Effect of dried distillers' grain, soybean meal and grain or canola meal and grain-based supplements on forage intake and digestibility

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Van De Kerckhove, A. Y., Lardner, H. A., Yu, P., McKinnon J. J. and Walburger, K. 2011. **Effect of dried distillers' grain, soybean meal and grain or canola meal and grain-based supplements on forage intake and digestibility**. Can. J. Anim. Sci. **91**: 123–132. Four ruminally cannulated beef heifers (72 wk of age) were individually fed a basal ration of 75% ground barley straw and 25% ground bromegrass hay [total digestible nutrients = 46.3, crude protein (CP) = 7.5 (% dry matter (DM))]. Heifers were supplemented with either (1) no supplement (CONT); (2) dried distillers' grains plus solubles [70:30 wheat:corn blend; dried distillers' grains plus solubles (DDGS)]; (3) commercial range pellet (COMM); or (4) barley grain and canola meal (BAR + CM). Forage intake, apparent total tract digestibility, passage rate, rate and extent of forage degradation, rumen pH and rumen ammonia nitrogen were measured. Forage intake, passage rate, and apparent total tract digestibility of DM, neutral detergent fiber, and acid detergent fiber were unaffected ($P > 0.41$) by treatment. Apparent total tract digestibility of CP was increased ($P = 0.02$) with supplements as compared with CONT, but did not differ ($P > 0.05$) among DDGS, COMM, and BAR + CM. Ruminal pH was not affected ($P = 0.20$) by treatment, but rumen ammonia-N was increased ($P < 0.01$) with all three supplements. Potentially degradable and undegradable forage fractions were decreased ($P < 0.02$) and there was a tendency ($P = 0.06$) for the rate of forage DM degradation to increase with supplementation. Supplementing forage diets with either DDGS, grain-soybean-canola- or grain-canola-based supplements did not increase the intake or digestibility of a forage-based diet. More research, however, is required to study the feasibility of feeding these supplements at greater levels with forage-based beef cattle diets.

Key words: Dried distillers' grains, wheat, corn, canola meal, voluntary intake, forage degradability, digestibility, rumen, ammonia nitrogen

Van De Kerckhove, A. Y., Lardner, H. A., Yu, P., McKinnon J. J. et Walburger, K. 2011. **Incidence des suppléments composés de drèches sèches de distillerie, de tourteau de soja et de grain ou de tourteau de canola et de grain sur l'ingestion et la digestibilité des fourrages**. Can. J. Anim. Sci. **91**: 123–132. Quatre génisses de boucherie (de 72 semaines) canulées au rumen ont reçu chacune une ration de base composée à 75 % d'orge moulue et à 25 % de brome moulu (UNT = 46,3, PB = 7,5 (% de la MS)). On a servi aux génisses soit (1) aucun supplément (témoin), (2) des drèches sèches de distillerie avec solubles (mélange 70:30 blé:maïs; DDGS), (3) des agglomérés du commerce (COMM) ou (4) de l'orge et du tourteau de canola (ORG + TC). Les auteurs ont mesuré la quantité de fourrages ingérée, leur digestibilité totale apparente dans le tractus digestif, la vitesse du transit, la rapidité et l'importance de la dégradation des fourrages, le pH du rumen et la concentration d'azote ammoniacal dans le rumen. Le traitement n'affecte pas l'ingestion du fourrage, la vitesse du transit ni la digestibilité totale apparente de la matière sèche, des fibres au détergent neutre et des fibres au détergent acide ($P >$ 0,41). La digestibilité totale apparente des protéines brutes augmente ($P = 0{,}02$) avec les suppléments, comparativement à la ration témoin, mais demeure la même ($P > 0{,}05$) pour les animaux recevant des DDGS, de la COMM et de l'ORG + TC. Le traitement ne modifie pas le pH du rumen ($P = 0{,}20$), mais on observe une hausse de la concentration du N ammoniacal ($P < 0{,}01$) avec les trois suppléments. La fraction des fourrages potentiellement dégradables ou non dégradables diminue ($P < 0{,}02$) et le taux de dégradation de la matière sèche du fourrage a tendance ($P = 0{,}06$) à augmenter avec l'apport de supplément. Enrichir les rations à base de fourrages avec des DDGS, un supplément de grain-soja-canola ou de grain-canola n'accroît pas l'ingestion ni la digestibilité de la ration. Néanmoins, il faudra entreprendre des recherches plus poussées pour savoir si on pourrait ajouter une plus grande quantité de ces suppléments aux rations des bovins de boucherie à base de fourrages.

Mots clés: Drèches sèches de distillerie, blé, maïs, tourteau de canola, ingestion volontaire, capacité de dégradation des fourrages, digestibilité, rumen, azote ammoniacal

Abbreviations: **ADF**, acid detergent fiber; **ADIN**, acid detergent insoluble nitrogen; **BAR + CM**, barley grain and canola meal; **COMM**, commercial range pellet; **CP**, crude protein; **D**, potentially degradable fraction; **DDGS**, dried distillers' grains plus solubles; **DM**, dry matter; **DMI**, dry matter intake; **Kd**, degradation rate; **NDF**, neutral detergent fiber; **S**, soluble fraction; **TDN**, total digestible nutrients; **U**, undegradable fraction

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Supplementation is often required to improve the use of low-quality forages in ruminant diets. Several studies have documented the positive effects of protein supplementation on forage intake (Chase and Hibberd 1987; DelCurto et al. 1990a, b). Increased forage intake is often associated with improved forage digestion and increased particulate passage rate (McCollum and Galyean 1985; Beaty et al. 1994; Mathis et al. 1999). It is widely accepted that protein supplementation improves the N status within the rumen, supporting microbial growth, thereby optimizing rumen fermentation and facilitating forage digestion.

Cellulolytic bacteria are the main organisms responsible for forage digestion. As such, maintaining favorable rumen conditions for cellulolytic bacteria is crucial for maximizing the utilization of low-quality forages. Ideal rumen pH is between 6.3 and 6.8 (Hiltner and Dehority 1983; Hoover 1986), while the threshold pH below which cellulolysis is inhibited is 6.0 to 6.1 (Mould and Ørskov 1983; Mould et al. 1983). Ruminal ammonia-N (NH_3-N), the main source of N for microbial protein synthesis, results from microbial degradation of rumen degradable protein (RDP) (Heldt et al. 1999; Mathis et al. 2000; Reed et al. 2007). Satter and Slyter (1974) suggested 2 to 5 mg dL^{-1} of ruminal NH_3-N is required for maximal bacterial synthesis in vitro.

Forages can be fractionated into three degrees of degradation: (1) immediately soluble (S); (2) potentially degradable (D); and (3) undegradable (U) (Ørskov and McDonald 1979; Robinson et al. 1986). The rate of degradation (Kd) describes how much feed can be digested per unit of time (Van Soest 1994). Rumen environment, forage solubility, and microbial activity can impact forage degradation within the rumen (Van Soest 1994). Therefore, supplementation can influence the rate and extent of forage degradation as well as the rate at which feedstuff leaves the rumen.

As ethanol production continues to increase in western Canada, wheat dried distillers' grains plus solubles (DDGS) and wheat-corn DDGS blends will continue to become more available to beef producers. Due to their nutritional density, there is potential to use DDGS as a supplement for beef cows consuming low-quality forages. Traditional cereal grain (barley, wheat) supplementation is recognized to depress forage intake (Chase and Hibberd 1987; Bodine and Purvis 2003), while protein supplements (soybean, canola) are known to increase dry matter intake (DMI) of low-quality forages (DelCurto et al. 1990b; Koster et al. 1996). As such, the objectives of this experiment were to determine the effects of different supplements (grain-soybean-canola; grain-canola) including wheat-based DDGS on voluntary DMI, digestibility, and passage rate of low-quality forages. The effect of supplement on rumen pH and ammonia-N concentrations, as well as the rate and extent of forage degradation were also investigated.

MATERIALS AND METHODS

Animals, Housing, and Experimental Design

Four ruminally fistulated Hereford cross heifers (72 wk of age) (body weight $\pm$ SD; 630 ± 39 kg) were housed in individual pens (3.6 m $\times$ 3.6 m) with rubber mats for footing in the Department of Animal and Poultry Science's Livestock Research Barn on the University of Saskatchewan campus (Saskatoon, Saskatchewan, Canada). The average temperature in the barn was 17.6°C, 18.8°C, 14.4°C, and 12.6°C for periods 1 through 4, respectively. Each heifer received an intramuscular injection of Vitamin AD-500 Injection (Vetoquinol Canada, Inc.) prior to the start of the trial. Guidelines for animal care (Canadian Council on Animal Care 1993) were followed.

A 4×4 Latin square design was used to determine the voluntary intake, digestibility, rumen fermentation parameters, and passage rate of four diets. Each period was 24 d long and consisted of a 10-d dietary adaptation period, a 7-d voluntary intake period, and a 7-d collection period. Heifers were adjusted to the barn environment and the basal forage ration for 15 d prior to the start of the trial. The basal forage diet consisted of 75% ground barley straw and 25% ground bromegrass hay to simulate a low-quality forage. Forages were ground using a tub grinder (Haybuster H-1000) fitted with a 10.2-cm screen. Heifers were fed twice daily at 0800 and 1600. The animals were fed to voluntary intake levels throughout the trial, with the exception of 3 d of restricted feeding at the beginning of the 7-d collection period. Water was available ad libitum via automated watering bowls throughout the trial.

Treatment Diets

Four treatment diets contained basal forage (75:25 barley straw:grass hay) supplemented with (i) no supplement (CONT); (ii) dried distillers' grains plus solubles (DDGS, 70:30 wheat:corn blend); (iii) commercial range pellet (COMM); or (iv) rolled barley grain and canola meal (BAR + CM). The DDGS was a 70% wheat, 30% corn blend obtained from Husky Energy (Lloydminster, SK). The commercial range pellet was custom formulated by FeedRite Ltd. (Humboldt, SK) to be nutritionally similar to the DDGS supplement. Supplemented diets were formulated to be isocaloric and isonitrogenous (Table 1). Daily supplement amounts fed per animal were 0.7 kg DDGS, 0.7 kg commercial range pellet and 0.4 kg rolled barley + 0.6 kg canola meal. Chemical composition of all ingredients is shown in Table 2. Due to the nature of the forage, the CONT diet was expected to be deficient in both energy and crude protein (CP) [National Research Council (NRC) 1996] (Table 1). All supplements were fed at 0745 each morning and were topdressed with 28 g of cobalt-iodized salt [97.0% salt (min), 38.5% Na, 150 ppm I, 100 ppm Co; Federated Co-operatives Ltd, Saskatoon, SK] and 57 g of mineral [16.0% Ca, 8.0% P, 4.0% Na, 5.0% Mg, 30 ppm Se,

Table 1. Ingredients and chemical composition of treatment rations[z]

	Treatment[y]			
	DDGS	COMM	BAR+CM	CONT
Ingredients		(% of ration DM)		
Straw	67.8	67.8	65.2	75.5
Hay	22.6	22.6	21.7	23.6
DDGS	8.5	–	–	–
Commercial range pellet[x]	–	8.5	–	–
Rolled barley	–	–	4.8	–
Canola meal	–	–	7.2	–
2:1 Mineral	0.67	0.67	0.67	0.67
Salt	0.33	0.33	0.33	0.33
Chemical composition[w]				
CP (% DM)	10.2	10.2	10.4	7.5
NDF (% DM)	72.4	70.3	68.2	74.7
ADF (% DM)	46.0	45.3	44.2	48.5
Lignin (% DM)	7.6	7.6	7.3	8.3
TDN (% DM)	48.9	49.8	51.0	46.3
DE (Mcal kg^{-1} DM)	2.1	2.2	2.2	2.0

[z]Rations formulated using CowBytes Beef Ration Balancer Program. Version 4. (Alberta Agriculture Food and Rural Development 1999).
[y]DDGS = heifers supplemented with wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); COMM = heifers supplemented with commercial range pellet; BAR+CM = heifers supplemented with rolled barley grain and canola meal; CONT = heifers received no supplement.
[x]Ingredient composition of commercial range pellet was soybean meal (396 kg t^{-1} as mixed), wheat shorts (150 kg t^{-1} as mixed), canola meal (400 kg t^{-1} as mixed), ground barley (44 kg t^{-1} as mixed), molasses (10 kg t^{-1} as mixed).
[w]Calculated from average nutrient composition of ingredients. TDN and DE calculated using Penn State equations (Adams 1995).

10 100 ppm Zn, 70 ppm I, 5500 ppm Fe, 4650 ppm Mn, 3050 ppm Cu, 35 ppm Co, 3000 ppm Fl (max), 500 000 IU kg^{-1} vitamin A (min), 50 000 IU kg^{-1} vitamin D_3 (min), 1500 IU kg^{-1} vitamin E (min); Federated Co-operatives Ltd, Saskatoon, SK]. All heifers were observed to ensure that all supplement was consumed. The mineral supplement was withheld on day 17 to day 24, as digestibility was determined using acid insoluble ash as an internal marker. Forages were fed at 0800, after supplements had been consumed. Supplements were usually completely consumed before the forage was fed.

Data Collection

Following a 10-d dietary adjustment period, voluntary intake was determined over 7 d (days 11–17) by weighing all feed and orts. Orts were collected daily and composited by heifer within period. Once voluntary intake was determined, heifers were restricted to 90% of ad libitum intake for 3 d (days 18 to 20) to estimate digestibility using acid insoluble ash (AIA) as an internal marker. Any orts remaining were deposited directly into the rumen prior to feeding the next day. Fecal (500 g) samples were collected at 0800, 1200, 1600, and 2000 on days 19 to 22 and immediately dried at 55°C for 48 h, ground through a 1-mm screen (Retsch ZM-1 grinder, Haan, Germany) and composited by heifer within each period. Straw, hay, and supplement samples were composited by period prior to laboratory analysis.

On the first day of restricted feeding (day 18), 200 g of ytterbium (Yb) labeled forage prepared by immersion (Mader et al. 1984) was dosed directly into the rumen to measure total tract passage rate. Fecal samples were collected at 0, 4, 8, 12, 16, 20, 24, 28, 32, 36, 48, 52, 56, 60, 72, 76, 80, 84, 96, 100, 104, and 108 h post-dosing (Vogel et al. 1989). The fecal samples were immediately dried at 55°C for 48 h and ground through a 1-mm screen (Retsch ZM-1 grinder, Haan, Germany).

On day 21 of each period, rumen fluid was sampled every 2 h for 12 h beginning at 0730, prior to supplement feeding. The samples were collected from three locations of the rumen (cranial-ventral, ventral, and caudal ventral) as well as a sample from the rumen mat. All four samples were combined and strained through four layers of cheesecloth and fluid pH was measured (Model 265A portable pH meter; Orion Research Inc., Beverly, MA). Fluid was placed in duplicate 10-mL test tubes. Fluid samples were acidified with 2 mL of 50% H_2SO_4 and frozen for future rumen ammonia-N analysis.

Table 2. Chemical composition of forages and supplements fed to heifers

	Forage		Supplement			
Nutrient[z]	Barley straw	Grass hay	DDGS	Commercial range pellet	Barley grain	Canola meal
DM (%)	96.6	96.4	92.4	92.8	91.4	92.7
CP (% DM)	6.3	11.7	39.0	38.7	12.2	43.5
NDF (% DM)	77.9	67.1	52.0	26.9	14.5	30.2
ADF (% DM)	50.7	43.5	21.4	12.8	5.0	20.6
ADL (% DM)	8.1	9.5	–	–	–	–
Phosphorus (% DM)	–	–	0.83	0.77	0.29	1.03
Sulfur (% DM)	–	–	0.72	0.84	0.23	1.32
NDIN (% N)	–	–	3.8	1.0	0.1	0.9
ADIN (% N)	7.6	17.0	–	–	–	–
IVOMD (% DM)	55.5	62.5	86.7	90.1	91.7	86.6
DE (Mcal kg^{-1} DM)	2.0	2.3	3.2	3.5	3.7	3.2

[z]ADL, acid detergent lignin; IVOMD, in vitro organic matter digestibility; NDIN, neutral detergent insoluble nitrogen.

Nylon bags (40-μm pore size) containing 5.25 (75%) and 1.75 (25%) g dry matter intake (DM) of ground straw and hay, respectively (ground through a 2-mm screen), were incubated for 0, 2, 4, 8, 12, 24, 48 and 72 h in rumen of each heifer using the gradual in, all out procedure (Yu 2005). All bags were removed at 2000 on day 24. After removal, bags were immediately submerged and rinsed six times in cold water prior to drying and dried at 55°C for 48 h (McKinnon et al. 1991). The 0 h incubation samples were washed under the same conditions, but without incubation in the rumen. Forage residue was weighed and composited by incubation time for a total of eight samples per heifer per period. Prior to laboratory analysis, in situ residue material was re-ground through a 1-mm screen.

Forage samples were collected weekly and supplement samples were collected every 2 wk throughout the trial. Forage samples were dried at 55°C for 72 h to determine DM content and these along with supplement samples were ground through a 1-mm screen.

Laboratory Analysis

The DM concentration of all samples was determined by drying at 55°C for 72 h in a forced-air oven according to the procedure outlined by the Association of Official Analytical Chemists (method #930.15; AOAC 2000). Crude protein was analyzed for N content using a combustion N analyzer (Leco FP-528, Leco Corporation, St. Joseph MI). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed using an ANKOM 200 Fiber Analyzer (ANKOM Technology, Fairport, NY; method 973.18). Neutral detergent fiber was analyzed without sodium sulfite in order to further determine neutral detergent insoluble nitrogen content of the samples (Hertz and Mertens 1996). Neutral detergent insoluble nitrogen and acid detergent insoluble nitrogen (ADIN) concentrations were determined using the 2400 Kjeltec Analyzer Unit (FOSS Tecator, Hoganas, Sweden). Lignin content was evaluated using the beaker method outlined by ANKOM Technology (ADF method 973.18 followed by 72% H_2SO_4).

Total digestible nutrients (TDN; %DM) and digestible energy (Mcal kg^{-1} DM) were calculated for forage samples using the Penn State grass-legume equation based on ADF, and for supplement samples using the Penn State cereal grain equation based on ADF (Adams 1995).

In vitro dry matter digestibility and in vitro organic matter digestibility were estimated using the filter bag technique (Daisy^{II}, ANKOM Technology Corporation, Fairport, NY). Artificial saliva was inoculated with rumen fluid strained through four layers of cheesecloth. Rumen fluid was collected from a ruminally fistulated Holstein cow fed 70% silage and 30% concentrate (custom pellet; DM basis).

Ytterbium chloride labeled forage and fecal were analyzed for Yb according to the procedure of Lopez Molinero et al. (1988) as modified by Vicente et al. (2004). The natural logarithm of the Yb concentration was regressed against time for fecal samples collected post-dosing (Titgemeyer et al. 2004). Natural logarithms were used to normalize the data and create a linear line for regression analysis. The negative slope of the natural logarithm was estimated as the total tract passage rate (% h^{-1}).

Composited feed samples from each period as well as composited fecal samples collected on days 18 to 22 were analyzed for AIA to determine digestibility (Van Keulen and Young 1977). Digestibility was calculated using the following equation (Cochran and Galyean 1994):

$$Digestibility\ (\%) = 100 - 100 * \left[\left(\frac{marker\ in\ feed}{marker\ in\ feces} \right) * \left(\frac{nutrient\ in\ feces}{nutrient\ in\ feed} \right) \right]$$

Rumen fluid samples were thawed and centrifuged (Beckman Centrifuge; Model TJ-6; Palo Alto, CA at 10 000 $\times g$ for 10 min prior to ammonia nitrogen (NH_3-N) analysis. The phenol-hypochlorite method was used to determine ammonia in ruminal fluid (Broderick and Kang 1980).

Data Analysis

In situ data were fitted to the modified first-order kinetics equation with lag time to determine rate and extent of forage degradation (Ørskov and McDonald 1979; Robinson et al. 1986):

$$R(t) = U + D^{(-Kd*(t-T0))}$$

where $R(t)$ is the residue of the incubated material after t h of rumen incubation (g kg^{-1}), U is the undegradable fraction (%), D is the potentially degradable fraction (%), $T0$ is the lag time (h), and Kd is the degradation rate (% h^{-1}).

Effective degradability (ED; g kg^{-1}) of DM, CP, NDF, and ADF was determined using the nonlinear (NLIN) parameters (U, D, and Kd) calculated by the above equation and also the following equation:

$$ED = S + D * \left[\frac{Kd}{(Kp + Kd)} \right]$$

where S is the soluble fraction (%) as determined by the samples incubated for 0 h and Kp is the rate of passage (4.0% h^{-1}; Yu et al. 2004).

Intake, total tract digestibility, rumen fermentation parameters (pH and NH_3-N), and passage rate were analyzed as a Latin square design with period and heifer as random effects. The Proc Mixed procedure of SAS software was used to complete statistical analysis (SAS Institute, Inc. 2003). Means were separated using

Tukey's multi-treatment comparison method (Saxton 1998) and differences were considered significant when $P < 0.05$. The experimental model was:

$$Y_{ijk} = \mu + \rho_i + \delta_j + \alpha_k + e_{ijk}$$

where μ is the overall mean, ρ_i is the fixed effect of the ith period, δ_j is the random effect of the jth heifer, α_k is the fixed effect of the kth treatment, and y_{ijk} is the observation for the experimental unit in the ith period, jth cow, and the kth treatment effect. Calculated values for Kd, T0, S, D, U, and ED of DM and NDF were analyzed in a similar fashion.

RESULTS AND DISCUSSION

Voluntary Dry Matter Intake

Total DM intake was greater ($P = 0.02$) for heifers fed supplemented diets as compared with those fed the control diet; however, forage intake did not differ ($P = 0.42$) across treatments (Table 3). Because there was no difference in forage intake, total intake differences are reflective of the supplement fed.

Despite supplementation, DMI of forage was not different ($P > 0.05$) across treatments. Similar to the barley grain and canola meal supplement in this study, Winterholler et al. (2009) fed a greater quantity of wheat middlings–cottonseed meal supplement compared with cottonseed meal and found no resulting difference ($P = 0.10$) in forage intake. These results are comparable with those of Ferrell et al. (1999), who reported intake of bromegrass hay (4.3% CP; 73.9% NDF) was not affected by supplementation of energy (cornstarch, molasses, and soybean oil), energy plus urea, energy plus soybean meal (SBM), or energy plus ruminally undegraded protein (RUP; 50:50 mixture of blood and feather meals). Similarly, Bohnert et al. (2002) concluded the lack of supplementation effect on forage intake was due to an already high NDF intake in unsupplemented control steers consuming low-quality meadow hay (5% CP; 61% NDF; 31% ADF). Reed et al. (2007) reported intake of forage OM was not different when steers were supplemented with low, medium, or high levels of RUP and equal levels of energy and RDP compared with steers receiving no supplement. These authors hypothesized that prairie grass hay (6% CP; 69.1% NDF) provided adequate RDP or, alternatively, that sufficient N recycling occurred to prevent forage intake reductions.

In the current study, average straw quality was greater than expected, thus the basal forage diet was of higher quality than anticipated. Initial formulation of diets using CowBytes Beef Ration Balancer Program (Version 4.6.8; Alberta Agriculture, Food and Rural Development) software indicated the control ration (no supplement) contained 6.0% CP and 77.5% neutral detergent fiber. However, based on the average nutrient composition of straw and hay collected throughout the trial, the basal ration was 7.5% CP and 74.7% NDF (Table 1). Based on these data, CP levels supplied appeared adequate to meet the requirements of non-pregnant, non-lactating beef heifers (NRC 1996). Therefore, forage quality was not likely to limit forage intake, thus reducing supplement affects on forage intake (Ferrell et al. 1999; Reed et al. 2007).

Table 3. Effect of supplement on voluntary dry matter intake, apparent total tract digestibility, and particulate matter passage rate

	Treatment[z]					
Item	CONT	COMM	BAR+CM	DDGS	SEM	*P* value
Forage intake (DM)						
kg d^{-1}	7.0	7.5	7.4	7.4	0.25	0.42
% BW	1.13	1.18	1.19	1.16	0.034	0.50
Supplement intake						
kg d^{-1}	0.00	0.75	1.08	0.75	N/A	N/A
% BW	0.00	0.12	0.17	0.11	N/A	N/A
Total intake						
kg d^{-1}	7.0*b*	8.2*a*	8.4*a*	8.2*a*	0.32	0.02
% BW	1.13*b*	1.30*a*	1.34*a*	1.29*a*	0.044	0.02
Apparent total tract digestibility						
DM (%)	56.0	61.1	61.6	63.4	2.9	0.41
CP (% DM)	46.4*b*	61.8*a*	62.5*a*	63.9*a*	3.2	0.02
NDF (% DM)	59.0	61.8	62.6	65.0	2.9	0.56
ADF (% DM)	52.0	56.2	56.6	58.9	3.1	0.51
Particulate passage rate (% h^{-1})	3.2	3.8	4.1	4.2	0.58	0.29

[z]CONT = heifers received no supplement; COMM = heifers supplemented with commercial range pellet; BAR+CM = heifers supplemented with 4.8% rolled barley grain and 7.3% canola meal; DDGS = heifers supplemented with wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend). BW, body weight

a, *b* Means with different letters in the same row are significantly different ($P < 0.05$) using Tukey's multi-treatment comparison method. SEM = standard error of mean.

Apparent Total Tract Digestibility

The apparent total tract digestibility of CP was greater ($P = 0.02$) for supplemented diets than for the control diet (Table 3). Bhatti et al. (2008) found apparent total tract CP digestibility was increased when orchardgrass was fed with alfalfa at a 3:1 ratio. Similarly, protein supplementation increased apparent total tract N disappearance as a result of increased intestinal digestion in a study by Bohnert et al. (2002). Increased CP digestibility for the supplemented diets is likely a function of the increased CP content in the diets and the greater digestibility of CP from the supplement compared with CP from forage (Stern et al. 1983). Some studies (Church and Santos 1981; Hannah et al. 1991; Koster et al. 1996) have found a negative apparent CP digestibility in unsupplemented animals consuming low-quality forages. This may indicate the occurrence of N recycling, where endogenous blood urea nitrogen is transferred into the rumen to supply N for ruminal microbes as a result of low N intake (Egan 1980; Kennedy and Milligan 1980; Bunting et al. 1989). In the current study, CP digestibility of the CONT diet was 46.4%, suggesting that the basal ration did not require extensive N recycling as CP requirements were satisfied.

Apparent total tract digestibility of DM, NDF, and ADF did not differ ($P > 0.41$) between diets (Table 3). These results agree with those of Reed et al. (2007), who found total tract digestibility of NDF and ADF was unaffected ($P > 0.11$) when grass hay (6% CP; 69% NDF) was supplemented with graded levels of rumen undegraded protein. Bhatti et al. (2008) saw no difference ($P = 0.23$) in apparent total tract digestibility of DM, NDF, ADF, cellulose, and hemicellulose when orchardgrass hay was fed with or without alfalfa (3:1 ratio, respectively). Likewise, Lintzenich et al. (1995) and Hannah et al. (1991) found no difference ($P > 0.10$) in NDF digestibility between steers consuming dormant bluestem forage supplemented with various forms of alfalfa, soybean meal and sorghum grain or not supplemented. However, Lintzenich et al. (1995) noted a tendency for NDF digestibility to increase as a result of alfalfa supplementation. Conversely, while there was no difference in DM digestibility of ammoniated wheat straw, Beck et al. (1992) found NDF digestibility was decreased ($P = 0.05$) when sorghum grain and/or soybean meal were supplemented. These authors suggested the reduced NDF digestibility was a result of decreased ruminal pH, which limited rumen microbial growth. In this study, supplementation did not influence total tract forage, digestibility perhaps due to the level of forage CP (7–10%) in the diets. In a review of the effects of forage chemical composition on intake and digestibility, Minson (1990) reported that digestibility of forages with CP levels greater than 7 was not increased by supplementation.

Total Tract Particulate Passage Rate

Total tract particulate passage rate was not affected ($P = 0.29$) by supplement strategy (Table 3). These results were not unexpected, since forage DM intake did not differ ($P > 0.05$) among treatments. Particulate passage rate and forage DM intake have been found to be positively correlated (Thornton and Minson 1973; McCollum and Galyean 1985; Guthrie and Wagner 1988). However, several studies (Judkins et al. 1987; Stokes et al. 1988; Beck et al. 1992) have found passage rate and forage intake to be unaffected ($P > 0.05$) by supplementation of low-quality forage diets.

The average passage rate for all diets was 3.84% h^{-1}, and is similar to those reported by Chase and Hibberd (1989). Judkins et al. (1987) also observed similar values of 4.29, 3.35, 3.36% h^{-1} for ruminally cannulated steers grazing blue gamma rangeland and supplemented with pelleted alfalfa, cottonseed meal, or no supplement, respectively. Passage rates also did not differ for beef cows consuming prairie grass hay (5.6% CP), supplemented with either cottonseed meal and/or corn grain or no supplement (control) (Freeman et al. 1992). Conversely, Stokes et al. (1988) found a linear ($P < 0.05$) increase in particulate passage rate (2.21, 3.01, 3.31% h^{-1}) when prairie hay (4.8% CP; 73% NDF) was supplemented with graded levels of soybean meal. Similarly, Guthrie and Wagner (1988) observed a linear ($P < 0.01$) increase (2.08, 2.17, 2.63, 2.86, 3.47% h^{-1}) in passage rate when supplementing prairie hay (5.2% CP) with soybean meal- or grain-based supplements. McCollum and Galyean (1985) found total mean retention time was reduced when beef steers consuming prairie hay (6.1% CP; 67.7% NDF) were supplemented with cottonseed meal. Finally, our data show passage rate was not affected by supplementation as forage DM intakes were similar among diets.

Ruminal pH and Ammonia Nitrogen

There was no effect ($P = 0.20$) of supplement on ruminal pH when rumen fluid was sampled at varying intervals (Fig. 1). This lack of effect is likely due to the low level of supplement in relation to total feed intake (Freeman et al. 1992). However, typical diurnal patterns were observed, with ruminal pH dropping post-feeding, then recovering. Judkins et al. (1978) observed similar ruminal pH patterns when blue gamma range was supplemented with alfalfa pellets and cottonseed meal cake. In the current study, ruminal pH ranged from 6.38 to 6.76 (Fig. 1). These levels are suitable for the normal function of cellulolytic bacteria (Mould and Ørskov 1983; Mould et al. 1983; Hoover 1986) and are above the threshold of acidosis ($pH \leq 5.8$) (Beliveau 2008). Average ruminal pH levels found in the current study are similar to those found in other studies (McCollum and Gaylean 1985; Stokes et al. 1988; Beck et al. 1992) when low-quality forages were supplemented.

Supplemented diets had higher ($P < 0.01$) rumen NH_3-N concentrations than the control diet (Fig. 2).

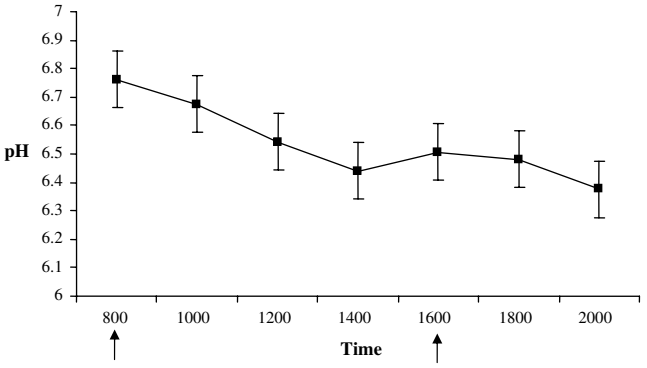

Fig. 1. Average rumen pH over time (P values: treatment = 0.20; time <0.01; treatment $\times$ time $=0.15$); arrows represent feeding times. Vertical bars are standard errors.

This agrees with previous research where supplementation of forage diets resulted in higher NH_3-N concentrations than unsupplemented controls (Guthrie and Wagner 1988; Koster et al. 1996). However, there was no difference ($P>0.05$) between the DDGS, COMM, and BAR+CM supplemented diets. Ruminal NH_3-N values were affected ($P<0.01$) by sampling time, paralleling the diurnal patterns observed in ruminal pH measurements. Previous research indicates that peak NH_3-N concentrations are generally observed 1 to 3 h after feeding (McCollum and Galyean 1985; Stokes et al. 1988; Koster et al. 1996). In the current study, peak NH_3-N occurred at 2 h post-feeding for all treatments. Stokes et al. (1988) theorized the post-feeding peak of NH_3-N was a result of rapid liberation of N from supplements and slow initiation of ruminal forage digestion.

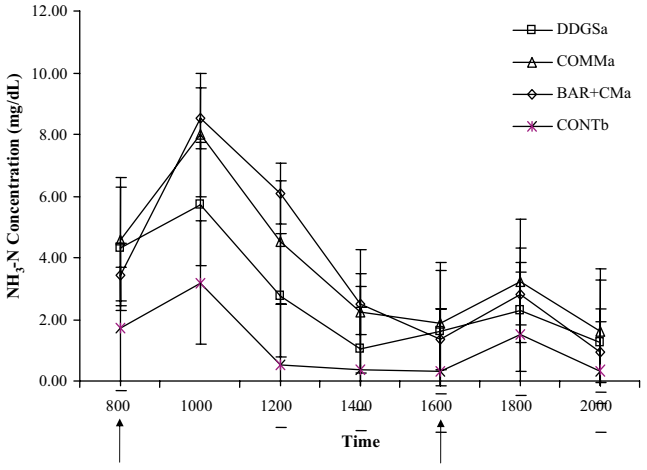

Fig. 2. Effect of supplementation on ruminal ammonia-N concentration (P values: treatment <0.01; time <0.01; treatment $\times$ time <0.01; arrows represent feeding times). Vertical bars are standard errors. Means within a time without common letter are significantly different ($P<0.05$).

In this study, average ruminal NH_3-N concentration was 1.13 mg dL^{-1} for the CONT treatment. Satter and Slyter (1974) suggested 2 to 5 mg dL^{-1} ruminal NH_3-N was required in vitro for maximal bacterial synthesis. As such, microbial efficiency may have been compromised for the control diet. While available ruminal NH_3-N is important for fiber digestion (McCollum and Horn 1990; Mathis et al. 2000), digestibility of DM and NDF were not lower ($P>0.5$) for the control diet compared with the supplemented diets and forage intake was similar ($P>0.05$) for all diets. In addition, apparent crude protein digestibility was not negative for the control diet or any of the supplemented diets. While rumen microbial synthesis may not have been maximized, it was likely not compromised to an extent that would have impaired rumen function.

Rate and Extent of Forage Degradation

The D fraction of DM and NDF decreased ($P<0.02$), whereas the U fraction increased ($P<0.01$) as a result of supplementation (Table 4). Because of this, the extent of forage DM and NDF degradation decreased ($P<0.01$) with supplementation. Supplements may have provided more readily available nutrients to the rumen microbes, potentially meeting nutritional requirements of rumen microflora without extensive degradation of the forage in the diet (Russell and Baldwin 1978). This may account for the reduced extent of forage degradation in the supplemented diets and only a numeric increase for total tract digestibility of either DM or fibers (Table 3). Alternatively, potential shifts in microbial population as a results of supplement strategy have reduced the extent of forage degradation within the rumen (Bowman and Sanson 2000).

Lag time ($T0$), the S fraction, and the ED of DM and NDF were not affected ($P>0.10$) by treatment (Table 4). Reed et al. (2007) found the NDF lag time of grass hay (6.0% CP; 69.1% NDF) was unaffected ($P>0.50$) by RUP supplementation and averaged 5.35 h. These values are considerably higher than DM and NDF lag times found in the current study (mean 0.55 h and 2.07 h, respectively). Greater N availability within the rumen supports microbial growth (Van Soest 1994) and Russell and Baldwin (1978) have demonstrated preferential substrate use within the rumen, which could potentially account for the lower lag times observed in the current study. The S fraction and effective degradability of dry matter observed in the current study (mean 12.78 and 35.12%, respectively) were similar to the values of $12.6 \pm 4.1\%$ and $37.0 \pm 3.8\%$, respectively, reported by Mathison et al. (1999).

The rate of DM degradation tended ($P=0.06$) to be higher in supplemented treatments compared with the control. Microbial efficiency may have been improved as a result of increased N availability within the rumen for the supplemented diets (Ortiz-Rubio et al. 2007). This would improve the rate of forage degradation in the supplemented diets compared with the degradation

Table 4. Effect of supplement on in situ degradability of dry matter and neutral detergent fiber of incubated forage (75:25 straw:hay)

Item	Treatment[z]				SEM	*P* value
	DDGS	COMM	BAR+CM	CONT		
Dry matter (%)						
Degradation rate (Kd; h^{-1})	4.09	4.04	4.05	2.64	0.453	0.06
Lag time (*T*0; h)	0.44	0.65	0.77	0.34	0.206	0.53
Immediately soluble fraction (*S*; %)	12.96	13.07	12.88	12.22	0.286	0.20
Potentially degradable fraction (*D*; %)	46.47*b*	46.06*b*	47.16*b*	53.88*a*	1.340	<0.01
Undegradable fraction (*U*; %)	40.58*a*	40.87*a*	39.96*a*	33.91*b*	1.399	<0.01
Effective degradability (EDDM; %)	35.57	36.11	35.65	33.15	1.179	0.34
Neutral detergent fiber (% DM)						
Degradation rate (Kd; $\%h^{-1}$)	4.02	4.11	3.70	2.72	0.443	0.14
Lag time (*T*0; h)	1.74	2.42	1.37	2.74	0.524	0.34
Immediately soluble fraction (*S*; %)	5.90	7.30	5.47	4.87	0.660	0.10
Potentially degradable fraction (*D*; %)	51.58*b*	50.09*b*	53.94*b*	61.10*a*	1.675	0.02
Undegradable fraction (*U*; %)	42.41*a*	43.03*a*	40.59*a*	33.87*b*	1.823	<0.01
Effective degradability (EDNDF[y]; %)	31.42	32.25	30.84	28.42	1.223	0.27

[z]DDGS = heifers supplemented with wheat-based dried distillers' grains with solubles (70:30 wheat:corn blend); COMM = heifers supplemented with commercial range pellet; BAR+CM = heifers supplemented with 4.8% rolled barley grain and 7.3% canola meal; CONT = heifers received no supplement.
[y]EDNDF, effective degradability of neutral detergent fiber.
a, *b* Means with different letters in the same row are significantly different ($P < 0.05$) using Tukey's multi-treatment comparison method. SEM = standard error of mean.

in the unsupplemented diet. Reed et al. (2004) found no difference ($P = 0.87$) in grass hay Kd as a result of field pea supplementation.

The rate of NDF degradation was not affected ($P = 0.14$) by supplement strategy in the current study. Similarly, Caton et al. (1988) found NDF degradation of dormant bluestem rangeland was not affected ($P > 0.10$) by cottonseed meal supplementation. Likewise, grass hay NDF Kd was not different ($P = 0.24$) between unsupplemented and RUP supplemented treatments in a study by Reed et al. (2007). However, NDF Kd was greater ($P = 0.05$) for the high level (40.6% DM) of RUP supplement compared with the medium level supplement (19.6% DM) (Reed et al. 2007).

CONCLUSION

Supplementing a forage-based diet of 75% barley straw and 25% grass hay with either wheat-based DDGS, range pellet or a combination of barley grain and canola meal did not affect forage intake, apparent total tract digestion, or particulate passage rate compared with an unsupplemented forage ration. The lack of supplementation effect may be attributed to the quality of the forage used, as forage and RDP intake were higher than expected in the control diet. Furthermore, the low level of supplement inclusion in the total diet may also have minimized any potential response due to treatment effects. Rumen pH was not affected by supplementation, thus maintaining a rumen environment favorable to cellulolytic bacteria. Supplementation did increase ammonia-N levels in the supplemented diets, which may have relieved sub-acute ruminal N deficiencies within the rumen. The rate of forage DM degradation tended to increase as a result of supplementation, while the extent of degradation decreased for both DM and neutral detergent fiber. This would indicate that rumen microbes possibly utilized supplement nutrients to meet their requirements instead of extensively degrading the diet forage. Based on our research, wheat-based DDGS has similar supplementation potential as a commercial range pellet or barley grain and canola meal mixture. Wheat-based DDGS can be used adequately as a supplement for ruminant diets consuming low-quality forages.

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