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**Evaluation of Barley Silage with Varying Ruminant In Vitro
Fiber Digestibility on Lactation Performance and Chewing
Activity of Lactating Dairy Cows in Comparison with Corn
Silage**

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ABSTRACT:

There is limited knowledge on the effect of barley silage with different ruminal in vitro NDF digestibility (ivNDFD) on dairy cow performance and chewing activity. The objective of this study was to assess the effects of barley silage varieties selected for varying rates of ivNDFD on lactation performance and chewing activity of high-yield dairy cows in comparison with a new corn silage hybrid. A 4×4 Latin square design was applied in this study with four mid-lactating multiparous Holstein cows. The cows were fed diets containing 49% barley-based concentrate and 51% forage (DM basis). The results show that cows fed corn silage produced more milk ($P<0.05$) and had greater ($P<0.05$) feed efficiency than cows fed barley silages. Cows fed barley silage with relatively higher ruminal ivNDFD did not show significant difference from the cows fed other barley silage varieties in milk yield and total chewing activity. The preliminary results indicated that a univariate approach with only one factor consideration (ivNDFD) might not be a satisfactory method for evaluating and ranking barley silage quality. However, a large-scale animal study with different stages of lactation (early, mid- to late-) is warranted to confirm this finding. This new corn forage hybrid may be an appropriate option as forage source for high producing dairy cows in western Canada.

Key Words: ruminal in vitro fiber digestibility, lactation performance, silage, chewing activity

Abbreviation: **ADL** = acid detergent lignin; **bm3** = brown midrib corn; **BS** = barley silage; **CS** = corn silage; **DMD** = dry matter digestibility; **DMI** = dry matter intake; **ECM** = energy-corrected milk; **FCM** = fat-corrected milk; **ivNDF**= ruminal in vitro

- 44 NDF digestibility; **peNDF** = physically effective neutral detergent fiber; **TMR** = total
45 mixed ration; **VFA** = volatile fatty acids

For Review Only

INTRODUCTION

It is important to provide high producing dairy cows with satisfactory dietary nutrients to maintain their high levels of milk production and body maintenance (NRC, 2001). In western Canada, it is a challenge to produce forage crops due to the restricted growing season that limits the growth range of cropping alternatives (Bootsma and Brown, 1995). Barley silage is well-suited for production in such growing season with relatively low heat requirement (Wallsten and Hatfield, 2016).

The single time point incubation for 30 h ruminal in vitro NDF digestibility (ivNDFD) analysis is widely used for evaluating and ranking forages (Oba and Allen, 1999). Selecting forages with increased ivNDFD has been reported to improve the lactation performance of dairy cattle. Oba and Allen (1999) found that an one percent unit increase in ivNDFD equated to 0.25 kg/d increase in 4% fat-corrected milk yield (FCM) and 0.17 kg/d increase in dry matter intake (DMI). Several studies have confirmed the positive effect of feeding forage with increased ivNDFD on DMI and productivity of dairy cattle (Ferraretto and Shaver, 2015). Effects of forage ivNDFD on milk production have been extensively studied for corn silage. The corn silage hybrids for increased ivNDFD have been developed and commercially available in the US. However, knowledge on the effects of barley silage with different ivNDFD on dairy cattle performance is very limited (Oba and Allen, 2011). Previous research by Nair et al. (2016) showed differences in ruminal in vitro digestible fiber concentration among seven varieties of barley silage grown in western Canada. However, effects of barley with different ruminal in vitro digestible fiber concentration on the productivity of lactating dairy cows and chewing activities have not been studied for those varieties.

The corn grown in the Canadian prairies is different from the corn hybrid varieties grown in warmer climates such as United States (Abeysekara et al., 2013a,b). These differences are attributed to some limitation during growing season (i.e. lower growing temperatures). Successful growth of corn in Canadian prairies depends on the availability of crop heat unit, and corn is considered more suitable to areas receiving a minimum of 2000 to 2100 crop heat units (McCartney et al., 2009). Recently, new hybrids were introduced in western Canada. These new hybrids require a lower crop heat unit. However, no lactation performance study was conducted on any of these corn varieties. In order to establish these hybrids as a forage crop, these must be compared against other conventional forage crops such as whole plant barley silage. The objective of this study was to assess the effects of different varieties of barley silage with varying ruminal ivNDFD on lactation performance and chewing activity of high-yield dairy cows in comparison with the corn silage. The hypothesis of this study was that forage with higher ruminal ivNDFD would improve lactation performance and enhance chewing activity.

MATERIALS AND METHODS

All experimental procedures used in this study were approved by the University of Saskatchewan Animal Care Committee (UCACS Protocol No. 19910012). All cows were housed at the Rayner Dairy Research and Teaching Facility (RDRTF), University of Saskatchewan, Saskatoon, Canada and cared for according to the guidelines of the Canadian Council on Animal Care (2009)

Preparation of Silage

Three barley varieties were selected based on the screening study by Nair et al. (2016) from seven varieties of barley silage using 30 h ivNDFD as an approach for ranking silage varieties. The seven varieties (Conlon, Copeland, Cowboy, Falcon, Legacy, Metcalfe, and Xena) of barley silages were collected within two years (2012 and 2013). Total number of 80 samples were collected from different dairy and beef operations in Saskatchewan and Alberta. These barley varieties have shown some differences in 30 h ivNDFD (range = 26% to 37%). The varieties with the higher and lower ivNDFD after 30 h of incubation were selected for beef, sheep, and dairy study in Saskatchewan and Alberta. This study reports dairy work. All barley varieties were of the two-row type. The ivNDFD of CDC Cowboy (Ardell Seeds, Vanscoy, SK), CDC Copeland (Wylie Farms Ltd., Biggar, SK), and Xena (Crop Production Services, Bow Island, AB) were 37%, 28% and 26%, respectively.

One corn forage variety was selected in the current study (P7213R) based on the previous screening study done at University of Saskatchewan (Abeysekara et al., 2013a,b). In the screening study, six corn forage varieties were selected: Pioneer P7443R, Pioneer P7213R, Pioneer P7535R (Pioneer Hi-Bred International Inc., Johnston, IA), Hyland Baxxos RR, Hyland SR22, and Hyland SR06 (Hyland Seeds, Blenheim, ON, Canada). The results of the previous screening study showed Pioneer P7213R has higher feeding value compared to other corn forage varieties (Abeysekara et al., 2013a,b).

The three barley varieties with different digestible fiber concentrations were grown on the University of Saskatchewan Research Farm (latitude: 52.15 ° N, Longitude: 106.61° W and altitude 491 m) in 2014 under dry land conditions under the same management conditions, to avoid the effect of environment on silage quality, particularly

ivNDFD. Barley varieties were seeded on May 20, 2014, in 12 ha of non-irrigated land, and harvested on July 31, 2014, at the mid-dough growth stage. Consideration was taken to seed and harvest all barley varieties at the same maturity stage, to account for the environmental effect and growing duration period, although the optimum harvesting for those forages are different where CDC Cowboy is preferred to be harvested at late maturing while CDC Copeland and Xena are optimum at medium maturing as reported by Fedko (2015). The DM yield for all barley forages averaged 7.8 Mg/ha. The cost of production for each barley forage variety was \$28.6 /wet Mg. All barley varieties were cut at 10-cm above ground and chopped to 10-mm by a forage harvester. The chopped forages stored directly in a pile without using inoculation and covered with plastic for 40 d. The corn variety (hybrid 7213R, Pioneer, Warman, SK), was also grown at the University of Saskatchewan Research Farm and was seeded May 29, 2014, in 18.2 ha of non-irrigated land, and harvested on September 29, 2014, after reaching target heat units at about 33% DM. The DM yield of corn forage was 16.7 Mg/ha. The cost of corn forage was \$30.3 /wet Mg. Corn forage was chopped at 1.95-cm theoretical cut length and processed with a 1-mm roller clearance and stored in a pile using double-layer cover without inoculation. All barley forages were ensiled for 40 d (then opened and used for beef cattle performance trial first), while corn silage was ensiled for 120 d (then opened for this dairy trial together with the barley silages). Then, the storage period for barley silage when dairy trial started was about 200 days. The chemical composition of the silage as sampled at two different times from the silos before starting the experiment is presented in Table 1. Wet chemistry analyses were conducted commercially (Cumberland Valley Analytical Service, Inc. Maugamsville, MD). Samples from the barley and corn

silages were taken, and frozen at -20°C until processing. On the day of processing, samples were thawed at 4°C . All samples were processed for measuring pH, lactate, ammonia, and volatile fatty acid (VFA) concentrations. For the ruminal in vitro study, the silage samples were collected and dried at 55°C for 48 h. These samples were a composite (4 kg of each) of three month of sampling, collected during our lactation trial. The dried samples were ground to pass a 1-mm screen (Christy & Norris mill 8" Lab mill, Christy Turner Ltd, Chemsford, UK).

Experimental Cows and Diets

Mid-lactating multiparous Holstein cows ($n=4$; average BW = 703 ± 78 kg; DIM = 101 ± 25 ; parities = 2.75 ± 0.83) were used in a 4×4 Latin square design. The cows were housed indoors individually in tie-stalls at the Rayner Dairy Research and Teaching Facility, University of Saskatchewan, Saskatoon, SK, Canada. The cows were fed diets containing 49% barley-based concentrate and 51% forage (on DM basis). The forage consisted of 10% alfalfa hay and 41% whole-plant silages. The four whole-plant silages were: corn silage (P7213R), CDC Cowboy BS, CDC Copeland BS, and Xena BS. The nutrient composition of the experimental forages is presented in Table 1. For barley silage, the diets were formulated to be similar in ingredient composition to associate changes in cow performance and total chewing activity with change in barley forage variety. For corn silage, the diet was formulated to have similar CP level to barley silage-based diets. The 30 h ruminal ivNDFD of corn silage, CDC Cowboy, CDC Copeland and Xena varieties were 32, 39, 38, and 30%, respectively. The diets were formulated using the NDS Professional (Version 3, RUM&N - NDS Professional, Reggio Nell'Emilia,

Emilia-Romagna, Italy) to supply adequate metabolizable energy and metabolizable protein for dairy cattle in 120 days in milk producing 42 kg of milk. Diets were offered as a TMR for ad libitum intake (approximately 5% orts on an as-fed basis) and refusals were removed and weighed before each morning feeding.

The experimental period lasted for 23 d with each experimental period comprising 2 d diet change-over period, 16 d adaptation period, and 5 d sampling period. During the change-over period, diets were gradually adjusted to the subsequent diet by feeding the dairy cows diet content 25% of new TMR + 75% of older TMR in the first day and 50% new TMR + 50% of older TMR in the second day. Cows were individually fed a TMR at 0900 and 1600 h and milked three times daily at 0430, 1230 and 1900 h. Samples of silages and hay were collected weekly, and the DM content was used to adjust diets to maintain the specified forage to concentrate ratio.

Feed ingredient and orts samples were collected during the last 5 d of each period and pooled by cow and by period for chemical analysis. Representative samples of the offered TMR were taken during sampling period for particle size determination. Samples for particle size determination were sieved using the 2-screen (19- and 8-mm) Penn State Particle Separator (PSPS; Lammers et al. 1996). The separated fractions were weighed and dried prior to calculation of physically effective NDF (peNDF) as described by Lammers et al. (1996). The method of the calculation of peNDF consisted of the sum of particles retained on sieves of 19- and 8-mm of PSPS multiplied by the NDF concentration of the diet. The amount of feed offered and refused was recorded in last 10 d of each period for feed intake determination.

Chewing activity (i.e. eating, ruminating) for cows was monitored over 24 h period on d 19 and 20 of each period using cameras with digital video recorder (QSEE, QC908 HD DVR, China). Each recording commenced before the morning feed. Observations were made at five minute intervals for time spent eating, and ruminating as described by Mugerwa et al. (1973).

The yield of milk was recorded at each milking during the last 10 d of each experimental period. Milk samples were collected in the last 3 d of each sampling period (21, 22 and 23 d), preserved with potassium dichromate, and tested at CanWest DHI (Edmonton, AB) for milk fat (% fat yield), protein (% protein yield), lactose (% lactose yield), milk urea, and total solids (%). Somatic cell count was determined using a near infrared analyzer (Foss System 4000, Foss Electric, Hillerød, Denmark). Solids-not-fat was calculated as follow: protein + lactose + other solids factor, where, in Canada, other solids factor is taken as 0.9759 % of milk. This comprises minerals plus components not measured by the near infrared analyzer. Minerals in milk are about 0.72%. Energy-corrected milk (ECM) was calculated according to Bernard (1997): $ECM [kg] = (0.3246 \times \text{milk yield [kg]}) + (12.86 \times \text{milk fat [kg]}) + (7.04 \times \text{milk protein [kg]})$.

Cumulative Gas Production of Silages

Cumulative gas production of silages was measured in batch culture (mL/g OM) as described by Eun et al. (2007). Approximately 0.5 g sample (1-mm) was weighed in triplicate into acetone washed filter bags (F57, Ankom Technology, Macedon, NY). The bags were sealed and placed into 100-ml serum bottles. Two different rumen-cannulated Holstein cows were used and rumen fluids were collected 2 h after feeding from two rumen-cannulated Holstein cows. The ruminal in vitro experimental runs were also

performed on two different days. The cows were fed a total mixed ration twice daily at 0800 and 1600. The total mixed ration feed (kg DM feed/d) was formulated with 6.3 kg barley silage, 3.4 kg corn silage, 4.5 kg chopped alfalfa hay, and 13.8 kg barley-based concentrate to meet the NRC requirement for lactating dairy cows. Each serum bottle received 15 mL of strained ruminal fluid and 45 mL of McDougall's buffer, during which oxygen-free CO₂ was flushed. The bottles were capped with a 14-mm butyl rubber stopper and crimp sealed. Three blanks which contained 60 mL of medium without feed samples were used for each incubation time. Sealed bottles were incubated in an oscillating shaker at 39°C with an oscillation speed of 125 rpm for 30 h. Headspace gas production was measured at 3, 6, 9, 12, 24 and 30 h by inserting a 23-gauge (0.6 mm) needle attached to a pressure transducer (Model PX4200-015GI; Omega Engineering, Inc., Laval, QC, Canada) connected to a visual display device (Data Track, Christchurch, UK). Pressure values, corrected for the gas released from the blanks, were used to generate volume estimates using the equation described by Mauricio et al. (1999).

Chemical Analysis

All the dried forages, silage and diet samples, were ground through a 1-mm screen (Retsch ZM-1, Brinkmann Instruments Canada Ltd., Mississauga, ON, Canada) for use in chemical analyses. Dry matter (method 930.15), ash (method 942.05), crude fat (method 2003.05), and CP (method 990.03) were analyzed according to AOAC (2000). For estimation of CP, N was determined using a Leco FP 528 Nitrogen Combustion Analyzer (Leco, St Joseph, MI). The acid detergent fiber (ADF), NDF, and acid detergent lignin (ADL) values were also analyzed according to Van Soest et al. (1991) method

combined with an ANKOM A200 filter bag technique (ANKOM Technology Corp., Fairport, NY, USA). Amylase and sodium sulfite were used in the NDF analysis. For silage fermentation measures, the frozen samples were thawed overnight at 4°C and used for measuring pH, VFA, lactate, and ammonia concentrations according to Zahiroddini et al. (2004) and Chaves et al. (2011). Concentration of VFA was quantified using a gas chromatograph (Model 5890, Hewlett-Packard Lab, Palo Alto, CA) with a capillary column (30 m × 0.32 mm i.d., 1-µm Phase thickness, Zebron ZB-FAAP, Phenomenex, Torrance, CA) and flame ionization detection, and crotonic acid (trans-2-butenic acid) was used as the internal standard. Ammonia-N concentrations were measured according to the method described by Rhine et al. (1998).

Statistical Analysis

The LSD data were analyzed using Proc Mixed SAS 9.4 (SAS Institute, Cary, NC). Data for intake, milk production and chewing activity were analyzed with the following model: $Y_{ijk} = \mu + T_i + P_j + C_k + e_{ijk}$, where: Y_{ijk} = the observation of the dependent variable; μ = the overall mean; T_i = the fixed effect of the i^{th} treatment; P_j = the fixed effect of the j^{th} period; C_k = the random effect of the k^{th} cow; e_{ijk} = the random error associated with the observation. The final variance and covariance structure model were selected based on AIC and BIC values in the variance and covariance structure assumption models testing results (Tempelman et al., 2001).

The cumulative gas production and ruminal ivNDFD data were analyzed as randomized complete block design. The statistical model used to analyze these parameters was $Y_{ijk} = \mu + T_i + B_j + e_{ijk}$, where, Y_{ijk} = an observation of the dependent

variable; μ = the population mean for the variable; T_i = the treatment effect, as a fixed effect; B_j = block effect of two ruminal in vitro runs with two fistulated dairy cows, as random effects; e_{ijk} = the random error associated with the observation. Results are reported as least squares means, compared using the Tukey correction for multiple comparisons.

Significance was declared at $P \leq 0.05$ and a trend at $0.05 < P < 0.10$ unless otherwise stated. Comparison between the corn silage vs. average all barley silages-based diets was carried out using a SAS Contrast Procedure of SAS (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Chemical Profile of the Silage and Cumulative Gas Production of Silages

Chemical characteristics of barley and corn silages are presented in Table 1. Starch concentration was higher in CS (26.4 %DM), intermediate for Copeland and Xena BS (average 14.3 %DM), and lower for Cowboy BS (8.7 %DM). A previous study by Nair et al. (2016) reported a lower starch concentration for Cowboy (14.7%), compared to Copeland (21.0 %DM) and Xena (20.0 %DM). The fiber concentration differs between silages, where Cowboy BS had higher NDF concentration, compared with other barley forages (55 vs. 50 % DM). The fiber concentration for all barley varieties in the present study was greater than that reported by Nair et al. (2016). The lower starch and higher NDF concentration for barley silage varieties in the present study may be attributed to effect of maturity and/or environmental conditions that altered the chemical profile of the selected forages (Yu et al., 2004). In the present study, the DM yield of all barley forage

varieties was lower than corn forage (7.8 vs 16.7 Mg/ ha). These results would suggest that new corn hybrids with low crop heat unit may produce high quality forage to meet the nutrient requirements of high producing dairy cattle. Further research is warranted to confirm this finding.

Ruminal in vitro gas production and ruminal ivNDFD of silages are presented in Table 2. There were no differences among barley silages in gas production during 30 h of incubations ($P > 0.10$). However, CS had higher cumulative gas production after 30 h of incubation than barley silage varieties (147 vs. 132 mL/g OM; $P = 0.03$). The average ivDMD in CS was greater than all barley silage varieties (60 vs. 57 %; $P = 0.02$). The greater digestibility and gas production of CS are attributed to the large portion of non-structural carbohydrates in CS compared with barley silage varieties. The difference in ensiling time between CS and BS may have some effect in ivDMD (Der Bedrosian et al., 2012). The results showed Cowboy BS had a higher ruminal ivNDFD compared to Xena BS (39 vs. 29 %, $P = 0.02$; Table 2). It has been reported that forage fiber digestibility could be influenced by many variables, such as the stage of maturity (Yu et al., 2004), soil type, climate conditions, growing conditions (Chow et al., 2008). To our opinion, the stage of maturity is the most important. A previous study also showed ruminal ivNDFD was higher in Cowboy BS than Xena and Copeland BS (Nair et al., 2016).

Feed Intake

The results in the current study (Table 4) showed the cows fed corn silage-based diet tended to improve the DM and OM intakes ($P < 0.10$), compared with cows fed barley silage-based diets. These findings are in agreement with Benchaar et al. (2014), where

they found that replacing barley silage-based diet with corn silage-based diet is associated with increase in DMI in dairy cattle. The higher DM intake in corn silage could be attributed to the lower and higher NDF and starch concentrations, respectively, and therefore higher energy density in the corn silage-based diet than barley silage-based diets. The corn silage-based diets had a lower peNDF compared to barley silage diets (9.7 vs. 15.8 % DM, Table 3); the reduction in peNDF would in turn enhance the feed intake. Fischer et al. (1994) observed greater intakes of DMI when multiparous cows were fed short alfalfa silage, compared with long alfalfa silage.

Intakes of DM, OM, CP and NDF were not affected by the barley silage-based diets ($P > 0.10$, Table 4). Feeding dairy cattle diets with high fiber concentrations is likely to limit feed intake by physical fill and ruminal distension. Oba and Allen (1999) found forages with higher ruminal ivNDFD could increase DM intake by 0.17 kg for every one-unit increase in ivNDFD. The lack of effect of Cowboy BS-TMR with increased ruminal ivNDFD on DM intake in the present study is in agreement with previous short-term studies on dairy cows fed barley silage-based TMR or corn silage-based TMR with higher ruminal ivNDFD (Weiss and Wyatt 2006; Chow et al., 2008; Holt et al., 2010, 2013; Oba and Swift, 2014). Compared with the other two barley silage, Cowboy BS had higher ivNDFD but also higher in NDF concentration too, higher NDF concentration, so one could have cancelled the other. That may be the main reason why the lack of effect of Cowboy BS-TMR with increased ruminal ivNDFD on DM intake.

Milk Production and Composition

Cows fed CS had higher milk, FCM, ECM, protein, lactose, and solids-not-fat yields than cows fed barley silages (Cowboy BS-TMR, Copeland BS-TMR, Xena BS-TMR; $P < 0.05$; Table 4). The cows fed a corn silage-based diet had improved feed efficiency compared with cows fed barley silage-based diets (1.57 vs. 1.37 ± 0.07 ECM/DMI, $P = 0.03$). The higher milk yield is attributed to the higher DM digestibility in CS, compared to cows fed barley silage-based diets. The difference in ensiling time between CS and BS might affect ivDMD and consequently might also affect milk production (eg. milk, FCM, ECM; Der Bedrosian et al., 2012). In the present study, the corn silage based-diet had higher metabolizable energy (Table 3) than barley silage-based diets by 4.5%, thus the increase in milk yield and feed efficiency may have resulted from higher metabolizable energy concentration.

There was no difference among all forages in milk fat concentration. There was no effect of P7213R CS-TMR on protein and milk urea N compositions compared to other diets. However, the cows fed P7213R CS-TMR produced more milk protein, compared to barley silage diets (1.17 vs. 1.03 kg/d; $P = 0.02$). Benchaar et al. (2014) found replacing barley silage with corn silage increased the protein concentration and yield. They attributed these increases to higher N utilization by animals that fed corn silage-based diet compared to the cows that fed barley silage-based diets.

There were no differences among all barley silage-based diets on milk yield or milk composition and feed efficiency (Table 4). Oba and Allen (1999) found a one-unit increase in ruminal ivNDFD equated to 0.25 kg/d increase in 4% FCM yield. The lack effect of Cowboy BS-TMR on milk production or composition and feed efficiency are attributed to its limited effect on DM intake. Tine et al. 2001 observed brown midrib corn

silage (bm3) with higher ruminal ivNDFD could provide greater energy concentration to dry cows at maintenance, due to the higher fiber digestibility, but this effect was alleviated when cows fed bm3 corn silage during lactation. Those authors suggested any increases in milk production because of feeding bm3 corn silage should be driven by increasing DM intake. They also suggested most of additional metabolizable energy due to feeding bm3 corn silage diets was partitioned toward tissue energy gain but not milk energy. Oba and Allen (1999) concluded dairy cows took more advantage from the increased NDF digestibility of corn silage because it allowed them to consume more DMI that supported higher milk yield.

There was no effect of the barley silage-based diets on milk fat percentage or milk fat yield ($P > 0.10$). Milk fat percentage is primarily related to the supply of digestible carbohydrates concentration in the diets. The amount of forage, NDF concentration, and peNDF has been also reported to affect rumen microbiota and milk fat percentage (Santos, 2002). In the current study, all barley silages have similar milk fat concentration because they have similar peNDF and NDF concentration.

Eating and Ruminating

Time spent eating, ruminating, or total chewing activity, either expressed as min/d, min/kg DM or, min/kg NDF were not affected by feeding cows barley silage with increased ruminal ivNDFD (Table 5). The effects of increased ruminal ivNDFD of forages on eating and ruminating time are not consistent in literature; higher ruminal ivNDFD of forages was revealed to influence positively (Zebeli et al., 2006), negatively (Taylor and Allen, 2005), or not (Oba and Allen, 2000) the chewing activities in dairy

cattle. The lack effect of Cowboy BS-TMR with the higher ruminal in vitro digestible fiber concentration on chewing activity is attributed to its limited effect on the DM intake.

In this study, P7213R CS-TMR had a lower level of peNDF (by 48%; Table 3) compared with the barley silage-based TMR. The mean time of ruminating tended to lower in P7213R CS-TMR compared to other diets (508 vs. 578 min/d; $P=0.07$). This reduction in ruminating time reflects the peNDF level in P7213R CS-TMR compared to other diets. Yang and Beauchemin (2006) observed that reducing peNDF by decreasing the chop length of barley silage from 9.5 to 4.8 mm did not affect DMI or time spent eating, but reduced time spent ruminating (by 80 min/d).

CONCLUSION

This study showed that cows fed corn silage produced significantly more milk and had greater feed efficiency than cows fed barley silages. Cows fed barley silage with relatively higher ruminal ivNDFD did not show significant difference from the cows fed other barley silage varieties with lower ruminal ivNDFD in milk yield and total chewing activity.

The barley forage selected, based on its higher ruminal in vitro NDF digestibility did not correspond with a greater effect on lactation performance due to its limited effect on feed intake compared to other barley forage varieties. It is a challenge to select barley forage based on single time point NDF digestibility; the year-to-year effect could alter NDF and rumen fermentable neutral detergent fiber levels. It is necessary to breed new hybrids with higher fermentable neutral detergent fiber concentration that would tolerate

any climatic condition. These results indicate feeding a corn silage-based diet increased energy density (less lignin and higher starch) in the rumen, compared to other barley silage-based diets.

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Abeysekara, S., Christensen, D. A., Niu, Z., Theodoridou, K. and Yu, P. 2013a. Molecular structure, chemical and nutrient profiles, and metabolic characteristics of the proteins and energy in new cool-season corn varieties harvested as fresh forage for dairy cattle. *J. Dairy Sci.* **96**: 6631–6643.

Abeysekara, S., Christensen, D. A. Yu, P. 2013b. Characterizations of structural, biochemical and nutritive profiles in silage among cool-season corn cultivars in relation

409 to heat units (aCHU, dCHU) with curvilinear response and multivariate analyses. J.
410 Agric. Food Chem. **61**: 12315–12326 (DOI:10.1021/jf403245c)

411 **AOAC. 2000.** Official Method 985.01, Metals and other elements in plants and pet
412 foods. In, Official Methods of Analysis of the Association of Official Analytical
413 Chemists (17th ed). Gaithersburg, MD: AOAC International.

414 **Benchaar, C., Hassanat, F., Gervais, R., Chouinard, P. Y., Petit, H. V. and Massé, D.**
415 **I. 2014.** Methane production, digestion, ruminal fermentation, nitrogen balance, and milk
416 production of cows fed corn silage- or barley silage-based diets. J. Dairy Sci. **97**: 961–
417 974.

418 **Bernard, J. K. 1997.** Milk production and composition responses to the source of protein
419 supplements in diets containing wheat middlings. J. Dairy Sci. **80**: 938–942

420 **Bootsma, A. and Brown, D.M. 1995.** Risk analysis of crop heat units available for corn
421 and other warm-season crops in Ontario. Agriculture and Agri-Food Canada, Technical
422 Bulletin 1995-1E.

423 **Canadian Council on Animal Care. 2009.** Guidelines on: The Care and Use of Farm
424 Animals in Research, Teaching and Testing. CCAC, Ottawa, ON, Canada.

425 **Chaves, A. V., Baah, J., Wang, Y., Mcallister, T. A. and Benchaar. C. 2012.** Effects
426 of cinnamon leaf, oregano and sweet orange essential oils on fermentation and aerobic
427 stability of barley silage. J. Sci. Food Agric. **92**: 906-915.

428 **Chow, L.O., Baron, V.S., Corbett, R. and Oba, M. (2008).** Effects of planting date on
429 fibre digestibility of whole-crop barley and productivity of lactating dairy cows. J. Dairy
430 Sci. **91**: 1534-1543.

- 431 **Der Bedrosian, M.C., Nestor, K.E. and Kung Jr, L. (2012).** The effect of hybrid,
432 maturity and length of storage on the composition and nutritive value of corn silage. *J.*
433 *Dairy Sci.* **95**: 5115–5126.
- 434 **Eun, J. S., and Beauchemin. K. A. 2007.** Enhancing in vitro degradation of alfalfa hay
435 and corn silage using feed enzymes. *J. Dairy Sci.* **90**: 2839–2851.
- 436 **Fedko, A. 2015.** Varieties of cereal and oilseed crops for Alberta. Alberta Agriculture
437 and Rural Development. Agdex 100/32-1. Accessed online:
438 [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/agdex14708](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex14708) [May 30, 2016]
- 439 **Ferraretto, L. F. and Shaver, R. D. 2015.** Effects of whole-plant corn silage hybrid type
440 on intake, digestion, ruminal fermentation, and lactation performance by dairy cows
441 through a meta-analysis. *J. Dairy Sci.* **98**: 2662–2675.
- 442 **Fischer, J. M., Buchanan-Smith, J. G., Campell, C., Grieve, D. G. and Allen, O. B.**
443 **1994.** Effects of forage particle size and long hay for cows fed total mixed rations based
444 on alfalfa and corn. *J. Dairy Sci.* **77**: 217–229.
- 445 **Hall, M. B., Hoover, W. H., Jennings, J. P. and Miller T. K. 1999.** A method for
446 partitioning neutral detergent-soluble carbohydrates. *J. Sci. Food Agric.* **79**: 2079–2086.
- 447 **Hall, M. B. 2009.** Analysis of starch, including maltooligosaccharides, in animal feeds: A
448 comparison of methods and a recommended method for AOAC collaborative study. *J.*
449 *AOAC Int.* **92**: 42–49.
- 450 **Holt, M. S., Williams, C. M., Dschaak, C. M., Eun, J.-S. and Young. A. J. 2010.**
451 Effects of corn silage hybrids and dietary nonforage fiber sources on feed intake,
452 digestibility, ruminal fermentation, and productive performance of lactating Holstein
453 dairy cows. *J. Dairy Sci.* **93**: 5397–5407.

- 454 **Holt, M. S., Eun, J.-S., Thacker, C. R., Young, A. J., Dai, X. and Nestor Jr. K. E.**
455 **2013.** Effects of feeding brown midrib corn silage with a high dietary concentration of
456 alfalfa hay on lactational performance of Holstein dairy cows for the first 180 days of
457 lactation. *J. Dairy Sci.* **96**: 515–523.
- 458 **Lammers, B. P., Buckmaster, D. R. and Heinrichs. A. J. 1996.** A simplified method
459 for the analysis of particle sizes of forage and total mixed rations. *J. Dairy Sci.* **79**: 922 -
460 928.
- 461 **Mauricio, R. M., Mould, F. L., Dhanoa, M. S., Owen, E., Kulwant, C. S. and**
462 **Theodorou. M. K. 1999.** A semi-automated in vitro gas production technique for
463 ruminant feedstuff evaluation. *Anim. Feed Sci. Technol.* **79**: 321–330.
- 464 **McCartney, D., Fraser, J. and Ohama, A. 2009.** Potential of warm-season annual
465 forages and brassica crops for grazing: A canadian review. *Can. J. Anim. Sci.* **89**, 431-
466 440.
- 467 **Mugerwa, J. S., Christensen, D. A. and Ochetim. S. 1973.** Grazing behaviour of exotic
468 dairy cattle in Uganda. *East Afr. Agric. For. J.* **39**:1–11.
- 469 **Nair, J., Christensen, D., Yu, P., Beattie, A. D., McAllister, T., Damiran, D., Fuhr, L.**
470 **and McKinnon, J. J. 2016.** A nutritional evaluation of common barley varieties grown
471 for silage by beef and dairy producers in western Canada. *Can. J. Anim. Sci.* In Press.
- 472 **NRC. 2001.** Nutrient requirements of dairy cattle, 7th revised edition. National Academy
473 Press, Washington, DC, USA.
- 474 **Oba, M. and Swift. M. L. 2014.** Short communication: effects of feeding falcon or tyto
475 whole-plant barley silage on milk production and feed efficiency. *Can. J. Anim. Sci.* **94**:
476 151–153.

- 477 **Oba, M., and Allen, M. S. 2011.** The impact of improving NDF digestibility of corn
478 silage on dairy cow performance. In: Proceedings of the 22nd annual Florida ruminant
479 nutrition symposium, pp. 105–117, University of Florida, Gainesville, FL.
- 480 **Oba, M., and Allen, M. S. 1999.** Evaluation of the importance of the digestibility of
481 neutral detergent fiber from forage: Effects on dry matter intake and milk yield of dairy
482 cows. *J. Dairy Sci.* **82**: 589–596.
- 483 **Rhine, E. D., Sims, G. K., Mulvaney, R. L. and Pratt. E. J. 1998.** Improving the
484 Bertholot reaction for determining ammonium in soil extracts and water. *Soil Sci. Soc.*
485 *Am. J.* **62**: 473–480.
- 486 **Santos, J.E.P. 2002.** Feeding for Milk Composition. In: Proc. VI Intern. Cong. on
487 Bovine Medicine, pp 163-172, Spanish Association of Specialists in Bovine Medicine
488 (ANEMBE), Santiago de Compostela, Spain.
- 489 **Taylor, C. C. and Allen. M. S. 2005.** Corn grain endosperm type and brown midrib 3
490 corn silage: Site of digestion and ruminal digestion kinetics in lactating cows. *J. Dairy*
491 *Sci.* **88**: 1413–1424.
- 492 **Tempelman, R.J., Douglass, L.W. and Craig, B.A 2001.** NCR-170 FASS Mixed
493 Model Workshop Notes -2001 IAAFSC National Meetings.
- 494 **Tine, M. A., Mcleod, K. R., Erdman, R. A., and Baldwin, R. L. 2001.** Effects of
495 brown midrib corn silage on the energy balance of dairy cattle. *J. Dairy Sci.* **84**: 885–895.
- 496 **Van Soest, P.J., Robertson, J.B. and Lewis, B.A. 1991.** Methods for dietary fiber,
497 neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. *J.*
498 *Dairy Sci.* **74**: 3583–3597.

- 499 **Wallsten, J. and Hatfield, R. 2016.** Cell wall chemical characteristics of whole-crop
500 cereal silages harvested at three maturity stages. *J. Sci. Food Agri.* **96**: 3604-3612.
- 501 **Weiss, W. P. and Wyatt, D. J. 2006.** Effect of corn silage hybrid and metabolizable
502 protein supply on nitrogen metabolism of lactating dairy cows *J. Dairy Sci.* **89**:1644-
503 1653.
- 504 **Yang, W. Z. and Beauchemin, K. A. 2006.** Effects of physically effective fiber on
505 chewing activity and ruminal pH of dairy cows fed diets based on barley silage. *J. Dairy*
506 *Sci.* **89**: 217–228.
- 507 **Yu, P., Christensen, D. A. and McKinnon, J. J. 2004.** In situ rumen degradation
508 kinetics of timothy and alfalfa as affected by cultivar and stage of maturity. *Can. J. Anim.*
509 *Sci.* **84**: 255-263.
- 510 **Zahiroddini, H., Baah, J., Absalom, W. and McAllister, T.A. 2004.** Effect of an
511 inoculant and hydrolytic enzymes on fermentation and nutritive value of whole crop
512 barley silage. *Anim. Feed Sci. Technol.* **117**: 317–330.
- 513 **Zebeli, Q., Tafaj, M., Steingass, H., Metzler, B., Drochner, W. 2006.** Effects of
514 physically effective fiber on digestive processes and milk fat content in early lactating
515 dairy cows fed total mixed rations. *J. Dairy Sci.* **89**: 651–668.

Table 1. Chemical and silage fermentation profiles for corn and barley silages

Items	Silages ¹			
	Corn	Barley		
	P7213R-CS	Cowboy-BS	Copeland-BS	Xena-BS
Chemical profile, %DM ²				
DM	33.8	27.5	31.0	30.5
Ash	5.7	8.3	7.4	8.2
EE	2.7	2.9	2.8	2.6
CP	9.1	11.7	11.2	10.7
Starch	26.4	8.7	13.3	15.3
NDF	44.4	55.0	51.0	48.4
ADF	25.3	34.3	31.9	30.0
Hemicellulose	19.1	20.7	19	18.4
Silage fermentation				
pH	3.89	4.03	4.13	4.27
VFA, % DM				
Acetate	0.98	2.08	2.41	2.44
Propionate	0	0.045	0.083	0.315
Butyrate	0	0.108	0.006	0.001
Lactate	7.43	9.17	6.8	4.98
Ammonia	0.15	0.31	0.27	0.28

¹ P7213R-CS = P7213R corn silage; Cowboy-BS = CDC Cowboy barley silage with a higher ivNDFD; Copeland-BS= CDC Copeland barley silage with an intermediate ivNDFD; Xena-BS= Xena barley silage with a lower ivNDFD.

²ADF = acid detergent fiber; hemicellulose = NDF – ADF

Table 2. Accumulated gas production, and ruminal in vitro dry matter and neutral detergent fiber digestibility of barley silages with varying digestible fiber concentration compared with corn silage determined by using fistulated dairy cows

Items	Silages ¹				SEM ²	P- value	P- value
	Corn (C)	Barley (B)					Contrast
	P7213R- CS	Cowboy- BS	Copeland- BS	Xena-BS			C vs. B
Asymptotic cumulative gas volume (mL/g OM)							
3 h	18.9	24.8	20.8	17.6	6.06	0.37	0.53
6 h	45.0	41.9	43.4	40.4	6.55	0.86	0.51
9 h	69.7	57.7	60.8	58.7	4.96	0.23	0.05
12 h	86.9	73.2	75.9	72.5	4.73	0.11	0.02
24 h	131.2	117.2	119.0	113.5	6.91	0.12	0.02
30 h	146.6	133.2	134.1	128.7	6.36	0.16	0.03
In vitro ruminal nutrient digestibility, %							
DM-30 h (ivDMD)	59.5a	54.8b	57.5ab	56.5ab	1.12	0.03	0.02
NDF-30 h (ivNDFD)	32.4ab	39.0a	38.0ab	29.7b	4.67	0.02	0.26

¹P7213R-CS = P7213R corn silage; Cowboy-BS = CDC Cowboy barley silage with a higher ivNDFD; Copeland-BS = CDC Copeland barley silage and Xena-BS = Xena barley silage with a lower ivNDFD.

²SEM = standard error of mean

Means with different letters in the same row differ ($P < 0.05$).

Table 3. Ingredient and chemical composition of TMR of the four diet treatments

Items	Diets ¹			
	Corn	Barley		
	P7213R CS-TMR	Cowboy BS-TMR	Copeland BS-TMR	Xena BS-TMR
Ingredient composition, % ²				
Alfalfa hay	10.3	10.3	10.3	10.3
Corn silage	41.0	-	-	-
Barley silage	-	41.0	41.0	41.0
Barley Grain 75% PI	20.7	24.3	24.3	24.3
Corn Grain Ground Medium	6.7	6.4	6.4	6.4
Canola Meal Solvent	11.3	10.2	10.2	10.2
Soybean Meal 47.5 Solvent	4.3	2.1	2.1	2.1
Corn Gluten Meal 60%	0.4	0.4	0.4	0.4
Corn Dist Medium Spirits	0.8	0.8	0.8	0.8
Premix	1.3	1.3	1.3	1.3
RP10 palmitic	0.9	0.9	0.9	0.9
Molasses Cane	0.5	0.5	0.5	0.5
PotMagSulfate	0.1	0.1	0.1	0.1
Sodium Bicarbonate	0.5	0.5	0.5	0.5
Salt White	0.2	0.2	0.2	0.2
Limestone	0.9	0.7	0.7	0.7
Nutrient composition, % ³				
DM	49.1	43.4	46.4	45.4
OM	93.3	92.1	93.1	93.6
CP	16.0	15.6	15.7	16.3
Starch	27.2	21.9	23.5	24.4
NDF	31.7	35.9	34.9	32.8
ME (Mcal/kg)	2.28	2.18	2.19	2.17
NE _L (Mcal/kg)	1.47	1.40	1.41	1.40
DM retained for TMR, % ⁴				
19.0 mm	5.5	4.8	6.0	6.6
8.0 mm	25.0	38.3	41.4	40.6
Pan	69.5	56.9	52.6	52.8
pefps-2s	0.31	0.43	0.47	0.47
peNDFps- 2s, % of DM	9.7	15.5	16.5	15.5

¹P7213R CS-TMR= P7213R corn silage-based TMR; Cowboy BS-TMR = CDC Cowboy barley silage-based TMR; Copeland BS-TMR= CDC Copeland barley silage- based TMR; Xena BS-TMR = Xena barley silage-based TMR.

²Premix: formulated to contain: 16% Calcium, 6.5% Phosphorus, 10.4% Chloride, 6.3% Sodium, 2% Potassium, 0.4% Sulfur, 1,500 mg of Magnesium, 675 mg of Copper, 2500 mg of Zinc, 1,500 mg of Manganese, 3,000 mg of Iron, 20 mg of Selenium, 80 mg of Iodine, 30 mg of Cobalt, Vitamin A ('000 i.u.) = 330, Vitamin D ('000 i.u.) = 60, Vitamin E (i.u.) = 1.

³ME = metabolizable energy; NE_L= net energy lactation.

⁴Particle size distribution of diets was measured using the Penn State Particle Separator; pefps-2s = physical effectiveness factor determined as the proportion of particles retained on 2 sieves (Lammers et al., 1996); peNDFps- 2s= physically effective NDF determined as dietary NDF concentration multiplied by pefps-2

Table 4. Feed intake, milk yield and milk compositions in lactating dairy cows fed diets containing corn silage or CDC Cowboy, CDC Copeland Xena barley silages

Items	Diets ¹				SEM ²	P- value	P- value Contrast
	Corn (C)	Barley (B)					C vs. B
	P7213R	Cowboy	Copeland	Xena			
	CS-TMR	BS-TMR	BS-TMR	BS-TMR			
Intake, kg/cow/d							
DM	28.08	24.76	24.93	27.46	1.350	0.14	0.10
OM	25.61	23.04	23.59	25.62	1.348	0.13	0.07
CP	4.03	3.72	3.63	4.04	0.198	0.36	0.31
NDF	8.94	8.88	8.71	9.04	0.475	0.30	0.55
Milk Yield, kg/d ³							
Milk	40.14a	35.25b	35.94b	34.78b	1.711	0.04	0.01
FCM	42.16	36.53	37.25	37.29	2.455	0.08	0.02
ECM	40.21a	36.35b	36.16b	36.10b	1.994	0.03	0.06
Fat	1.51	1.33	1.35	1.36	0.116	0.35	0.10
Protein	1.17	1.02	1.06	1.02	0.049	0.06	0.02
Lactose	1.78a	1.52b	1.56b	1.60b	0.068	0.04	<0.01
Solids-not-fat	3.37a	2.84b	2.92b	3.02b	0.129	0.05	0.01
Milk composition ⁴							
Fat, %	3.46	3.70	3.71	3.89	0.221	0.37	0.20
Protein, %	2.91	2.89	2.93	2.93	0.062	0.91	0.91
Lactose, %	4.42	4.38	4.45	4.45	0.058	0.77	0.86
Total solids, %	11.91	11.88	12.18	12.25	0.241	0.24	0.36
SNF, %	8.31	8.26	8.35	8.35	0.111	0.80	0.91
MUN, mmol/L	12.69	12.83	13.03	12.95	1.096	0.99	0.83
SCC, 1 ³ cells /ml	105.2	40.3	112.2	39.7	18.48	0.27	0.25
Efficiency							
FCM/DMI	1.61	1.37	1.43	1.44	0.079	0.14	0.07
ECM/DMI	1.57	1.32	1.40	1.39	0.071	0.12	0.03

¹P7213R CS-TMR= P7213R corn silage-based TMR; Cowboy BS-TMR = CDC Cowboy barley silage-based TMR; Copeland BS-TMR= CDC Copeland barley silage- based TMR; Xena BS-TMR = Xena barley silage-based TMR.

²SEM = standard error of mean; Means with different letters in the same row differ ($P < 0.05$).

³FCM = Fat-corrected milk; ECM = Energy-corrected milk.

⁴SNF = Solids-not-fat; MUN = Milk urea nitrogen; SCC = Somatic cell count.

Table 5. Total chewing activity in lactating dairy cows in lactating dairy cows fed diets containing corn silage or CDC Cowboy, CDC Copeland Xena barley silages

Items	Diets ¹				SEM ²	P-value	P- value Contrast
	Corn (C)	Barley (B)					C vs. B
	P7213R CS-TMR	Cowboy BS-TMR	Copeland BS-TMR	Xena BS- TMR			
Eating							
Min/d	318	321	297	316	26.5	0.90	0.78
Min/kg DM	11.9	11.9	11.6	12.4	0.83	0.90	0.96
Min/kg NDF	37.9	32.8	33.2	38.0	2.36	0.32	0.22
Ruminating							
Min/d	507.5	590.5	590	554.8	31.0	0.26	0.07
Min/kg DM	19.3	22.4	22.6	22.1	2.11	0.50	0.16
Min/kg NDF	60.9	62.6	64.9	67.3	6.19	0.72	0.50
Total chewing activity							
Min/d	826	911	887	871	37.2	0.46	0.18
Min/kg DM	31.3	34.2	34.3	34.5	2.46	0.68	0.27
Min/kg NDF	98.7	95.3	99.2	104.3	6.99	0.73	0.89

¹P7213R CS-TMR= P7213R corn silage-based TMR; Cowboy BS-TMR = CDC Cowboy barley silage-based TMR; Copeland BS-TMR= CDC Copeland barley silage- based TMR; Xena BS-TMR = Xena barley silage-based TMR.

²SEM = standard error of mean.