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Digestibility and growth performance of feedlot cattle fed pelleted grain screenings

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Digestibility and growth performance of feedlot cattle fed pelleted grain screenings

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Feed and Fecal NIRS in feedlot cattle fed pelleted grain screenings

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Digestibility and growth performance in feedlot cattle fed pelleted grain screenings. Can. J. Anim. Sci. **XX**: YY-ZZ. The impact of two different grain screening pellets (GSP) on the chemical profile of feces, feed digestibility, growth performance and carcass traits of feedlot heifers was measured. Near infrared spectroscopy (NIRS) was used to predict differences in the chemical composition and energy content of GSP and feces. Heifers (445 ± 35.5 kg) were allocated to 15 pens (10 heifers/pen) and offered three diets 1) 76% barley grain (DM basis; control); 2) light screening pellets (LSP) and 3) heavy screening pellets (HSP), where GSP replaced 20% barley grain. In controls, fecal starch tended to be higher ($P = 0.09$) and NDF lower ($P < 0.01$) than heifers fed GSP diets. Fecal nitrogen (N) and EE were also higher ($P < 0.05$) in heifers fed the control as compared to GSP diets. The ADG of heifers fed LSP tended to be lower ($P < 0.06$) than the control diet. Gain:feed in controls was higher ($P < 0.02$) than in those fed GSP diets. Both ADG and G:F, were positively associated with fecal N, and starch, but negatively associated with NDF. Compared to direct measurements, NIRS over predicted total digestible nutrient (TDN) content of GSP, but did predict most differences in chemical composition.

Key words: feedlot cattle, screening pellets, near infrared spectroscopy, feed efficiency

Abbreviations: ADF, acid detergent fibre; ADG, average daily gain; ADL, acid detergent lignin; aTTD, apparent total tract digestibility; CP, crude protein; DM, dry matter; DMI, dry matter intake; EE, ether extract; GE, gross energy; G:F, gain:feed; GSP, grain screening pellets; HSP, heavy grain screening pellet diet; LSP, light grain screening pellet diet; NIRS, near

infrared spectroscopy; **N**, nitrogen; **NDF**, neutral detergent fibre; **OM**, organic matter; **PC**, principle component; **PCA**, principle component analysis.

Introduction

The expansion of the biofuel industry has increased demand for cereal grains, encouraging producers to seek cheaper alternative by-product feeds for cattle. Grain and pea screenings, dried distillers' grains (DDG), canola meal, and oat hulls have become common substitutes for cereal grains in beef cattle diets. Grain screenings are the primary by-product arising from the Canadian grain industry, and it is estimated that there are as much as one million tonnes of feed screenings available in western Canada each year (PAMI 2000). In Saskatchewan alone, over 600,000 tonnes of grain screenings are produced annually (PAMI 2000).

In Canada, grain screenings consist of mixtures of broken grain, chaff, weed seeds, and dust (Marx et al. 2000) and are often pelleted which allows for a more defined nutrient composition when fed (Thomas and van der Poel 1996). Typically grain screenings are higher in protein and fibre, but lower in energy than cereal grains (Marx et al. 2000), and can account for up to 50% of the diet DM in barley-based diets without compromising the growth performance of feedlot steers (Pylot et al. 2000). As the ingredient and chemical composition of screenings varies considerably, they are marketed primarily on the basis of bulk density, rather than on their nutrient composition (Beames et al. 1986; Marx et al. 2000).

Immediate assessment of the feed value of screenings is desired so purchasers can use them to formulate balanced diets for feedlot cattle. Near infrared spectroscopy (NIRS), a rapid alternative method to wet chemistry is currently used by some feedlot producers and feed mills to predict the nutritional value and energy content of grain screenings (Gibb, personal

communication). However, predictions of energy content are derived from calculations based on nutrient or anti-nutritional components of the feed (NASEM 2016; Owens et al. 1999; Weiss 1992) rather than actual cattle growth performance.

In addition to feed, NIRS has been applied to measure the feces of cattle and relate it to feedlot growth performance and efficiency (Jancewicz et al. 2016b). When fed high grain diets, starch is the major source of dietary energy for cattle, and its concentration in feces has been shown to be a predictor of starch digestibility (Zinn et al. 2002; Zinn et al. 2007; Zinn et al. 2011). In contrast to cereal grains, grain screenings are typically quite low in starch with a larger proportion of their energy value being associated with the presence of digestible lipids, proteins, and fiber (Marx et al. 2000). Using NIRS to predict fecal nutrient concentrations and digestibility within compositionally diverse ingredients such as grain screenings could be useful information for the nutritional management of feedlot cattle.

The objectives of this research were to assess the impact of feeding two different grain screening pellets (GSP) on the chemical profile of feces, feed digestibility, growth performance and carcass traits of feedlot heifers. In addition, the extent to which NIRS could predict the chemical composition and the energy value of GSP and the digestibility and growth performance using the feces of heifers fed GSP was evaluated.

Materials and Methods

Grain screening pellets

Two different GSP were manufactured at Hi-Pro Feeds (Lethbridge, AB). On a DM basis, the light screenings pellet (LSP) contained a 60:40 mixture of “heavy” and “light” screenings whereas the heavy screenings pellet (HSP) contained 77.5% “heavy” screenings, 10%

millrun, 10% beet pulp, and 2.5% canola oil to raise the levels of crude protein (CP), neutral detergent fiber (NDF) and EE (Table 1). In the industry light screenings range from approximately 90 to 155 g/L, with 206 g/L being the minimum for distribution in Lethbridge AB, whereas heavy screenings can range from approximately 335 to 618 g/L. Light screenings typically contain more chaff and hulls, whereas heavy screenings are composed of more broken small grains, weed seeds, and canola. The exact parent grain composition of the screenings was not known since they were separated solely on the basis of light versus heavy, and collected over several months. Light and heavy screenings were a mixture arising from the cleaning of predominantly barley grain, lentils and canola. Light screenings contained more chaff and hulls whereas heavy screenings contained more broken small grains, weed seeds, and canola. The two lots of GSP were prepared for the entire experiment and transported to the Lethbridge Research Center for use over the duration of the study.

Experimental Design, Animals, Housing, and Diets

The study received institutional animal care approval and was conducted according to the guidelines established by the Canadian Council on Animal Care (2009). A total of 150 yearling British crossbred heifers (445 ± 35.5 kg) were housed in pens, bedded with straw, and provided with free access to water. The experiment was conducted as a completely randomized design with 3 dietary treatments and 5 replicate pens per treatment. Each pen housed 10 heifers, with pens being randomly assigned to diet. Upon arrival at the research feedlot, heifers were ear tagged, implanted with a growth promoter (Component TE-S with Tylan, Elanco Animal Health, Guelph, ON, Canada), and vaccinated (Pyramid 4 modified-live vaccine, Fort Dodge Animal Health, Overland Park, KS; Vision[†] 7, Intervet Int., Millsboro, DE). Heifers were transitioned

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from a barley silage diet to their respective high grain diet by increasing the level of barley grain and decreasing the level of silage by 11% every 5 d. The control diet included 76% dry-rolled barley, 10% wheat distillers' grains, 9% barley silage, and 5% supplement (DM basis). Pelleted grain screenings were substituted for 20% of the barley grain in both the LSP and HSP diets at the start of the transition period. Diets were formulated to meet or exceed NASEM recommendations (2016). Barley grain was obtained from a single source and was dry-rolled to a processing index of 81%, calculated as the weight of the grain after dry rolling divided by the weight of whole unprocessed grain. Both monensin sodium and tylosin phosphate were included in the diets at 33 and 11 ppm, respectively. Melengestrol acetate was also included in the diet at 0.43 mg d^{-1} to suppress estrus (Table 1).

Initial body weight ($445 \pm 35.5 \text{ kg}$) was determined by weighing the heifers on two consecutive days after they had adapted to the finishing diets and were re-implanted after 50 d on feed. Feed was delivered once daily in the morning and heifers were fed to appetite to minimize orts. Heifers were fed finishing diets for 100 d to a target slaughter weight of 600 kg, before being transported to a commercial abattoir and all slaughtered on the same day.

Feed Sampling and Analysis

Samples of grain, barley silage, TMR and orts were collected weekly and composited after 50 d and 100 d. Sub-samples of the GSP were collected from the bins monthly (500 g). Wheat DDGS and supplement were collected twice throughout the experiment. The processing index of the grain was verified by weighing barley samples every two wks before and after processing. The DM content of ingredients, TMR, and orts was determined by drying (200 g) at 55°C for 48 h in

a forced air oven, followed by grinding through a 0.75-mm screen of a Retsch grinder (Verder Scientific, Inc, Newton, PA) and retained for chemical analysis.

Fecal Collections

Just prior to the morning feeding on d 18, 45, and 78 of the finishing diets, four fecal subsamples (> 200g) were collected from the floor of each pen. The time points were selected so as to represent the full finishing period. Fresh fecal samples were collected from pats in a manner that ensured that they were not contaminated with soil, bedding, or urine as described previously (Jancewicz et al. 2016a; 2016b). Samples were pooled by pen on an equal wet weight basis (400 g total), generating 45 samples over the feeding period. Samples were dried at 55°C and ground through a 0.75 mm screen of a Retsch grinder in preparation for scanning using NIRS.

NIRS Analysis of GSP and feces

Near infrared spectroscopy calibrations for nutrient composition and total digestible nutrients (TDN, %) of GSP were developed prior to the initiation of the feedlot experiment. The calibrations included an independent set of GSP from the current feedlot study and were part of a larger commercial research study. The calibrations were derived from 101 samples of GSP collected from feedlots as well as from GSP manufacturers (West Central Pelleting, Wilkie, SK and C.B. Constantini, Brooks, AB; Supplementary Table 1). The predicted chemical constituents included OM, starch, N, ADF, NDF, ADL, and EE, and TDN. The TDN value was determined using calculations according to Conrad et al. (1990) with the refinements of Owens et al. (1999):

$$\text{TDN} = 0.98 \times (100 - \text{NDF} - \text{CP} - \text{Ash} - \text{EE}) + (0.984 - 0.0016 \times \text{NDF}) \times \text{CP} + 2.7 \times (\text{EE} - 1) + 0.75 \times (\text{NDF} - \text{ADL}) \times (1 - (\text{ADL}/\text{NDF})^{0.667} - 7)$$

prior to calibration development. The GSP were

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ground using a heavy duty electric spice grinder (Waring, Stamford, CN) for 3-, 3 sec periods, and scanned in a 250 mL quartz bottom sample cup using a Spectra Star near-Infrared analyzer (2400 model) Top Window Series (Unity Scientific, Brookfield, CT, USA). The scan was conducted between 1250 and 2350 nm in 1-nm increments and scanned samples were retained for chemical analysis and used in the development of the calibrations.

Calibrations for OM, starch, N, ADF, NDF, ADL, and EE, and TDN were developed using partial least squares regression in Unity Calibration Software (Ucal) version 2.0.0.31 (Unity Scientific, Brookfield, CT, USA). The same mathematical treatment to the raw spectra was applied to each calibration, “1, 8, 10, 1”, where the first digit was the order of the derivative, the second was the gap over which the derivative was calculated, the third was the number of data points used in the running average for smoothing of derivative spectra, and the fourth was the number of data points over which the second smoothing was applied (Shenk et al. 1989). Derivative spectra were used to emphasize small or large absorption peaks, and minimize overlapping peaks and baseline correction (Giese and French 1955). Both the standard normal variate, and detrend functions were applied (Barnes et al. 1989).

The predictive ability of NIRS calibrations strongly depends on the spectral similarities of the unknown samples and the calibration set. Principle component analysis (PCA) was used to visualize the differences in spectral populations of the two GSP in the feedlot study and those within the calibration set. The two subsamples of the LSP and HSP fed in the feedlot study were packed into 250-mL quartz bottom cups and scanned as described above. The export function in Ucal was used to convert spectra into a format that could be imported into Unscrambler® X version 10.3 (CAMO software, Oslo, Norway) to generate the PCA graphs. The full spectra were used with no trimming (1100 to 2398 nm). Both the standard normal variate and detrend

functions were applied, as well as a derivative of 1, and a gap of 7 nm. A scatter plot of principle component (PC) scores for each sample within the GSP of the feedlot set, and the GSP within the calibration set were plotted along the first two PC factors (x axis = Factor 1, y axis= Factor 2). Outliers were identified using the Hotelling's T^2 distribution to define differences in population means in multivariate statistics. The samples outside of the defined Hotelling's T^2 ellipses were designated as outliers from the entire spectral population at a confidence level of 95%.

For fecal samples, previously developed NIRS calibrations (Jancewicz et al. 2016a) were used to predict fecal OM, starch, N, NDF, ADF, ADL, EE, and apparent total tract digestibility (aTTD) of DM, OM, starch, NDF, ADF, and gross energy (GE). Fecal samples were packed into a small quartz ring cup and scanned between 1250 and 2350 nm, in 1-nm increments. Two subsamples were scanned in duplicate. The mathematical treatment applied to the raw spectra was "1, 8, 8, 1", but all other mathematical functions were the same as above. Principle component analysis was used to visualize the differences in spectral populations of the fecal samples in the feedlot study and those within the calibration sets for both chemical composition and digestibility. To generate the PCA graphs, the same procedure was applied as for the GSP.

Chemical Analysis

Ground samples of TMR and ingredients from the feedlot study, and GSP that were used in the development of calibrations were analyzed for analytical DM [Association of Official Analytical Chemists (AOAC) 2005, method 930.15], OM (AOAC, method 942.05), starch, N, NDF, ADF, ADL, EE, and ash (AOAC, method 942.05). Samples were further ground in a ball mill (Mixer Mill MM2000, Retsch, Haan, Germany) for determination of starch and N. Starch was determined using a YSI 2700 Biochemistry Analyzer (Yellow Springs, OH). Nitrogen (AOAC

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992.23) was quantified using a LECO N analyzer (Joseph, MI) as described by Watson et al. 2003. The ANKOM fiber analyzer (ANKOM technology Corp., Fairport, NY) was used for sequential determination of NDF and ADF in duplicate, with heat stable α -amylase and sodium sulphite included in the NDF analysis. Acid detergent lignin was extracted using 72% sulphuric acid after the ADF procedure (Van Soest et al. 1991). Ether extract (EE; AOAC 2005, method 2003.05) was extracted in a Soxtec HT6 System (Foss, Eden Prairie, MN) using anhydrous diethyl ether, followed by drying. Ash was determined by subtracting the OM content from 100 (% DM basis). Total digestible nutrients were calculated using wet chemistry values and the equation derived by Owens et al. (1999).

Growth performance and Carcass Quality

The average DMI of steers in each pen was estimated by subtracting the amount of TMR DM delivered to the pen each week from the amount of orts DM. Average daily gain (ADG) was calculated by subtracting the final weight just prior to slaughter from initial weight both measured on two consecutive days and dividing the result by the number of days on feed (100). Gain:feed was calculated as kg of body weight gained per kg of DMI. Average daily gain and G:F were expressed as shrunk weights (live weight $\times$ 0.96)

All heifers were slaughtered at a federally inspected facility at the end of the experiment. The weight of the warm carcass was determined after the hide was removed and the carcass eviscerated (with kidneys removed). Back fat thickness, rib eye area, and percentage of Choice and Prime quality grades were determined by personnel of the Canadian Beef Grading Agency (Canada Beef 2014). Lean meat yield (%) was estimated using the equation: $57.96 - 0.027 \times \text{carcass weight} + 0.202 \times \text{rib eye area} - 0.703 \times \text{back fat thickness}$, as described by Basarab et al.

(2003). The percentage of B4 carcasses (dark cutters) was reported, along with the percentage of livers with at least 1 abscess. When the liver had at least 4 small abscesses or at least 1 abscess with a diameter greater than 2.5 cm, it was designated as severe (Klinger et al. 2007).

Energy Calculations as determined from NIRS of the GSP and measured performance

The net energy for maintenance (NEm) content of each diet was calculated from BW, DMI, and ADG as described by Zinn et al. (2002) using the estimates of energy gain (EG, Mcal/d) and the maintenance energy (EM, Mcal/d) expended based on growth performance for a medium frame yearling heifer [$EG = 0.0557 \times (\text{average weight} \times 478/\text{mature weight})^{0.75} \times ADG^{1.0971}$; where average weight is the mean shrunk weight (full weight $\times 0.96$) and mature weight was 625 kg (defined as the weight at which protein deposition stops and all subsequent gain is fat) and $EM = 0.077 \times MBW^{0.75}$ (NASEM 2016)]. The NE values of the diet for maintenance (NEm) was estimated from the performance and feed intake using the quadratic formula [$x = -b \pm \sqrt{(b^2 - 4ac)}/2a$], where $a = -0.877DMI$, $b = 0.877EM + 0.41DMI + EG$, and $c = -0.41EM$ (Zinn and Shen, 1998). Net energy of maintenance was converted between NEg and TDN using the equations $TDN = (NEm + 0.5058)/0.0305$ and $NEg = 0.877 \times NEm - 0.41$ (Zinn et al. 2002; NASEM 2016).

The NEm content of the GSP was calculated as described by Zinn et al. (2002); [(NEm of GSP diet – NEm of control diet)/proportion of GSP in diet + NEm of barley grain], where 0.2 is the proportion of GSP in the diet and 2.06 is the NEm of the barley it displaced.

Statistical analysis

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To determine the difference between wet chemistry and NIRS predictions of chemical composition and TDN of the two GSP, the Proc MIXED procedure in SAS (Version 9.2; SAS Inst. Inc. Cary, NC) was used, with Diet and Method and their interaction as fixed effects.

Differences among treatments for the NIRS predicted fecal composition and aTTD of nutrients were identified using the PROC MIXED function for repeated measures of SAS. The model included treatment (T), day of sampling (D; $i = 1, 2$, and 3 , representing collection d 18, 45, and 78) and the interaction of treatment $\times$ day (T $\times$ D). The interaction was only retained if $P < 0.05$. The model used was $Y_{ijk} = \beta_0 + \beta_1 T_{ijk} + \beta_2 D_{ijk} + \beta_3 T \times D_{ijk} + \epsilon_{ijk}$, where ϵ_{ijk} is the random error associated with each observation. A first-order autoregressive structure was used to model repeated measures on individual pens at each day. Least square means of the treatments were separated using the PDIFF statement.

Dry matter intake, ADG, and G:F from the feedlot study were analyzed as a completely randomized design using the mixed procedure of SAS with pen as the experimental unit, and treatment as a fixed effect. The model used for the analysis was $Y_{ijk} = \mu + \alpha_i + \epsilon_{ijk}$, where Y was the observation of the dependent variable, μ is the population mean, α_i is the fixed effect of treatment, and ϵ_{ijk} is the random error associated with the observation. Carcass characteristics were analyzed as a completely randomized design using Proc MIXED of SAS except for categorical variables such as carcass grade, B4 carcasses, and number of liver abscesses which were analyzed using the Chi square option of Proc GLIMMIX.

To determine associations between the fecal nutrients, digestibility, and DMI, ADG, G:F, and NEg, bivariate regression was performed using PROC REG function. The model was $Y_{jk} = \beta_0 + \beta_1 X_{jk} + \mu_{jk} + \epsilon_{jk}$, where Y is the dependent variable (overall DMI, ADG, G:F or NEg), X is the independent variable (average of fecal nutrient concentration, or digestibility over three times

points), μ_j was the random effect for pen, j was pen, β_0 was the average y intercept, and ϵ_{ijk} was the associated error.

For all statistical analyses, significance was declared at $P \leq 0.05$ and trends at $P \leq 0.10$.

Results

Composition of grain screenings pellets and diets

Compared to LSP, HSP were greater in starch (23.2 vs 20.5%) and EE (6.7 vs 4.2 %), but after formulating the TMR, differences in EE were much less pronounced (2.8 vs 2.3%) owing to the 20% inclusion rate (Table 1). Diets were isonitrogenous, but the control diet was approximately 8% higher in starch, 6% lower in NDF, 4% lower in ADF and 0.5 and 1% lower in EE as compared to the LSP and HSP diets.

Principle component analysis demonstrated that the two GSP from the feedlot study differed from the mean population of the rest of the spectra at a confidence level of 95% (Figure 1). As only two types of pellets ($n=2$) were examined, we could not use standard measures for determining the accuracy and precision of the GSP calibration equations. Instead of using coefficients of determination of calibration (R^2_{cal}), and standard error of calibration (SEC), we compared the two methods by mean separation of the diets and the analytical method (wet chemistry versus NIRS; Supplementary Table 2). There was no effect ($P > 0.05$) of method for DM, NDF, and EE, whereas all other constituents varied between NIRS vs wet chemistry. Interactions ($P < 0.03$) between diet and method were found for DM, starch, ADL, and ash.

Fecal DM and NIRS predicted nutrient composition and digestibility

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The DM did not differ ($P = 0.64$) among feces collected from heifers fed the three diets (Table 2). Organic matter, N, and EE levels were greater ($P < 0.01$), and NDF was lower ($P < 0.05$) in feces collected from heifers fed the control diet as compared to those fed the LSP or HSP diets. There was also a tendency ($P = 0.09$) for fecal starch to be greater in heifers fed the control diet as compared to the GSP diets. Principle component analysis demonstrated that none of the fecal samples from the current study were outliers to the population of spectra for chemical composition (95% confidence level; Figure 2A). This was expected as a subset of these samples was used in calibration development (Jancewicz et al. 2016a).

There were no differences in aTTD of nutrients or GE among treatments (Table 2). It is evident from the PCA graph (Figure 2B) that the feces collected from the LSP heifers were furthest from the mean population of the NIRS calibration for digestibility, compared to feces obtained from the heifers fed the control and HSP diets, but none were considered outliers according to the Hotelling's T^2 distribution.

Performance of cattle and carcass traits

Initial and final BW and DMI of heifers did not differ ($P \geq 0.18$) among diets. The ADG tended to be greater ($P = 0.06$) for heifers fed the control diet as compared to LSP, with no differences observed between control and HSP or LSP and HSP diets (Table 3). The G:F was greater ($P = 0.02$) for control heifers than for heifers fed GSP. With the exception of a more ($P = 0.05$) B4 carcasses (dark cutters) in the control group, there were no differences ($P \geq 0.41$) in other measured carcass characteristics including hot carcass weight, back fat thickness, rib eye area or liver abscesses among heifers fed different diets.

Prediction of energy values using NIRS of GSP and growth performance

Predicted performance parameters (NEm and NEg) determined from the feedlot study indicated that the control diet was 8.0% and 10.6% greater in NEm and NEg than the LSP and 6.84% and 8.41% higher than HSP, respectively (Table 4). The NEm and NEg were calculated to be 1.31 and 0.74 for the LSP, and 1.39 and 0.81 for the HSP. Predictions using NIRS of the TDN value of both GSP using the equation of Owens et al. (1999) resulted in values similar but slightly higher than those calculated directly from measured growth performance (62.3 vs 59.6% for LSP and 66.7 vs 64.3% for HSP; Table 4).

Associations between NIRS predicted fecal composition, digestibility, and growth performance

We were unable to find associations between growth performance and fecal nutrient composition or aTTD of nutrients in heifers fed the two GSP diets, except for a negative association between ADG and fecal ash ($R^2 = 0.45$, $P = 0.03$; data not shown). When the control diet was included in the regression equation, digestibility of GE was positively associated with DMI ($R^2 = 0.31$, $P = 0.03$). Positive associations were also found between ADG and fecal N ($R^2 = 0.30$, $P = 0.03$), and fecal starch ($R^2 = 0.26$, $P = 0.05$), and negative associations between ADG and fecal NDF ($R^2 = 0.46$, $P < 0.01$), and ADL ($R^2 = 0.61$, $P < 0.01$). There were tendencies for G:F to be positively associated to fecal OM ($R^2 = 0.25$, $P = 0.06$), N ($R^2 = 0.25$, $P = 0.05$), starch ($R^2 = 0.20$, $P = 0.09$) and EE ($R^2 = 0.23$, $P = 0.07$) and negatively associated with fecal NDF ($R^2 = 0.23$, $P = 0.07$; data not shown).

There was no association found between aTTD of GE and NEg when all three diets were combined, however a positive association ($R^2 = 0.61$, $P = 0.01$) was found between aTTD of GE and NEg when only GSP diets were considered.

Discussion

Composition of grain screenings pellets and diets

In Canada, grain screenings mainly arise as a result of the cleaning of barley, wheat and canola for export, and consist of contaminants such as broken grains, weed seeds, hulls, chaff and dust (Beames et al. 1986). They are classified based on the level of uncleaned grain, and the major categories include No. 1 feed screenings, No. 2 feed screenings; refuse screenings, and uncleaned screenings (Beames et al. 1986). The screenings used in this study were refuse screenings, which contain on average 70% chaff plus dust as well as grain and weed seeds (Tait et al. 1986). The merit of feeding grain screenings to livestock is in cost savings, as they are considered a waste by-product as opposed to an actual grain. However, the downside is their reduced starch and greater structural carbohydrate content as compared to grain (Marx et al. 2000; Mustafa et al. 2000). This typically results in a reduction in G:F when screenings are added to the diets of beef cattle (Górka et al. 2013; Joy et al. 2015). Due to the lower energy content of screenings, oil is often added to screenings to increase their energy density (Górka et al. 2013; Górka et al. 2015; Joy et al. 2015).

In the current study, two GSP were manufactured with the assumption that heavier screening would generate GSP with a higher energy density. In addition, millrun, beet pulp, and canola oil were added to the HSP to raise the levels of crude protein (CP), neutral detergent fiber (NDF), EE, and other nutrients while maintaining a chemical profile typical of screenings. This also ensured that two distinct pellets were created to test the predictive capabilities of NIRS. Although the classification and exact parent grain composition of our GSP were unknown, the starch content of both GSP was lower than GSP reported by Marx et al. 2000 (26.2% DM) who

fed sheep a mixture (85:15) of refuse screenings and lentil screenings. The NDF and ADF values for both LSP and HSP were also higher than the NDF (33.7%) and ADF (20.9%) values reported by Marx et al. (2000). The CP, ADF, EE, and ash content of both GSP were all within the ranges of refuse screening pellets as reported by Beams et al. (1986; 10.6-19.3% CP, 22.8-37.2% ADF, 3.2-8.6% EE, and 7.6-12.8% ash).

Considering the diversity in the composition of screenings that make up GSP, a rapid analytic technique such as NIRS to evaluate chemical composition is highly advantageous. Although the predictability of our GSP calibrations cannot be properly assessed with so few samples, our data show that NIRS estimates were close to those estimated by wet chemistry, demonstrating the potential to use NIRS to estimate the feed value of GSP (supplementary Table 2). The interactions we observed indicate that for some constituents, NIRS over- or under-predicted their presence in LSP or HSP, but without R^2_{cal} or *SEC* values, we cannot measure the accuracy or precision of the calibrations. However, NIRS calibrations did under predict CP, ADF, and ash for both GSP. Since the completion of the current study, additional sources of GSP have been continually collected to increase the sample size of the calibration set. For any NIR work, ensuring that the population and range of unknown samples is encompassed by the calibration set, will improve the predictability of calibrations.

Fecal DM and NIRS predicted nutrient composition and digestibility

Consistent with the fact that by-products such as grain screenings are typically higher in fibre and lower in starch content relative to grains (Marx et al. 2000; Mustafa et al. 2000), our findings demonstrated the same trends in the feces of GSP fed cattle relative to control. Contrary to this, fecal N and EE concentrations did not match the differences in dietary levels. Despite the

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diets being isonitrogenous, fecal N was lower in both GSP diets, and EE in the feces was lower with GSP despite having higher levels of dietary EE than the control diet. These results are likely due to greater microbial turnover and excretion of microbial protein and lipids in the control diet, an observation that is frequently associated with more fermentable diets (Beauchemin et al. 2001).

Marx et al. (2000) found that increasing levels of GSP in place of barley grain resulted in a reduction in DM digestibility in sheep, a response attributed to the greater fibre content of GSP (Marx et al. 2000). Similarly, NDF and GE digestibility were found to decrease with increasing GSP, with no differences in CP or ADF digestibility (Marx et al. 2000). Górka et al. (2015) fed increasing levels of high-lipid, high-fiber pellets and observed linear decreases in organic matter and NDF digestibility. There were no differences in predicted digestibilities using NIRS between the GSP diets and the control diet. Lipid supplementation is known to directly reduce ruminal fibre digestibility (Hess et al. 2008) and shift the site of starch and fibre digestion to lower parts of the gastrointestinal tract of finishing cattle (Plascencia et al. 2003). Pylot et al. (2000) reported that apparent NDF digestibility increased with inclusion of increasing rates of canola screening despite an increase in dietary lipid content from 6.7 to 16.2% of diet DM. Similar to Górka et al. (2015), it is unlikely that lipid inclusion negatively affected digestibility in the present study since ether extract content did not exceed 6% of diet DM (Zinn and Jorquera 2007).

The dissimilarity between the present study and previous studies may be due to the lower (20% of diet DM) inclusion of GSP compared to Marx et al. (2000; 25 to 100% of diet DM) and Górka et al. (2015; 30 to 90% of diet DM). Aside from starch, our predicted digestibilities were greater than those reported by Górka et al. (2015), even for the control diets, a result that may

reflect the lower DMI in our study. Additionally, Górka et al. (2015) predicted digestibility using Yb and Cr as markers as opposed to NIRS predictions derived from total collection methods. Our digestibility predictions were comparable for DM, CP, and GE digestibility to those reported by Marx et al. (2000), when GSP were included at 25% of the diet DM for sheep. However, NDF and ADF digestibility were 15% higher, a result that may reflect the inclusion of beet pulp in the HSP. Additionally, the NIRS calibrations for NDF and ADF digestibility that we used have substantially lower R^2_{cal} and SEC values compared to other nutrient digestibility calibrations, hence the risk for error is greater (Jancewicz et al. 2016a). Since there were no pelleted ingredients in diets used for the development of the digestibility calibrations, it is likely that the feces of GSP fed cattle are not adequately represented by the calibration set, a possibility that was particularly evident for the LSP diet.

Performance of cattle and carcass traits

A second objective of this study was to determine the effects of feeding the two GSP on performance measures and carcass quality. Certain characteristics of GSP have been found to reduce feedlot cattle performance. Firstly, by-products such as grain, pea, canola screenings and oat hulls are typically high in fibre, and are often lower in dietary energy than grains (Marx et al. 2000). Thus, screening can lower the energy density of the diet (Marx et al. 2000), unless energy dense lipids are added (Górka et al. 2013; 2015). Secondly, the fine physical structure of most by-products and the reduction in particle size associated with grinding prior to pelleting reduces fibre retention time in the rumen, digestibility, and G:F (Abouheif et al. 2012). Although we did not find any detrimental effects on nutrient digestibility with GSP or differences in DMI, we did find that ADG tended to be lower for LSP compared to control heifers, and a reduction in G:F of

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heifers was observed for both GSP diets as compared to the control diet. Joy et al. (2015), fed high-fat by-product pellets to finishing steers at 30% of diet DM for 120 d, and although there was no impact on DMI or ADG, G:F was reduced. Górka et al. (2013) fed a similar high-fat by-product pellet as a partial replacement for barley grain and canola meal in finishing diets for steers at 30% and 60%. In their study, ADG did not differ among treatments, but DMI was higher and G:F was lower for both pelleted diets as compared to the control diet. Pylot et al. (2000) concluded that canola screenings can be included as a source of fibre in barley-based diets for feedlot cattle, however, levels in excess of 50% of diet DM, compromised both ADG and G:F. Our study shows that even at an inclusion rate of 20%, reductions in G:F occurred with LSP.

Feeding GSP has not had consistent effects on carcass traits. Positive effects on carcass yield were reported when high lipid by-products were fed in the latter 60 d of the finishing period, but negative effects when fed for 120 d (Joy et al. 2015). Others have reported no effect of GSP on carcass characteristics (Górka et al. 2013). In the present study, we did not observe any differences among treatments, however, we did note low lean meat yields and high B4 carcasses for both control and GSP diets, and a tendency for higher B4 carcasses in the control fed heifers. The meat yield reported is slightly lower than those reported in Joy et al. (2015; 60%), but greater than Moya et al. (2015; 48.5%) where an 89% grain diet was fed to feedlot cattle.

The high B4 dark cutters (12 to 32% of heifers from each diet) can be due to multiple factors including sex of the cattle, the use of growth promotants, and stressful events. The current study used heifers and previous data compiled over a 3 yr period, identified a higher percentage of dark cutters in heifers than steers (Scanga et al. 1998). This effect may be related to an

increase in mounting activities, but also the lighter weight of the dark cutters may reflect the predisposition of heifers to this trait (Tarrant 1989). Since we did not monitor mounting behaviour of the heifers closely throughout the study, we cannot verify that this occurred.

Prediction of energy values using NIRS of GSP and growth performance

Considering the success of NIRS in predicting nutrient content of feed ingredients (de Boever et al. 1995) it was not surprising that NIRS could predict the TDN of GSP, especially when calculated based on chemical composition. Near infrared spectroscopy is currently being used to predict the value of GSP using equations based on their chemical composition (Gibb, personal communication). Although our predicted values overestimated those calculated from actual performance, NIRS was able to differentiate TDN between LSP and HSP. Many factors must be considered when measuring animal performance, including breed, sex, animal behaviour, diet, use of growth promotants, and climate. Therefore, there is a great chance of over or under predicting actual values when only using ingredient composition for prediction. Our small margin of error and the ability to rapidly differentiate between two GSP using NIRS at the time of purchase could allow producers to assess the value of GSP and their expected effect on the growth performance of feedlot cattle.

Associations between NIRS predicted fecal composition, digestibility, and growth performance

Aside for fecal ADL, the lack of associations between growth performance and fecal nutrient composition or aTTD of nutrients in heifers fed the two GSP diets was likely due to lack of statistical differences in fecal composition in aTTD, or DMI, ADG, and G:F for the GSP diets. Had the differences in composition of the two GSP been greater, this may have translated into

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differences in fecal composition and nutrient digestibility and enabled us to test for such associations. We can conclude that the greater G:F we observed in control cattle was associated with greater fecal OM, starch, N, and EE, and lower NDF compared to the GSP diets, and similar conclusions can be made for ADG. The greater OM, starch, and lower NDF in feces is related to greater performance since the control diet contained more high energy nutrients, and was lower in NDF. Greater fecal N and EE possibly reflect increased microbial protein synthesis in the rumen and greater excretion of microbial protein in the feces, a possibility supported by Beauchemin et al. (2001) where microbial protein synthesis in the rumen increased by 50% when barley was processed to a greater degree.

The positive association observed between aTTD of GE and NEg for the GSP diets is consistent with Jancewicz et al (2016b), where aTTD of GE and NEg was found to differ between barley and wheat diets. Near infrared spectroscopy-predicted aTTD of GE was capable of predicting differences in NEg in the current study, but the lack of association found when all three diets were combined, suggests that separate calibrations for digestibility may be required for diets that contain GSP. It is also likely that if fecal samples from metabolism studies feeding GSP were added to the calibrations for digestibility, prediction accuracy would be improved. This is also reflected by the differences in the PCA graph between the feces of GSP fed heifers in the current study and the calibration set for digestibility.

Conclusion

Feedlot cattle diets and ingredients are highly variable as they are dependent on fluctuations in feed costs. Producers choose to feed by-product feeds when the price of grain is high, with an understanding of the costs and benefits. Considering the compositional diversity of

GSP, implementing NIRS in feedlots is a practical tool to immediately evaluate their feed value. Additionally, NIRS of the feces also shows potential to predict the growth performance (NEg) of feedlot cattle. Replacing 20% barley grain with GSP in our study did not affect nutrient digestibility or DMI, but ADG and G:F were reduced, and this was evident by changes in fecal composition. Near infrared spectroscopy can predict the energy content of GSP similar to performance estimates, and be applied in commercial feedlots to assess pellet quality at the time of purchase and diet formulation for feedlot cattle.

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Table 1: Ingredient composition of grain screening pellets, and ingredient and chemical composition of total mixed diets fed to cattle with and without grain screening pellets.

Item	Diets		
	Control	LSP	HSP
<i>Pellet ingredient composition % DM basis</i>			
Heavy Screenings		60.0	77.5
Light Screenings		40.0	
Millrun (ground)			10.0
Beet Pulp (ground)			10.0
Canola Oil			2.5
<i>Pellet chemical composition % DM basis</i>			
Dry Matter		91.0	90.8
Organic Matter		91.7	92.0
Starch		23.2	20.5
Crude protein		13.9	13.0
Crude fiber		17.2	17.1
Neutral detergent fiber		38.8	40.0
Acid detergent fiber		24.4	25.7
Lignin		4.5	4.8
Ether extract		4.2	6.7
Ash		8.3	8.0
TDN		69.0	71.0
<i>Diet Ingredient composition, % DM basis</i>			
Dry rolled barley, PI = 81	76.0	56.0	56.0
Barley silage	9.0	9.0	9.0
Wheat dried distillers grain	10.0	10.0	10.0
Supplement ^a	5.0	5.0	5.0
LGSP		20.0	
HGSP			20.0
<i>Diet Chemical Composition, % DM basis</i>			
Dry Matter	84.3	84.9	84.8
Organic Matter	95.0	94.1	93.9
Starch	48.4	40.8	40.3
Crude Protein	14.3	14.6	14.4
Neutral detergent fiber	20.5	26.1	26.5
Acid detergent fiber	9.5	13.3	13.9
Lignin	1.9	2.6	2.6
Ether extract	1.8	2.3	2.8
Ash	5.0	5.9	6.1
TDN	75.1	72.4	72.9

Note : PI, processing index of grain, calculated as the ration of the bushel weight after processing over the bushel weight before processing; LSP, diet fed with light grain screening pellets; HSP, diet fed with heavy grain screening pellets; ^aSupplement composition (as fed basis) is 54.5% Barley chop, 10.0% canola meal, 25.0% CaCO₃, 2.5% molasses, 3.0% NaCl, 1.0% feedlot premix, 2.0% Urea, 0.07% Vitamin E (50%), 1.0% canola oil, 0.05% flavour, 0.31% rumensin premix, 0.36% melegestrol acetate, 0.23% Tylan 40. TDN calculated by Owens (1999).

Table 2: Chemical composition of feces and nutrient digestibility as predicted using near infrared spectroscopy calibrations of feces (n=15) collected from heifers fed the control diet and light and heavy GSP replacing 20% barley silage at three time points over the feeding period.

Item	Diets				
	Control	LSP	HSP	SEM	<i>P</i> value
Chemical composition (% DM basis)					
Dry matter (%)	19.8	20.2	20.2	0.36	0.64
Organic matter	87.0a	85.3b	85.8b	0.33	0.01
Starch	8.7	6.5	7.2	0.72	0.09
Nitrogen	2.6a	2.4b	2.4b	0.030	<0.01
Neutral detergent fibre	50.3b	53.8a	52.8a	0.69	<0.01
Acid detergent fibre	30.7	31.7	30.9	0.66	0.52
Acid detergent lignin	6.6	7.0	6.8	0.15	0.12
Ether extract	1.7a	1.4c	1.5b	0.03	<0.01
Digestibility (% of intake)					
Dry matter	77.9	77.5	77.5	0.42	0.73
Organic matter	79.1	78.2	78.1	0.45	0.26
Starch	94.3	94.7	95.0	0.32	0.36
Crude protein	73.6	73.7	73.2	0.48	0.70
Neutral detergent fibre	55.8	55.3	56.2	0.38	0.28
Acid detergent fibre	42.4	43.7	41.9	0.68	0.21
Gross energy	79.5	79.9	80.9	0.48	0.14

Note: LSP, diet fed with light grain screening pellets; HSP, diet fed with heavy grain screening pellets. Values with different letters differ ($P < 0.05$).

Table 3: Growth performance and Carcass Quality of heifers fed control diet and light or heavy GSP replacing 20% barley grain

Item	Diets			SEM	P value
	Control	LSP	HSP		
Growth Performance					
Initial BW (kg)	429.4	423.7	429.1	14.31	0.95
Final BW <i>d100</i> (kg)	617.4	601.1	613.3	14.17	0.71
DMI (kg DM/d)	11.8	12.2	12.5	0.24	0.18
sADG (kg/d)	1.88	1.77	1.84	0.03	0.06
sGain:Feed, (kg/kg DM)	0.160a	0.145b	0.148b	0.0032	0.02
Carcass Quality					
Carcass weight (kg)	378.3	372.7	374.9	3.78	0.57
Backfat (mm)	16.2	16.8	16.3	0.62	0.78
Ribeye area (cm ²)	91.6	90.3	91.5	1.27	0.72
Saleable Lean meat yield (%)	54.8	54.3	54.9	0.56	0.74
Choice + Prime (%)	23	29	27		0.41
Chi Square analysis of categories					
B ⁴ (%)	32	22	12		0.05
No. liver abscess (%)	94	92	94		1
Severe abscess (%)	2	2	2		1

Note: LSP, diet fed with light grain screening pellets; HSP, diet fed with heavy grain screening pellets; B⁴, grading is assigned to those carcasses that have dark purple rather than bright red meat. sADG and sGain:Feed correspond to shrunk weights (live weight*0.96). Values with different letters differ ($P < 0.05$).

Table 4: Total digestible nutrients and energy content of grain screening pellets determined from actual performance of heifers fed either light or heavy GSP at the end of the finishing period of from NIRS predictions of light and heavy GSP.

	LSP		HSP	
	Actual Performance	NIRS	Actual Performance	NIRS
Energy Value				
TDN (%)	59.6	62.3	64.3	66.7
NEm (Mcal kg ⁻¹) of pellets	1.31	1.39	1.45	1.52
NEg (Mcal kg ⁻¹) of pellets	0.74	0.81	0.86	0.82

Note: LSP, diet fed with light grain screening pellets; HSP, diet fed with heavy grain screening pellets; TDN, total digestible nutrients; NEm, net energy of maintenance; NEg, net energy of gain. Calculated from $TDN = NEm + 0.5058/0.0305$; Calculated from $NEg = 0.877 * NEm - 0.41$; Performance calculated based on average animal weights, DMI, ADG as $.0557 * (AVG\ BW * 478 / \text{mature weight}) + 0.75 * ADG$, where mature weight of 600 kg was used NEm of GSP diet - NEm of control diet/0.2-2.06, where 0.2 = proportion of GSP in diet and 2.06 = NEm of the barley it displaced.

Figure 1: Principal component graph displaying the spectra of the light (LSP) and heavy (HSP) grain screening pellets (GSP) manufactured for the feedlot study in relation to the pellets in the NIRS calibration set for GSP composition.

A

B

Figure 2: Principal component graph displaying the spectra of fecal samples collected from heifers fed the control diet, light, and heavy grain screening pellet diets in relation to the fecal samples in A) the NIRS calibration set for chemical composition, and B) the NIRS calibration set for digestibility.