GM)	993	9.3 a	656 ab	125 a	807 a	427 a	117 a	175 a	82 a	675 a
	Wheat	992	9.3 a	642 b	123 a	808 a	433 a	145 a	177 a	84 a	670 a
	Canola	991	9.2 a	699 a	125 a	806 a	421 a	148 a	172 a	85 a	662 a
	LSD _{0.05}	NS	NS	48.4	NS	NS	NS	NS	NS	NS	NS