INFLUENCE OF GRAIN TYPE AND OIL CONCENTRATION OF DRIED CORN DISTILLERS GRAIN WITH SOLUBLES ON RUMINAL FERMENTATION AND IN VITRO GAS PRODUCTION IN CATTLE FED HIGH-CONCENTRATE DIETS

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Complete List of Authors:	Keomanivong, Faithe Ruch, Megan Rodenhuis, Mary Crouse, Matthew Kirsch, James Bauer, Marc; North Dakota State University, Animal Sciences Borhan, Md Saidul Rahman, Shafiqur Swanson, Kendall ; North Dakota State University, Animal Sciences
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**INFLUENCE OF GRAIN TYPE AND OIL CONCENTRATION OF DRIED CORN
DISTILLERS GRAIN WITH SOLUBLES ON RUMINAL FERMENTATION AND IN
VITRO GAS PRODUCTION IN CATTLE FED HIGH-CONCENTRATE DIETS**

**Faithe E. Keomanivong^a, Megan C. Ruch^a, Mary A. Rodenhuis^a, Matthew S. Crouse^a,
James D. Kirsch^a, Marc L. Bauer^a, Md S. Borhan^b, Shafiqur Rahman^b, and Kendall C.
Swanson^{a,*}**

F. E. Keomanivong, M. C. Ruch, M. A. Rodenhuis, M. S. Crouse, J. D. Kirsch, M. L.

Bauer, and K. C. Swanson: Department of Animal Sciences, North Dakota State University,
Fargo, ND 58108-6050, USA

M. S. Borhan and S. Rahman: Department of Agricultural and Biosystems Engineering, North
Dakota State University, Fargo, ND 58108-6050, USA

Corresponding author: Kendall Swanson (e-mail: kendall.swanson@ndsu.edu)

Abbreviations: DDGS, dried corn distillers grain with solubles; NH₃, ammonia; VFA, volatile
fatty acid, CH₄, methane, CO₂, carbon dioxide.

ABSTRACT: To determine the effects of grain type (rolled-corn vs rolled-barley) and dried corn distillers grains with solubles (DDGS) oil concentration (low = 4.5 % vs moderate = 7.9 %) on ruminal pH, ammonia (NH₃) and volatile fatty acid (VFA) concentrations, in vitro enteric methane (CH₄) and carbon dioxide (CO₂) production, and digestive enzyme activity, eight ruminally cannulated Holstein steers (715 ± 61.4 kg) were used in a 4 × 8 Latin rectangle with a 2 × 2 factorial arrangement of treatments. Diets were offered for ad libitum intake. Experimental periods were 24 d with 7 d of diet adaptation, 7 d of sample collection, and a 10-d transition between periods. No differences were observed for ruminal NH₃, total VFA concentration, pH, or in vitro concentration of CH₄ or CO₂ after 24 hr of incubation among treatments. The lag time for in vitro gas production and degradation was greater ($P = 0.03$) from steers fed diets containing rolled-corn than rolled-barley. There were grain type × DDGS interactions ($P \leq 0.02$) observed for α -amylase and trypsin activity (U/L ruminal fluid). Maltase activity (U/L ruminal fluid) was greater ($P \leq 0.01$) in steers fed diets containing rolled-corn than rolled-barley and in steers fed diets containing low- compared to moderate-oil DDGS. These results indicate that, although ruminal enzyme activity was influenced, feeding different grain types (rolled-corn vs. rolled-barley) or DDGS with differing oil concentration (moderate vs. low) did not negatively influence ruminal fermentation or in vitro CH₄ production.

Keywords: bovine, digestive enzymes, dried distillers grains with solubles, fermentation, grain

INTRODUCTION

Corn and barley are commonly used in cattle finishing diets in North America. This is largely due to the grain accessibility and the need to provide sufficient amounts of dietary energy

for efficient growth and finishing. Corn is typically thought to have a greater concentration of net energy than barley (NRC 1996). However, starch in barley has more complete and rapid fermentation (Theurer 1986) resulting in a more rapid rate of volatile fatty acid (VFA) production in the ruminal fluid, which can lead to acidotic conditions and, consequently, reduced ruminal function of amylolytic bacteria and protozoa impeding the breakdown of starch (Stone 2004). However, barley has greater concentrations of protein and a more balanced supply of amino acids allowing for the possibility of reduced protein supplementation (NRC 1996).

Distillers grains are also commonly included in finishing diets to reduce feed costs while maintaining an energy value similar to, or greater than corn or barley (Klopfenstein et al. 2008). In recent years, ethanol plants have begun extracting greater amounts of oil to be used in biodiesel production and providing additional commodities for a value-added market (Saunders and Rosentrater 2009). Continued research on the feeding value of dried corn distillers grains with solubles (DDGS) is necessary with the changing composition of DDGS because of changes in processing at ethanol plants.

Changes in DDGS composition may influence the value of the product and this also could be dependent on the predominant grain used in the diet for finishing cattle. Different grain types (barley or corn) and changes in distillers byproducts, such as changing oil concentration, have the potential to influence the ruminal environment by influencing the microbial and enzymatic action on feed (Hobson and Stewart 1997) thus potentially influencing cattle performance in both negative and positive ways. We hypothesize that feeding diets containing DDGS with differing oil concentration will influence ruminal fermentation differently in diets containing rolled-corn than rolled-barley. Therefore, the objective of this study was to determine the influence of grain type (rolled-corn vs. rolled barley) and DDGS oil concentration (low vs.

moderate) on ruminal ammonia (NH_3) and VFA concentrations, ruminal pH, in vitro gas production and methane (CH_4) and carbon dioxide (CO_2) concentrations, and ruminal digestive enzyme activity.

MATERIALS AND METHODS

Animals, Experimental Design and Dietary Treatments

This experiment was approved by the North Dakota State University Animal Care and Use Committee.

Animal use and experimental design have been previously described (Rodenhuis et al. 2018). Eight Holstein steers weighing 715 ± 61.4 kg were surgically fitted with a ruminal cannula (Bar Diamond, Inc., Parma, ID) and randomly assigned to four dietary treatments in a 4×8 Latin rectangle design with a 2×2 factorial arrangement. Two animals were assigned to each treatment per period to determine the impact of grain type (rolled-corn vs rolled-barley) DDGS oil concentration (low = 4.5 % vs moderate = 7.9 %) on ruminal pH, NH_3 and VFA concentration, in vitro CH_4 and CO_2 concentration, and digestive enzyme activity. The DDGS were sourced from 2 different ethanol plants in the upper Great Plains of the USA and typically would be marketed to purchasers in the upper Great Plains and Western Canada. Steers were housed in individual tie stalls (1.0×2.2 m) in a temperature-controlled (15°C) environment. Dietary treatments (**Tables 1 and 2**) were offered to ensure ad libitum intake and approximately 6% feed refusal daily. Dietary treatments consisted of 1) rolled-corn and low-oil DDGS, 2) rolled-corn and moderate-oil DDGS, 3) rolled-barley and low-oil DDGS and 4) rolled-barley and moderate-oil DDGS. Diets were formulated to meet or exceed requirements for ruminally degradable intake protein, metabolizable protein, vitamins, and minerals for a steer gaining 1.6

kg/d (NRC 1996). Corn silage was used as the source of forage and was included in the diet at 20% on a DM basis. Before the initiation of the experiment, steers were adapted to high-grain diets over 21 days. Each treatment period consisted of 24 days allowing for 7 d of diet adaptation, 7 d of sample collection, and 10 d rest in which all steers were offered an intermediate dietary transition (50% of the previous and upcoming dietary treatment) before being provided the next dietary treatment.

Treatment diets were prepared weekly and stored at 4°C. Samples were collected immediately following diet mixing and preserved at -20°C until analyses. Orts were collected at 0700 daily. Each animal's consumption was calculated and animals were offered fresh feed by 0800.

After each experimental period, feed samples were dried for 48 hours at 60°C in a forced-air Grieve SB-350 oven (The Grieve Corporation, Round Lake, IL, USA) and ground to pass a 2-mm screen using a Wiley mill (Model #3; Arthur H. Thomas, Philadelphia, PA, USA). Feed samples were analyzed for DM, ash, CP (Kjeldahl method; Procedure numbers: 934.01, 942.05, 2001.11 respectively; (AOAC 1990)) and NDF (assayed with heat stable amylase and sodium sulfite and expressed inclusive of residual ash) and ADF (Robertson and Van Soest 1981). Starch was analyzed using the methods of Herrera-Saldana and Huber (1989) using a microplate spectrophotometer (Synergy, H1 Microplate reader, BioTek Instruments, Winooski, VT, USA). Ether extract, Ca, and P concentrations also were determined (AOAC 1990; Procedure numbers 968.08, 965.17, and 920.39, respectively).

Ruminal pH, NH₃, and VFA Analysis

Approximately 200 mL of ruminal fluid was collected from the cranial-ventral region of the rumen using a suction strainer and placed into whirl-pak bags (Nasco; 532-mL) from d 3 to 5 in a manner that allowed a sample to be collected every other hour in a 24-h cycle. Samples were taken at 0200, 0800, 1400 and 2000 h on d 3, 0400, 1000, 1600, and 2200 h on d 4 and 0600, 1200, 1800, and 0000 h on d 5. After ruminal fluid collection, pH was immediately measured using an IQ Scientific pH meter (Hach Company, Loveland, CO, USA). Once pH was recorded, samples were stored frozen (-20°C) until the end of the collection period at which point they were thawed and centrifuged at $2000 \times g$ for 20 min. The liquid portion was filtered through a $0.45\text{-}\mu\text{m}$ filter and the supernatant separated and analyzed for NH_3 (Broderick and Kang 1980). Ruminal VFA concentrations were determined by gas chromatography (Hewlett Packard 5890A Series II GC, Wilmington, DE, USA) and separated on a capillary column (Nukol, Supelco, Bellefonte, PA, USA) using 2-ethyl butyric acid as the internal standard (Goetsch and Galyean 1983).

Ruminal α -amylase, trypsin activity, and maltase activity

Ruminal fluid (100 μl) collected from each 2 hr time point was added to a 0.9 % NaCl solution (700 μl) and homogenized using a Vortex Genie 2 mixer (Scientific Industries Inc., Bohemia, NY, USA). Activity of α -amylase was determined using the procedure of Wallenfels et al. (1978) utilizing a kit from Teco Diagnostics (Anaheim, CA, USA). Maltase activity was determined using the methods previously described (Bauer et al. 2001a; Bauer et al. 2001b) with a modification of the Turner and Moran (1982) technique. Trypsin activity was assayed using the methods described by Geiger and Fritz (1986). Analyses were adapted for use on a microplate spectrophotometer (SpectraMax 340, Molecular Devices, San Jose, CA, USA). One unit (U) of enzyme activity equals 1 μmole product produced per min.

Gas Production

Gas production was measured on d 1 and 7 of each collection period from ruminal fluid collected using a suction strainer at 0700 (before feeding) with 2 replicates per animal and therefore 8 replicates per treatment. The in vitro procedure consisted of adding 0.375 g of the treatment diet to an Ankom fermentation vessel (Gas Pressure Monitor, Ankom Technology Corp., Macedon, NY, USA) along with 212.5 mL of a McDougall's buffer (McDougall 1948) and ruminal fluid solution in a 4:1 ratio. McDougall's buffer was prepared by 0700 the morning of each analysis with the collection of ruminal fluid immediately following. Each module was purged with CO₂, sealed with the Ankom pressure monitor cap (Ankom Technology Corp.), and then placed in an oscillating water bath (Northwest Scientific Incorporated) at 39°C for 24 h, with the oscillation set at 125 rpm. A wireless gas pressure monitoring system was used to measure the changes in pressure inside the flask relative to atmospheric pressure as a consequence of the gas produced during fermentation. Data were transferred via an Ankom wireless system to a computer equipped with software that allows the data to be stored in a spreadsheet. Data obtained from this system were converted from pressure units to volume units (mL) using the formula reported by Lopez (2007).

To measure the concentration of CH₄ produced in the headspace of the Ankom flask, 15 mL of gas was collected over the 24 h of incubation from the septa port using a gas tight syringe and tested using subsequent gas chromatograph analysis (Model No. 8610C, SRI Instruments, Torrance, CA, USA, 90502 (Borhan et al. 2012)).

Calculations and Statistical Analysis

Data were analyzed as a 4×8 Latin rectangle with a 2×2 factorial arrangement of treatments using the Mixed procedure of SAS (SAS Inst. Inc., Cary, NC). The model included the effects of animal, period, grain type (rolled-corn vs rolled-barley) and DDGS oil concentration (low vs moderate), and the interaction between grain type $\times$ DDGS oil concentration. Ruminal pH, the concentration of VFA and NH_3 , and digestive enzyme activity over time was measured using the Mixed procedure of SAS with repeated measures with the model including animal, period, grain type, DDGS oil concentration, hour, grain type $\times$ DDGS oil concentration, grain type $\times$ hour, and DDGS oil concentration $\times$ hour. Appropriate (minimize information criterion) covariance structures were utilized (Wang and Goonewardene 2004).

Individual measurements of gas production were calculated using a nonlinear model in SAS and the equation $\text{gas} = A * (1 - \exp(-(b * (\text{time} - c) + d * (\sqrt{\text{time}} - \sqrt{c}))))$ where A is equal to the asymptotic gas formation (mL gas), b is equal to the fractional rate (hr^{-1}), c is the lag time before measurable gas production (hr), and d is a rate constant ($\text{hr}^{-1/2}$) (France et al. 2005)). Degradation rate at 1, 12, and 24 hr were calculated using the predicted components of the gas production model. Gas production data were analyzed using repeated measures (run; d 1 and d 7) in the MIXED procedure of SAS with the effects of animal, period, grain type and DDGS oil concentration, grain type $\times$ DDGS oil concentration, run, grain type $\times$ run, DDGS oil concentration $\times$ run, and grain type $\times$ DDGS oil concentration $\times$ run. Appropriate (minimize information criterion) covariance structures were utilized (Wang and Goonewardene 2004). There were no interactions between run and dietary treatments so only main effect means of grain type and DDGS oil concentration are presented. Statistical significance was declared at $P \leq 0.05$.

RESULTS

Ruminal NH_3 , pH, and total VFA concentration was not influenced by dietary treatment (**Table 3**). There was a tendency ($P = 0.05$) for ruminal isovaleric acid concentration to be greater in steers fed diets containing moderate- than low-oil DDGS. Ruminal valeric acid concentration was decreased ($P = 0.03$) in steers fed diets containing rolled-corn than rolled-barley.

There was a grain type $\times$ DDGS oil concentration interaction ($P = 0.03$) for ruminal α -amylase activity with activity the least ($P < 0.05$) in ruminal fluid from steers fed diets containing rolled-barley with moderate-oil DDGS compared to other dietary treatments (**Table 4**). Ruminal maltase activity was greater ($P \leq 0.01$) in ruminal fluid from steers fed diets containing rolled-corn than rolled-barley and ruminal fluid from steers fed diets containing low- than high-oil DDGS. There also was a grain type $\times$ DDGS oil concentration interaction ($P = 0.01$) for ruminal trypsin activity with activity greatest ($P < 0.05$) in steers fed diets containing rolled-corn and low-oil DDGS compared to the other dietary treatments.

The lag time for in vitro gas production was longer ($P = 0.03$) in ruminal fluid from steers fed diets containing rolled-corn than rolled-barley (**Table 5**). The rate of ruminal degradation was greater ($P = 0.03$) in ruminal fluid from steers fed diets containing barley at 1 hr and tended to be greater at 12 hr ($P = 0.06$) and 24 hr ($P = 0.07$). No differences ($P > 0.05$) in CH_4 and CO_2 concentration after 24 h of in vitro incubation were observed among the dietary treatments.

DISCUSSION

It should be pointed out that NDF and ADF concentrations were greater and starch concentrations lesser in the moderate-oil compared to the low-oil DDGS which could potentially influence the responses observed in this experiment. However, it is unlikely that nutrient

differences, other than oil, between the DDGS sources tested in this experiment had large influences on the observed results. Our results have practical significance as the sources of the DDGS are major suppliers of DDGS to feedlots both in the USA and in Canada.

Ruminal NH_3 concentrations are influenced by the amount and degradability of the crude protein in the diet along with the rate of fermentation (Oh et al. 2008). The concentration of ruminal NH_3 , however, was not influenced by the dietary treatments in the current experiment. This is likely due to the formulation of the dietary treatments to have similar concentrations of ruminally degradable intake protein.

While ruminal pH was not influenced by dietary treatment, it is interesting to note that the highest pH measurements occurred at 0800 (data not shown; before feed delivery). Ruminal pH began to drop after feeding indicating that the ruminal microbes were becoming more active and feed was undergoing nutrient breakdown (Gonzalez et al. 2012). Chan et al. (1997) reported an increase in the concentration of butyric acid in the ruminal fluid in lactating Holstein cows fed a high-fat (7.2%) compared with a medium-fat (4.6%) diet while acetate and propionate were unaffected. The concentrations of acetate and propionate also were not influenced by DDGS oil concentration in the current study. However, no effects of DDGS oil concentration were observed for ruminal fluid butyric acid concentration. Although the total VFA concentration, along with acetate, butyrate, and propionate were not different between dietary treatments, isovaleric and valeric acid were influenced by treatment with isovaleric acid concentration tending to be greater in ruminal fluid from steers fed diets containing moderate-oil DDGS while valeric acid concentration was greater in ruminal fluid from steers fed barley-based diets. Isovaleric acid and valeric acid are increased during the microbial deamination and decarboxylation of valine and leucine, respectively (Hobson and Stewart 1997), therefore

suggesting that oil concentration and grain source may have influenced the degradation of some amino acids in the rumen. . The addition of urea to the corn-based diets may have contributed to the lower concentration of ruminal valeric acid as Payne and Morris (1970) reported that adding urea to high-grain diets for steers resulted in a decreased proportion of valeric acid in ruminal fluid.

Research suggests that rolled-corn is not digested as extensively in the rumen as rolled-barley (Galloway et al. 1993; Yang et al. 1997). This is thought to be largely because of a more complex protein matrix in corn than in barley (McAllister et al. 1993) which is likely why the lag time for in vitro gas production was greater and the ruminal degradation rates were lower in ruminal fluid from steers fed diets containing corn than barley. This is also supported by research showing that in situ starch and dry matter degradation rates are slower in the rumen of cattle fed corn- than barley-based diets (Herrera-Saldana et al. 1990). However, the lack of a response in ruminal VFA concentrations may indicate minimal effects on energy supply from ruminal fermentation between steers fed diets containing DDGS with differing oil concentration. This is further supported from results from our companion study indicating no differences in growth performance in steers fed diets containing DDGS with differing oil concentration (Rodenhuis et al. 2017).

Research has suggested finishing cattle fed barley-based diets emit greater amounts of enteric methane than cattle fed corn-based diets (Beauchemin and McGinn 2005). Other studies have reported reductions in CH₄ when cattle were fed diets containing greater concentrations of lipid (Benchaar et al. 2015; Hünerberg et al. 2013). Typically, these results occur due to the inhibited growth of the ruminal protozoa and reduction of methanogens (Knapp et al. 2014). However, no differences were observed in the current experiment for in vitro CH₄ and CO₂

concentration after 24 hr of incubation in the current study. This may be because the diets provided were not divergent enough in nutrient composition to measure variation in CH₄ and CO₂ production in vitro. Overall though, the finding that the acetate:propionate ratio was unaffected by treatment is consistent with the lack of an effect on CH₄ concentration as the acetate:propionate ratio is typically a good indicator of changes in CH₄ production (Russell 1998).

Degradation of starch and protein in the rumen is complex and is the result of a diverse complement of enzymes produced by a diverse microbial ecosystem. Generally it is thought that the microbial ecosystem is very responsive to changes in substrate which results in changes in microbial species and the resulting enzyme activity (Kotarski et al. 1992). Less is known, however, about how practical changes in feed ingredients or management influences digestive enzyme activity in the rumen. The observed interaction between grain type and DDGS oil concentration resulting in the lowest α -amylase activity in ruminal fluid from steers fed diets containing barley with moderate-oil DDGS may indicate greater impacts on amylolytic bacteria and thus α -amylase activity with increasing oil concentration in the presence of more rapidly fermentable starch. In fact, research has suggested that lipid supplements influence several different microbial species (Potu et al. 2011) and it is probable that carbohydrate and starch composition play an important role in determining the effects of dietary lipids on microbial composition in the rumen. When starch is digested by α -amylase it is broken down into smaller polysaccharides and disaccharides including maltose (Coleman 1969). Interestingly, maltase activity in ruminal fluid was greater in steers fed diets containing rolled-corn and was also greater in steers fed low-oil DDGS. This may suggest that source (or amount) of starch and oil concentration may influence the population of microbes responsible for producing maltase

activity. The observed interaction between grain type and DDGS oil concentration resulting in the greatest trypsin activity in ruminal fluid from steers fed diets containing rolled-corn with low-oil DDGS indicates that dietary oil concentration may influence proteolytic microbes differently depending on grain type. In support of this finding that lipid concentrations in DDGS may influence proteolytic activity in the rumen, research has suggested that defatting corn byproducts results in an increase in the population of proteolytic bacteria in the rumen (Williams et al. 2010).

In conclusion, reducing oil concentration of DDGS and feeding different grain types influences ruminal enzymatic function which could potentially lead to changes in digestion and nutrient utilization. However, the lack of change in ruminal pH, NH_3 , in vitro gas production and the concentrations of CH_4 and CO_2 over 24 hr of incubation indicate that feeding high-concentrate diets containing 25% DDGS with differing oil concentration in both corn- and barley-based diets does not negatively influence ruminal fermentation.

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Conflicts of Interest

We declare that we have no conflicts of interest.

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Table 1. Dietary composition and analyzed nutrient concentration of diets.

Item	Rolled-corn		Rolled-barley	
	Low-oil DDGS	Moderate-oil DDGS	Low-oil DDGS	Moderate-oil DDGS
<u>Composition, % of DM</u>				
Rolled corn	50	50	-	-
Barley	-	-	50	50
Low-oil DDGS	25	-	25	-
Moderate-oil DDGS	-	25	-	25
Corn Silage	20	20	20	20
Limestone	2	2	2	2
Urea	0.15	0.15	-	-
Salt	0.05	0.05	0.05	0.05
Vitamin premix ^a	0.01	0.01	0.01	0.01
Mineral premix ^b	0.05	0.05	0.05	0.05
Monensin ^c	0.02	0.02	0.02	0.02
Tylosin ^d	0.01	0.01	0.01	0.01
Fine-ground corn	2.46	2.46	2.61	2.61
Chromium oxide	0.25	0.25	0.25	0.25
<u>Feed Analysis, % of DM</u>				
OM	94.0	93.9	93.7	93.8
CP	14.8	15.3	15.3	15.4
NDF	26.2	29.6	28.5	29.7
ADF	9.5	10.1	11.0	11.6
EE	3.24	4.35	2.35	3.03
Ca	1.09	1.16	1.15	1.07
P	0.46	0.46	0.50	0.48
Starch	52.9	50.4	46.1	46.1

Note: From Rodenhuis et al. (2018); DDGS, dried corn distillers grains plus solubles; DM, dry matter; EE, ether extract; OM, organic matter; NDF, neutral detergent fiber; ADF, acid detergent fiber.

^aContained 48,510 kIU/kg vitamin A and 4,630.5 kIU/kg vitamin D.

^bContained 36.2 g/kg Ca, 25.6 g/kg Cu, 160 g/kg Zn, 65.0 g/kg Fe, 40.0 g/kg Mn, 1.050 mg/kg I, and 250 mg/kg Co.

^cContained 176.4 g monensin/kg premix.

^dContained 88.2 g tylosin/kg premix.

Table 2. Analyzed Nutrient Concentration of DDGS (DM basis)

	Low-Oil DDGS	Moderate-Oil DDGS
Analyses, % of DM		
CP	31.6	32.6
NDF	34.8	46.1
ADF	10.9	14.2
EE	4.5	7.9
Ca	0.04	0.04
P	1.04	0.93
Starch	8.87	3.57

Note: DDGS; dried corn distillers grains plus solubles; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; EE, ether extract.

Table 3. Ruminant NH₃ concentration, pH, and VFA concentration of steers consuming rolled corn- vs rolled barley-based diets with DDGS containing low- or high-oil concentration^a

Item	Rolled-corn		Rolled-barley		SEM	P - Values			
	Low-oil DDGS	Moderate-oil DDGS	Low-oil DDGS	Moderate-oil DDGS		Grain	DDGS	Grain × DDGS	Hour
NH ₃ , mM	13.8	11.1	10.9	10.4	1.48	0.26	0.33	0.33	<0.001
pH	5.83	5.90	5.92	5.93	0.3999	0.13	0.28	0.42	<0.001
Total VFA, mM	197	193	184	186	9.2	0.30	0.91	0.72	<0.001
VFA, mol/100 mol									
Acetic	31.1	33.0	33.2	30.6	1.74	0.92	0.83	0.21	0.68
Propionic	22.8	23.7	23.4	23.5	1.60	0.89	0.75	0.80	<0.001
Isobutyric	3.71	3.70	3.86	3.70	0.211	0.73	0.71	0.74	<0.001
Butyric	22.0	19.3	18.6	19.9	1.89	0.46	0.72	0.30	0.35
Isovaleric	11.2	12.3	9.58	11.5	0.728	0.12	0.05	0.57	<0.001
Valeric	9.21	7.97	11.4	10.8	1.057	0.03	0.39	0.76	0.01
Acetate:Propionate	1.49	1.48	1.55	1.40	0.147	0.95	0.60	0.63	<0.001

Note: DDGS, dried corn distillers grains plus solubles; VFA, volatile fatty acids.

^aData are presented as least square means per treatment ± SEM, n = 8; P ≥ 0.06 for treatment by hour interactions.

Table 4. Ruminal digestive enzyme activity of steers consuming rolled corn- vs rolled barley-based diets with with DDGS containing low- or high-oil concentration^a

Item	Rolled-Corn		Rolled-Barley		SEM	<i>P</i> - Value			
	Low-oil DDGS	Moderate-oil DDGS	Low-oil DDGS	Moderate-oil DDGS		Grain ×			
						Grain	DDGS	DDGS	Hour
α-Amylase, U/L ruminal fluid	132 ^a	131 ^a	144 ^a	106 ^b	13.5	0.45	0.02	0.03	0.59
Maltase, U/L ruminal fluid	334	258	280	222	28.0	0.01	<0.001	0.56	0.02
Trypsin, U/L ruminal fluid	275 ^a	218 ^b	207 ^b	211 ^b	14.4	0.002	0.02	0.01	0.006

Note: DDGS, dried corn distillers grains plus solubles; U, units (1 μmole product produced per min).

^aData are presented as least square means per treatment ± SEM, n = 8; *P* ≥ 0.31 for treatment by hour interactions .

Table 5. Gas production and in vitro CH₄ and CO₂ concentration of steers consuming rolled corn- vs rolled barley-based diets with DDGS containing low- or high-oil concentration^a

Item	Rolled-corn		Rolled-barley		SEM	P - Values		
	Low-oil DDGS	Moderate-oil DDGS	Low-oil DDGS	Moderate-oil DDGS		Grain	DDGS	Grain × DDGS
A, mL	188	116	191	121	52.4	0.87	0.17	0.97
b, hr ⁻¹	0.153	0.126	0.100	0.095	0.0282	0.13	0.56	0.67
c, hr	0.148	0.144	0.057	0.027	0.0484	0.03	0.72	0.78
d, hr ^{-1/2}	0.482	0.456	0.407	0.297	0.1374	0.39	0.61	0.75
Ruminal degradation rate (hr ⁻¹) at:								
1 hr	0.128	0.110	0.227	0.198	0.4253	0.03	0.57	0.89
12 hr	0.108	0.100	0.174	0.147	0.0304	0.06	0.56	0.76
24 hr	0.105	0.098	0.168	0.142	0.0293	0.07	0.56	0.74
CH ₄ , mL/L of gas	22.2	24.8	24.4	23.3	1.58	0.80	0.61	0.22
CO ₂ , mL/L of gas	59.4	55.8	57.1	54.5	2.16	0.41	0.17	0.84
CH ₄ :CO ₂	0.385	0.462	0.443	0.440	0.0333	0.57	0.25	0.22

Note: DDGS, dried corn distillers grains plus solubles; A, asymptote; b, fractional rate (hr⁻¹); c, lag time (hr); d, rate constant (hr^{-1/2}).

^aData are presented as least square means per treatment ± SEM, n = 8.