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Ruminant Nutrition

Effects of hempseed cake on ruminal fermentation parameters, nutrient digestibility, nutrient flow, and nitrogen balance in finishing steers

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Abstract

Five ruminally and duodenally cannulated red angus steers (n = 5; initial body weight [**BW**] = 542 kg, SD = 40 kg) were used in a three-period Youden square design consisting of three 21-d periods, three treatments, and five steers (one or two steers per treatment within each period) to evaluate the effect of feeding hempseed cake on ruminal fermentation parameters, organic matter (**OM**) intake, total tract nutrient digestion, and nitrogen (**N**) balance in steers fed finishing diets. The control (**CON**) diet contained 75% dry-rolled corn, 20% corn silage, and 5% supplement (DM basis). The dried corn distillers grains plus solubles (**DDGS**) and hempseed cake (**HEMP**) diets contained 55% dry-rolled corn, 20% corn silage, 20% dried corn distillers grains plus solubles or hempseed cake, and 5% supplement (DM basis). Total ruminal volatile fatty acid concentration was greater ($P < 0.01$) in steers fed the HEMP diet than in steers fed the DDGS or CON diets. Ruminal fluid pH was not influenced ($P = 0.93$) by treatment. Organic matter intake tended ($P = 0.07$) to be greater and OM total tract digestibility was less ($P = 0.03$) in steers fed the HEMP diet compared with steers fed the DDGS or CON diets. Ruminal true and total tract apparent N digestibility was greater ($P < 0.01$) in steers fed the HEMP diet than steers fed the DDGS or CON diets. Duodenal flow of essential, nonessential, and total amino acids was not influenced ($P \geq 0.37$) by dietary treatment, but the lack of response was likely because ruminally degradable protein (**RDP**) supply exceeded the RDP requirement. Steers fed the HEMP diet had greater ($P < 0.01$) N retention (g/d) than steers fed the DDGS diet, which was greater ($P < 0.01$) than steers fed the CON diet, suggesting that feeding hempseed cake improved utilization of N. Although inclusion of hempseed cake decreased total tract OM digestibility compared with dried corn distillers grains or corn, improvements in N utilization suggest that hempseed cake could be a useful alternative feed ingredient for finishing cattle diets.

Lay Summary

This experiment evaluated the effects of dietary inclusion of hempseed cake or dried corn distillers grains plus solubles on ruminal fermentation parameters, organic matter (**OM**) intake, total tract nutrient digestion, and nitrogen (N) balance in steers fed finishing diets. Steers were assigned to one of three dietary treatments (no byproduct [**CON**], 20% dried corn distillers grains plus solubles [**DDGS**], or 20% hempseed cake [**HEMP**]; dry matter basis). Hempseed cake had greater acid detergent fiber concentrations, which resulted in greater acid detergent fiber flow to the small intestine and reduced total tract organic matter digestibility in steers fed the HEMP diet than in steers fed the DDGS or CON diets. Steers fed the HEMP diet had greater ruminal and total tract N digestibility, and greater ruminal ammonia concentrations than steers fed DDGS or CON diets, suggesting that the crude protein in hempseed cake is degraded to a greater extent in the rumen and total tract. Although inclusion of hempseed cake decreased total tract OM digestibility compared with dried corn distillers grains or no byproduct, the observed greater ruminal and total tract N digestibility suggest that it could be a useful alternative feed ingredient for finishing cattle diets.

Key words: digestion, finishing cattle, hempseed cake, nitrogen balance, ruminal fermentation, site of digestion

Abbreviations: AA, amino acids; ADF, acid detergent fiber; BW, body weight; CP, crude protein; CON, diet containing no byproduct inclusion; DDGS, diet containing dried corn distillers grains plus solubles; DM, dry matter; DMI, dry matter intake; EAA, essential amino acids; HEMP, diet containing hempseed cake; N, nitrogen; NDF, neutral detergent fiber; NEAA, nonessential amino acids; OM, organic matter; RDP, ruminally degradable protein; VFA, volatile fatty acids

Introduction

There has been renewed interest in industrial hemp production after its removal from the list of US Drug Enforcement Agency Schedule 1 drugs as a result of the 2018 Agricultural Improvement Act (USDA, Agriculture Marketing Service, 2021). Processing of the hempseed for oil extraction has increased with the rise in demand for hemp oil for human use (Mark et al., 2020). The byproduct of hempseed oil extraction is hempseed cake (or meal), which is high in neutral detergent fiber (**NDF**), acid detergent fiber (**ADF**), and crude protein (**CP**; 50%, 34%, and 35% respectively). However, there are limited markets for the byproduct because hemp and hemp byproducts cannot be fed to livestock or pets without FDA approval through the Association of American Feed Control Officials (Kleinhenz et al., 2020).

It has been shown that feeding hempseed cake at 20% of the diet dry matter (**DM**) resulted in decreased average daily gain and gain:feed in heifers fed finishing diets compared

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with heifers fed dried corn distillers grains plus solubles (Winders et al., 2022). Corn distillers grains plus solubles is a commonly used byproduct fed in finishing diets in the United States (Samuelson et al., 2016) and has a similar nutrient composition to hempseed cake (CP, NDF, ether extract; Table 1) except that hempseed cake has a greater concentration of ADF. Information is needed on the digestibility and nutrient utilization of diets containing hempseed cake to further explore the potential use of hempseed cake as a feed ingredient in finishing diets. The objective of this experiment was to determine the influence of feeding a diet containing hempseed cake in comparison to diets containing dried corn distillers grains plus solubles or a control diet containing no byproduct on organic matter (**OM**) intake, ruminal fermentation parameters, nutrient digestibility, nutrient flow to the small intestine, and nitrogen (**N**) balance when fed to finishing steers.

Materials and Methods

All animal care and management practices were approved by the North Dakota State University Institutional Animal Care and Use Committee.

Animals, experimental design, and dietary treatments

Five ruminally and duodenally cannulated red angus steers (n = 5; initial body weight [**BW**] = 542 kg, SD = 40 kg) were used in a three-period Youden square design consisting of three periods, three treatments, and five steers assigned randomly to one of three treatment sequences (one or two steers per period per treatment) to evaluate the effect of hempseed cake on OM intake, total tract nutrient digestion, N balance, and ruminal fermentation parameters. Six steers were initially assigned randomly to one of three treatment sequences, but one steer was removed because of issues adapting to the collection stanchions. The control (**CON**) treatment contained 75% dry-rolled corn, 20% corn silage, and 5% supplement (DM basis). The dried corn distillers grains plus solubles treatment (**DDGS**) contained 55% dry-rolled corn, 20% corn silage, 20% dried corn distillers grains plus solubles, and 5% supplement (DM basis). The hempseed cake treatment (**HEMP**) contained the same ingredients as the DDGS treatment except hempseed cake replaced DDGS (DM basis; Tables 1 and 2). The 20% inclusion level for dried corn distillers grains plus solubles and hempseed cake was selected as this is a common inclusion level for similar byproducts feeds used in practice (Samuelson et al., 2016). Diets were formulated to meet or exceed ruminally degradable and metabolizable protein, mineral, and vitamin requirements (NASEM, 2016). Supplement was formulated to provide 40 mg/kg monensin (Rumensin, Elanco Animal Health, Greenfield, IN) and 1% urea (DM basis) in the complete diet as well as minerals and vitamins.

Before the beginning of the experiment, steers were adapted to a high-concentrate diet over a 16-d period. For each 21-d experimental period, steers were individually housed in slatted floor pens for 13 d. Steers were then moved to 1.1 × 2.2 m individual stanchions for sample collection for the remaining 8 d. Diet transitions were done for 7 d at the beginning of each period by offering a blend of the diet from the previous period and the diet from the following period (75:25 on day 1, 50:50 on days 2 to 4, and 25:75 on days 5 to 7). Diets were mixed twice a week in a stationary ribbon mixer (model HD-5, Davis Precision Horizontal Batch Mixer; H.C. Davis Sons Manufacturing Co., Inc., Bonner Springs, KS) and stored in 200 L barrels in a cold room (4 °C). Chromic oxide (Hall Technologies, St. Louis, MO) was used as an external marker and was included at 0.25% of diet DM to determine nutrient flow. Dietary treatments (fed once daily) and water were offered for ad libitum intake, feed refusals were weighed back daily, and adjustments for feed offered were made on a DM basis: if feed refusal was less than 0.45 kg (feed refusal weights were taken on an as-fed basis) feed offered was increased by 0.45 kg DM, if feed refusal was between 0.45 and 1.36 kg, feed offered was held the same as the previous day, and if feed refusal was greater than 1.36 kg, feed offered was reduced by 0.45 kg. Feed, feed refusals, ruminal pH, fecal, and urine collections (days 13 to 20), ruminal fluid and duodenal fluid collections (days 15 to 17), ruminal contents for bacterial isolation (day 20), and endotoxin challenge using lipopolysaccharide (LPS; day 21; data not shown) occurred within each period.

Table 1. Composition of diets containing no byproduct (CON), dried corn distillers grains plus solubles (DDGS), or hempseed cake (HEMP)

Ingredient, % of diet DM	Treatments[1]		
	CON	DDGS	HEMP
Corn grain	75	55	55
Dried corn distillers grains plus solubles	0	20	0
Hempseed cake	0	0	20
Corn silage	20	20	20
Supplement	5	5	5
Fine ground corn	1.57	1.57	1.57
Limestone	2	2	2
Salt	0.1	0.1	0.1
Urea	1	1	1
Chromic oxide	0.25	0.25	0.25
Vitamin premix[2]	0.01	0.01	0.01
Trace mineral premix[3]	0.05	0.05	0.05
Rumensin-90[4]	0.02	0.02	0.02

[1]Treatments consisted of 0% byproduct (CON), 20% dried corn distillers grains plus solubles (DDGS), or 20% Hempseed cake (HEMP; DM basis).
[2]Contained 48,510 kIU/kg vitamin A and 4,630 kIU/kg vitamin D.
[3]Contained 3.62% calcium (Ca), 2.56% copper (Cu), 16% zinc (Zn), 6.5% iron (Fe), 4% manganese (Mn), 1,050 mg/kg iodine (I) and 250 mg/kg cobalt (Co).
[4]Formulated to supply monensin (Rumensin-90, Elanco Animal Health, Greenfield, IN) at 40 mg/kg.

Sample collection

Diet samples (50 g) were collected at 0800 daily during and composited within period. Feed refusals were weighed at 0830 and sampled daily (10% of weight). Feed and feed refusal composites were stored at –20 °C until later analysis. Steers were fitted with fecal collection bags during each collection period. A harness was used for fecal bag attachment. Fecal bags were removed twice daily (0700 and 1800), feces were mixed by hand, and composited (5% of weight, as-is basis) within steer and period, and stored at –20 °C until later analysis. Urine was collected using a urine funnel and vacuum pump. Urine funnels were attached with adjustable belting to allow for steer movement while keeping the funnel in place.

Table 2. Nutrient composition of diets containing no byproduct (CON), dried corn distillers grains plus solubles (DDGS), or hempseed cake (HEMP), and of dried corn distillers grains plus solubles and hempseed cake.

Item	Treatments[1]			Byproducts[2]	
	CON	DDGS	HEMP	Dried corn distillers grains plus solubles	Hempseed cake
Dry matter, %	69.7	69.0	71.2	92.1	94.2
Nutrient analysis, % of DM[3]					
Organic matter	94.7	93.5	94.2	93.4	93.9
Starch	54.3	45.4	39.1	—	—
Crude protein	10.3	14.9	17.7	29.8	35.0
Ether extract	2.89	3.59	4.36	9.84	9.45
NDF	22.8	27.3	32.9	47.3	49.5
ADF	9.3	10.8	19.2	14.4	33.8
Sulfur	0.12	0.22	0.19	—	—
Calcium	0.54	0.59	0.44	0.26	0.11
Phosphorus	0.34	0.47	0.58	1.01	1.31
Calcium:phosphorus	1.62	1.24	0.76	0.25	0.08
Gross energy, kcal/g	4,212	4,356	4,437	—	—
Amino acids, % of DM					
Arginine	0.32	0.47	1.28	—	—
Histidine	0.19	0.29	0.37	—	—
Isoleucine	0.28	0.44	0.58	—	—
Leucine	0.82	1.29	1.16	—	—
Lysine	0.27	0.37	0.53	—	—
Methionine	0.17	0.23	0.32	—	—
Phenylalanine	0.36	0.54	0.67	—	—
Threonine	0.29	0.44	0.52	—	—
Tryptophan	0.06	0.09	0.14	—	—
Valine	0.38	0.58	0.74	—	—
Alanine	0.59	0.85	0.80	—	—
Aspartic acid	0.51	0.78	1.30	—	—
Cysteine	0.17	0.25	0.25	—	—
Glutamic acid	1.26	1.94	2.41	—	—
Glycine	0.32	0.46	0.63	—	—
Proline	0.60	0.94	0.78	—	—
Serine	0.31	0.47	0.61	—	—
Tyrosine	0.21	0.35	0.42	—	—

[1]Treatments consisted of 0% byproduct (CON), 20% dried corn distillers grains plus solubles (DDGS), or 20% Hempseed cake (HEMP; DM basis).
[2]Byproduct nutrient analyses for the individual byproducts (DDGS and HEMP).
[3]Average of diet samples taken each period.

Tubing ran from the funnel spout to a series of two 20 L containers (Nalgene polypropylene heavy-duty vacuum carboy, Thermo Scientific, Waltham, MA) that were connected to a vacuum pump (Gast DOA-P704-AA High-Capacity Vacuum Pump, Cole Parmer, Vernon Hills, Chicago, IL) that pulled urine from the funnel to the carboys. Carboys contained 250 mL of 6 *N* HCL to maintain urine pH < 3. Every other day or whenever the containers were full (whatever came first), urine was weighed, composited (2% of weight, as-is basis), composited within steer and period, and stored at –20 °C until later analysis.

Reticuloruminal pH was monitored throughout the experiment using indwelling data transmission boluses that were inserted into the reticulum via ruminal cannula at the beginning of the experiment (SmaXtec Premium Bolus; Animal Care GmbH, Graz, Austria). Calibration of pH probes was done before placing in each steer. Reticulorumen pH data were collected every 10 minutes and averaged and analyzed by hour, and for daily minimum, average, and maximum pH readings. Ruminoreticulum pH data from the 7-day collection period were used for analyses.

Ruminal fluid and duodenal digesta (approximately 200 mL) were collected into whirl-pak bags (532 mL; Nasco, Fort Atkinson, WI) on days 15 to 17 of each period. Ruminal fluid was collected using a metal strainer connected to a vacuum pump (Gast DOA-P704-AA High-Capacity Vacuum Pump, Cole Parmer) from various spots below the fiber mat in the rumen. Samples were taken at 0000, 0600, 1200, and 1800 on day 15; 0400, 1000, 1600, and 2200 on day 16; and 0200, 0800, 1400, and 2000 on day 17 to account for every other hour across a 24-hr period. Ruminal fluid and duodenal digesta samples were stored at –20 °C until the end

of the experiment. Duodenal fluid was thawed, composited (100 mL from each sample), freeze dried (Virtis Co., Gardiner, NY), and subsampled for analysis.

On day 20 of each period, a 4-kg sample of ruminal contents was collected for bacterial isolation from several locations within the rumen of each steer to ensure both the liquid and fiber phases were represented in the sample. The contents were then mixed with 2 L of a solution containing 3.7% formaldehyde and 0.9% NaCl and stored at −20 °C until the end of the experiment. Contents were thawed and blended using a commercial, heavy-duty blender (model 37BL19CB6, Waring Products division, New Hartford, CT), strained through four layers of cheese cloth, and freeze died prior to chemical analysis.

Sample analyses

Feed, feed refusals, and fecal samples were dried for 48 h at 60°C in a forced air oven (Grieve SB-350, The Grieve Corporation Round Lake, IL), ground to pass through a 1-mm screen (Wiley mill, model No. 3; Thomas Scientific, Swedesboro, NJ), while duodenal samples were freeze dried.

Bacterial isolation was accomplished by centrifuging samples in 250-mL bottles at 500 × g for 20 min to remove protozoa and feed particles. The supernatant was removed and centrifuged at 30,000 × g for an additional 20 min to pellet bacteria, which was frozen and lyophilized before being analyzed.

Feed, feed refusals, fecal, duodenal, and bacterial samples were analyzed for DM and ash using standard procedures (AOAC, 1990). Feed, feed refusals, fecal, and duodenal samples were analyzed for neutral detergent fiber (NDF) and acid detergent fiber (ADF; Robertson and Van Soest, 1981) using an Ankom fiber analyzer (Ankom technology Corp, Fairport, NY). Purine concentrations were measured in the duodenal digesta and bacterial samples using the UV/VIS spectrophotometry method of Zinn and Owens (1986) to determine duodenal bacterial flow. Feed, feed refusals, duodenal, and fecal samples were analyzed for starch concentration (Hall, 2000). Feed, feed refusals, duodenal, bacterial, fecal, and urine samples were analyzed for nitrogen (N) concentration using the Kjeldahl method (AOAC, 1990). Total calcium and phosphorus concentrations were measured in the feed (AOAC, 1990). Chromium was measured in the feed, fecal, ruminal and duodenal samples using the UV/VIS spectrophotometry method of Fenton and Fenton (1979).

Feed, bacteria, and duodenal samples were analyzed for individual amino acid (**AA**) concentrations using high-performance liquid chromatography at the University of Missouri Agricultural Experiment Station Chemistry Laboratory (AOAC, 1990). Total AA, total essential AA (**EAA**), and total nonessential AA (**NEAA**) were calculated by summing the AA concentrations within each category. EAA consisted of histidine, arginine, threonine, lysine, methionine, valine, isoleucine, leucine, phenylalanine, and tryptophan. NEAA consisted of glutamic acid, glycine, aspartic acid, serine, alanine, cysteine, proline, and tyrosine. Total AA consisted of all EAA and NEAA listed previously.

Ruminal fluid samples were centrifuged at 2,000 × g for 20 min, and the liquid portion was filtered through a 0.45 µm filter and analyzed for ammonia using the UV/VIS spectrophotometry method (Broderick and Kang, 1980). For ruminal volatile fatty acid (**VFA**) analysis, 5 mL of rumen fluid was acidified with 1 mL of meta-phosphoric acid, centrifuged at 15,000 × g, and analyzed using gas chromatography (Hewlett Packard 5890A Series I GC, Wilmington, DE) using a capillary column (Nukol, Supelco, Bellefonte, PA) and 2-ethyl butyric acid as the internal standard.

Calculations

Nutrient total tract apparent digestibility was calculated by subtracting fecal concentration of the nutrient from the amount of nutrient consumed, and dividing by nutrient intake. Total nutrient flow to the small intestine was calculated based on the ratio of nutrients to chromium in the duodenal digesta as compared with intake (Merchen, 1988). Total tract Cr recovery ranged from 76% to 85% and was not influence by treatment. Purines were used as a bacterial marker to calculate bacterial organic matter (OM) and N leaving the abomasum. Ruminal OM disappearance was calculated as OM intake minus the difference between bacterial OM and total OM reaching the duodenum. Feed N escape to the small intestine was calculated by subtracting bacterial N from total N. Duodenal AA flow (g/d) from the feed was calculated by subtracting bacterial AA flow from total AA flow. Bacterial AA flow was calculated using AA concentrations and the ratio of DM to chromium in the duodenal digesta. Bacterial efficiency was calculated by dividing g of bacterial N by kg of OM truly fermented. Nitrogen retention was calculated by subtracting urinary and fecal N from N intake.

Statistical analysis

Nutrient digestibility and pH range data were analyzed using the MIXED procedure in SAS 9.4 (SAS institute Inc., Cary, NC) as a 3 × 5 Youden square, and all five steers received each treatment. The model included period and treatment as fixed effects and steer as a random effect. One experimental unit was removed from the AA flow data because it was an outlier, with AA ruminal bypass percent exceeding 100% for all AA. Volatile fatty acid, ammonia, and average pH data were analyzed as repeated measures using the MIXED procedure of SAS, with hour as the repeated variable. Four covariance structures (autoregressive 1, compound symmetry, Toeplitz, and unstructured) were compared for each repeated measure analysis, and compound symmetry was selected based on having the lowest fit statistics. Steer within period was considered the experimental unit. Treatment and hour (for VFA, ammonia, and average pH) were included in the model as fixed effects and treatment by day interactions were tested. Pairwise comparisons (least significant difference approach) were used to analyze differences among treatment means when the treatment P was significant. Linear and quadratic effects of hour were tested using contrast coefficients that were generated using PROC IML procedure of SAS for all repeated measures analyses. Treatment differences were considered different when $P \leq 0.05$, and tending to be different when $P > 0.05$ and $P \leq 0.10$.

Results

Ruminal fermentation parameters

A treatment by hour interaction ($P = 0.01$) was observed for ruminal ammonia concentration (Table 3) and occurred primarily because of differences in the magnitude of difference between treatments more so than re-ranking of treatments. Steers fed the HEMP diet had greater ($P \leq 0.04$) ruminal ammonia concentrations from samples from all hours

Table 3. Ammonia (NH_3), volatile fatty acid (VFA), and pH means of steers fed diets containing no byproduct (CON), dried corn distillers grains plus solubles (DDGS), or hempseed cake (HEMP)

Item	Treatment[1]			SEM[2]	P		
	CON	DDGS	HEMP		Treatment	Hour	Treatment × hour
NH_3, mmol	6.3[a]	12.8[b]	19.8[c]	1.0	< 0.01	< 0.01	0.01
Total VFA, mmol	113[a]	120[a]	130[b]	3	< 0.01	0.53	0.96
VFA, mol/100 mol							
Acetic	48.9	51.4	52.8	1.78	0.32	0.03	< 0.01
Propionic	19.4	19.3	17.7	1.72	0.74	0.79	0.26
Butyric	21.3	19.0	19.5	1.21	0.41	< 0.01	< 0.01
Isobutyric	2.01[ab]	1.86[a]	2.11[b]	0.07	0.05	< 0.01	< 0.01
Valeric	3.24	3.40	3.67	0.54	0.85	< 0.01	0.92
Isovaleric	5.23[a]	4.99[a]	4.19[b]	0.27	0.03	< 0.01	0.78
Acetic:propionic	2.90	2.86	3.03	0.28	0.91	0.53	0.16
pH							
Average	5.96	5.96	5.99	0.13	0.93	< 0.01	0.99
Minimum	5.49	5.50	5.60	0.12	0.48	-	-
Maximum	6.50	6.38	6.47	0.13	0.38	-	-

[1]Treatments consisted of 0% byproduct (CON), 20% dried corn distillers grains plus solubles (DDGS) or 20% hempseed cake (HEMP; DM basis). Treatment means sharing the same superscript do not differ ($P \leq 0.05$).

compared with steers fed the CON diet and at hours 3, 5, 9, 11, 13, 17, 19, and 23 compared with steers fed the DDGS diet (data not shown). Total ruminal VFA concentration was greater ($P < 0.01$) in steers fed the HEMP diet than in steers fed the DDGS or CON diets. A treatment by hour interaction ($P < 0.01$) was observed for acetic acid, butyric acid, and isobutyric acid because the magnitude of change between treatments across hour differed (data not shown). Isovaleric acid was greater ($P = 0.03$) in steers fed the DDGS and CON diets than in steers fed the HEMP diet. All other VFA and the acetic acid to propionic acid ratio were not influenced by dietary treatment. Average, minimum, and maximum pH were not influenced by treatment.

Nutrient digestibility

Organic matter intake tended to be greater ($P = 0.07$) in steers fed the HEMP diet than in steers fed the DDGS or CON diets (Table 4). Duodenal flow of feed, bacterial, and total OM was not influenced ($P \geq 0.11$) by dietary treatment. Ruminal OM disappearance was greater ($P = 0.05$) in steers fed the HEMP diet than in steers fed the DDGS diet, with steers fed the CON diet intermediate and not different from either diet. Fecal excretion of OM was greater ($P < 0.01$) in steers fed the HEMP diet than in steers fed the DDGS or CON diets. Apparent ruminal OM digestibility was greater ($P < 0.01$) in steers fed the HEMP or CON diets than in steers fed the DDGS diet. True ruminal OM digestibility was not influenced ($P = 0.19$) by dietary treatments. Intestinal apparent OM digestibility (as a percent of OM intake) was greater ($P = 0.01$) in steers fed the DDGS diet than in steers fed the CON diet, which was greater ($P < 0.01$) than steers fed the HEMP diet. Intestinal apparent OM digestibility (as a percent of OM entering the duodenum) was greater ($P < 0.01$) in steers fed the DDGS or CON diets than in steers fed the HEMP diet. Total tract apparent OM digestibility was greater ($P = 0.02$) in steers fed the CON or DDGS diets than in steers fed the HEMP diet.

Starch intake, duodenal flow, fecal output, apparent ruminal digestibility, apparent intestinal digestibility (as a percent of starch intake and as a percent of starch entering the duodenum), and total tract apparent digestibility was not influenced by dietary treatment (Table 5). Intake of NDF was greater ($P < 0.01$) in steers fed the HEMP than in steers fed the DDGS diet, which was greater ($P \leq 0.02$) than in steers fed the CON diet, and duodenal flow of NDF was not influenced by dietary treatment. Duodenal flow of NDF was not influenced by dietary treatment. Fecal NDF excretion was greater ($P < 0.01$) in steers fed the HEMP diet than in steers fed the DDGS or CON treatments. Apparent ruminal NDF digestibility was greater ($P = 0.04$) in steers fed the HEMP diet than in steers fed the CON diet, with steers fed the DDGS diet intermediate and not different from either diet. Intestinal apparent NDF digestibility (as a percent of NDF intake, and as a percent of NDF entering the duodenum) was greater ($P < 0.01$) in steers fed the DDGS or CON diets than in steers fed the HEMP diet, and NDF total tract apparent digestibility was not influenced by dietary treatment. Intake, duodenal flow, fecal output, and apparent ruminal digestion of ADF (as a percent of ADF intake) was greater ($P \leq 0.01$) in steers fed the HEMP diet than in steers fed the DDGS or CON diets. Intestinal apparent ADF digestibility (as a percent of ADF intake, and as a percent of ADF entering the duodenum) was greater ($P < 0.01$) in steers fed either the DDGS or CON diets than in steers fed the HEMP diet. Total tract apparent digestibility of ADF was not influenced by dietary treatment.

Nitrogen intake was greater ($P < 0.01$) in steers fed the HEMP diet than in steers fed the DDGS diet, which was greater ($P < 0.01$) than in steers fed the CON diet (Table 6). Duodenal flow of total, feed, and bacterial N was not influenced by dietary treatment. Fecal N excretion (g/d) was greater ($P = 0.01$) in steers fed the HEMP treatment than in steers fed the CON treatment, with steers fed the DDGS diet intermediate and not different from either diet. Urinary and total N excretion (sum of fecal and urinary N; g/d) was greater

Table 4. Organic matter (OM) intake and site of digestion in steers fed diets containing no byproduct (CON), dried corn distillers grains plus solubles (DDGS), or hempseed cake (HEMP)

Item	Treatments[1]			SEM	*P*
	CON	DDGS	HEMP		
OM intake, kg/d	8.46	8.69	10.71	0.78	0.07
Duodenal flow, kg/d					
Feed	2.59	2.96	2.97	0.37	0.75
Bacterial	1.32	1.51	1.59	0.14	0.11
Total	3.77	4.45	4.49	0.45	0.33
Fecal excretion, kg/d	1.69[a]	1.91[a]	2.80[b]	0.23	<0.01
Digestibility					
Apparent ruminal, % of intake	55.3[a]	49.2[b]	58.2[a]	1.7	< 0.01
True ruminal, % of intake	70.6	67.2	73.1	2.1	0.19
Intestinal, % of intake	23.9[a]	28.9[b]	15.9[c]	1.3	<0.01
Intestinal, % of entering duodenum	52.8[a]	56.7[a]	38.0[b]	2.4	<0.01
Total tract, % of intake	80.1[a]	78.2[a]	74.0[b]	1.5	0.02

[1]Treatments consisted of 0% byproduct (CON), 20% dried corn distillers grains plus solubles (DDGS), or 20% hempseed cake (HEMP; DM basis). Treatment means sharing the same superscript do not differ ($P \leq 0.05$). Treatment means sharing the same superscript do not differ ($P \leq 0.05$).

Table 5. Starch, neutral detergent fiber (NDF) and acid detergent fiber (ADF) intake and digestibility of steers fed diets containing no byproduct (CON), dried corn distillers grains plus solubles (DDGS), or hempseed cake (HEMP)

Item	Treatments[1]			SEM	*P*
	CON	DDGS	HEMP		
Starch					
Intake, kg/d	4.80	4.28	4.57	0.43	0.61
Duodenal flow, kg/d	0.44	0.47	0.59	0.08	0.40
Fecal excretion, kg/d	0.21	0.21	0.31	0.05	0.21
Apparent digestibility					
Ruminal, % of intake	91.0	89.4	87.1	1.2	0.12
Intestinal, % of intake	4.00	5.55	6.33	1.1	0.24
Intestinal, % of entering duodenum	38.8	51.7	49.5	9.7	0.36
Total tract, %	95.7	95.0	93.3	1.0	0.18
NDF					
Intake, kg/d	1.95[a]	2.53[b]	3.64[c]	0.19	< 0.01
Duodenal flow, kg/d	1.30	1.55	1.75	0.23	0.11
Fecal excretion, kg/d	0.85[a]	1.03[a]	1.70[b]	0.12	< 0.01
Apparent digestibility					
Ruminal, % of intake	28.2[a]	37.9[ab]	51.4[b]	6.8	0.04
Intestinal, % of intake	26.2[a]	21.3[a]	2.1[b]	4.0	< 0.01
Intestinal, % of entering duodenum	29.9[a]	33.1[a]	−2.0[b]	5.1	< 0.01
Total tract, %	56.7	59.4	53.3	2.6	0.12
ADF					
Intake, kg/d	0.80[a]	1.00[a]	2.09[b]	0.09	< 0.01
Duodenal flow	0.56[a]	0.68[a]	0.91[b]	0.07	0.01
Fecal excretion, kg/d	0.46[a]	0.52[a]	1.12[b]	0.06	< 0.01
Apparent digestibility					
Ruminal, % of intake	21.8[a]	30.3[a]	56.0[b]	4.7	< 0.01
Intestinal, % of intake	15.8[a]	17.6[a]	−8.9[b]	3.6	< 0.01
Intestinal, % of entering duodenum	16.1[a]	24.0[a]	−27.4[b]	7.0	< 0.01
Total tract, %	42.8	48.6	46.6	3.6	0.38

[1]Treatments consisted of 0% byproduct (CON), 20% dried corn distillers grains plus solubles (DDGS) or 20% hempseed cake (HEMP; DM basis). Treatment means sharing the same superscript do not differ ($P \leq 0.05$). Treatment means sharing the same superscript do not differ ($P \leq 0.05$).

($P < 0.01$) in steers fed the HEMP diet than in steers fed the DDGS diet, which was greater ($P \leq 0.03$) than in steers fed the CON diet. Apparent ruminal N digestibility was greater ($P < 0.01$) in steers fed the HEMP diet than in steers fed the DDGS diet, which was greater ($P = 0.02$) than in steers fed the CON diet. True ruminal N digestibility was greater ($P < 0.01$) in steers fed the HEMP diet than in steers fed the DDGS or CON diets. Intestinal apparent N digestibility (as a percent of N intake) was greater ($P < 0.01$) in steers fed the CON diet than in steers fed the DDGS diet, which was greater ($P < 0.01$) than in steers fed the HEMP diet. Intestinal apparent N digestibility (as a percent of N entering the duodenum) was greater ($P < 0.01$) in steers fed the DDGS or CON diets than in steers fed the HEMP diet. Bacterial efficiency tended to be greater ($P = 0.06$) in steers fed the DDGS diet compared with steers fed the HEMP or CON diets. Total tract apparent N digestion (g/d and as a percent of N intake) was greater ($P \leq 0.02$) in steers fed the HEMP diet than in steers fed the DDGS diet, which was greater ($P \leq 0.02$) than in steers fed the CON diet. Retention of N (g/d) was greater ($P < 0.01$) in steers fed the HEMP diet than in steers fed the DDGS diet, which was greater ($P = 0.02$) than in steers fed the CON diet, and retention of N (as a percent of N intake) was greater ($P = 0.04$) in steers fed the HEMP diet than in steers fed the CON treatment, with steers fed the DDGS treatment intermediate and not different from either diet.

AA intake and duodenal flow

Total, essential, and nonessential amino acid intake was greater ($P < 0.01$) in steers fed the HEMP diet than in steers fed the DDGS diet, which was greater ($P < 0.01$) than in steers fed the CON diet (Table 7). Furthermore, histidine, isoleucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine, aspartic acid, glutamic acid, glycine, serine, and tyrosine intakes were greater ($P < 0.01$) in steers fed the HEMP diet than in steers fed the DDGS diet, which was greater ($P \leq$

Table 6. N intake, digestibility, bacterial efficiency, and N balance of steers fed diets containing no byproduct (CON), dried corn distillers grains plus solubles (DDGS), or hempseed cake (HEMP).

Item	Treatments[1]			SEM	*P*
	CON	DDGS	HEMP		
N intake, g/d	151[a]	217[b]	313[c]	17	<0.01
Duodenal flow, g/d					
Feed	95	130	108	12	0.18
Bacterial	108	121	125	13	0.34
Total	202	251	232	21	0.21
Excretion, g/d					
Feces	44.4[a]	56.0[ab]	68.2[b]	5	0.01
Urine	81.7[a]	111.8[b]	154.9[c]	10.1	<0.01
Total	126[a]	168[b]	223[c]	14	<0.01
Digestibility					
Apparent ruminal, % of intake	-34.9[a]	-16.0[b]	26.9[c]	0.06	<0.01
True ruminal, % of intake	38.7[a]	40.3[a]	65.9[b]	0.05	<0.01
Intestinal, % of N intake	104.5[a]	90.2[b]	51.6[c]	5.4	<0.01
Intestinal, % of N entering duodenum	77.4[a]	77.6[a]	70.8[b]	1.3	<0.01
Total tract, % of N intake	70.2[a]	74.3[b]	78.5[c]	1.2	<0.01
Bacterial efficiency, g bacterial N/kg of OM truly fermented	9.5	12.4	8.7	1.3	0.06
Retention					
g/d	25.1[a]	49.4[b]	90.2[c]	7.7	<0.01
% of N intake	14.4[a]	22.1[ab]	29.4[b]	4.3	0.04

[1]Treatments consisted of 0% byproduct (CON), 20% dried corn distillers grains plus solubles (DDGS) or 20% hempseed cake (HEMP; DM basis). Treatment means sharing the same superscript do not differ ($P \leq 0.05$). Treatment means sharing the same superscript do not differ ($P \leq 0.05$).

0.02) than in steers fed the CON diet. Leucine, alanine, cysteine, and proline intake was greater ($P \leq 0.02$) in steers fed the DDGS or HEMP diets than in steers fed the CON diets and not different ($P \geq 0.13$) between DDGS and HEMP diets, and arginine intake was greater ($P < 0.01$) in steers fed the HEMP diet than in steers fed the DDGS or CON diets. Duodenal total flow of essential, nonessential, and total amino acids was not influenced ($P \geq 0.37$) by treatment. Duodenal total flow of all AA was not influenced ($P \geq 0.11$) by treatment except for proline which tended ($P = 0.08$) to be greater in steers fed DDGS or Hemp diets compared with steers fed the CON diet.

Duodenal flow of total and nonessential amino acids from feed tended to be greater ($P \leq 0.09$) in steers fed the DDGS diet than in the HEMP or CON diets and duodenal flow of EAA from feed was not influenced ($P \geq 0.11$) by treatment (Supplementary Table S1). Duodenal flow of histidine, leucine, alanine, cysteine, glutamic acid, and proline flow (g/d) from feed was greater ($P \leq 0.05$) in steers fed the DDGS diet than in steers fed the HEMP or CON diets. Ruminal bypass percent of total AA for steers fed CON and DDGS diets was 66.4% and 68.9%, respectively, which was greater ($P < 0.01$) than the ruminal AA bypass percent in steers fed the HEMP diet (36.8%). In general, ruminal bypass percent for individual AA followed a similar trend as with total AA.

Discussion

Because of increased interest in feeding hemp products to cattle, information is needed on the effects of hempseed cake on ruminal fermentation parameters, digestibility and flow of nutrients, and N balance in beef cattle fed finishing diets. We observed that steers fed the HEMP diet had greater ruminal VFA and ammonia concentrations, tended to have increased OM intake and decreased OM total tract digestibility, and greater ruminal and total tract N digestibility and retention.

The observed increase in ruminal ammonia and VFA concentrations in steers fed the HEMP diet suggests that greater ruminal N degradation and fermentation occurred (Russell et al., 1992; Bach et al., 2005). The greater ruminal ammonia concentration was likely because the HEMP diet contained greater amounts of CP and because N disappearance from the rumen was greater in steers fed the HEMP diet. The increase in total VFA concentration observed in steers fed the HEMP diet is consistent with the increase in the observed apparent ruminal OM disappearance. The lack of effect of dietary treatment on ruminal pH (average, minimum, and maximum) is somewhat surprising considering the dietary differences in carbohydrate composition (starch, NDF, ADF, etc.) and ruminal VFA concentration, particularly when comparing the HEMP diet to the CON diet. However, starch intake was not influenced by treatment and steers fed the HEMP diet had a tendency for greater intake and ruminal disappearance of OM, which likely contributed to the lack of response in ruminal pH to dietary treatment.

The observed tendency for greater OM intake in steers fed the HEMP treatment suggests hempseed cake inclusion did not limit feed intake and that perhaps OM intake may increase to compensate for lower OM total tract apparent digestibility of OM (Krehbiel et al., 2006), which is further supported by dietary energy differences reported previously for hempseed cake when included in finishing heifer diets (Winders et al.,

Table 7. Amino acid (AA) intake and total (feed + bacterial) AA flow of steers fed diets containing no byproduct (CON), dried corn distillers grains plus solubles (DDGS), or hempseed cake (HEMP)

Item, g/d	Intake			SEM	*P*	Total duodenal flow			SEM	*P*
	CON	DDGS	HEMP			CON	DDGS	HEMP		
Essential AA										
Arginine	27.7[a]	44.2[a]	145.0[b]	7.4	<0.01	46.6	54.6	57.5	6.1	0.40
Histidine	16.8[a]	27.3[b]	41.5[c]	3.5	<0.01	23.4	27.8	23.4	2.7	0.26
Isoleucine	25.3[a]	41.0[b]	65.6[c]	5.1	<0.01	56.1	64.0	59.4	7.0	0.62
Leucine	75[a]	119[b]	131[b]	15	<0.01	102	128	97	14	0.11
Lysine	23.2[a]	34.5[b]	59.9[c]	4.2	<0.01	82.2	84.7	84.9	8.1	0.96
Methionine	14.6[a]	21.7[b]	35.8[c]	2.7	<0.01	19.9	22.8	21.0	2.7	0.63
Phenylalanine	32.2[a]	50.6[b]	75.8[c]	6.8	<0.01	54.2	64.9	56.1	7.0	0.36
Threonine	25.5[a]	40.6[b]	58.4[c]	5.0	<0.01	53.1	60.7	57.1	6.2	0.59
Tryptophan	5.28[a]	8.44[b]	15.92[c]	1.03	<0.01	11.7	13.1	12.6	1.4	0.72
Valine	33.7[a]	54.1[b]	84.1[c]	6.5	<0.01	62.3	72.6	66.9	7.2	0.49
Total EAA	279[a]	442[b]	713[c]	57	<0.01	512	594	536	61	0.49
Nonessential AA										
Alanine	52.6[a]	79.1[b]	90.7[b]	9.7	<0.01	71.4	87.5	74.3	9.8	0.31
Aspartic acid	45.5[a]	72.6[b]	147.0[c]	9.5	<0.01	104	117	115	12	0.66
Cysteine	15.4[a]	23.5[b]	28.4[b]	2.9	<0.01	17.2	22.1	17.8	2.1	0.11
Glutamic acid	114[a]	180[b]	273[c]	24	<0.01	157	197	164	22	0.24
Glycine	28.2[a]	43.2[b]	71.3[c]	5.2	<0.01	65.5	71.4	67.5	10.8	0.88
Proline	54.8[a]	87.6[b]	88.5[b]	11.5	0.02	58.3	76.5	56.0	8.2	0.08
Serine	27.9[a]	43.7[b]	69.4[c]	5.8	<0.01	45.2	53.9	47.3	5.8	0.36
Tyrosine	19.2[a]	32.5[b]	47.4[c]	4.6	<0.01	46.6	56.0	49.2	5.7	0.34
Total NEAA	357[a]	562[b]	606[c]	72	<0.01	565	682	592	76	0.37
Total AA	636[a]	1,004[b]	1,528[c]	129	<0.01	1,076	1,276	1,128	137	0.42

[1]Treatments consisted of 0% byproduct (CON), 20% dried corn distillers grains plus solubles (DDGS), or 20% hempseed cake (HEMP; DM basis).
Treatment means sharing the same superscript do not differ ($P \leq 0.05$). Treatment means sharing the same superscript do not differ ($P \leq 0.05$).

2022). Although these authors observed no difference in dry matter intake (**DMI**) of heifers fed the HEMP diet compared with heifers fed the DDGS diet in a similarly designed finishing study, greater DMI has been observed when feeding hempseed cake in dairy cows (hempseed cake fed at up to 32% of diet DM) and lambs (hempseed cake fed at 22% of the diet DM; Karlsson et al., 2010; Karlsson and Martinsson, 2011). Furthermore, the observed increase in intake of CP, NDF, and ADF in steers fed the HEMP diet is largely because of the greater concentration of these nutrients within hempseed cake as well the tendency for greater OM intake. Greater apparent ruminal OM digestibility in steers fed the HEMP and CON diets than in steers fed the DDGS diet, as well as greater true ruminal N digestibility, total VFA concentration, and ruminal ammonia concentration in steers fed the HEMP diet compared with steers fed the DDGS or CON diets suggests that the crude protein in hempseed cake is more available for microbial degradation. The increase in ruminal total VFA concentration observed in steers fed the HEMP diet could be because of greater ruminally available nitrogen in hempseed cake, which can result in increased microbial fermentation and VFA production (Russell et al., 1992).

Interestingly, intestinal apparent digestibility of ADF (as a percent of intake, and as a percent of nutrient entering the duodenum) was lowest in steers fed the HEMP treatment compared with the DDGS and CON treatments. It should be pointed out that although intestinal digestibility values for hempseed cake were negative (–27.4%), which is likely not correct because of inherent challenges of using digestion markers to estimate digestibility, the differences between treatments are likely real, especially considering ADF flow to the small intestine was 33 to 63% greater in the DDGS and CON diets, respectively. Differences in ADF flow and intestinal digestibility were likely the primary reason for the observed decrease in total tract apparent OM digestibility for the HEMP diet compared with the DDGS or CON diet. The reduction in total tract apparent OM digestibility was not proportionate to the greater concentration of ADF in the HEMP diet, but apparent ruminal ADF digestibility was greater in steers fed the HEMP diet compared with the CON and DDGS diets, partially explaining the disproportionate reduction in total tract apparent OM digestibility. The observed lack of difference in starch intake was not expected because of the numerical and tendencies for increases in OM intake between steers fed the HEMP and CON diets and the DDGS and CON diets, respectively. Total tract apparent starch digestibility is similar to what others have observed when dry-rolled corn is the main starch-containing ingredient in similar finishing diets (Rodenhuis et al., 2018).

True ruminal N digestibility was 41% and 45% greater for the HEMP diet compared with DDGS and CON diets, respectively. Although intestinal N digestibility (as a percent of N entering the duodenum) was reduced for the HEMP diet by approximately 10% compared with the DDGS and

CON diets, the improvement in apparent ruminal N digestibility was greater than the reduction in intestinal apparent N digestibility, therefore improving total tract apparent N digestibility of the HEMP diet compared with the DDGS and CON diets by 5.4% and 11%, respectively. These results suggest that the ruminally degradable protein (**RDP**) fraction of hempseed cake CP is greater than the RDP fraction of CP for dried corn distillers grains plus solubles and dry-rolled corn, which is useful information when formulating diets to supply a specific amount of RDP and MP. This is further supported by the individual AA flow (g/d) data as less feed AA bypassed ruminal degradation for the HEMP treatment. Dietary AA bypass (ruminally undegraded AA) was 35.4% for the HEMP diet, which is similar to in situ ruminally undegradable protein of hempseed cake evaluated in lactating cows (Karlsson et al., 2012) and in vivo in growing lambs (Karlsson and Martinsson, 2011). Karlsson et al. (2012) reported slightly greater ruminal degradability of individual AA than what was found in the present experiment, likely because AA ruminal degradation and bypass percent in the present experiment was for the entire diet and not for a single ingredient. Dietary bypass AA percent for the CON and DDGS diets was 68.0% and 68.5%, respectively, which are slightly greater than the values reported in NASEM (2016) for dry-rolled corn and dried corn distillers grains plus solubles likely because these estimates are for the complete diet and not individual ingredients. The observed lack of differences in duodenal flow of AA was likely because ruminal crude protein supply exceeded requirements in all dietary treatments so changes in ruminal N degradation did not influence bacterial (NASEM, 2016), and thus, total AA flow. It should be noted that that the use of formaldehyde for prevention of bacterial lysis can decrease the recovery of tyrosine and to a lesser extent lysine, histidine, cystine, and glutamic acid (Gruber and Mellon, 1968), potentially influencing microbial contributions for these AA.

Although ruminal N disappearance in steers fed the HEMP diet was greater than in steers fed the DDGS or CON diets, total N excretion was greatest in steers fed the HEMP diet. The increased N excretion was likely because of the 31% and 52% greater N intake in steers fed the HEMP diet than in steers fed the DDGS and CON diets, respectively, and N intake and N excretion are positively correlated (Broderick, 2003; Waldrip et al., 2013). Urinary N is typically more positively correlated with N intake than fecal N, likely because N digestibility is not influenced by level of N intake (Waldrip et al., 2013) unless N is limiting. In the present experiment, N retention was greatest in steers fed the HEMP diet, which may suggest that N or energy were limiting in the CON and DDGS diets. However, N retention as a percent of N intake was not different between steers fed the HEMP and DDGS diets and steers fed the CON diet had reduced N retention as a percent of N intake compared with steers fed the HEMP diet.

Conclusions

The HEMP diet had a lower total tract OM digestibility than the DDGS or CON diets, likely because of the greater ADF concentration of hempseed cake and the resulting increase in duodenal ADF flow. Feed CP and ruminal AA degradability differences suggest that hempseed cake has greater ruminal degradability than dried corn distillers grains plus solubles or dry-rolled corn. This information could be used when formulating diets containing hempseed cake to supply a specific amount of RDP and MP. The observed increased ruminal CP digestibility in steers fed the HEMP diet likely was responsible for the greater observed total tract N digestibility. Although these data may suggest that feeding hempseed cake could increase N balance, further research is needed in diets differing in dietary CP, RDP, and starch concentrations. Overall, these data suggest that hempseed cake is a potentially useful alternative feed ingredient for finishing cattle diets.

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Conflict of Interest

The authors declare that they have no known financial, non-financial, or personal interest that could influence the subject matter or materials discussed in this paper in any way.

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