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Effects of sorghum wet distillers grains plus solubles in steam-flaked corn–based finishing diets on steer performance, carcass characteristics, and digestibility characteristics[1]

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ABSTRACT

Two studies were conducted to evaluate the effects of sorghum wet distillers grains (SWDGS) in finishing diets on steer performance, carcass characteristics, and nutrient digestibility. In Exp. 1, 240 steers (initial BW = 379 ± 1 kg) were fed steam-flaked corn–based diets with or without 25% SWDGS and 7.5, 10.0, or 12.5% alfalfa hay. There were no effects of alfalfa hay concentration on BW, DMI, ADG, or G:F ($P \geq 0.16$). Including SWDGS reduced ($P \leq 0.05$) ADG and G:F. Fat thickness decreased ($P = 0.03$) and DP tended to decrease ($P = 0.09$) linearly as level of alfalfa hay increased. Final BW of steers consuming diets containing 25% SWDGS were 12 kg lighter ($P = 0.05$) than those of steers fed diets without SWDGS. Hot carcass weight tended ($P = 0.09$) to be lighter for steers fed SWDGS. In Exp. 2, effects of corn processing method (steam-flaked corn and dry-rolled corn) and 20% corn wet distillers grains with solubles (CWDGS) or SWDGS inclusion on ruminal pH and in situ digestibility were evaluated. Cattle consuming diets containing SWDGS had a greater ($P \leq 0.05$) ruminal pH than steers consuming diets with CWDGS or no wet distillers grains with solubles. Including wet distillers grains with solubles did not affect ($P \geq 0.37$) steam-flaked corn or dry-rolled corn in situ DM digestibility. In situ digestibility of DM and NDF differed between CWDGS and SWDGS ($P < 0.0001$). Differences in performance and nutrient digestibility between CWDGS and SWDGS are the result of differences in the product rather than an interaction with corn processing method.

Key words: beef cattle, corn processing, digestibility, roughage concentration, sorghum distillers grains

INTRODUCTION

Grain sorghum grows well in warm regions without irrigation, making it a favorable option to corn for the

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southern plains region. Historically, Kansas and Texas have been the leaders in grain sorghum production (NASS, 2013), and sorghum continues to be used as a feedstock for ethanol production, making sorghum wet distillers grains plus solubles (**WDGS**) an available commodity for the beef industry. Distillers by-products, including WDGS, contain very little starch and are relatively high in NDF and ADF (Stock et al., 2000; Klopfenstein et al., 2008) when compared with grains that are replaced when WDGS are included in finishing diets. Roughage is included in finishing diets to help control subacute acidosis that may occur when high levels of starch are fed. Because WDGS are low in starch and high in fiber, it was assumed that including them in the diet would allow roughage levels to be reduced. This proved unsuccessful for Benton et al. (2007), who fed diets containing 30% WDGS with 0, 4, or 8% roughage and observed a positive gain response with increasing roughage levels.

A quadratic increase in G:F as level of WDGS increased was reported by Vander Pol et al. (2006), whereas Vasconcelos et al. (2007) reported a linear decrease in G:F as level of WDGS increased. Discrepancies in performance responses to dietary WDGS inclusion have been attributed to several factors including grain processing method, source of grain fermented, and use of added fat, among others (Klopfenstein et al., 2008; Cole et al., 2009). Vander Pol et al. (2006) used corn WDGS (**CWDGS**) in diets based on a 1:1 blend of dry-rolled corn (**DRC**) and high-moisture corn. Vasconcelos et al. (2007) used sorghum WDGS (**SWDGS**) in steam-flaked corn (**SFC**)–based diets because steam flaking is the most common grain processing method used in finishing diets, especially in the southern Great Plains (Vasconcelos and Galyean, 2007). Therefore, our objectives were to determine how to optimize the use of SWDGS in southern high plains finishing diets and to compare the digestibility of SWDGS to CWDGS in SFC-based diets.

MATERIALS AND METHODS

All animal care and management procedures were approved by the Amarillo Area Cooperative Research, Education, and Extension Team Institutional Animal Care and Use Committee composed of members from West Texas A&M University, Texas AgriLife Research, and the USDA-ARS-Conservation and Production Research Laboratory.

Exp. 1

A total of 240 crossbred steers (initial BW = 379 ± 1 kg) were used in a randomized complete block design to determine effects of alfalfa hay (**AH**) concentration in SFC-based finishing diets containing 25% SWDGS. Steers were limit fed (1.75% of BW) a common receiving diet containing 46% SFC, 45% AH, 7% glycerin, and 2% supplement (DM basis) for 7 d to minimize differences in gut fill (Klopfenstein, 2011) and weighed on 3 consecutive d (Stock et al., 1983) to obtain an initial BW for the finishing period. Steers were blocked by BW, stratified by BW within blocks, and randomly assigned to 1 of 24 pens (6 pens per treatment). Dietary treatments were then randomly assigned to pens within BW blocks. Pens housed 6, 9, or 18 steers, and the BW blocks were assigned by pen size to maintain balance in the number of steers for each treatment within blocks (1 BW block in 6 head pens, 4 BW blocks in 9 head pens, and 1 BW block in 18 head pens). Dietary treatments included a SFC-based [348 g/L (27 pounds/bushel)] control diet containing 0% SWDGS and 10% AH and diets containing 25% SWDGS with 7.5, 10.0, and 12.5% AH. All diets (Table 1) contained 5% crude glycerin and were formulated to contain equivalent ether extract and to provide 33 mg/kg monensin (Rumensin, Elanco Animal Health, Indianapolis, IN) and 8.7 mg/kg tylosin (Tylan, Elanco Animal Health). Steers were stepped up to the final finishing diets over a 21-d period using 3 steps containing 35, 25, and 15% AH after cattle were weighed onto the experiment. Diets were mixed and offered once daily in the morning in an amount to allow ad libitum intake.

Steers were vaccinated against viral pathogens using modified-live cultures of bovine rhinotracheitis virus, bovine viral diarrhea virus (Types 1 and 2), parainfluenza-3 virus, and bovine respiratory syncytial virus (Vista 5 SQ, Merck Animal Health, De Soto, KS) and clostridial bacteria including *Clostridium chauvoei*, *Clostridium septicum*, *Clostridium novyi*, *Clostridium sordellii*, and *Clostridium perfringens* Types C and D (Vision 7 with SPUR, Merck Animal Health) and were treated against internal and external parasites with an injectable anthelmintic (Ivomec Plus, Merial Ltd., Duluth, GA). All steers received an implant containing 24 mg of estradiol and 120 mg of trenbolone acetate (Revalor-S, Merck Animal Health) approximately 120 d before slaughter and were on feed an average of 154 d.

Steers were marketed by weight block when the average fat thickness of each block was visually estimated to be 1.27 cm. On the day of slaughter, feed was withheld and steers were pen weighed. A 4% shrink (NRC, 1996) was applied to determine final shrunk BW and to calculate DP. Cattle were transported 40 km to a federally inspected commercial facility (Tyson Fresh Meats Inc., Amarillo, TX) for slaughter and subsequent carcass data collection (West Texas A&M University Beef Carcass Research Center, Canyon, TX). Hot carcass weights were recorded on the day of slaughter. Twelfth-rib fat thickness, LM area, and called marbling score were recorded following a 48-h chill, and YG was calculated using carcass measurements (USDA, 1997). Live performance calculations were made using shrunk final BW, whereas carcass-adjusted final BW, ADG, and G:F were calculated using HCW and an average DP of 64.5. Dietary NE_m and NE_g values were calculated using the equivalent BW scaling approach of the NRC (1996) with a standard reference BW of 478 kg as described by Vasconcelos and Galyean (2008).

Table 1. Composition (DM basis) of steam-flaked corn–based finishing diets containing 25% sorghum wet distillers grains plus solubles and differing levels of alfalfa hay fed to steers during Exp. 1[1]

	Treatment[2]			
Item	CONT	7.5AH	10.0AH	12.5AH
Ingredient, %				
Steam-flaked corn	75.11	58.32	55.90	53.47
WDGS	—	25.00	25.00	25.00
Alfalfa hay	10.00	7.50	10.00	12.50
Cottonseed meal	3.67	—	—	—
Crude glycerin	5.00	5.00	5.00	5.00
Yellow grease	2.94	1.54	1.55	1.56
Limestone	1.29	1.34	1.26	1.17
Urea	1.29	0.60	0.60	0.60
Supplement[3]	0.70	0.70	0.70	0.70
Chemical composition, %				
CP	14.21	18.59	18.81	19.02
Ether extract	5.41	5.14	5.09	5.05
Ca	0.65	0.70	0.69	0.69
P	0.24	0.31	0.31	0.31
K	0.51	0.53	0.58	0.63
S	0.12	0.20	0.20	0.20

[1]Sorghum wet distillers grains plus solubles (WDGS) were purchased from Abengoa Bioenergy (Portales, NM) and contained 40.0% CP, 7.0% ether extract, 46.7% NDF, 0.29% Ca, 0.64% P, 0.73% K, and 0.45% S.

[2]CONT = steam-flaked corn–based control diet with 0% WDGS; 7.5AH, 10.0AH, and 12.5AH = steam-flaked corn–based diets containing 25% WDGS and 7.5, 10.0, and 12.5% alfalfa hay (AH), respectively.

[3]Formulated to provide a dietary DM inclusion of 0.30% salt, 60 mg/kg Fe, 40 mg/kg Zn, 30 mg/kg Mg, 25 mg/kg Mn, 10 mg/kg Cu, 1 mg/kg I, 0.15 mg/kg Co, 0.10 mg/kg Se, 1.5 IU/g vitamin A, 0.15 IU/g vitamin D, 8.81 IU/kg vitamin E, 33 mg/kg monensin, and 8.7 mg/kg tylosin.

Carcass-adjusted final BW was used as the mature weight in the analysis.

Steam-flaked corn was purchased 3 to 4 times a week from a local feedyard. Sorghum WDGS was purchased from Abengoa Bioenergy (Portales, NM) and was stored in a plastic silo bag within 24 h of delivery. Throughout the feeding period, feed refusals were collected, sampled, and dried to determine DM refusal. Refusals were subtracted from feed offered (DM basis) to calculate DMI. Ingredient samples were collected thrice weekly for wet ingredients (SWDGS and SFC) and once weekly for all other ingredients for DM determination. Ingredient DM was determined by drying in a 60°C oven for 48 h and was updated weekly for ration formulation. A composite sample was made for each ingredient using DM samples collected over the duration of the study and sent to a commercial laboratory (Servi-Tech Laboratories, Amarillo, TX) for CP, Ca, P, S, K, and ether extract (AOAC International, 2016; methods 988.05, 927.02, 965.17, 923.01, 983.02, 920.39, respectively). Data were analyzed as a randomized complete block design using the mixed model procedures (PROC MIXED) of SAS v.9.2 (SAS Institute Inc., Cary, NC) with pen serving as the experimental unit. The model included treatment as a fixed effect and weight block as a random effect. Preplanned orthogonal contrasts were developed to compare diets with and without SWDGS, as well as the linear and quadratic effects of level of AH in diets containing 25% SWDGS. Effects were considered significant when $P \leq 0.05$, and tendencies were declared when P-values were between 0.05 and 0.15.

Exp. 2

Six ruminally cannulated crossbred steers (BW = 472 kg) were used in a 6 × 6 Latin square design to determine effects of corn processing method and WDGS inclusion and source on ruminal pH and in situ digestibility of corn and WDGS. Dietary treatments were arranged in a 2 × 3 factorial, and factors included corn processing method (SFC and DRC) and WDGS inclusion and source [0% WDGS (**0WDGS**) and 20% CWDGS or SWDGS]. All diets contained 10% AH and 5% crude glycerin and were formulated to contain 6% dietary fat on a DM basis (Table 2). Periods were 21 d in length and consisted of a 16-d adaptation period followed by a 5-d collection period. Diets were fed once daily at 0700 h. Feed refusals were collected daily, weighed, and subtracted from the amount of feed offered the previous day to determine feed consumption. Feed was offered at 110% of feed consumption for the preceding day, with 10% of orts retained during d 17 through 21 of the period. Steers were individually fed in 2.4 × 3.6 m pens bedded with wood chips from d 1 to 14 and moved into 1.2 × 2.4 m crates on d 15 before the collection period.

Ruminal pH was determined by collecting ruminal fluid samples 4 times/d (d 17 to 19) with collection time advancing 2 h/d so that ruminal pH was measured every 2 h for a 24-h period. Rumen content samples were collected from at least 4 locations in the rumen, and contents were strained through 4 layers of cheesecloth. Fluid samples were swirled to homogenize and pH was immediately measured using a portable pH meter (Oakton II Series, Eutech Instruments, Singapore).

Dry matter (DRC, SFC, CWDGS, and SWDGS) and NDF (CWDGS and SWDGS only) digestibility were measured using the in situ nylon bag technique (Hopson et al., 1963). Dry-rolled corn was ground through a 6-mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ), whereas SFC, CWDGS, and SWDGS were not further processed. Wet (as is) samples were weighed into nylon bags in an amount to yield approximately 30 g of DM in each bag. Distillers grains were unprocessed and weighed as is to avoid further particle size reduction, which may inappropriately contribute to washout. This strategy has previously been employed for distillers grains (Corrigan et al., 2009; Meyer et al., 2012). Dry matter was determined for each substrate during each period, and all weights were corrected for DM. Samples were incubated in the rumen for 0, 2, 4, 8, 12, 16, 24, and 48 h. Samples were incubated only in steers consuming diets containing that sample. For example, SWDGS samples were incubated in steers receiving SWDGS in the diet (Table 2). Upon removal from the rumen, nylon bags were rinsed once in a plastic bucket filled with water. Bags were then transferred to a washing machine filled with warm tap water to large load capacity. Bags were washed 5 times with a 1-m agitation and 2-m spin. After washing, bags were dried at 60°C in a forced-air oven for 48 h and weighed. Neutral detergent fiber concentration was determined using the procedures of Vogel et al. (1999), with sodium sulfite and amylase (Ankom Inc., Fairport, NY) without ash correction.

All digestion curves for DM and NDF of WDGS and DM of corn were fitted for each feed within substrates using PROC NLIN in SAS and the Gauss-Newton method to obtain the fractional rate of fermentation per hour (Tedeschi et al., 2009). Digestibility data were analyzed as a 6 × 6 Latin square using mixed procedures (PROC MIXED) in SAS (SAS Institute Inc.). Steer within collection period was the experimental unit, and the model included corn processing method, WDGS inclusion, and their interaction as fixed effects. Steer and collection period were included as random effects. Repeated measures were used to test the effects of time on ruminal pH. The first-order autoregressive covariate structure was used and was based on the reduction of Akaike's criterion relative to the unstructured pattern (Littell et al., 2002). The model included fixed effects of time, corn processing method, WDGS inclusion, and all 2- and 3-way interactions. Random effects included animal, collection period, animal × time interaction, and collection period × time interaction. Effects were considered significant when $P \leq 0.05$, and tendencies were declared when P-values were between 0.05 and 0.15.

Table 2. Composition (DM basis) of steam-flaked corn (SFC)–based and dry-rolled corn (DRC)–based finishing diets containing 0 or 20% corn wet distillers grains plus solubles (WDGS) or sorghum WDGS fed to cannulated steers in Exp. 2[1]

	0% WDGS		20% Corn WDGS		20% Sorghum WDGS	
Item	SFC	DRC	SFC	DRC	SFC	DRC
Ingredient, %						
Corn	75.06	75.06	60.30	60.30	60.16	60.16
WDGS	—	—	20.00	20.00	20.00	20.00
Alfalfa hay	10.00	10.00	10.00	10.00	10.00	10.00
Cottonseed meal	4.38	4.38	—	—	—	—
Crude glycerin	5.00	5.00	5.00	5.00	5.00	5.00
Yellow grease	2.96	2.96	1.39	1.39	1.84	1.84
Limestone	0.45	0.45	0.74	0.74	0.72	0.72
Urea	0.16	0.16	0.57	0.57	0.26	0.26
Supplement[2]	2.00	2.00	2.00	2.00	2.00	2.00
Chemical composition, %						
CP	13.00	13.22	16.21	16.39	17.95	18.13
Ether extract	5.47	5.02	5.52	5.22	5.16	4.86
Ca	0.60	0.60	0.70	0.70	0.74	0.74
P	0.24	0.28	0.33	0.36	0.29	0.32
K	0.52	0.55	0.64	0.67	0.56	0.58
S	0.12	0.12	0.24	0.24	0.18	0.18

[1]Corn WDGS were purchased from Chief Ethanol Fuels (Hastings, NE) and contained 26.8% CP, 11.0% ether extract, 23.3% NDF, 0.06% Ca, 0.83% P, 1.16% K, 0.74% S. Sorghum WDGS were purchased from Abengoa Bioenergy (Portales, NM) and contained 40.0% CP, 7.0% ether extract, 43.9% NDF, 0.29% Ca, 0.64% P, 0.73% K, and 0.45% S.

[2]Formulated to provide a dietary DM inclusion of 0.30% salt, 60 mg/kg Fe, 40 mg/kg Zn, 30 mg/kg Mg, 25 mg/kg Mn, 10 mg/kg Cu, 1 mg/kg I, 0.15 mg/kg Co, 0.10 mg/kg Se, 1.5 IU/g vitamin A, 0.15 IU/g vitamin D, 8.81 IU/kg vitamin E, 33 mg/kg monensin, and 8.7 mg/kg tylosin.

RESULTS AND DISCUSSION

Exp. 1

Diet Composition. Sorghum WDGS used in the study contained 40.0% CP, 7.0% ether extract, 46.7% NDF, and 0.45% S. Crude protein was greater than expected, whereas ether extract was lower than expected. As a result, diets containing 25% SWDGS had a lower fat content than the control diet, even though diets were formulated to contain an equivalent fat content.

Cattle Performance. There were no linear or quadratic effects of AH concentration on final BW, DMI, ADG, or G:F ($P \geq 0.16$; Table 3). May et al. (2011) fed increasing levels of AH in SFC-based diets containing 15 or 30% WDGS and, similar to these results, reported no differences in final BW or ADG. However, a linear increase in DMI and a linear decrease in G:F were observed as AH concentration increased (May et al., 2011). Hales et al. (2014) reported decreased gross and retained energy when AH increasingly replaced DRC in diets containing 25% CWDGS. Results reported by Depenbusch et al. (2009) demonstrated that completely removing AH from diets containing sorghum distillers grains decreased final BW, DMI, and ADG.

On a live, shrunk basis, steers consuming diets containing 25% SWDGS were 12 kg lighter ($P = 0.05$; Table 3) at the end of the finishing period than steers fed diets without SWDGS. Additionally, including SWDGS in the finishing diet decreased ($P \leq 0.05$) ADG and G:F. When adjusted using a common DP, final BW and ADG tended ($P \leq 0.10$) to be lower and G:F was reduced ($P < 0.01$) when steers were fed diets with SWDGS compared with when steers were fed diets without SWDGS. Vasconcelos et al. (2007) reported similar results when increasing levels (up to 15%) of SWDGS were included in SFC-based diets containing added fat. They also reported a linear decrease in final BW, ADG, and G:F as level of SWDGS increased. Leibovich et al. (2009) also reported a reduction in final BW, ADG, and G:F when SWDGS were included at 15% of dietary DM in a SFC-based finishing diet with added fat. May et al. (2010) compared level (15 and 30%) and source of WDGS (corn, sorghum, and a 50:50 blend) in SFC-based diets. In that study, including WDGS, regardless of level or source, reduced carcass-adjusted final BW, ADG, and G:F. When comparing source of WDGS, cattle fed diets containing CWDGS had greater feed efficiency than cattle consuming diets with SWDGS or the 50:50 blend. Furthermore, live-basis G:F tended to be greater for cattle fed the 50:50 blend diet compared with those fed the diet with SWDGS (May et al., 2010).

Table 3. Effects of 25% sorghum wet distillers grains plus solubles (WDGS) and alfalfa hay (AH) concentration in finishing diets on performance and carcass characteristics of beef steers in Exp. 1[1]

		25% WDGS				*P*-value[3]		
Item	**CONT**	**7.5AH**	**10.0AH**	**12.5AH**	**SED[2]**	**CON**	**LIN**	**QUAD**
Pens								
Live performance[4]								
Initial BW, kg	379	381	380	379	1	0.10	0.11	0.79
Final BW, kg	642	626	630	634	7	0.05	0.27	0.94
DMI, kg/d	10.4	10.5	10.9	11.0	0.3	0.15	0.16	0.76
ADG, kg	1.73	1.62	1.65	1.69	0.05	0.05	0.18	0.93
G:F	0.166	0.154	0.152	0.153	0.004	<0.01	0.63	0.70
Carcass-adjusted performance[5]								
Final BW, kg	644	631	632	627	10	0.10	0.67	0.74
ADG, kg	1.74	1.64	1.66	1.64	0.06	0.08	0.97	0.76
G:F	0.168	0.157	0.153	0.148	0.006	<0.01	0.17	0.93
Carcass characteristics								
HCW, kg	418	410	410	407	6	0.09	0.67	0.72
DP[4]	65.1	65.4	65.1	64.1	0.7	0.67	0.09	0.60
Fat thickness, cm	1.47	1.65	1.58	1.46	0.08	0.16	0.03	0.69
Marbling score[6]	530	525	530	530	16	0.90	0.77	0.82
LM area, cm^2	90.4	92.2	91.4	92.5	2.0	0.31	0.88	0.56
USDA YG	3.37	3.37	3.35	3.17	0.14	0.53	0.17	0.51
Diet NE_m[7]	2.05	1.98	1.93	1.89	0.05	0.02	0.10	1.00
Diet NE_g[7]	1.38	1.32	1.29	1.25	0.05	0.02	0.12	0.95

[1]Dietary treatments: CONT = steam-flaked corn–based control diet with 0% WDGS; 7.5AH, 10.0AH, and 12.5AH = steam-flaked corn–based diets containing 25% WDGS and 7.5, 10.0, and 12.5% AH, respectively.

[2]SED = SE of the difference.

[3]Contrasts: CON = CONT vs. the average of 25% WDGS diets; LIN = linear effect of AH concentration within diets containing 25% WDGS; QUAD = quadratic effect of AH concentration within diets containing 25% WDGS.

[4]Final BW used for live performance and DP were measured live and shrunk 4% (NRC, 1996).

[5]Final individual BW calculated as individual HCW/64.5% (common DP).

[6]400 = Slight^0; 500 = Small^0; 600 = Modest^0.

[7]Dietary NE_m and NE_g concentrations were calculated as described by Vasconcelos and Galyean (2008), which used the equivalent BW scaling approach of the NRC (1996) with a standard reference weight of 478 kg.

In the present study there was a tendency for a linear decrease in calculated dietary NE_m ($P = 0.10$) and NE_g ($P = 0.12$) with increasing levels of AH (Table 3). Similarly, Parsons et al. (2007) and May et al. (2011) reported a linear decrease in NE_m and NE_g values as concentration of AH increased in diets containing wet corn gluten feed and WDGS, respectively. Dietary NE_m and NE_g values were lower ($P = 0.02$) for diets containing 25% WDGS compared with diets without WDGS. Leibovich et al. (2009) reported lower NE values when SWDGS were included at 15% of the finishing diet. However, May et al. (2010, 2011) did not observe differences in dietary NE values as a result of WDGS inclusion. Differences in calculated dietary NE values in response to distillers by-products may be attributable to such factors as processing method of the primary grain source, type of grain fermented, use of supplemental fat, amount of solubles added to the distillers grains, or energy density of the basal diet (Cole et al., 2009).

Carcass Characteristics. There were no quadratic effects ($P \geq 0.51$; Table 3) of AH concentration on carcass characteristics. Fat thickness decreased ($P = 0.03$) and DP tended to decrease ($P = 0.09$) linearly as level of AH increased. Parsons et al. (2007) reported quadratic responses to AH concentration for fat thickness and DP, with optimal AH level being 4.5% of DM in diets containing 40% wet corn gluten feed. On the other hand, May et al. (2011) reported that carcass characteristics were unaffected by AH concentration in diets containing WDGS. Hot carcass weight tended ($P = 0.09$) to be 9 kg lighter for steers fed diets containing WDGS, reflecting final BW differences. Fat thickness, DP, marbling score, LM area, and YG were not affected ($P \geq 0.16$) by WDGS inclusion. Vasconcelos et al. (2007), Leibovich et al. (2009), and May et al. (2010) reported a reduction in HCW when WDGS was included in finishing diets. Conversely, Depenbusch et al. (2009) and Quinn et al. (2011) reported no effects of distillers grains inclusion on carcass characteristics.

Exp. 2

There was no corn processing method × WDGS interaction detected ($P \geq 0.23$) for ruminal pH (data not shown), which is in agreement with Corrigan et al. (2009). However, a corn processing × time interaction was detected ($P < 0.0001$; Figure 1). Steers consuming DRC-based diets had a more gradual decline in ruminal pH following feeding relative to steers fed SFC-based diets. Similar results were reported by Cooper et al. (2002), who observed a treatment × time interaction in which steers fed SFC-based diets had a lower pH and more rapid decline in ruminal pH following feeding than steers fed DRC-based diets. Steam flaking increased the rate and extent of starch digestion compared with dry-rolling and was supported by total ruminal VFA production (Cooper et al., 2002).

A WDGS × time interaction was also detected ($P = 0.03$; Figure 2) in which cattle consuming diets containing SWDGS had a greater ($P \leq 0.05$) ruminal pH than steers consuming diets with CWDGS or 0WDGS. The NDF of the SWDGS was 43.9% compared with 23.3% for the CWDGS. Lower dietary starch content (compared with 0WDGS) and greater fiber content (compared with CWDGS and 0WDGS) of diets containing SWDGS likely favored an increase in fiber digestibility, resulting in an increase in ruminal pH. Leibovich et al. (2009) reported lower IVDMD and in vitro gas production for diets containing 15% SWDGS compared with diets without SWDGS, which presumably could result in higher ruminal pH. Luebbe et al. (2012) reported similar ruminal pH between steers consuming diets with and without CWDGS.

There were no interactions ($P \geq 0.44$) detected for DM digestibility characteristics of SFC and DRC when WDGS were included in the diet (Table 4). Differences ($P < 0.001$) in DM digestibility were observed between the corn processing methods; SFC was greater than DRC. This agrees with findings reported by Corrigan et al. (2009). The main effect of WDGS did not affect ($P \geq 0.37$) corn DM digestibility. At the time the study was

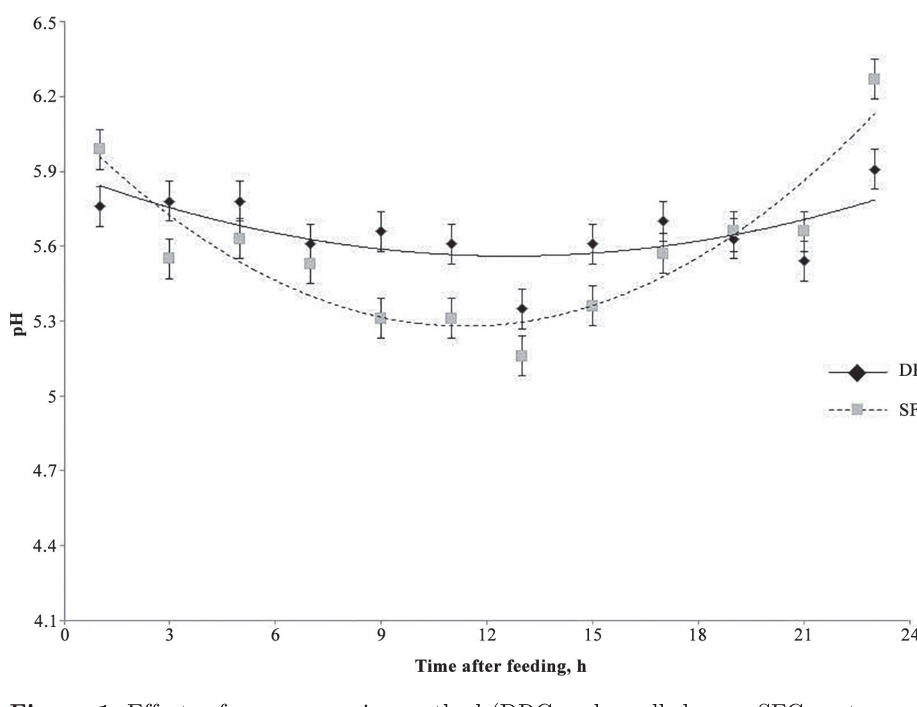

Figure 1. Effects of corn processing method (DRC = dry-rolled corn; SFC = steam-flaked corn) on ruminal pH of steers. Corn processing method × time interaction, $P < 0.0001$. Error bars indicate SEM within each time point.

Table 4. Effects of including 20% corn wet distillers grains plus solubles (WDGS) or sorghum WDGS in finishing diets on in situ DM digestibility of steam-flaked corn (SFC) and dry-rolled corn (DRC) in Exp. 2

	0% WDGS		20% Corn WDGS		20% Sorghum WDGS			*P*-value[3]		
Item[1]	SFC	DRC	SFC	DRC	SFC	DRC	SED[2]	Corn	WDGS	Interaction
a, %	39.0	19.2	39.4	23.3	40.2	20.8	2.5	<0.001	0.37	0.44
b, %	44.4	75.4	41.6	59.7	42.7	75.0	16.4	0.006	0.62	0.74
Rate, %/h	4.45	2.97	6.06	4.02	4.63	3.92	1.64	0.12	0.43	0.82
ERD, %	58.2	44.0	59.8	46.3	59.5	44.9	2.5	<0.001	0.45	0.93

[1]*a* = rapidly soluble fraction; *b* = potentially digestible fraction; Rate = fractional degradation rate of fraction *b*; Effective ruminal digestibility (ERD) = $a + b \times [\text{Rate}/(\text{Rate} + 5.00)]$.

[2]SED = SE of the difference.

[3]Overall treatment *F*-test, where Corn = main effect of corn processing method; WDGS = main effect of dietary WDGS; Interaction = interaction of corn processing method and dietary WDGS.

conducted, it was not clear if WDGS inclusion in finishing diets affected the digestibility of corn. In contrast to our findings, Corrigan et al. (2009) reported that in situ DM digestibility of DRC and SFC was greater in diets containing CWDGS; however, they included WDGS at 40% of dietary DM versus 20% inclusion in the current study. Furthermore, Corrigan et al. (2009) used a 22-h incubation to determine digestibility, whereas a rate calculation was used in the present study.

The effects of corn processing method on DM and NDF digestibility characteristics of WDGS are presented in Table 5. An interaction between corn processing and WDGS was detected ($P \leq 0.05$) for the potentially digestible fraction of both DM and NDF. In DRC-based diets, SWDGS had the greatest potentially digestible fraction, whereas CWDGS had the least potentially digestible fraction. The main effect of corn processing method did not affect DM or NDF digestibility ($P \geq 0.73$) of either CWDGS or SWDGS. Similarly, Corrigan et al. (2009) reported DM and NDF digestibility of WDGS were not affected by corn processing method. Digestibility of DM and NDF differed between CWDGS and SWDGS ($P < 0.0001$). Dry matter digestibility was greater for CWDGS than SWDGS, whereas NDF digestibility was greater for SWDGS than CWDGS. This was not the case with observations reported by Depenbusch et al. (2009) and May et al. (2010). Depenbusch et al. (2009) fed SFC-based diets containing either corn or sorghum distillers grains in both the wet and dried form and reported similar apparent total-tract DM digestibility between corn and sorghum distillers grains. May et al. (2010) included 15% corn or SWDGS in SFC-based diets and reported similar apparent total-tract digestibility of DM and NDF. Distillers grains may differ not only in the source of grain fermented but also in the amount of solubles added back to the grains, and this may contribute to inconsistencies in digestibility and performance responses. Cao et al. (2009) used cannulated cows to measure in situ digestibility of distillers grains containing varying levels of solubles. Ruminal DM digestibility increased with increasing levels of solubles. Because rate of degradation did not differ among solubles levels,

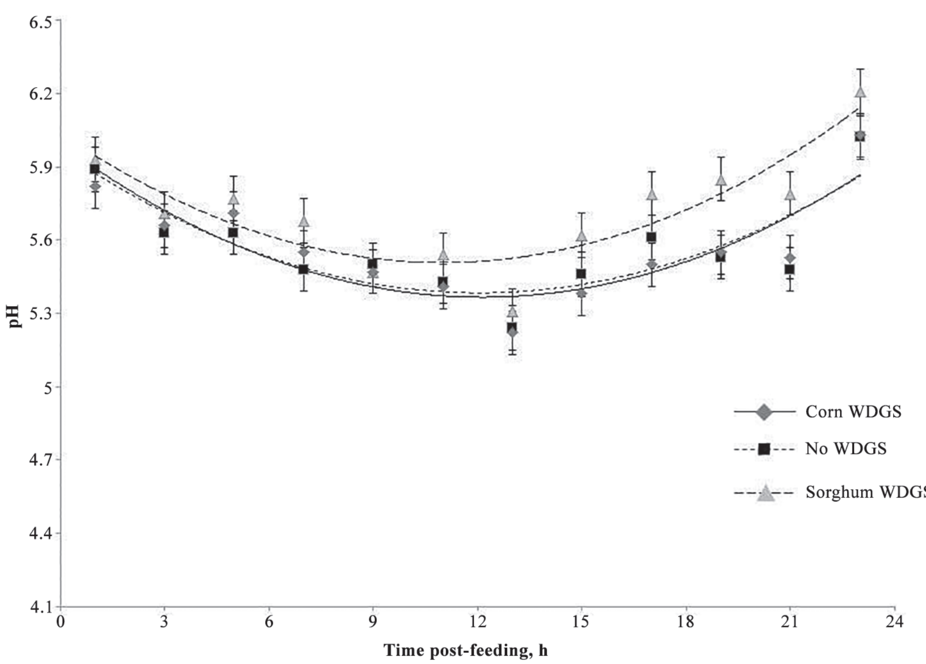

Figure 2. Effects of corn or sorghum wet distillers grains plus solubles (WDGS) included at 0 or 20% of dietary DM in finishing diets on ruminal pH. WDGS × time interaction, $P = 0.03$. Error bars indicate SEM within each time point.

Table 5. Effects of corn processing method [steam-flaked corn (SFC) or dry-rolled corn (DRC)] on in situ DM and NDF digestibility of corn wet distillers grains plus solubles (WDGS) or sorghum WDGS in Exp. 2

	Corn WDGS		Sorghum WDGS			*P*-value[3]		
Item[1]	SFC	DRC	SFC	DRC	SED[2]	Corn	WDGS	Interaction
DM								
a, %	59.9	60.3	41.4	38.1	2.0	0.31	<0.0001	0.21
b, %	38.1[ab]	16.1[b]	33.1[ab]	56.3[a]	12.9	0.95	0.10	0.05
Rate, %/h	2.82	5.10	3.15	2.21	2.90	0.57	0.29	0.19
ERD, %	66.3	67.6	50.3	50.1	2.1	0.73	<0.0001	0.60
NDF								
a, %	13.9	13.8	27.8	22.8	2.8	0.22	0.0002	0.23
b, %	24.1[bc]	19.9[c]	27.8[b]	38.4[a]	2.9	0.13	0.0006	0.005
Rate, %/h	6.31	12.7	4.82	5.09	4.33	0.29	0.16	0.33
ERD, %	24.7	24.2	39.8	40.2	2.4	0.95	<0.0001	0.77

[1]*a* = rapidly soluble fraction; *b* = potentially digestible fraction; Rate = fractional degradation rate of fraction *b*; Effective ruminal digestibility (ERD) = $a + b \times$ [Rate/(Rate + 5.00)].

[2]SED = SE of the difference.

[3]Overall treatment *F*-test, where Corn = main effect of corn processing method; WDGS = main effect of dietary WDGS; Interaction = interaction of corn processing method and dietary WDGS.

the authors attributed the differences in DM digestibility to solubles concentration (Cao et al., 2009).

IMPLICATIONS

Average daily gain and feed efficiency were reduced when SWDGS was included in the diet of finishing steers regardless of roughage level included. This is apparently the result of reduced NE_m and NE_g rather than NDF digestibility. The DM and NDF digestibility of WDGS was not affected by processing method of the corn. Therefore, although including SWDGS in traditional SFC diets may reduce ADG and G:F, it may be an economical substitution for more expensive SFC if the SWDGS is favorably priced and an improved cost of gain can be realized.

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