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Bryan W. Neville

Wayde J. Pickinpaugh

Lea J. Mittleider

Rebecca L. Moore

Kendall C. Swanson

See next page for additional authors

Authors
Bryan W. Neville, Wayde J. Pickinpaugh, Lea J. Mittleider, Rebecca L. Moore, Kendall C. Swanson, and Joel S. Caton

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Interaction of replacing corn silage with soyhulls as a roughage source with or without 3% added wheat straw in the diet: impacts on intake, digestibility, and ruminal fermentation in steers fed high-concentrate diets[1]

Bryan W. Neville[†,‡,2], Wayde J. Pickinpaugh[‡], Lea J. Mittleider[‡], Rebecca L. Moore[‡], Kendall C. Swanson[‖], and Joel S. Caton[‖]

[†]USDA-ARS, U.S. Meat Animal Research Center, Clay Center, NE 68933, USA
[‡]Carrington Research Extension Center, North Dakota State University, Carrington, ND 58421, USA
[‖]Department of Animal Sciences, North Dakota State University, Fargo, ND 58108, USA

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[2]Corresponding author: bryan.neville@usda.gov

ABSTRACT

Six ruminally cannulated steers [475.0 ± 49.6 kg initial body weight (BW)] were used in a 6 × 3 incomplete Latin square design (six treatments and three periods), to evaluate the impacts replacing of corn silage with pelleted soyhulls as roughage in high-concentrate finishing diets containing 30% modified distillers grains with solubles. Treatments were based on increasing dietary inclusion of soyhulls and consisted of: (1) Control (0), roughage supplied by dietary inclusion of 20% corn silage [dry matter (DM) basis]; (2) 50% replacement of corn silage with soyhulls (50); (3) 100% replacement of corn silage with soyhulls (100), and the same three treatments repeated with 3% added wheat straw (DM basis) replacing corn in the diet (0S, 50S, and 100S, respectively). Absolute dry matter intake (DMI; kg/d basis) tended to decrease both linearly and quadratically ($P \leq 0.09$) and proportional DMI (% of BW) decreased linearly ($P = 0.04$) with increasing soyhull inclusion but was not affected by the addition of straw in the diet ($P = 0.68$). Total tract digestibility of organic matter and crude protein were not affected by soyhull inclusion or added straw ($P \geq 0.32$). Ruminal pH did not differ ($P = 0.65$) with increasing soyhull inclusion but increased with the addition of straw ($P < 0.01$; 5.9 vs. 6.1 for no straw and straw, respectively). Molar proportions of acetate and butyrate decreased while propionate increased with increased soyhull inclusion ($P \leq 0.03$; linearly and quadratically, respectively). Ruminal fluid kinetics were unaffected by either rate of replacement of corn silage with soyhulls or wheat straw inclusion ($P \geq 0.13$). Decreases in DMI observed in this study would likely decrease finishing cattle performance and underscores the need for additional research before recommending this practice to cattle feeders.

Key words: beef cattle, digestibility, intake, ruminal pH, soyhulls

INTRODUCTION

Non-forage fiber sources, such as soyhulls, have been used within the dairy industry when forages are limited (Kononoff and Buse, 2020); however, soyhull use in finishing diets as a substitute for forage is currently not advised (NASEM, 2016). The small particle size of soyhulls may explain decreased rumination (Ferreira et al., 2011) and pH (Iraira et al., 2013) reported in previous research, and is consistent with other research on particle size (Beauchemin, 1991; Mertens, 1997). To address concerns regarding fiber functionality in the rumen, some authors have proposed evaluating fiber as physically effective fiber (peNDF) rather than the traditional measurement of NDF (Mertens, 1997).

Decreasing occurrences of ruminal acidosis is critical to optimizing feed efficiency and profitability for cattle producers. As the percentage of grain increases in the diet, the ability of soyhulls to replace more traditional roughage may be limited by the physical capabilities of the fiber in soyhulls to buffer against acidosis. However, when modified distillers grains with solubles (MDGS) are included in the diet total starch decreases creating opportunity to evaluate how use of nontraditional roughage source, such as soyhulls, impact digestibility and ruminal fermentation in comparison to more known roughages like corn silage. In addition, we wanted to evaluate how the addition of 3% wheat straw, a presumably more effective fiber source, may interact with the concurrent replacement of corn silage with wheat straw. Thus our objective was to evaluate intake, digestibility, ruminal fermentation, and ruminal fluid pH and kinetics with increasing replacement of corn silage with soyhulls in high-concentrate with and without 3% added wheat straw in diets containing 30% MDGS. Our hypothesis was that replacing corn silage with pelleted soyhulls would have minimal impacts on digestibility but would decrease ruminal pH. We further hypothesized that when including 3% wheat straw that ruminal pH would increase without any major shifts in intake, digestibility, or ruminal fermentation.

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MATERIALS AND METHODS

This study was approved by the North Dakota State University Institutional Animal Care and Use Committee before initiation of study procedures.

Animal Diets and Treatments

Six ruminally and duodenally cannulated steers [475.0 ± 49.6 kg initial body weight (BW)] were used in a 6 × 3 incomplete Latin square design (Youden Square; Cochran and Cox, 1992) with a 3 × 2 factorial arrangement to evaluate the influence of replacement of corn silage with pelleted soyhulls [0%, 50%, and 100% replacement Factor 1(Rate)] as roughage in high-concentrate finishing diets containing 30% MDGS (DM basis), and the influence of providing an additional 3% wheat straw or not [Factor 2 (Straw)], as a method of providing more physically effective fiber, when substituting corn silage for soyhulls. Treatments were: (1) Control (0)—roughage supplied by dietary inclusion of 20% corn silage [dry matter (DM) basis]; (2) 50% replacement of corn silage with soyhulls (50); (3) 100% replacement of corn silage with soyhulls (100), and the same three treatments repeated with 3% wheat straw (DM basis) replacing corn in the diet (0S, 50S, 100S, respectively). Dietary ingredient and nutrient composition are reported in Table 1. Steers were housed in individual stanchions (2.13 m × 1.73 m). Steers were fed a total mixed ration, two times a day at 0700 and 1900 hours and had continuous access to water. Feed was provided at a rate equal to: intake, kg/d = 3.830 + (0.0143 × (BW × 0.96)) as suggested by NASEM (2016). Feed offered was adjusted based on BW at the start of each study period. Orts, when present, were collected at 0700 hours each day before feeding.

Sample Collection

Sample collection and laboratory procedures generally followed those of Gilbery et al. (2007) and Leupp et al. (2009). Each collection period consisted of a 7-day adaptation period and 7-day collection period. Feed samples were collected once daily on days 7 through 14 and composited within steer and period. Orts were collected from days 7 to 14 and composited within steer and period. Chromic oxide (8 g) was placed into gelatin capsules and ruminally dosed twice daily at the time of each feeding from days 4 to 12 as an external marker. Duodenal fluid (100 mL) and fecal grab samples were collected on days 10 through 12 in a manner to allow for collection of a sample for every hour in a 12-h period (0700 to 1900 hours). Duodenal samples were composited within each steer and period and frozen at −20 °C until analysis. Fecal samples were immediately frozen and stored at −20 °C before being composited and mixed with a rotary mixer (model H-600, Hobart Manufacturing Co., Troy, OH).

Ruminal fluid was collected on day 13 at −2, 0, 2, 4, 6, 8, 10, and 12 h relative to feeding. Following the −2 h collection, 200 mL of CoEDTA was ruminally dosed for determination of ruminal fluid kinetics including dilution rate (FDR), fluid volume, fluid turn over (FTR), and fluid flow rate (FFR). Using a suction strainer, 100 mL of ruminal fluid was collected, and pH was recorded using a pH meter (symphony B10P; VWR International, LLC., Radnor PA). Immediately following determination of pH, ruminal fluid was acidified with 1 mL of 7.2 N Sulfuric acid and stored in a freezer at −20 °C. Calculations for ruminal fluid kinetics followed procedures outlined by Galyean (2010).

On day 14, ruminal evacuations were performed to determine DM fill. Ruminal contents were removed, weighed, and mixed prior to collection of subsamples for DM analysis. A 4-kg sample was also collected and 2 L of 3.7% (wt/vol) formaldehyde in 0.9% NaCl was added (Zinn and Owens, 1986) for isolation of bacterial cells and analysis for DM, ash, N, and purine content. After collection, samples were frozen at −20 °C before transport, thawing, and subsequent lab analysis.

Table 1. Ingredient and nutrient composition of diets fed to steers

	No straw[1]			Straw[1]		
	0	50	100	0	50	100
Ingredient, %						
Corn silage	20.0	10.0	–	20.0	10.0	–
Soyhulls	–	10.0	20.0	–	10.0	20.0
Wheat straw	–	–	–	3.0	3.0	3.0
Dry rolled corn	46.7	46.7	46.7	43.7	43.7	43.7
MDGS[2]	30.0	30.0	30.0	30.0	30.0	30.0
Limestone	0.8	0.8	0.8	0.8	0.8	0.8
Supplement[3]	2.5	2.5	2.5	2.5	2.5	2.5
Nutrient composition, % DM basis						
DM	66.3	67.5	68.8	66.4	67.0	69.9
Crude protein	15.2	14.9	15.9	14.4	15.5	15.8
NDF	36.5	42.1	40.1	37.0	37.8	38.6
ADF	14.7	15.0	16.1	13.8	15.5	14.5

[1]Soyhulls were included as either 50% (50) or 100% (100) of the silage 1:1 basis (DM) compared of control ration (0).
[2]MDGS = modified distillers grains with solubles.
[3]The supplement contained a minimum of 10% CP, 1.5% crude fat, 17.5% Ca, 0.1% P, 6.5% salt, 1.1% Mg, 0.1% K, 400 mg/kg Cu, 1,400 mg/kg Zn, 176,400 IU/kg vitamin A, 44,100 IU/kg of vitamin D, 727 IU/kg vitamin E, and contained 1,102 g/metric ton monensin (BP Balancer 10 RM1000, Purina Animal Nutrition, Arden Hills, MN). Inclusion of supplement was based on 0.25 kg steer^{-1}·d^{-1}assuming a 10 kg dry matter intake.

Table 2. Impacts of soyhull inclusion as a replacement for corn silage with and without added straw in feedlot diets on dry matter (DM) intake and ruminal fill[1]

	No straw[2]			Straw[2]			SE	*P*-values[3]				
	0	50	100	0	50	100		Rate	L	Q	Straw	R*S
Intake												
DM, kg	11.5	10.8	8. 8	11.2	11.3	9.8	1.10	0.11	0.06	0.09	0.64	0.77
DM, % of BW	2.4	2.3	1.8	2.2	2.2	1.9	0.19	0.08	0.04	0.07	0.68	0.80
Ruminal fill												
DM, kg	6.0	6.0	7.3	6.1	6.2	6.3	1.08	0.51	0.32	0.35	0.82	0.63
DM, % of BW	1.2	1.2	1.5	1.1	1.2	1.2	0.20	0.39	0.23	0.28	0.43	0.65

[1]Soyhulls were included as either 50 or 100% of the silage 1:1 basis (DM) compared of control ration (0).
[2]Wheat straw was included at a rate of 3% DM basis replacing corn.
[3]*P*-values: rate = overall impact of rate of soyhull inclusion, L = impact of soyhull inclusion rate as a linear function, Q = impact of soyhull inclusion as a quadratic function, Straw = impact inclusion or not of 3% wheat straw, and R*S = interaction of soyhull inclusion rate and inclusion of 3% wheat straw or not.

Laboratory Analysis

Feed, orts, and fecal samples were dried in a forced air oven (55 °C) for a minimum of 48 h. Dried samples were ground to pass a 2-mm screen in a Wiley Mill (Arthur H. Thomas, Philadelphia, PA). Duodenal samples were freeze dried (Virtis Genesis 25LL, The Virtis Company Inc., Gardiner, NY) and ground in a Wiley mill to pass a 1-mm screen. Diet, ort, duodenal, and fecal samples were analyzed for DM, ash, crude protein (CP), phosphorus, and calcium (methods 934.01, 942.05, 2001.11, 965.17, and 968.08, respectively; AOAC, 2010). Concentrations of neutral detergent fiber (NDF; Van Soest et al., 1991; as modified by Ankom Technology, Fairport, NY) and acid detergent fiber (ADF; Goering and Van Soest, 1970, as modified by Ankom Technology, Macedon, NY) were determined using an Ankom 200 Fiber Analyzer (Ankom Technology). Chromium concentrations were analyzed in duodenal and fecal samples by spectrophotometry (Fenton and Fenton, 1979).

Ruminal fluid samples were centrifuged at 20,000 × *g* for 20 min at 4 °C and supernatant taken for analysis of ammonia (Broderick and Kang, 1980). Ruminal fluid VFA concentrations (Goetsch and Galyean, 1983) were quantified using gas chromatography (Hewlett-Packard 5890A Series II GC, Wilmington, DE) with a capillary column. Cobalt concentration was determined with methods described by Uden et al. (1980) using an air-plus-acetylene flame and atomic absorption spectroscopy (model 3030B, PerkinElmer Inc., Wellesley, MA).

Bacterial cells were isolated from formaldehyde-treated ruminal contents. Ruminal contents were blended (Model 37b119, Waring, New Hartford, CT) and strained through 4 layers of cheesecloth. Samples were then centrifuged at 500 × *g* for 20 min to allow for separation of feed particles and protozoa. The supernatant was further centrifuged at 30,000 × *g* for 20 min to pellet any bacteria. Bacteria pellets were frozen, freeze-dried, and analyzed for DM, ash, CP (AOAC, 2010), and purines (Zinn and Owens, 1986).

Statistical Analysis

Data were analyzed as a 6 × 3 incomplete Latin Square using the Mixed procedures of SAS (SAS Inst. Inc., Cary, NC). The model included effects of period and rate of soyhull replacement, the inclusion of wheat straw or not, and the interaction of rate and straw inclusion as fixed effects and steer was included as a random effect. There was no significant rate by straw interaction present ($P \geq 0.07$) in the data therefore these interactions are not discussed in the following results. Data over time were analyzed as repeated measures. The model included period, treatment, and time. The time × treatment interaction was initially included but was not significant ($P > 0.05$) for any variable and was therefore removed from the model. Linear and quadratic contrasts were included to evaluate the impacts of rate of soyhull replacement of corn silage. Covariant structures were tested with Simple being selected as the best fit for the majority of the data presented based on fit statistics. LSMeans statement was used with Tukey adjustment to present treatment means. *P*-value of ≤0.05 was considered significant, *P*-values > 0.05 and ≤ 0.10 will be discussed as tendencies.

RESULTS AND DISCUSSION

Feed refusals averaged 4.9% (range 0.3% to 11.2%) of feed offered and were not affected by rate or corn silage replacement with pelleted soyhulls, inclusion of wheat straw, or the interaction of rate and straw ($P \geq 0.27$), period ($P = 0.41$; data not presented). Dry matter intake (DMI) tended to decrease both linearly and quadratically ($P \leq 0.09$; Table 2) with increasing soyhull replacement of corn silage in the diet, but was not affected by the addition of 3% wheat straw to the diet ($P = 0.64$). When expressed on a % of BW basis, both DMI and organic matter intake (OMI) decreased linearly with increasing soyhull replacement of corn silage in the diet ($P \leq 0.05$; Tables 2 and 3). DMI decreased by 2.7 (0.6% BW) and 1.4 kg/d (0.3% BW) when comparing the 0 and 100, and 0S and 100S treatments, respectively. This degree of decreased DMI would likely decrease performance of finishing cattle. Previous research reported that intake increased with increasing soyhulls inclusion (Hsu et al., 1987; Ferreira et al., 2011). However, diets fed by Hsu et al. (1987) contained 35% to 60% corn silage (DM basis) and those of Ferreira et al. (2011) included 10% hay, and soyhulls were being evaluated as an energy source not a roughage source. This is important to keep in perspective as differences in amount of physically effective fiber in the current diets and those of the previous studies would likely influence ruminal function including pH, VFA production, and intake.

Table 3. Impacts of soyhull inclusion as a replacement for corn silage with and without added straw in feedlot diets on organic matter (OM) intake and extent of digestion in beef steers[1]

	No straw[2]			Straw[2]			SEM	*P*-values[3]				
	0	50	100	0	50	100		Rate	L	Q	Straw	R*S
Intake												
OM, kg	10.8	10.2	8.3	10.5	10.6	9.2	1.02	0.11	0.06	0.08	0.68	0.76
OM, % of BW	2.2	2.1	1.7	2.1	2.0	1.8	0.14	0.08	0.05	0.06	0.62	0.80
Duodenal flow, kg/d	4.6	4.6	4.1	4.2	4.7	4.4	0.39	0.28	0.59	0.13	0.95	0.43
Fecal output, kg/d	2.4	2.7	2.2	2.5	2.5	2.2	0.18	0.04	0.09	0.01	0.84	0.63
Digestibility, %												
True ruminal	56.4	54.1	50.6	60.3	55.7	51.2	5.31	0.29	0.14	0.37	0.61	0.93
Total tract	76.9	73.4	73.7	77.0	76.1	75.5	2.69	0.52	0.32	0.94	0.43	0.86

[1]Soyhulls were included as either 50 or 100% of the silage 1:1 basis (DM) compared of control ration (0).
[2]Wheat straw was included at a rate of 3% DM basis replacing corn.
[3]*P*-values: Rate = overall impact of rate of soyhull inclusion, L = impact of soyhull inclusion rate as a linear function, Q = impact of soyhull inclusion as a quadratic function, Straw = impact inclusion or not of 3% wheat straw, and R*S = interaction of soyhull inclusion rate and inclusion of 3% wheat straw or not.

Changes in ruminal pH and digesta kinetics have also been proposed as factors affecting intake (Bartle et al., 1994; Galyean and Defoor, 2003). These concepts are addressed in more detail later in this manuscript, but with the lack of differences in organic matter (OM) digestibility, pH, and fluid kinetics these factors are unlikely the cause of decreased intake in this study. Nakamura and Owen (1989) reported no differences in DMI of dairy cows and concluded that rapid rate of digestion and/or rate of passage were occurring with greater inclusion of soyhulls. One potential explanation for reduction in feed intake could be attributed to ruminal fill, as previously discussed by Loest et al. (2001). In the current study, increasing rate of soyhull replacement of corn silage in high-concentrate finishing diets did not alter ruminal DM fill ($P \geq 0.32$; Table 2). Soyhulls fed in the current study were pelleted, and when exposed to moisture (water or ruminal fluid) the pellets expand potentially resulting in an increase bulk fill compared with non-pelleted soybean hulls, likely resulting in a slower eating rate compared with diets containing corn silage.

True ruminal and total tract digestibility of OM were not affected by the rate of substitution of corn silage with soyhulls ($P \geq 0.14$) or the addition of 3% wheat straw ($P \geq 0.43$; Table 3). Duodenal flow of OM was likewise not affected by either rate of substitution or inclusion of wheat straw to the diet ($P \geq 0.13$). Previous research has also reported DM digestibility decreased with increasing soyhull inclusion (Nakamura and Owen, 1989); however, diets fed by these researchers contained soyhulls as 0%, 50%, or 95.3% of concentrate portion of the diet, while alfalfa silage represented 50% of the total diet DM. Therefore, soyhulls were replacing corn in the diet and not roughage sources as in the present study and were thereby serving different functions within the diet. Again, it is worth noting that while OM digestibility was not different intake did tend to decrease in a manner that would likely decrease growth performance of cattle if soyhulls were utilized in the same manner as the current study.

True ruminal digestibility of CP decreased ($P = 0.04$; Table 4) with increasing replacement of corn silage with soyhulls but was not affected ($P = 0.12$) by addition of 3% wheat straw. True ruminal CP digestibility decreased from 46.9% to 27.6% when considering the average of the 0 and 0S, and 100 and 100S treatments, respectively. Total tract CP digestibility was not affected by either rate of substitution of corn silage with soyhulls ($P \geq 0.44$) or inclusion of wheat straw to the diet ($P = 0.69$). Soyhulls contain on average 53.1 ± 9.06% ruminal undegradable protein (NASEM, 2016) and contain more CP compared to corn silage and may partly explain the differences observed in this study. Total CP flow and feed CP flow to the duodenum was unaffected by either rate of substitution ($P \geq 57$) or addition of wheat straw ($P \geq 0.48$). However, microbial crude protein flow while not affected by rate of substitution of corn silage with soyhulls ($P = 0.19$) was greater ($P = 0.03$) when 3% wheat straw was included. Microbial efficiency was unaffected by either rate of substitution of corn silage for soyhulls ($P \geq 0.21$) or the inclusion of added straw ($P \geq 0.46$). It is important to keep the overall protein content of the diets fed in the current study in context. In the current study, our diets ranged from 14.9% to 15.9% CP largely due to the high inclusion rate of MDGS, had the dietary protein concentration been lower the differences observed in CP digestibility and microbial flow may be differed as a result.

In the current study, replacing corn silage with soyhulls did not affect ruminal pH ($P = 0.65$; Table 5); however, adding wheat straw to the diet did increase ($P < 0.01$) ruminal pH compared with the same diets without wheat straw. The fact replacing greater amounts of corn silage with soyhulls did not influence ruminal pH is interesting. Based on lower expected effective fiber concentration of soyhulls we had anticipated that ruminal pH would have decreased with increasing soyhull replacement of corn silage. Soyhulls were found to be less effective in promoting rumination than ground corn (Ferreira et al., 2011). The response in ruminal fluid pH to the addition of 3% wheat straw to the diet was expected, and likely represents increases in rumination and addition of buffers from salvia to the rumen (Allen et al., 1997). In previous research, steers fed soyhulls as the sole source of roughage had an average pH of 5.87 and spent over 13 h/d with a ruminal pH below 5.8 (Iraira et al., 2013). Steers fed a combination of corn silage and soyhulls spent less time ruminating than those fed 20% corn silage (Goulart et al., 2020). As a comparison, our average pH value was 5.8 for steers with roughage source being either corn silage or soyhulls without added

Table 4. Impacts of soyhull inclusion as a replacement for corn silage with and without added straw in feedlot diets on crude protein intake and extent of digestion in beef steers[1]

	No straw[2]			Straw[2]			SEM	*P*-values[3]				
	0	50	100	0	50	100		Rate	L	Q	Straw	R*S
Intake, kg/d	1.7	1.6	1.4	1.7	1.8	1.6	0.21	0.40	0.24	0.27	0.39	0.97
Fecal output, kg/d	0.5	0.5	0.4	0.5	0.5	0.4	0.03	0.02	0.05	<0.01	0.81	0.78
Microbial efficiency[4]	17.2	17.3	21.3	18.4	19.9	24.2	4.20	0.36	0.21	0.26	0.46	0.97
Duodenal CP flow, kg/d												
Microbial	0.6	0.6	0.6	0.7	0.8	0.7	0.06	0.33	0.23	0.19	0.03	0.67
Feed	0.9	1.0	1.1	0.9	0.9	1.0	0.12	0.41	0.22	0.33	0.59	0.98
Total	1.6	1.6	1.6	1.7	1.7	1.7	0.15	0.83	0.57	0.75	0.48	0.88
Digestibility, %												
True ruminal	41.9	38.5	21.5	51.9	47.8	33.7	8.22	0.07	0.04	0.06	0.12	0.97
Total tract	70.9	69.9	68.5	72.5	70.6	69.5	3.98	0.72	0.44	0.70	0.69	0.99

[1]Soyhulls were included as either 50% or 100% of the silage 1:1 basis (DM) compared of control ration (0).
[2]Wheat straw was included at a rate of 3% DM basis replacing corn.
[3]*P*-values: rate = overall impact of rate of soyhull inclusion, L = impact of soyhull inclusion rate as a linear function, Q = impact of soyhull inclusion as a quadratic function, Straw = impact inclusion or not of 3% wheat straw, and R*S = interaction of soyhull inclusion rate and inclusion of 3% wheat straw or not.
[4]Grams of microbial N/kg of OM truly fermented.

Table 5. Impacts of soyhull inclusion as a replacement for corn silage with and without added straw in feedlot diets on ruminal fluid pH, VFA concentrations, and ruminal fluid kinetics in beef steers[1]

	No straw[2]			Straw[2]			SEM	*P*-values[3]				
	0	50	100	0	50	100		Rate	L	Q	Straw	R*S
Ruminal pH	5.8	6.0	5.8	6.1	6.0	6.1	0.09	0.89	0.77	0.65	<0.01	0.24
Ammonia, mMol	6.7	4.4	2.4	6.0	7.5	4.9	1.61	0.25	0.13	0.19	0.24	0.49
Volatile fatty acids												
Total, mMol	180.2	184.0	194.2	173.9	177.8	170.3	16.43	0.95	0.76	0.94	0.38	0.83
Acetate, %	46.9	45.5	41.8	50.9	50.0	44.0	2.38	0.07	0.03	0.07	0.10	0.87
Propionate, %	29.9	28.5	37.6	23.1	21.8	29.8	3.13	0.04	0.05	0.02	0.02	0.98
Butyrate, %	12.7	14.5	8.4	15.0	17.8	13.7	2.06	0.09	0.21	0.03	0.06	0.76
Ac:Prop[4]	1.6	1.7	1.1	2.2	2.4	1.6	0.28	0.08	0.08	0.04	0.02	0.96
Fluid kinetics[5]												
FDR, %/h	9.8	7.0	8.6	8.9	8.3	10.6	1.46	0.23	0.85	0.13	0.64	0.44
Volume, L	60.9	80.7	58.4	66.7	74.2	54.3	12.53	0.29	0.57	0.13	0.89	0.87
FTO, h	10.5	16.2	12.0	12.3	13.7	9.6	2.70	0.29	0.83	0.16	0.68	0.67
FFR, L/h	5.9	5.0	4.9	5.4	5.5	5.7	0.32	0.26	0.19	0.82	0.46	0.07

[1]Soyhulls were included as either 50% or 100% of the silage 1:1 basis (DM) compared of control ration (0).
[2]Wheat straw was included at a rate of 3% DM basis replacing corn.
[3]*P*-values: Rate = overall impact of rate of soyhull inclusion, L = impact of soyhull inclusion rate as a linear function, Q = impact of soyhull inclusion as a quadratic function, Straw = impact inclusion or not of 3% wheat straw, and R*S = interaction of soyhull inclusion rate and inclusion of 3% wheat straw or not.
[4]Acetate to propionate ratio.
[5]FDR = fluid dilution rate (%/h), FTO = fluid turn over time (h), FFR = fluid flow rate (L/h).

straw. Differences between previous research and the current project also include the inclusion of 30% MDGS in the diet. Including MDGS may change the quantity of roughage needed for ruminal fermentation by decreasing the amount of starch in feedlot diet (Krehbiel et al., 1995; Klopfenstein et al., 2008). The continued evaluation of ruminal pH in cattle fed soyhulls under traditional pen-fed feedlot scenarios is needed to understand how group feeding behavior may impact animal intake and resultant ruminal pH.

Ruminal ammonia concentration was not affected ($P \geq 0.13$; Table 5) by rate of substitution of corn silage with soyhulls or by the addition of 3% wheat straw to the diet ($P = 0.24$). Previous research has demonstrated that increasing roughage inclusion increased ruminal ammonia (Weiss et al., 2017). It is possible that the overall high protein content of our diets is masking responses, or the minimal separation in diet fiber content was simply not enough to elicit that same response as report by Weiss et al. (2017).

Neither replacing corn silage with soyhulls ($P \geq 0.76$) nor the inclusion of 3% wheat straw impacted total VFA concentration ($P = 0.38$; Table 5) Concentrations of acetate ($P = 0.03$; linear) and butyrate ($P = 0.03$; quadratic) decreased with increasing soyhull inclusion and tended to be greater in steers fed added wheat straw (P = 0.10 and P = 0.06, respectively) compared with those not provided added straw. The opposite response was observed for propionate concentration, with soyhull inclusion quadratically increasing (P = 0.02) and straw inclusion decreasing (P = 0.02) propionate concentrations. The observed results on VFA concentrations in the current study align well with steers fed soyhulls as a roughage source (Iraira et al., 2013). While the increase in propionate would be a positive attribute of increasing dietary soyhull inclusion, it is unlikely that this increase would compensate for the decrease in overall intake of cattle fed soyhulls as their sole roughage source. Fluid kinetics, including FDR, volume, FTO, and FFR were not affected by either rate of soyhull inclusion ($P \geq 0.13$; Table 5) or addition of wheat straw to the diet ($P \geq 0.46$). Intake has been reported to affect FDR (Estell II and Galyean, 1985); however, the decrease in intake observed in the current study did not have this affect.

In conclusion, the current study demonstrated the need for caution in utilizing soyhulls as a roughage source in high-concentrate finishing diets due to the potential for decreased intake with replacement of corn silage with soyhulls. While the predominant changes to intake are likely driving responses in digestibility and rumen fermentation in this study, these changes when taken together would likely decrease feedlot cattle performance and underscores the need for additional research prior to recommending feeding soyhulls as a roughage source to cattle feeders. Data evaluating soyhulls as a roughage source in high-concentrate diets are lacking and more research on the impacts of soyhull inclusion on performance of feedlot cattle would be needed to fully understand the impacts of utilizing this feed resource as a potential forage replacement. Specifically, the impacts of soyhull inclusion on bunk behavior and individual animal intake when managed under group settings.

Conflict of interest statement

Partial support for this research was provided by North Dakota Soybean Council and the Nodrth Dakota State Board of Agricultural Research and Education—Research Fund. We declare that during the writing of the manuscript titled: Interaction of replacing corn silage with soyhulls as a roughage source with or without 3% added wheat straw in the diet: impacts on intake, digestibility, and ruminal fermentation in steers fed high-concentrate diets, there were no conflicts of interest.

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