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Complete List of Authors:	Nair, Jayakrishnan; University of Saskatchewan, Animal and Poultry Science Christensen, David; University of Saskatchewan, Animal and Poultry Science Yu, Peiqiang; University of Saskatchewan, Department of Animal and Poultry Science beattie, aaron; University of Saskatchewan, Crop Development Centre McAllister, Tim; Agriculture and Agri-Food Canada, Lethbridge Research Centre Damiran, Daalkhaijav; University of Saskatchewan, Animal and Poultry Science Preston, Natalie; Agriculture and Agri-Food Canada Lethbridge Research Centre Fuhr, Leland; DairtSmart Nutrition Services McKinnon, John; University of Saskatchewan, Animal and Poultry Science
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A Nutritional Evaluation of Common Barley Varieties Grown for Silage by Beef and Dairy Producers in Western Canada

Jayakrishnan Nair¹, David Christensen¹, Peiqiang Yu¹, Aaron D. Beattie², Tim McAllister³,
Daalkhaijav Damiran¹, Natalie Preston^{1,3}, Leland Fuhr⁴ and John J. McKinnon^{1,5}

¹Department of Animal and Poultry Science, University of Saskatchewan, Saskatoon,
Saskatchewan, Canada S7N 5A8

²Department of Plant Sciences, University of Saskatchewan, Saskatoon, Saskatchewan, Canada
S7N 5A8

³Lethbridge Research Centre, Agriculture and Agri-Food Canada, Lethbridge, Alberta, Canada
T1J 4B1

⁴Dairysmart Nutrition, Saskatoon, Saskatchewan, Canada S7W 0K7

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⁵Corresponding author:

John McKinnon
Department of Animal and Poultry Science, University of Saskatchewan, 51 Campus Drive,
Saskatoon, Saskatchewan, Canada, S7N 5A8
Fax: (306) 966-4151
Phone: (306) 966-4137
Email: john.mckinnon@usask.ca

ABSTRACT: This study evaluated the nutritional and neutral detergent fiber digestibility (NDFD) characteristics of seven barley varieties (Conlon, CDC Copeland, CDC Cowboy, Falcon, Legacy, AC Metcalfe and Xena) grown for silage. Commercial samples (N = 80) harvested at the mid-dough stage were collected over two years (2012 and 2013). Average pH and dry matter (DM) content were 4.05 ± 0.17 and $36.8 \pm 4.1\%$. Falcon and AC Metcalfe had higher ($P < 0.05$) CP relative to CDC Copeland and Xena with intermediate values for the other varieties. Acid (ADF) and neutral (NDF) detergent fiber content were higher ($P < 0.05$) for CDC Cowboy relative to Conlon. Starch was higher ($P < 0.05$) for Legacy and Conlon than CDC Cowboy with intermediate values for other varieties. Legacy had a greater ($P < 0.05$) NDFD_{6h} while CDC Cowboy had a greater ($P < 0.05$) NDFD_{30h}. Indigestible NDF (INDF; % of NDF) was greater ($P < 0.05$) for AC Metcalfe relative to CDC Cowboy and Falcon. These results indicate that barley varieties vary with respect to chemical composition, NDFD and INDF content. Selection for higher NDFD_{30h} could result in improvements in DM and DE intake and performance of growing beef cattle.

Key words: Barley silage, chemical composition, *in vitro* NDF digestibility, indigestible NDF, Daisy^{II}

Abbreviations: ADICP, acid detergent insoluble crude protein; ADF, acid detergent fiber; BW, body weight; CP, crude protein; DE, digestible energy; DM, dry matter; DMI, dry matter intake; EE, ether extract; ESC, ethanol-soluble carbohydrate; INDF, indigestible neutral detergent fiber; NDF, neutral detergent fiber; NDFD, neutral detergent fiber digestibility; NDICP, neutral detergent insoluble crude protein; NE, net energy; NE_g, net energy for growth; NE_m, net energy for maintenance; NFC, non-fiber carbohydrate; NSC, non-structural carbohydrate; RDP, rumen degradable protein; TDN, total digestible nutrients.

INTRODUCTION

Whole-crop barley (*Hordeum vulgare* L.) silage is the principal forage source for feedlot and dairy operations in Western Canada (McAllister et al., 1995; Hristov and McAllister 2002). More than 250 varieties of barley are grown in Canada. These varieties can be classified in a number of different ways, including feed versus malting; two row versus six row; and hulled versus hullless (Canadian Food Inspection Agency 2015). Despite the importance of barley silage in ruminant diets, producers are often faced with a lack of information on which variety to grow for silage, particularly from the perspective of nutritional quality. Hence, when making variety selections, producers tend to place more emphasis on yield and other agronomic characteristics like disease and lodging resistance rather than on the nutritional value of the forage.

One area where barley breeding holds promise is to select silage varieties for high neutral detergent fiber (NDF) digestibility (NDFD). Neutral detergent fiber content of barley silage can range from 36.7 (Addah et al., 2012a) to 62.3% (% DM; Dairy one forage lab, Ithaca, NY). Ruminal and total tract digestibility of NDF is lower than that of non-structural carbohydrates such as starch (Huhtanen et al., 2006). Studies with high NDFD corn varieties (i.e. brown mid-rib; BMR) have shown improved dry matter intake (DMI; Rook et al., 1977; Oba and Allen 1999b; Barrière et al., 2004) and milk yield (Oba and Allen 1999b; Ballard et al., 2001; Ebling and Kung 2004) in dairy cattle. These improvements in dairy cow performance were attributed to reduced rumen fill, increased ruminal turnover of NDF and potential improvement in dietary energy status in cattle fed the high NDFD forage (Mertens 1987; Oba and Allen 1999b; Oba and Allen 2000). As well, Oba and Swift (2014) reported no improvement in DMI or milk yield but better feed efficiency (kg milk per kg DMI) in dairy cattle fed a barley silage variety with a higher 30 h NDFD (NDFD_{30h}; cv. Falcon) relative to one with a lower NDFD_{30h} (cv. Tyto). With respect to beef cattle, to the author's knowledge there has been very little research that has

examined the NDFD characteristics of barley silage and the potential differences that may exist between varieties.

Most advanced mechanistic feed evaluation systems (CNCPS, CPM dairy; Van Amburgh et al., 2007; Tylutki et al., 2008) calculate forage energy values on the basis of digestible cell soluble and cell wall fractions (Traxler et al., 1998). The indigestible fraction of NDF (INDF) is not available to rumen microbes and contributes no usable energy to the animal. In newer versions of mechanistic feed evaluation models, INDF is being evaluated to improve the prediction of total NDF digestibility and the accuracy of balancing ruminant diets (Harper and McNeill 2015). This research suggests that selection pressure by plant breeders for increased NDFD may result in new or improved barley forage varieties that allow producers to select varieties with enhanced nutritional as well as agronomic qualities.

This study involved collection of barley silage samples and key agronomic information over two crop years from beef and dairy producers in Saskatchewan and Alberta. The objective was to compare varieties that are grown by cattle producers for nutrient composition as related to modern feed formulation systems (CNCPS, CPM dairy) and to determine variety differences on the extent of 6 and 30 h NDFD and INDF content.

MATERIALS AND METHODS

Sample Collection and Selection

A total of 135 barley silage samples representing 16 varieties were collected over 2 years (2012-2013) from beef (n = 11), dairy (n = 95) and mixed (n = 29) operations in south-central Saskatchewan and the Lethbridge region of Alberta with the help of feed industry consultants. From this total, 80 samples representing seven varieties were selected for analysis. These

included 39 samples from 2012 and 41 from 2013. Selection was based on a minimum of three replicates per variety per year and on the stage of maturity (mid-dough stage as determined by the producer) at harvest (Table 1). Selected varieties included Conlon which is a smooth awn 2 row feed and malting type barley; CDC Copeland and AC Metcalfe which are 2 row malting barley varieties with rough awns; CDC Cowboy and Xena, both 2 row feed barley varieties with rough awns; and Falcon and Legacy which are 6 row varieties with smooth awns.

From the majority of sites, samples were collected using a drill driven silage sampler (Star quality samplers Inc., Irricana, AB) with 2.86 cm diameter cutting tip attached to a 150 cm long probe. Samples were collected from a minimum of four to nine spots from each silo, composited and vacuum packed in duplicate. Of these, one was sent to Cumberland Valley Analytical Services (CVAS, Hagerstown, MD) for chemical analysis and the other frozen at -20°C until processing at a later stage. For processing, frozen samples were thawed overnight at 4°C and a subsample was used for pH, volatile fatty acids (VFA), lactate, succinate and ammonia concentrations. The remaining sample was dried and analyzed for 6 and 30 h *in vitro* incubation (Daisy^{II} system; Damiran et al., 2008) and indigestible NDF by 288 h ruminal incubation (Huhtanen et al., 1994). Agronomic data collected included cultivar, seeding and harvest date and stage of maturity at harvest.

Silage Processing for Volatile Fatty Acids, Lactate, Succinate and Ammonia Concentration

Silage samples were processed for analysis of pH, VFA, lactate and ammonia as described by Zahiroddini et al., (2004) and Addah et al., (2012b). Briefly, fresh silage samples (15 g) were combined with 135 mL double distilled water and blended at 18 000 rpm for 30 s in a commercial blender (Oster[®] 12 speed blender, Sunbeam Corporation Ltd., Brampton, ON). The suspension was filtered through two layers of cheese cloth and the pH was measured

immediately in duplicate using an Accumet Research AR 50 dual channel pH meter (Fisher Scientific, Waltham, MA). Subsequently, 40 mL of the extract was transferred to a 50 mL centrifuge tube (VWR International, Radnor, PA) and stored on ice until centrifuged at $12\,000 \times g$ for 15 min at 4°C using Beckman Coulter Avanti® J-E centrifuge (Beckman Coulter Inc., Brea, CA). The supernatant (5 mL) was transferred to a 15 mL centrifuge tube (VWR International, Radnor, PA) containing 1 mL of 25% metaphosphoric acid and was used for the analysis of VFA, lactate and succinate. For ammonia analysis, 1.6 mL of the supernatant was transferred to a 2 mL tube with screw cap top and 'O' ring containing 150 µL of 65% trichloroacetic acid (Addah et al., 2012b). Samples were frozen at -20°C until analyzed.

***In vitro* Incubation (Daisy^{II} System)**

The Daisy^{II} incubation technique (Ankom Technology Corporation, Fairport, NY) was used to estimate *in vitro* ruminal organic matter and NDFD (Wilman and Adesogan 2000; Damiran et al., 2008). Samples were weighed (0.5 g) in acetone rinsed Ankom F57 filter bags (5.0 × 5.5 cm., Ankom Technology Corporation, Fairport, NY), heat sealed and stored until incubation. Both 6 and 30 h incubations consisted of two runs with four replicates of each sample per run. Four Daisy^{II} incubators were used for each run, each with four glass fermentation jars placed on rotating racks within the cabinet. Each jar had a plastic separation panel with holes and lids with gas relief valves. Each Daisy^{II} incubator contained all 80 samples of the 7 varieties, with incubators maintained at 39.5°C. Each jar contained 20 randomly allocated samples, two standards (AAFCO standard 1090; average NDF content of 39.6% DM) and two blanks. Rumen fluid was collected from three ruminally cannulated beef heifers fed a 25:75 concentrate:roughage (DM basis) diet for *ad libitum* intake. Daisy^{II} incubation and subsequent

digestion with neutral detergent solution was carried out as per Damiran et al., (2008) and AOAC (2002.04), respectively.

Indigestible NDF

Eight ruminally cannulated beef heifers (452 ± 10 kg; Mean $\pm$ SD) were used for the determination of INDF by the *in situ* method. Heifers were housed in one of the pens of the Beef Cattle Research and Teaching Unit at the University of Saskatchewan. During the trial, cattle were fed a diet consisting of 50% barley silage, 45% barley grain and 5% supplement (% DM) for *ad libitum* intake (5 to 10% refusal), with feed delivery at 0800. Diets were formulated to meet or exceed the NRC (2000) requirement for all the major nutrients. All heifers were cared for as per the guidelines of Canadian Council on Animal Care (CCAC 2009).

For each sample, 3 g was weighed in triplicate into 5×10 cm size custom made *in situ* bags (6 μ m pore size, part no. 07 – 6/5, Sefar America Inc., Depew, NY). In total there were 240 bags (80 samples from 2011 and 2012 all weighed in triplicate). Bags were assigned randomly to each heifer. Sample bags were placed in a laundry bag with a weight to keep the samples immersed and placed in the ventral sac of the rumen and incubated for 288 h (Huhtanen et al., 1994). Total number of bags incubated in the rumen did not exceed 30 per animal.

After incubation, the bags were removed from the rumen and rinsed in cold water until the rinse water was clear. After rinsing, the bags were soaked in cold water for 30 min. Bags were then dried at 55°C for 48 h. After drying, the weight of the bag with residue was recorded.

Chemical Analysis

All silage samples were dried in a forced-air oven at 55°C for 72 h. After drying, the samples were ground through a 1-mm screen (Christy & Norris 20 cm arm Lab mill, Christy Turner Ltd. Chelmsford, UK). Samples were analyzed in duplicate according to the Association of Official

Analytical Chemists (2000) for DM by drying at 135°C (method 930.15; AOAC 2000), ash (method 942.05; AOAC 2000) and NDF with amylase and sodium sulfite (method 2002.04; AOAC 2000). Indigestible NDF in bags after ruminal incubation were analyzed using the same method.

Samples for VFA were analyzed using a Hewlett Packard model 5890A series plus II gas-liquid chromatograph (Hewlett Packard Co., Palo Alto, CA) with a 30m Zebron free fatty acid phase fused silica capillary, 0.32 mm i.d. and 1µm film thickness column (Phenomenex, Torrance, CA). Crotonic acid was used as an internal standard. Samples for lactic and succinic acid were methylated and then quantified using the method of Kudo et al., (1987) using the same column and chromatograph as for VFA with malonic acid as an internal standard. Concentration of ammonia was determined by the colorimetric method using the phenol-hypochlorite procedure outlined by Broderick and Kang (1980).

Samples were analyzed for DM by drying at 135°C (method 930.15; AOAC 2000), CP (method 990.03; AOAC 2000) using a Leco FP 528 Nitrogen Combustion Analyzer (Leco, St Joseph, MI), soluble protein by the borate-phosphate procedure (Krishnamoorthy et al., 1982), acid detergent insoluble crude protein (method 990.03; AOAC 2000), neutral detergent insoluble crude protein (method 990.03; AOAC 2000), rumen degradable protein by the procedure outlined by Krishnamoorthy et al., (1983), ADF (method 973.18; AOAC 2000) and NDF by the method of Van Soest et al., (1991) with the addition of amylase and sodium sulfite. Lignin was determined as described by Goering and Van Soest (1970), ethanol soluble carbohydrate by the method of Hall et al., (1999), starch as described by Hall (2009), ash (method 942.05; AOAC 2000), fat using a tecator extraction unit (method 2003.05; AOAC 2000) and minerals including Ca, P, Mg, K, S, Na, Cl, Fe, Mn, Zn and Cu (method 985.01; AOAC 2000).

Calculations and Statistical Analysis

Non-fiber carbohydrate (NFC) is calculated as $\text{NFC, \%} = 100 - (\text{CP \%} + \text{Fat \%} + \text{Ash \%} + \text{NDF \%} + \text{NDFICP \%})$; Linn 2003) where NDFICP is neutral detergent fiber insoluble crude protein. Nonstructural carbohydrate content (NSC) is calculated as sum of sugars, starch, organic acids and fructans (NRC 2001). Total digestible nutrient (TDN) is calculated as per Weiss summative equation (Weiss 1998) as $\text{TDN} = 0.98 \times (100 - \text{NDFn} - \text{CP} - \text{ash} - \text{EE}) + e^{0.012 \times \text{ADIN}} \times \text{CP} + 2.25 \times (\text{EE} - 1) + 0.75 \times (\text{NDFn} - \text{Lignin}) \times [1 - (\text{Lignin} / \text{NDF})^{0.667}] - 7$ where NDFn = nitrogen free neutral detergent fiber calculated as $\text{NDF} - \text{NDICP} (\% \text{ DM})$, $\text{NDICP} = \text{NDIN} \times 6.25$ and ADIN expressed as a % of total N. Indigestible NDF (INDF_{288}) was calculated as $\text{INDF}_{288} = [\text{NDF}_{288} \div \text{NDF}] \times 100$ where INDF_{288} is the total indigestible NDF fraction (% NDF); NDF_{288} is the amount of NDF remaining in the bag after 288 h of incubation (g) and NDF is the amount of NDF in the bag before ruminal incubation (g). Digestible NDF (DNDF, %) was calculated as $(100 - \text{INDF}_{288} \%)$. The NDFD (6 and 30 h; % NDF) was calculated as $\text{NDFD} (\% \text{ NDF}) = (\text{NDF in feed} - \text{NDF in residue after } in vitro \text{ incubation}) \div \text{NDF in feed}$. The NDFD (6 and 30 h; % DNDF) was calculated as $\text{NDFD} (\% \text{ DNDF}) = (\text{NDF in feed} - \text{NDF in residue after } in vitro \text{ incubation}) \div \text{DNDF in feed}$.

Chemical composition of selected silage varieties was analyzed as a randomized complete block design (RCBD) with year as a random blocking factor using a mixed model procedure of SAS (version 9.4; SAS Institute, Inc. Cary, NC) using the model:

$$Y_{ijk} = \mu + V_i + \beta_j + \varepsilon_{ijk}$$

where Y_{ijk} is the observation of the dependent variable, μ is the population mean, V_i is the fixed effect of variety ($i = 1$ to 7), β_j is the random effect of block ($j = 1$ to 2) and ε_{ijk} the random error associated with the observation. The Daisy^{II} NDFD data were analyzed as RCBD with year as a

random blocking factor using a mixed model procedure of SAS (Version 9.4, SAS Inc. 2013) using the model:

$$Y_{ijklm} = \mu + V_i + \beta_j + D_k + R_l + \varepsilon_{ijklm}$$

where Y_{ijklm} is the observation of the dependent variable, μ is the population mean, V_i is the fixed effect of variety ($i = 1$ to 7), β_j is the random effect of block ($j = 1$ to 2), D_k is the random effect of Daisy^{II} ($k = 1$ to 4), R_l is the random effect of run ($l = 1$ to 2) and ε_{ijklm} the random error associated with the observation.

Indigestible NDF data were analyzed as RCBD with year as a random blocking factor using a mixed model procedure of SAS (Version 9.4, SAS Inc. 2013) using the model:

$$Y_{ijkl} = \mu + V_i + \beta_j + R_k + \varepsilon_{ijkl}$$

where Y_{ijkl} is the observation of the dependent variable, μ is the population mean, V_i is the fixed effect of variety ($i = 1$ to 7), β_j is the random effect of block ($j = 1$ to 2), R_k is the random effect of run ($k = 1$ to 3) and ε_{ijkl} the random error associated with the observation. Denominator degrees of freedom were determined using the Kenward-Roger option. Growing days was used as a covariate to analyze any potential effect of variation in maturity at harvest on chemical and digestibility parameters. Mean separation was done by Tukey's test. Significant differences and trends were declared at $P \leq 0.05$ and $P \leq 0.10$, respectively.

RESULTS AND DISCUSSION

The intent of this study was to carry out a survey of the nutritional quality of barley silage varieties commonly grown by beef and dairy producers. In Western Canada, barley silage is commonly harvested at the early to mid-dough stage of maturity as this stage is considered by many in industry optimal from the point of view of balancing DM yield with acceptable nutrient

quality (McAllister and Hristov 2000; Kaulbars and King 2004). For this reason, only samples harvested at mid-dough stage of plant growth were used for this study. In addition, to determine if variation in maturity at harvest influenced the chemical and digestibility results, the number of growing days was used as a covariate. The analysis of covariance results indicated no significant effects of the covariate and thus was removed from the model.

Detailed chemical composition of the selected barley varieties are presented in Tables 2 through 5. The average pH of the silage samples across the varieties was 4.05 ± 0.07 (Mean $\pm$ SD; Table 2), indicating adequate ensiling in all samples. AC Metcalfe had a higher pH ($P < 0.05$) than Xena with other varieties being intermediate in pH and not differing from each other. Acosta et al., (1991) reported that whole crop barley is easily ensiled owing to its low buffering capacity and high fermentable carbohydrate content. This is evident in the results of this study as the mean pH of the samples was within the range of 3.98 to 4.17, which is considered to be a pH range that is reflective of well-preserved whole crop cereal silages (Jacobs et al., 2009). Similarly, the DM of the varieties ranged from 35.0 – 38.3% which is within the range (30.0 to 40.0%) reported to be optimal for barley silage (Baron et al., 1992). There was no effect of variety on EE content, but CDC Cowboy and Falcon silages had higher ash content ($P < 0.05$) relative to CDC Copeland and Xena with other varieties being intermediate. Calcium concentration of CDC Cowboy, Legacy and AC Metcalfe was higher ($P < 0.05$) than Xena. Falcon had the highest P content ($P < 0.05$), while Xena the lowest.

The average CP content across varieties was $11.2 \pm 0.9\%$ (Mean $\pm$ SD; % DM), ranging from 10.2 to 12.5% (% DM; Table 3). Crude protein content of Falcon and AC Metcalfe was higher ($P < 0.05$) than that of CDC Copeland and Xena. Greater CP content of barley varieties like Falcon and AC Metcalfe are of value in feed formulations for high producing dairy cattle and rapidly

growing beef cattle that require a supplemental CP content in the diet. For example, early lactation dairy rations are typically formulated for 17.0 to 19.0% CP (Castro et al., 2010; Barlow et al., 2012) while many backgrounding diets for beef cattle are formulated to 12.5 to 13.5% CP (Beliveau and McKinnon 2008; Gibb et al., 2008). Varieties with a higher CP content would help offset protein supplementation costs. Falcon had a higher soluble protein (SP) content ($P = 0.05$) relative to Legacy. There was no effect of variety on SP as a % of CP, ADICP or ADICP as a % of CP, averaging 63.1 ± 2.8 (Mean $\pm$ SD; % CP), 0.89 ± 0.07 (Mean $\pm$ SD; % DM) and 8.0 ± 0.4 % (Mean $\pm$ SD; % CP), respectively, across silage varieties. A review of literature indicated that the ADICP (% CP) of barley silage harvested at the mid-dough stage of maturity varied from less than 5% (Zahiroddini et al., 2006; Baah et al., 2011) to over 15% (Zahiroddini et al., 2004; Addah et al., 2012a). The ADICP is the protein fraction contained in the ADF residue which includes protein associated with lignin and tannin, maillard reaction proteins and other heat damaged proteins (Licitra et al., 1996). This protein fraction is biologically unavailable as it is highly resistant to microbial and mammalian enzymes, consequently providing no metabolizable amino acids to the small intestine (Sniffen et al., 1992). The ADICP is regarded as a good indicator of protein damage due to heating in conserved forages (Acosta et al., 1991). For most feeds, no adjustment in CP is needed when ADICP is less than 10% of CP content of the feed. However, when ADICP as a % of CP exceeds 10%, the CP content of a feed can be adjusted to account for the unavailable ADICP fraction (Van Soest 1994).

AC Metcalfe had higher ($P < 0.05$) NDICP content relative to Conlon, CDC Copeland and Xena. Neutral detergent insoluble crude protein is the fraction of CP associated with the cell wall that is insoluble in neutral detergent solution. This fraction is slowly degraded in the rumen and the majority escapes to the small intestine depending on passage rate (Sniffen et al., 1992). For

producers looking to increase both CP and RDP content of the diet, based on these results, AC Metcalfe would be an appropriate variety to grow.

Among the barley varieties analyzed, Falcon had the highest ($P < 0.05$) while Xena the lowest RDP (% DM) content, with all other varieties not differing in this parameter. Rumen degradable protein (RDP) represents the fraction of intake CP that is degraded by ruminal microbes to ammonia, amino acids or dipeptides in the rumen. This fraction consists of NPN, amino acids and true protein that are degraded in rumen fluid (A_1 , A_2 , B_1 , B_2 and B_3 protein fractions; CNCPS) with varying rates of ruminal degradation and passage rates (Tylutki et al., 2008). Rumen microbes require RDP for microbial protein synthesis. A deficiency in RDP will result in reduced carbohydrate digestion, microbial yield and poor performance whereas excess RDP will result in loss of N as urea. Rumen degradable protein as a % of CP however, did not differ among varieties ($P > 0.05$) and averaged 81.6 ± 1.4 (Mean $\pm$ SD; % CP). Similar RDP (% CP) across varieties indicate that microbial protein synthesis from barley protein is likely to vary little among varieties.

The fiber, carbohydrate and energy fractions of the silage varieties are given in Table 4. Acid detergent fiber content averaged $27.7 \pm 1.6\%$ (Mean $\pm$ SD; % DM) across varieties with CDC Cowboy and AC Metcalfe having higher ADF values ($P < 0.05$) than Conlon. Similar to ADF, CDC Cowboy had higher ($P < 0.05$) NDF content than Conlon and Legacy. Average NDF content across the varieties was 44.4 ± 2.7 (Mean $\pm$ SD; % DM). The values for ADF and NDF (range of 26.1 to 30.2 and 41.6 to 48.6 % respectively; % DM) observed in the present study is typical for barley silages harvested at the mid-dough stage (Acosta et al., 1991; Khorasani et al., 1997; Addah et al., 2012b). In a recent evaluation of forage type barley varieties for forage yield and nutritive value in the Peace region of Alberta, Gill et al., (2013) reported a greater ADF

(33.0%) and NDF (52.5%) content for CDC Cowboy relative to other 2 row barley varieties evaluated. Forage NDF content has been reported to be negatively correlated to DMI in beef (Reid et al., 1988) and dairy cattle (Arelovich et al., 2008). Waldo (1986) reported that NDF is the single best chemical predictor of voluntary DMI in ruminants. As well, Galyean and Defoor (2003) reported that dietary NDF accounts for 92% of variation in DMI of steers. Greater dietary NDF content regulates the DMI of cattle fed high forage diets through gut fill as forage NDF is less dense, digested slowly and retained in the rumen longer than other dietary components (Allen 2000; Allen and Bradford 2009). In dairy cattle, it has been reported that depending on forage quality, DMI is negatively affected when NDF intake as a % of BW reaches 1.2 to 1.5% (Mertens 1985; Murphy 2004). Based on these observations, it is likely that DMI of growing cattle fed high NDF barley varieties like CDC cowboy and AC Metcalfe will be impacted to a greater extent relative to those fed low NDF varieties like Conlon, Falcon and Legacy.

Across the silage samples, lignin concentration ranged from 3.7 to 4.5% and averaged $4.0 \pm 0.3\%$ (Mean $\pm$ SD; % DM). Lignin content of AC Metcalfe was higher ($P < 0.05$) relative to CDC Copeland. Rustas et al., (2011) reported similar lignin values (5.8 ± 3.9 , Mean $\pm$ SD; % DM) for barley samples ensiled at the mid-dough stage. Moreover, lignin as a % of NDF did not vary ($P > 0.05$) across the varieties and averaged 9.1 ± 1.2 (Table 4). Lignin concentration has been reported to be negatively correlated to cell wall digestibility (Jung and Deetz 1993). Cross linking of lignin with cell wall components prevents physical access by hydrolytic microbial enzymes for cell wall degradation (Jung and Deetz 1993).

Legacy had higher ($P < 0.05$) NFC and NSC concentrations than CDC Cowboy. Non fiber carbohydrate (NFC) represents the highly digestible cell contents including sugars, starches and pectins, while nonstructural carbohydrates (NSC) include sugars and starches. In the current data set, starch content of Legacy was the highest ($P < 0.05$) while CDC Cowboy had the lowest. Average starch concentration across the varieties was $20.6 \pm 3.3\%$ (Mean $\pm$ SD; % DM), ranging from 14.7 to 24.7% (DM). A review of literature indicated that barley harvested at the mid-dough stage has a starch content ranging from 16.6% (Zahiroddini et al., 2006) to $25.5 \pm 1.5\%$ (Mean $\pm$ SD; % DM; Zahiroddini et al., 2004; Addah et al., 2011, 2012b; Baah et al., 2011). The starch content of barley silage is highly correlated with energy content. This is evident from Table 4 where total digestible nutrient content which averaged $65.9 \pm 1.4\%$ (Mean $\pm$ SD; % DM), ranged from 63.6 to 67.4% with Conlon and CDC Copeland having higher ($P < 0.05$) TDN than CDC Cowboy and AC Metcalfe, with intermediate values for the remaining varieties. Similar TDN value for CDC Cowboy (63.2; % DM) was also reported by Gill et al., (2013). These authors reported a lower TDN, NE_m ($1.26 \text{ Mcal kg}^{-1} \text{ DM}$) and NE_g ($1.07 \text{ Mcal kg}^{-1} \text{ DM}$) values for CDC Cowboy relative to other 2 row barley varieties evaluated. It should be noted that the TDN value of a feed ingredient is calculated directly by a summative approach (Weiss, 1998; NRC 2001) and is highly dependent on nutrient composition and digestibility. As digestibility of starch is greater than that of the cell wall components (Huhtanen et al., 2006), a greater starch content corresponds to a greater TDN value for high starch barley varieties like Conlon, Legacy and Falcon relative to that of low starch barley varieties like CDC Cowboy and AC Metcalfe (Table 4).

There was no difference ($P > 0.05$) in the concentration of fermentation products among varieties (Table 5). Concentration of lactate ($57.4 \pm 4.8 \text{ g kg}^{-1} \text{ DM}$; Mean $\pm$ SD) and acetate

(14.7 ± 3.1 g kg⁻¹ DM; Mean $\pm$ SD) were similar to values reported by Addah et al., (2011) and Baah et al., (2011) for barley ensiled at the mid-dough stage. Butyrate concentration of all the samples was within the range for good quality silage (< 2.5 g kg⁻¹ DM; Ward and de Ondarza 2008). Lactate to acetate ratio for all the silage varieties in the present study was greater than 3:1. This is a good indicator of the efficiency of silage fermentation, as a ratio of 3:1 or greater is ideal for well-preserved silage (Jalč et al., 2009).

Neutral detergent fiber digestibility is a measure of the rumen digestion coefficient of NDF (Francis 2012). It is estimated from *in vitro* incubations which in the literature have ranged from 24 (Dado and Allen 1996) to 48 h (Vogel et al., 1999; Hoffman et al., 2003). While there is some debate as to the preferred length of incubation, 30 h has been suggested to more accurately reflect the ruminal retention of forage NDF (Hoffman et al., 2003; Oba and Allen 2011). The importance of NDFD lies in the fact that it influences the energy value of a forage and can be used in calculations to provide a more accurate measure of TDN and NE by taking into account the digestibility of NDF and other nutrient components in calculations (NRC 2001). In this study, NDFD as a % of NDF after 6 h of incubation (NDFD_{6h}, % NDF) ranged from 1.67 to 4.83% (Table 6). Legacy and Falcon had higher ($P < 0.05$) NDFD_{6h} followed by AC Metcalfe and CDC Cowboy while CDC Copeland, Conlon and Xena exhibited the lowest NDFD_{6h}. Similarly, Legacy had higher NDFD_{6h} as a % of total digestible NDF (NDFD_{6h}, % of DNDF) while Falcon and AC Metcalfe had intermediate values and Conlon, CDC Copeland, CDC Cowboy and Xena having the lowest. Attachment of fiber digesting ruminal microorganisms to the forage is essential for ruminal fiber digestion (Varga and Kolver 1997). The period of time required for ruminal fiber digestion to initiate (lag time) varies depending on forage type, nature of the microbes and the ruminal environment (McAllister et al., 1995). Van Soest et al., (2005) reported

that a 6 hour *in situ* incubation of forage is a good estimate of lag time with most forages exhibiting an average lag time of 4 hours. The NDFD_{6h} results indicates that the time required for initiation of fiber digestion is less than 6 h for all varieties and that minimal differences exist between the barley varieties in initiation of fiber digestion.

In terms of NDFD_{30h} expressed as a % of NDF, CDC Cowboy had the highest ($P < 0.05$) while Legacy the lowest NDFD_{30h} with the other varieties exhibiting intermediate values (Table 6). In contrast, AC Metcalfe had the highest ($P < 0.05$) NDFD_{30h} (% DNDF) value, while Conlon, Falcon and Xena had the lowest with other varieties intermediate and not different from one another. Greater NDFD of forages has been reported to improve the DMI of cattle (Oba and Allen 1999a) when intake is limited by rumen fill. Oba and Allen (1999b) reported 0.17 kg increase in DMI and 0.25 kg increase in 4% fat corrected milk with a one-unit increase in NDFD. Similar improvements in DMI could also be expected for beef cattle fed barley silage based backgrounding diets. Barley varieties like CDC Cowboy with a greater NDFD_{30h} are expected to improve the DMI and milk yield in dairy cattle and feedlot performance of beef cattle relative to barley varieties like Legacy and Xena having a lower NDFD_{30h}, provided the composition of these forages are similar across varieties.

Indigestible NDF content is used as an indicator of forage digestibility and used for digestible energy predictions in mechanistic rumen models (Kramer et al., 2012; Krizsan and Huhtanen 2013). Among the barley varieties evaluated in this study, AC Metcalfe had a higher ($P < 0.05$) INDF₂₈₈ (% DM) content than Falcon, CDC Cowboy and Conlon with other varieties being intermediate. When expressed as a % of NDF, AC Metcalfe also had a higher ($P < 0.05$) INDF₂₈₈ (% NDF) content than CDC Cowboy and Falcon (Table 6) with other varieties being intermediate and not different from one another. These results indicate that the digestible NDF

pool of CDC Cowboy is higher relative to AC Metcalfe (59% versus 42%) with intermediate values for the other varieties (Table 6). This despite the fact that AC Metcalfe and CDC Cowboy had similar NDF contents (47.3 versus 48.6% DM, respectively; Table 4). These results highlight the value of approaches to estimate ruminal availability of NDF. For example, while AC Metcalfe had a higher ($P < 0.05$) NDFD_{30h} (%DNDF), CDC Cowboy had a higher NDFD_{30h} (%NDF). However, since the potentially digestible NDF pool for AC Metcalfe is less than that of CDC Cowboy (Table 6), the potential contribution of NDF to digestible energy is greater in CDC Cowboy than in AC Metcalfe. Such traits may be valuable selection tools for forage breeders looking to improve varieties from a nutritional perspective.

These differences in *in vitro* NDFD between barley varieties grown for silage also have important implications for cattle producers. As reported by Oba and Allen (1999b) with corn silage and Oba and Swift (2014) with barley silage, feeding high producing dairy cows forages with a higher NDFD improves performance in terms of DMI, milk yield and efficiency of milk production. Although similar studies with beef cattle are lacking, feeding a high NDFD barley silage variety to backgrounding or finishing cattle would have the potential to improve performance through enhanced ruminal fiber digestibility, and increased DM and digestible energy intake. It should be pointed out however, that even though CDC Cowboy had the highest NDFD_{30h}, (% NDF), it also had the highest NDF content (48.6, % DM) and the lowest starch content (14.7, % DM). It is not possible to predict from the current data set the degree to which the higher NDFD offsets the lower starch content in terms of overall digestible energy content. Further research is required to determine the implications of these contrasting chemical and digestive characteristics of the barley varieties used in this study on performance parameters of beef and dairy cattle.

CONCLUSION

Seven varieties of barley grown in each of two years and harvested at mid-dough stage of maturity by cattle producers in Saskatchewan and Alberta were compared on the basis of nutrient content and NDFD. Variability in CP, ADF, NDF and starch content indicates that the barley varieties tested are inherently different in chemical composition. Crude protein content of AC Metcalfe was greater than that of Xena. CDC Cowboy had the highest ADF and NDF content and lowest starch content. As well, CDC Cowboy ranked higher in terms of NDFD_{30h} (% NDF) followed by Conlon, CDC Copeland, Falcon and AC Metcalfe with Legacy and Xena ranked lower. CDC Cowboy also had the highest potentially digestible NDF pool while AC Metcalfe the lowest. However, silage fermentation parameters including VFA, lactate and ammonia concentrations were similar across the varieties. Results indicate that there is potential for plant breeders to select barley forage varieties for nutritional characteristics that could allow producers to grow barley silage with enhanced nutrient and digestibility parameters.

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Table 1. Barley silage varieties and number of samples used for chemical analysis, *in vitro* incubation (Daisy^{IIa} system) and INDF^b

Variety ^c	No. of samples	
	2012	2013
Conlon	5	5
CDC Copeland	6	5
CDC Cowboy	5	3
Falcon	3	3
Legacy	3	9
AC Metcalfe	8	7
Xena	9	9
Total	39	41

^aFilter bag technique (Damiran et al., 2008) for *in vitro* incubation.
^bIndigestible NDF determined by rumen incubation of samples for 288 h.
^cVarieties selected based on replicate samples for each year and mid-dough stage of maturity at harvest.

Table 2. Composition and forage quality of barley silage varieties collected in 2012 and 2013

<i>Item</i> ^b	Variety							SEM ^a	<i>P</i> value
	Conlon	CDC Copeland	CDC Cowboy	Falcon	Legacy	AC Metcalfe	Xena		
pH	4.05 <i>ab</i>	4.02 <i>ab</i>	4.11 <i>ab</i>	3.98 <i>ab</i>	4.10 <i>ab</i>	4.17 <i>a</i>	3.94 <i>b</i>	0.052	< 0.01
DM	35.5	37.0	36.9	35.0	37.4	38.3	36.2	1.33	0.61
<i>Composition (% DM)</i>									
EE	3.3	3.1	3.0	3.1	2.8	3.1	2.9	0.15	0.28
Ash	7.1 <i>ab</i>	6.5 <i>b</i>	7.8 <i>a</i>	7.8 <i>a</i>	7.4 <i>ab</i>	7.4 <i>ab</i>	6.6 <i>b</i>	0.31	< 0.01
Ca	0.34 <i>ab</i>	0.30 <i>ab</i>	0.37 <i>a</i>	0.33 <i>ab</i>	0.39 <i>a</i>	0.38 <i>a</i>	0.26 <i>b</i>	0.023	< 0.01
P	0.30 <i>abc</i>	0.29 <i>bc</i>	0.32 <i>ab</i>	0.34 <i>a</i>	0.27 <i>bc</i>	0.30 <i>ab</i>	0.26 <i>c</i>	0.022	< 0.01

Note: Means within a column not sharing a lowercased italic letter differ significantly at the $P < 0.05$ level.

^aSEM, pooled standard error of mean.

^bDM, dry matter; EE, ether extract; Ca, calcium; P, phosphorus.

Table 3. Composition of protein fractions of barley silage varieties collected in 2012 and 2013

	Variety							SEM ^a	<i>P</i> value
	Conlon	CDC Copeland	CDC Cowboy	Falcon	Legacy	AC Metcalfe	Xena		
<i>Item^b (% DM unless otherwise stated)</i>									
CP	10.9 ^{abc}	10.4 ^{bc}	11.6 ^{abc}	12.5 ^a	10.5 ^{abc}	12.2 ^a	10.2 ^c	0.69	< 0.01
SP	7.1 ^{ab}	6.7 ^{ab}	7.3 ^{ab}	8.1 ^a	6.2 ^b	7.4 ^{ab}	6.7 ^{ab}	0.42	0.05
SP, %CP	65.3	64.1	62.5	65.1	58.6	60.3	66.0	2.24	0.07
ADICP	0.85	0.85	0.95	0.87	0.86	1.01	0.84	0.101	0.11
ADICP, %CP	7.8	8.3	8.1	7.1	8.0	8.4	8.3	0.53	0.60
NDICP	0.92 ^b	0.94 ^b	1.07 ^{ab}	1.12 ^{ab}	0.99 ^{ab}	1.21 ^a	0.97 ^b	0.110	< 0.01
NDICP, % CP	8.4	9.1	9.2	9.1	9.2	9.9	9.4	0.53	0.35
RDP	9.0 ^{ab}	8.5 ^{ab}	9.5 ^{ab}	10.3 ^a	8.4 ^{ab}	9.8 ^{ab}	8.4 ^b	0.52	< 0.01
RDP, %CP	82.7	82.1	81.3	82.6	79.3	80.2	83.0	1.12	0.08

Note: Means within a column not sharing a lowercased italic letter differ significantly at the $P < 0.05$ level.

^aSEM, pooled standard error of mean.

^bDM, dry matter; CP, crude protein; SP, soluble protein; ADICP, acid detergent insoluble crude protein; NDICP, neutral detergent insoluble crude protein; RDP, rumen degraded protein.

Table 4. Composition of fiber, carbohydrate and energy fractions of barley silage varieties collected in 2012 and 2013

	Variety							SEM ^a	P value
	Conlon	CDC Copeland	CDC Cowboy	Falcon	Legacy	AC Metcalfe	Xena		
<i>Item^b (% DM unless otherwise stated)</i>									
ADF	26.1 <i>b</i>	27.6 <i>ab</i>	30.2 <i>a</i>	26.3 <i>ab</i>	26.7 <i>ab</i>	29.6 <i>a</i>	27.7 <i>ab</i>	1.02	< 0.01
ADF, % NDF	62.3	62.4	62.4	62.2	63.9	62.5	61.8	1.18	0.72
NDF	41.9 <i>c</i>	44.3 <i>abc</i>	48.6 <i>a</i>	42.2 <i>bc</i>	41.6 <i>c</i>	47.3 <i>ab</i>	44.8 <i>abc</i>	1.21	< 0.01
Lignin	3.82 <i>ab</i>	3.71 <i>b</i>	4.40 <i>ab</i>	3.75 <i>ab</i>	3.95 <i>ab</i>	4.46 <i>a</i>	4.04 <i>ab</i>	0.294	0.01
Lignin, % NDF	9.14	8.42	9.14	8.89	9.44	9.44	9.00	0.558	0.36
ESC	3.39	4.31	3.24	1.76	3.10	2.42	3.41	0.875	0.17
NFC ^c	37.8 <i>a</i>	36.7 <i>ab</i>	30.1 <i>b</i>	35.6 <i>ab</i>	38.5 <i>a</i>	31.2 <i>b</i>	36.4 <i>a</i>	1.72	< 0.01
Starch	22.8 <i>a</i>	21.0 <i>ab</i>	14.7 <i>b</i>	22.5 <i>ab</i>	24.7 <i>a</i>	18.3 <i>ab</i>	20.0 <i>ab</i>	1.73	< 0.01
Starch, % NFC	60.6	57.1	48.5	61.6	63.2	56.6	54.5	3.59	0.12
NSC ^d	26.2 <i>ab</i>	25.3 <i>abc</i>	17.9 <i>c</i>	24.3 <i>abc</i>	27.8 <i>a</i>	20.7 <i>bc</i>	23.4 <i>abc</i>	1.84	< 0.01
TDN ^e	67.4 <i>a</i>	67.2 <i>a</i>	63.6 <i>b</i>	66.6 <i>ab</i>	66.2 <i>ab</i>	64.4 <i>b</i>	66.2 <i>ab</i>	1.09	< 0.01

Note: Means within a column not sharing a lowercased italic letter differ significantly at the $P < 0.05$ level.

^aSEM, pooled standard error of mean.

^bADF, acid detergent fiber; NDF, neutral detergent fiber; ESC, ethanol soluble carbohydrate; NFC, non-fiber carbohydrate; NSC, non-structural carbohydrate; TDN, total digestible nutrients; CVAS, Cumberland Valley Analytical Services.

^cNFC calculated as $\text{NFC, \%} = 100 - (\text{CP \%} + \text{Fat \%} + \text{Ash \%} + \text{NDF \%} + \text{NDFICP \%})$; CVAS, Hagerstown, MD.

^dNSC calculated as $\text{NSC, \%} = \text{sugars \%} + \text{starch \%}$; CVAS, Hagerstown, MD.

^eTDN calculated as per Weiss summative equation (Weiss 1998); CVAS, Hagerstown, MD.

Table 5. Fermentation characteristics of barley silage samples collected in 2012 and 2013

<i>Item (g kg⁻¹ DM)</i>	Variety							SEM ^a	<i>P</i> value
	Conlon	CDC Copeland	CDC Cowboy	Falcon	Legacy	AC Metcalfe	Xena		
VFA									
Acetate	18.9	10.7	13.3	16.5	11.1	16.2	16.4	3.01	0.39
Propionate	0.36	0.08	0.22	0.69	0.04	0.34	0.21	0.207	0.49
Butyrate	0.61	0.66	0.62	0.50	0.54	0.64	0.50	0.300	0.66
Isobutyrate	0.05	0.07	0.03	0.20	0.04	0.05	0.08	0.047	0.31
Valerate	0.10	0.09	0.10	0.68	0.06	0.09	0.24	0.173	0.27
Isovalerate	0.06	0.07	0.07	0.36	0.04	0.06	0.13	0.088	0.31
Caproate	0.11	0.11	0.12	0.31	0.08	0.11	0.13	0.048	0.10
Lactate	56.7	66.4	55.0	60.5	52.8	53.0	57.6	6.89	0.44
Lactate:Acetate ratio	3.97 <i>b</i>	8.13 <i>a</i>	4.84 <i>ab</i>	5.02 <i>ab</i>	5.60 <i>ab</i>	5.06 <i>ab</i>	3.90 <i>b</i>	0.612	< 0.01
Succinate	4.85	3.63	3.07	3.79	4.00	5.07	5.32	0.612	0.06
Ammonia	2.34	2.09	2.18	2.88	1.81	2.43	2.11	0.234	0.14

Note: Means within a column not sharing a lowercased italic letter differ significantly at the *P* < 0.05 level.

^aSEM, pooled standard error of mean.

Table 6. Neutral detergent fiber digestibility and indigestible NDF content of barley silage varieties collected in 2012 and 2013

	Variety							SEM ^a	P value
	Conlon	CDC Copeland	CDC Cowboy	Falcon	Legacy	AC Metcalfe	Xena		
<i>Items^b (% NDF unless otherwise stated)</i>									
NDFD _{6h}	1.67 <i>c</i>	1.58 <i>c</i>	2.37 <i>bc</i>	4.32 <i>a</i>	4.83 <i>a</i>	3.02 <i>b</i>	2.06 <i>c</i>	0.294	< 0.01
NDFD _{6h} , % DNDF	3.56 <i>c</i>	3.83 <i>c</i>	4.02 <i>c</i>	8.13 <i>b</i>	11.25 <i>a</i>	7.20 <i>b</i>	4.72 <i>c</i>	0.735	< 0.01
NDFD _{30h}	30.5 <i>bc</i>	31.1 <i>b</i>	37.0 <i>a</i>	31.6 <i>b</i>	27.6 <i>d</i>	30.8 <i>b</i>	28.8 <i>cd</i>	2.55	< 0.01
NDFD _{30h} , % DNDF	58.5 <i>c</i>	65.8 <i>b</i>	62.5 <i>bc</i>	57.5 <i>c</i>	62.7 <i>bc</i>	71.1 <i>a</i>	59.0 <i>c</i>	4.41	< 0.01
INDF ₂₈₈ , % DM	22.0 <i>bc</i>	23.6 <i>abc</i>	22.4 <i>bc</i>	19.7 <i>c</i>	24.6 <i>ab</i>	27.8 <i>a</i>	25.3 <i>ab</i>	2.33	< 0.01
INDF ₂₈₈	50.7 <i>abc</i>	52.8 <i>ab</i>	41.0 <i>c</i>	45.1 <i>bc</i>	55.5 <i>ab</i>	58.0 <i>a</i>	51.2 <i>abc</i>	3.66	< 0.01
DNDF	49.3 <i>abc</i>	47.2 <i>bc</i>	59.0 <i>a</i>	54.9 <i>ab</i>	44.5 <i>bc</i>	42.0 <i>c</i>	48.8 <i>bc</i>	3.66	< 0.01

Note: Means within a column not sharing a lowercased italic letter differ significantly at the $P < 0.05$ level.

^aSEM, pooled standard error of mean.

^bNDFD_{6h} and NDFD_{30h}, neutral detergent fiber digestibility as measured after 6 and 30h *in vitro* incubation (Daisy^{II} system) respectively as % of NDF and digestible NDF; INDF₂₈₈, indigestible NDF measured based on 288 h *in situ* incubation; DNDF, potentially digestible NDF.