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Comparison of Chemical Composition and Rumen Degradation Kinetics of Three Forages: Whole Plant Barley, Whole Plant Foxtail Millet and Grass-Legume Hay

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Abstract

The objective of this study was to determine the chemical composition and *in situ* rumen degradability of whole plant barley (*Hordeum vulgare*), whole plant foxtail millet (*Setaria italica*) and smooth bromegrass (*Bromus inermis Leyss*)-alfalfa (*Medicago sativa* L.) (grass-legume) hay, collected during a companion field grazing study. Relative to grass-legume hay, barley and millet were higher ($P = 0.05$) in crude protein (CP) and soluble CP, and lower ($P = 0.02$) in neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, neutral detergent insoluble CP, and acid detergent insoluble crude protein. The potentially undegradable fraction of CP averaged 32% lower for barley and millet, compared to grass-legume hay, while CP soluble fraction was 36 and 64% higher ($P < 0.05$) for barley and millet, respectively, than for grass-legume hay. Millet had the highest NDF degradability ($P = 0.03$) and grass-legume hay the least. Barley and millet had greater ($P = 0.02$) effective degradability of dry matter (DM), CP, and NDF than grass-legume hay. Millet had the highest ($P = 0.01$) degradable and lowest undegradable fractions of DM and NDF, and lowest soluble fraction of NDF and rate of CP degradation ($P < 0.05$). Results indicate that whole plant barley and millet have greater nutritive value than grass-legume hay and may be suitable annual forages for extensive grazing.

Keywords: grass-legume hay, rumen degradability, swath grazing, whole-plant barley, whole-plant millet

1. Introduction

Backgrounding of beef cattle is defined as a controlled rate of growth for weaned beef calves to promote muscle deposition and maximize frame size prior to feeding a nutrient dense diet for deposition of fat to obtain a greater carcass weight at slaughter (Vaage et al., 1998). Traditionally in western Canada, spring-born beef calves are fall weaned at 6 mo of age and bunk fed sun-cured grass-legume hay in a confined pen feeding system (Kumar et al., 2012). However, feed costs are a major contributor to the total cost of production for this type of program. The grazing season in western Canada can be extended by utilizing field harvested and grazed annual forage crops. Annual forages are well suited to provide high quality forage compared to perennial crops due to flexible seeding dates and greater yields resulting in improved cattle performance in backgrounding systems (McCartney et al., 2008; Aasen et al., 2004). Whole-plant barley (*Hordeum vulgare* L.) or whole plant millet (*Setaria italica* L.) can be alternative annuals to perennial forages for winter swath grazing because of the relatively high yield and nutritive value (Mackay et al., 2003; McCartney et al., 2008; McCartney et al., 2009). Previous work has indicated that fiber content of mown forage left in field increased, while protein and *in vitro* organic matter digestibility decreased from September to February due to weathering (Volesky et al., 2002). However, limited information exists regarding the potential nutritive value and degradation kinetics of these annual forages to meet nutrient requirements of growing calves in extensive grazing systems. This study was conducted to quantify the chemical composition and rumen degradation characteristics of dry matter (DM), crude protein (CP) and neutral detergent fiber (NDF) of two annual forages, field harvested whole plant barley and whole plant foxtail millet compared to perennial grass-legume hay.

2. Materials and Methods

2.1 Forage Management

The forages were derived from a companion field grazing study (Kumar et al., 2012) conducted at the Western Beef Development Centre's Termuende Research Ranch located at Lanigan, Saskatchewan, Canada (51°51′N; 105°02′W) with an average altitude of 540 m above sea level. Mean monthly temperatures for July, August, September, October, November, December and January were 17.0, 17.3, 11.3, 4.9, -6.3, -19.3, and -19.1 °C in 2008 and 2009. Total precipitation at the study site for July, August, September, October, November, December, and January was 68.0, 52.0, 46.5, 29.2, 16.8, 18.0 and 11.4 mm for 2008 and 2009, respectively.

Eight-ha each of forage barley (*Hordeum vulgare*, *cv*. Ranger) and foxtail millet (*Setaria italica*, *cv*. Golden German) were seeded May 29, 2008 at 109 and 17 kg/ha, respectively along with fertilizer at 22.7 kg actual N per hectare. On September 7, 2008, both annual crops were mown to 10 cm stubble height using a 6 m New Holland 2550SP Windrower and left in field in 1.0 m wide windrows, with barley and millet at the soft dough and 30% heading stage, respectively. In an adjacent 8 ha field, a perennial forage, smooth bromegrass (*Bromus inermis Leyss*)-alfalfa (*Medicago sativa* L.) (70:30 grass-legume composition) was mown July 10 at 30% bloom and harvested as large (650 kg) round bales and transported to an open storage area. The barley, millet and grass-legume hay crops yielded 6159, 3182 and 5732 kg DM/ha, respectively. For the current study, representative replicate (n = 10) samples of each forage (whole plant barley, whole plant millet and grass-legume hay) were collected post-mowing (annual forages) or harvesting (perennial forage; smooth bromegrass, late anthesis; alfalfa, full bloom), at 2 different sampling dates, October 4, 2008 and January 22, 2009. Samples were dried at 55 °C for 48 h and then ground using a Wiley Mill (Model #2, Arthur H. Thomas Co., Philadelphia, PA, USA) to pass through a 2.0 mm screen to determine rumen degradation kinetics. To determine chemical composition, forage samples were ground to pass through a 1.0 mm screen.

2.2 In Situ Trial

Four dry multiparous Holstein cows (mean body weight, 891±54 kg) used for the *in situ* trial were fitted with ruminal cannulae (13 cm i.d.; Bar Diamond Inc., Parma, ID, USA), and housed in 3 × 3 m pens with water always available in the Livestock Research Building at the University of Saskatchewan, Saskatoon, Saskatchewan, Canada. Cannulated animals were adapted *ad libitum* to a high forage (90:10 bromegrass-alfalfa mix; CP = 95 g/kg DM; NDF = 647 g/kg DM; acid detergent fiber (ADF) = 403 g/kg DM) hay diet for 21 d prior to the *in situ* trial. Hay was offered twice daily, in equal portions at 0800 and 1600 h during the adaptation and experimental *in situ* periods. All cows were cared for and managed in accordance with the guidelines of the Canadian Council on Animal Care (2009).

Rumen degradation kinetics were determined using the nylon bag (pore size ~40 μm; 10 × 20 cm) *in situ* technique, as described by Yu et al. (2004). Samples (field sampled October and January) (3 forages × 2 sampling dates) of barley, millet and grass-legume hay were incubated to determine the rate and extent of rumen degradation with 5, 4, 3, 2, 2, 2 and 2 bags for 72, 48, 24, 12, 8, 4 and 0 h of incubation, respectively, during three experiment periods. All the bags were allocated to the four dry Holstein cannulated cows. A polyester mesh bag (45 × 45 cm), attached to a 90 cm string and secured to the outside of the cannula opening was used for placing and keeping the nylon bags in the ventral sac of the rumen. Bags with sample (7 g/bag; ratio of sample size to bag surface area of ~19 mg/cm^2) were incubated in the rumen according to the "gradual in, all out" procedure according to Yu (2004). After incubation, all bags were removed from the rumen and rinsed with cool tap water as described by Yu et al. (2004). The soluble fraction (S) was determined after rinsing the 0 h bags along with other bags. After squeezing out the excessive water from the bags, all bags were dried in a forced air oven at 55 °C for 48 h. All residue samples were weighed after drying and removed from the bags and pooled according to forage, sampling date and incubation time. All pooled residues were ground to pass through a 1-mm screen (Retsch ZM 100, Haan, Germany) for CP and NDF analysis. Dry matter, CP, and NDF disappearance were calculated as the difference between original and residue amounts after ruminal incubation.

2.3 Calculations and Statistical Analysis

The proc NLIN procedure of SAS (2003) using Gauess-Newton method of iterative least square regression was used to estimate the rumen degradation kinetics. The first order kinetic equation of Orskov and McDonald (1979), $R(t) = U + D \times \exp(-K_d \times (t - T_0))$, where R(t) = residue of incubated material after t h of rumen incubation (g/kg); U = potentially undegradable fraction (g/kg); D = potentially degradable fraction (g/kg); T_0 = lag time (h); and K_d = degradation rate (/h), was used by fitting the percentage of DM, CP, and NDF residues obtained from the incubation. The effective degradability of DM (EDDM), CP (EDCP), and NDF (EDNDF) was estimated using non-linear parameters (S, D, U, and K_d) obtained from the above equation and were calculated as EDDM (g/kg) = S + D × $K_d/(K_p + K_d)$, where S = soluble, or 'wash-out' fraction (g/kg), and $K_{p.}$ = estimated rate of outflow from the rumen (/h). A K_p value of 0.04 /h was used to represent the rumen turnover rate (Yu et al., 2004). The EDCP and EDNDF were estimated similar to EDDM.

Representative samples (n = 5) of the three forages were analyzed for content of DM according to the procedure outlined by the Association of Official Analytical Chemists (2000) (method #930.15). Forages and their residues after *in situ* incubation were analyzed for ADF and NDF (neutral detergent fiber, with α-amylase without sodium sulfite in the ND solution) using an ANKOM 2000 Fiber Analyzer (ANKOM Technology, Fairport, NY; method #973.18). Acid detergent insoluble CP (ADICP) and neutral detergent insoluble CP (NDICP) content were determined by Kjeldahl analysis of the acid detergent insoluble and neutral detergent insoluble residues, respectively (AOAC, 2000; method #984.13). The reported ADF and NDF values were not adjusted for NDICP and ADICP. Soluble crude protein (SCP) measured as buffer soluble CP was extracted with bicarbonate-phosphate buffer solution using the technique described by Licitra et al. (1996). Lignin (sa, sulphuric acid technique) content was analyzed according to the procedure of Robertson and Van Soest (1981).

Statistical analyses were conducted using the Proc Mixed procedure of SAS (SAS Institute Inc., Cary, NC., 2003) as a split-plot design. The model included fixed effect of forage (the whole-plot) and sampling date (date: subplot). The model used was: $Y_{ijr} = \alpha_i + \beta j + e_{ijr}$; where Y_{ijr} is the variable studied, α_i is the forage, βj is the sampling date, and e_{ijr} is the residual standard deviation used as the error term. Analysis showed that the effect of sample date and forage × date interaction effects were not significant (P > 0.05) however forage was significant (P < 0.05). Therefore sample date and forage × date were removed from the model and data were re-analyzed to assess only the main effect of forage (barley, millet, and grass-legume hay). Means were separated using the Tukey-Kramer multi-treatment comparison method and differences were considered significant when P < 0.05.

3. Results

The three forages differed in chemical composition mainly due to harvest maturity and method (Table 1). As barley forage was harvested at soft-dough stage and millet forage at 30% heading, the composition of these annuals differed (P = 0.04) from the perennial grass-legume hay baled at 30% bloom in mid-summer (Table 1).

Annual forages, barley and millet were higher (P = 0.05) in CP and SCP, but lower (P = 0.02) in ADF, NDF, lignin (sa), NDICP and ADICP compared to perennial grass-legume hay (Table 1). Millet CP was 1.2 and 1.7 times higher (P = 0.01) than barley forage or perennial grass-legume hay, respectively. There was no observed change in grass-legume hay quality as the perennial forage was not exposed to field weathering like the barley and millet annual forages.

Table 1. Chemical composition of whole plant barley, whole plant millet and grass-legume hay

Item	Forage^z			SEM
	Barley	Millet	Grass-legume hay	
DM (g kg^{-1})	655^b	517^c	860^a	8.7
ADF (g kg^{-1} DM)	365^c	414^b	487^a	7.5
NDF (g kg^{-1} DM)	577^c	650^b	729^a	16.9
Lignin (g kg^{-1} DM)	57^b	61^b	87^a	5.3
CP (g kg^{-1} DM)	119^b	136^a	82^c	2.9
SCP (g kg^{-1} CP)	327^b	377^a	283^b	15.7
NDICP (g kg^{-1} CP)	287^c	370^b	473^a	38.0
ADICP (g kg^{-1} CP)	149^b	145^b	178^a	17.7

Note. ^{z} Forage × sampling date interaction was not detected (*P* > 0.05); $^{a\text{-}c}$ Different superscripts within rows indicate differences (*P* < 0.05).

There were no interactions between forage type and sampling date in the degradation kinetics of DM, CP, and NDF, so these were pooled between forages (Table 2). The barley and millet samples had similar (P = 0.10) effective degradability of DM (EDDM), but EDDM of these forages was 14% greater (P = 0.001) than the grass-legume hay. For DM degradation, significant differences were found between the three forages for T_0 (P = 0.02). The lower value in DM T_0 of barley may be due to the lower lignin (57 vs 87 g/kg DM; Table 1) and ADF content 365 vs 487 g/kg DM; Table 1) compared to grass-legume hay. The potentially degradable DM fraction

(D) was 27 and 12% greater (P = 0.01) for millet (502 g/kg DM) and barley (445 g/kg DM) respectively, than for grass-legume hay (396 g/kg DM). While the potentially undegradable DM fraction (U) was 40% lower (P = 0.04) for millet, compared to grass-legume hay. Although, no differences (P = 0.09) were detected in the rate of degradation of DM between forages; numerically the rate of degradation was greatest for barley (0.077/h), intermediate for grass-legume hay (0.063/h) and least for millet (0.055/h). Therefore, even though the potentially degradable DM fraction of millet was higher (P < 0.05) than barley, the effective degradability of millet DM was similar (P > 0.05) to barley, probably due to the slower rate of degradation of the millet forage. The grass-legume hay had the lowest (P < 0.05) effective degradability for DM, CP, and NDF among all three forages. The lower effective DM degradability of the grass-legume hay (463 g/kg DM) as compared to either barley or millet may have been due to the reduced potentially degradable DM fraction and low extent of degradation (Table 2). No differences (P = 0.11) were observed in potentially degradable fraction and rate of degradation between the two sampling dates.

Table 2. *In situ* rumen degradation kinetics of whole plant barley, whole plant millet and grass-legume hay

Item	Forage[z]			SEM
	Barley	Millet	Grass-legume hay	
Dry matter (g kg^{-1} DM)				
Lag time (T_0; h)	0.3[b]	1.4[ab]	2.4[a]	0.48
Soluble fraction (S; g kg^{-1})	245	235	235	10.6
Degradable fraction (D; g kg^{-1})	445[b]	502[a]	396[c]	11.6
Undegradable fraction (U; g kg^{-1})	310[b]	263[c]	369[a]	10.7
Rate of degradation (Kd; h^{-1})	0.08	0.06	0.06	0.010
Effective degradability (EDDM; g kg^{-1})	531[a]	524[a]	463[b]	11.7
Crude protein (g kg^{-1} CP)				
Lag time (T_0; h)	0.6	0.8	2.3	0.57
Soluble fraction (S; g kg^{-1})	302[a]	363[a]	222[b]	25.7
Degradable fraction (D; g kg^{-1})	447	405	460	33.4
Undegradable fraction (U; g kg^{-1})	251[b]	232[b]	318[a]	14.3
Rate of degradation (Kd; h^{-1})	0.14[a]	0.07[b]	0.09[b]	0.16
Effective degradability (EDCP; g kg^{-1})	610[a]	573[a]	463[b]	20.9
Neutral detergent fiber (g kg^{-1} NDF)				
Lag time (T_0; h)	2.8	2.0	4.2	0.78
Soluble fraction (S; g kg^{-1})	34[a]	2[b]	11[b]	6.1
Degradable fraction (D; g kg^{-1})	537[b]	669[a]	506[b]	15.6
Undegradable fraction (U; g kg^{-1})	429[b]	329[c]	484[a]	17.5
Rate of degradation (Kd; h^{-1})	0.06	0.05	0.07	0.015
Effective degradability (EDNDF; g kg^{-1})	279[ab]	315[a]	239[b]	20.1

Note. [a-c] Different superscripts within rows indicate differences (P < 0.05); [z] Forage × sampling date interaction was not detected (P > 0.05).

For CP degradation kinetic characteristics, significant differences (P < 0.05) were observed on S, U and EDCP between the three forages. The soluble fraction of CP was 36 and 64% higher (P < 0.05) for barley and millet, respectively, than for grass-legume hay. The potentially undegradable fraction of CP averaged 32% lower for barley and millet, compared to grass-legume hay (318 g/kg; Table 2).

Barley and millet did not differ (P = 0.71) in CP rumen degradation kinetics, but the rate of CP degradation was roughly two times higher (P = 0.05) for barley compared to millet. More specifically, barley was found to have degraded almost twice as fast (0.14/h) than millet (0.07/h), while millet and grass-legume hay had similar (P = 0.08) degradation rates.

As the EDCP of millet was similar (P > 0.05) with that of barley, a possible reason for this may be due to the higher CP content of millet compared to barley and similar extents of degradation between the forages. Overall, higher ($P < 0.05$) rumen degradation parameters for CP were observed for barley and millet than for the grass-legume hay, although no differences ($P > 0.05$) were observed in the potentially degradable fraction of CP between the forages. Similarly, the greater effective degradability of CP of barley and millet compared to the grass-legume hay ($P < 0.05$), was likely due to similar ($P > 0.05$) higher soluble CP fractions of barley and millet compared to the grass-legume hay ($P < 0.05$). In general, barley had a high ($P = 0.04$) rumen soluble NDF fraction and millet forage had the highest degradable ($P = 0.02$) and effectively degradable ($P = 0.03$) fractions. Whereas, barley and grass-legume hay were similarly lower ($P < 0.05$) in comparison to millet for the degradable NDF fraction. The millet forage contained the lowest undegradable fraction of NDF (329 g/kg), while the undegradable fraction of NDF was highest ($P < 0.05$) for grass-legume hay. The difference ($P < 0.05$) in effective NDF degradability observed between millet and grass-legume hay forages may be attributed to the difference in the potentially degradable NDF fractions.

4. Discussion

Harvest timing of cool season annuals can have an effect on nutritive value, providing superior quality forage compared to perennial forages (May et al., 2007). Crude protein content of millet in the current study was higher than for foxtail millet (94 g/kg DM) reported by Neville et al. (2006), in an earlier beef cattle grazing trial. May et al. (2007) found the CP content of Golden German foxtail millet was sufficient (97 g/kg DM) to meet nutritional requirements for beef cattle winter grazing and field weathering did not reduce feed quality. In contrast, a decrease in swathed millet CP concentration was observed by Munson et al. (1999) as the grazing period advanced. Additionally, CP concentration of windrowed forage millet increased over time (October to February) in a winter grazing trial conducted by Mackay et al. (2003). In the present study, CP content was higher in whole plant millet than in grass-legume hay, suggesting that millet nutritive value was not affected by field weathering. As feed protein is the most abundant source of N in ruminant diets, rumen degradation of CP is crucial to ruminants and degradation kinetics are significant to quantify microbial protein synthesis and metabolizable protein supply to the animal (Tamminga et al., 2007). The nutritive value of grass-legume hay in the current study was similar to values reported in previous studies (Neville et al., 2006; Van De Kerckhove et al., 2011).

Mean values for CP, NDF, ADF, ADL, NDICP, and ADICP of barley are in agreement with results reported in other swathed barley grazing experiments offered to beef cattle (McCartney et al., 2004; Kelln et al., 2011). The stability in CP content of swathed whole plant barley over winter months as reported by Aasen et al. (2004) supports the results of the current study. In contrast, in an earlier study by Baron et al. (2006), field barley swath CP content was 135 g/kg DM initially, declining to 121 g/kg DM as the grazing period progressed from September to February. Although NDF content of the grass-legume hay was greater than millet or barley NDF level, there was no difference ($P = 0.32$) in dry matter intake of beef calves grazing these forages in a companion study (7.5, 6.8 and 7.7 kg/d for grass-legume hay, millet and barley, respectively; Kumar et al., 2012). Increases in swathed barley NDF and ADF content as the grazing period advanced during winter was reported by Baron et al. (2006) and Aasen et al. (2004), which is in contrast to the current study that indicated no weathering effect on CP or ADF content during the companion swath grazing backgrounding study (Kumar et al., 2012) conducted from October to January at Lanigan, Saskatchewan, Canada. Unlike, the consistent forage ADF levels observed in the current study, an increase in ADF in swathed millet during the winter has been reported by Munson (1999). MacKay et al. (2003) however, reported no change in swathed millet ADF and NDF levels from October to February.

Baron et al. (2006) observed a linear decrease for organic matter digestibility from September to February of whole plant barley swath, cut at similar stage of maturity (soft dough) and averaged over a four year period (613 g/kg DM), decreasing from 628 to 521 g/kg DM. This is in contrast to the constant but lower level of EDDM for barley (590 g/kg DM) in the current study. The higher degradation rate of barley compared to millet may be due to the higher estimates of ruminal escape for protein of barley compared to millet, suggesting resistance of barley protein to microbial attack (McAllister et al., 1990). Edmunds et al. (2012) indicated rumen undegradable protein (RUP) values for conserved meadow grass-legume (80:20 grass:legume composition) hay were similar to grass-legume hay in the current study, averaging 299 g per kilogram. As a general trend, RUP from sun-cured forage harvested and stored (grass-legume hay) is higher than forages harvested at differing maturity stage and left in field during winter for grazing.

The lack of change in quality of whole plant annual forages would suggest minimal field weathering during the present study. According to Kumar et al. (2012), sampling of swathed annual forages was conducted in cooler temperatures and minimal precipitation but with greater snow depth compared to average climatic conditions during winter period. This agrees with Mackay et al. (2003), who suggested that low precipitation during the winter might not affect the quality of windrowed forages. Similarly, McCartney et al. (2009) reported that weathering in the swath did not reduce feed quality of Golden German foxtail millet.

5. Conclusions

The results of the present study indicate swathed whole plant barley and whole plant millet had greater DM, CP, and NDF degradability compared to grass-legume hay. Whole plant millet comprised higher degradable and lower undegradable fractions of DM and NDF, while whole plant barley had a higher soluble fraction of NDF and rate of CP degradation. Comparing the extent of degradation of annual forages to perennial forage, these study findings indicate the potential for either whole plant barley or millet to supply the required nutrients for growing beef cattle in grazing backgrounding systems in western Canada.

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