Effects of roughage concentration in steam-flaked corn-based diets containing wet distillers grains with solubles on feedlot cattle performance, carcass characteristics, and in vitro fermentation

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ABSTRACT: Two studies were conducted to evaluate effects of wet distillers grains with solubles (WDG) and dietary concentration of alfalfa hay (AH) on performance of finishing beef cattle and in vitro fermentation. In both studies, 7 treatments were arranged in a 2 × 3 + 1 factorial; factors were dietary concentrations (DM basis) of WDG (15 or 30%) and AH (7.5, 10, or 12.5%) plus a non-WDG control diet that contained 10% AH. In Exp. 1, 224 beef steers were used in a randomized complete block (initial BW 342 kg ± 9.03) finishing trial. No WDG × AH interactions were observed (P > 0.12). There were no differences among treatments in final shrunk BW or ADG (P > 0.15), and DMI did not differ with WDG concentration for the overall feeding period (P = 0.38). Increasing dietary AH concentration tended (P < 0.079) to linearly increase DMI, and linearly decreased (P < 0.05) G:F and calculated dietary NEm and NEg concentrations. Carcasses from cattle fed 15% WDG had greater yield grades (P = 0.014), with tendencies for greater 12th-rib fat (P = 0.054) and marbling score (P = 0.053) than those from cattle fed 30% WDG. There were no differences among treatments (P > 0.15) in HCW, dressing percent, LM area, KPH, proportions of cattle grading USDA Choice, and incidence of liver abscesses. In Exp. 2, ruminal fluid was collected from 2 ruminally cannulated Jersey steers adapted to a 60% concentrate diet to evaluate in vitro gas production kinetics, H2S production, IVDMD, and VFA. Relative to the control substrate, including WDG in substrates increased (P < 0.01) H2S production and decreased total gas production (P = 0.01) and rate of gas production (P = 0.03). Increasing substrate WDG from 15 to 30% increased (P < 0.05) H2S production and decreased (P < 0.001) total gas production, with a tendency (P = 0.073) to decrease IVDMD and fractional rate of gas production (P = 0.063). Treatments did not significantly affect (P > 0.09) molar proportions or total concentration of VFA. Results indicate that including 15 or 30% WDG in steam-flaked corn-based diets did not result in major changes in feedlot performance or carcass characteristics, but increasing AH concentration from 7.5 to 12.5% in diets containing WDG decreased G:F. Including WDG in substrates decreased rate and extent of gas production and increased H2S production. Changes in various measures of in vitro fermentation associated with AH concentrations were not large.

Key words: beef cattle, distillers grains with solubles, feedlot, in vitro dry matter disappearance

INTRODUCTION

Subacute acidosis might be decreased when distillers grains (DG) are included as ≥20% of feedlot diets as a result of the increased fiber, protein, and fat and decreased starch in DG (Owens et al., 1998; Klopfenstein et al., 2008). Because DG has relatively high concentrations of NDF and ADF compared with grain and other concentrates it replaces in the diet (Klopfenstein et al., 2008), a practical consideration is whether the dietary concentration of roughage should be altered when DG are included in feedlot diets. Benton et al. (2007) evaluated roughage concentration and source in feedlot diets containing 30% wet DG plus solubles (WDG) and dry-rolled corn (DRC) or high-moisture corn (HMC).
Comparisons for alfalfa hay (AH) included at 4 or 8% of diet DM, corn silage included at 6 or 12% of diet DM, and corn stalks included at 3 or 6% of dietary DM were made relative to a control with no added roughage. Compared with the control, adding roughage increased final BW, DMI, and ADG, with no effect on G:F. Moreover, feeding the greater concentrations of roughage increased final BW, DMI, and ADG. Miller et al. (2009) fed heifers AH at 3, 6, 9, 12, and 15% of the diet, respectively, in steam-flaked corn (SFC)-based diets containing 25% dry corn DG with solubles. As dietary roughage increased, DMI and HCW increased quadratically, with the greatest response in heifers fed diets containing 12% AH.

The effects of roughage concentration in SFC-based diets that contain WDG have not been studied. Thus, the objective of our 2 experiments was to evaluate effects of WDG (15 or 30%) and AH (7.5, 10, or 12.5%) concentrations (DM basis) in SFC-based diets on feedlot performance, carcass characteristics, and various measures of in vitro fermentation.

MATERIALS AND METHODS

All procedures involving live animals were approved by the Texas Tech University Animal Care and Use Committee.

Exp. 1

Treatments and Cattle. A randomized complete block design with a 2 × 3 + 1 factorial arrangement of treatments was used. Dietary factors consisted of 2 concentrations of WDG (15 and 30%) and 3 concentrations of AH (7.5, 10, and 12.5%) compared with a 0% WDG, 10% AH control diet; all concentrations are expressed on a DM basis. Thus, the resulting 7 SFC-based diets (Table 1) were no WDG (CON) diet, and diets containing 15% WDG with 7.5, 10, or 12.5% AH (DG15-L, DG15-M, and DG15-H, respectively) or 30% WDG with 7.5, 10, or 12.5% AH (DG30-L, DG30-M, and DG30-H, respectively). All diets were formulated to meet or exceed nutrient requirements recommended by NRC (1996) and to contain equal concentrations of ether extract and degraded intake protein (DIP; based on NRC, 1996 tabular values) and are further described in Table 1. A premix provided Rumensin and Tylan (33 and 11 mg/kg, DM basis, respectively; Elanco Animal Health, Indianapolis, IN). The WDG was acquired from an ethanol plant in Plainview, TX, and was produced from a blend of corn grain and no more than 10% sorghum grain. The WDG was transported from the ethanol plant to the Texas Tech University Burnett Center located near New Deal, TX, and stored in a plastic silage bag for the duration of the experiment. A composite sample of the WDG was collected by combining samples from each load as the WDG was unloaded into the silage bag; this sample was stored at −5°C until chemical analyses were conducted.

Beef steers (British crossbred; 248 total) were purchased from 2 sale barns in the Texas Panhandle and shipped to the Texas Tech University Burnett Center. On arrival in early March 2009, cattle were weighed [Silencer Squeeze Chute, Moly Mfg. Inc., Lorraine, KS; overhead scale with 2 Avery Weigh-Tronix (Fairmont, MN) load cells; readability ±0.45 kg]. The scale was validated with 454 kg before each use, and calibrated as needed. Cattle were given individual ear tags; vaccinated (Vista 5 SQ and Vision 7 with SPUR, Intervet/Schering-Plough Animal Health, De Soto, KS); treated with an external parasiticide (Ivermectin, Merial Animal Health, Duluth, GA) and an oral dose of dewormer (Safeguard, Intervet/Schering-Plough Animal Health); and injected with 10 mg/kg of BW of tilmicosin phosphate (Micotil, Elanco Animal Health). Steers were implanted with Ralgro (36 mg of zeranol, Intervet/Schering-Plough Animal Health) approximately 2 wk after arrival. After processing, cattle were housed in open-lot, soil-surfaced pens with 14 to 16 steers/pen. After approximately 18 d, the cattle were switched to a 73% concentrate, SFC-based diet.

In late March, all cattle were individually weighed, and 224 steers (BW 342 kg ± 9.03) were selected for use in the experiment. The cattle were stratified by BW into 8 blocks of 28 steers each. Within each block, steers were assigned randomly to 1 of the 7 dietary treatments, resulting in 8 pens/treatment. The cattle were then moved to 56 concrete (4 steers/pen), partially slotted-floor pens (2.9 m wide × 5.6 m deep; 2.4 m of linear bunk space) on April 3, where they continued to be fed the 73% concentrate diet for another 4 d, at which time they were switched to an 85% concentrate, SFC-based diet. One week later, all cattle were weighed in the morning before feeding to obtain an individual initial BW, and the experimental diets (Table 1) were fed. At this time, the feed delivery was decreased to 95% of the quantity delivered the previous day, with adjustments for the change in moisture content of the 15 and 30% WDG diets. On d 35 of the experiment period (50 d after the initial implant), all cattle were reimplanted with Revalor-S (120 mg of trenbolone acetate and 24 mg of estradiol, Intervet/Schering-Plough Animal Health).

Feed Mixing and Feeding, Cattle Weighing, and Routine Management. From 0700 to 0730 h daily, estimates of the approximate quantity of unconsumed feed remaining in the feed bunk were made for each of the 56 pens of cattle. Feed bunks were managed in an effort to maintain ≤0.45 kg of residual feed remaining before fresh feed was delivered. Diets were mixed in a paddle mixer (1.27-m³ volume; Marion Mixers Inc., Marion, IA) and transferred by a drag-chain conveyor to a tractor-pulled mixer/delivery unit (Roto-Mix 84-8, Dodge City, KS; scale readability of ± 0.454 kg), which was used to deliver feed to each pen. The mixer was checked visually to ensure adequate cleanout and thereby decrease the potential for diet cross-contamination.
Samples of WDG were taken weekly during the experiment to determine DM content, whereas other dietary ingredients were sampled for DM content every other week (forced-air oven for 15 h at 100°C). In addition, samples of mixed feed taken from the feed bunks for each treatment were collected weekly throughout the experiment and composited across weigh periods. Composited feed samples and WDG collected during unloading were analyzed by a commercial laboratory (SDK Laboratories, Hutchinson, KS). Analyses performed were N (FP-200, Leco Corp., St. Joseph, MI) using official method 992.15 (AOAC, 1995); Ca and K using official method 968.08 (AOAC, 1995); P using official method 965.17 (AOAC, 1995); S using official method 985.01 (AOAC, 1995); and ether extract using official method 920.39 (AOAC, 1995). Determination of ADF was conducted using an Ankom 200 Fiber Analyzer using procedures of Goering and Van Soest (1970) as modified by Ankom Technology, Fairport, NY. Analytical results for the WDG used in both experiments are shown in Table 2.

Steers were weighed at 35-d intervals throughout the experiment. Individual, nonshrunk BW measurements (scale readability ± 0.45 kg) were taken at the start of the experiment and immediately before shipment for slaughter. Intermediate BW (d 35, 70, and 105) obtained during the course of the experiment were measured, samples of mixed feed taken from the feed bunks for each treatment were collected weekly throughout the experiment and composited across weigh periods. Composited feed samples and WDG collected during unloading were analyzed by a commercial laboratory (SDK Laboratories, Hutchinson, KS). Analyses performed were N (FP-200, Leco Corp., St. Joseph, MI) using official method 992.15 (AOAC, 1995); Ca and K using official method 968.08 (AOAC, 1995); P using official method 965.17 (AOAC, 1995); S using official method 985.01 (AOAC, 1995); and ether extract using official method 920.39 (AOAC, 1995). Determination of ADF was conducted using an Ankom 200 Fiber Analyzer using procedures of Goering and Van Soest (1970) as modified by Ankom Technology, Fairport, NY. Analytical results for the WDG used in both experiments are shown in Table 2.

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sured on a pen basis using a platform scale that was validated with 454 kg of certified weights before each use. Before each weigh day, residual feed was removed, analyzed for DM content, and feed deliveries were adjusted for DM in the orTs.

When approximately 60% of the steers in a BW block were deemed to have achieved a sufficient composition-endpoint to reach USDA Choice, they were shipped via commercial transport to a commercial abattoir located in Plainview, TX. There were 3 slaughter dates, with cattle in blocks 1 through 3, 4 through 6, and 7 and 8 on feed for 176, 154, and 133 d, respectively. Pen means for ADG and DMI were included in the data file, and G:F was computed as the quotient of ADG divided by daily DMI. Performance-based estimates of dietary NE<sub>e</sub> and NE<sub>r</sub> concentrations were calculated as described by Vasconcelos and Galyean (2008).

**Carcass Evaluation.** Carcass data included HCW, LM area, KPH, 12th-rib fat, and calculated USDA yield grade. Livers were classified as either not condemned or as A−, A, or A+ for the presence of abscesses using a scale similar to Brown et al. (1975). Hot carcass weight and dressing percent data for cattle that were identified as having excessive carcass trim (1 CON, 1 DG15-H, and 1 DG30-M) were excluded from the analysis. In addition, 4 animals either died or were removed from the experiment for reasons not related to treatments (1 CON, 1 DG15-H, DG15-M, DG15-H, DG30-L, DG30-M, and DG30-H) were used. Before inclusion in substrates, the WDG was dried in a forced-air oven for 24 h at 50°C. Remaining ingredients (excluding corn oil) were air-dried for 48 h with a fan blowing air across the surface of the samples. Once dried, ingredients were ground to pass a 2-mm screen in a Wiley mill and mixed into their respective substrates. Substrates were sent to a commercial laboratory for the analyses as described in Exp. 1 (SDK Laboratories), except for NDF, which was measured in our laboratory using an Ankom 200 Fiber Analyzer (Ankom Technology) according to procedures of Van Soest et al. (1991; as modified by Ankom Technology). A heat stable α-amylose (Ankom Technology) was added to substrate samples to remove residual starch.

**In Vitro Analyses.** A modified Tilley and Terry (1963) procedure was used for all 3 in vitro systems. An incubation time of 24 h was chosen because of the high-concentrate substrates used in the experiment, and this time is similar to the value reported by Ramirez et al. (1985) for ruminal mean retention time of dysprosium-labeled SFC (24.3 h). In addition, Ramirez et al. (1985) and Brown et al. (1998) observed that 85 to 95% of grain IVDMD occurred in a 24-h incubation period. Approximately 1 g ± 0.05 g of each substrate was dried using a forced-air oven overnight at 100°C to calculate substrate DM. Ruminal fluid was collected from 2 ruminally cannulated Jersey crossbred steers (BW = 535 kg) fitted with a 7.62-cm ruminal cannula and housed at the Burnett Center. The steers were fed a 60% concentrate (DM basis) diet containing SFC, cottonseed meal, ground AH, and corn oil were used to mix 7 treatment substrates for in vitro fermentation studies. These substrates were used to evaluate IVDMD, in vitro rate of gas production, H<sub>2</sub>S production, and VFA proportions and concentrations. Substrates were balanced for ether extract and approximately 8% DIP (based on tabular values of NRC, 1996). Because the 7 treatment substrates were similar to the diets fed in Exp. 1, the same treatment designations in Exp. 1 (CON, DG15-L, DG15-M, DG15-H, DG30-L, DG30-M, and DG30-H) were used. When approximately 60% of the steers in a BW block were deemed to have achieved a sufficient composition-endpoint to reach USDA Choice, they were shipped via commercial transport to a commercial abattoir located in Plainview, TX. There were 3 slaughter dates, with cattle in blocks 1 through 3, 4 through 6, and 7 and 8 on feed for 176, 154, and 133 d, respectively. Pen means for ADG and DMI were included in the data file, and G:F was computed as the quotient of ADG divided by daily DMI. Performance-based estimates of dietary NE<sub>e</sub> and NE<sub>r</sub> concentrations were calculated as described by Vasconcelos and Galyean (2008).

**Statistical Analyses.** Performance and carcass data were analyzed as a randomized complete block design with a 2 × 3 + 1 factorial arrangement of treatments with pen as the experimental unit. Data were analyzed using the Mixed procedure (SAS Inst. Inc., Cary, NC). The random effect of block was included in the statistical model, with treatment as a fixed effect. Preplanned orthogonal contrasts evaluated were the effects of the control treatment to WDG treatments, AH (7.5, 10, and 12.5%; linear and quadratic responses), and WDG inclusion (15 vs. 30%), as well as AH × WDG inclusion interactions. The proportions of cattle grading USDA Choice or greater were analyzed with the GLIMMIX procedure of SAS (binomial proportion), with the ILINK option used to calculate the treatment proportions and SE. Block was a random effect, and the same contrast statements were used as described previously. The α-level for all analyses was ≤0.05, with P-values between 0.05 and ≤0.10 considered tendencies.

**Exp. 2**

**Treatments.** Feed ingredients consisting of SFC, cottonseed meal, AH, WDG (same source as Exp. 1), urea, and corn oil were used to mix 7 treatment substrates for in vitro fermentation studies. These substrates were used to evaluate IVDMD, in vitro rate of gas production, H<sub>2</sub>S production, and VFA proportions and concentrations. Substrates were balanced for ether extract and approximately 8% DIP (based on tabular values of NRC, 1996). Because the 7 treatment substrates were similar to the diets fed in Exp. 1, the same treatment designations in Exp. 1 (CON, DG15-L, DG15-M, DG15-H, DG30-L, DG30-M, and DG30-H) were used. Before inclusion in substrates, the WDG was dried in a forced-air oven for 24 h at 50°C. Remaining ingredients (excluding corn oil) were air-dried for 48 h with a fan blowing air across the surface of the samples. Once dried, ingredients were ground to pass a 2-mm screen in a Wiley mill and mixed into their respective substrates. Substrates were sent to a commercial laboratory for the analyses as described in Exp. 1 (SDK Laboratories), except for NDF, which was measured in our laboratory using an Ankom 200 Fiber Analyzer (Ankom Technology) according to procedures of Van Soest et al. (1991; as modified by Ankom Technology). A heat stable α-amylose (Ankom Technology) was added to substrate samples to remove residual starch.

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**Gas and H<sub>2</sub>S Production.** Procedures for total gas and H<sub>2</sub>S production have been described in detail.
by Quinn et al. (2009) and May et al. (2010a). In brief, approximately 0.7 ± 0.01 g of substrate (as-is basis) was weighed and placed in a 125-mL serum bottle. Each serum bottle received 37.5 mL of McDougall’s buffer (McDougall, 1948) and 12.5 mL of strained ruminal fluid, after which each bottle was flushed with CO₂, capped with a butyl rubber stopper, and crimp-sealed. Sealed bottles were incubated in an oscillating shaker (Environ-Shaker, Lab-Line Industries, Melrose Park, IL) for 24 h at 39°C with an oscillation speed of 125 rpm. Total gas produced in the bottle was measured using a water displacement method, and a sample headspace gas in each vial was analyzed for H₂S using a method based on the conversion of N-N-dimethyl-p-phenylenediamine to methylene blue. The CV for the slope of the standard curve over duplicate assays was 4.85%. Samples were corrected for differences in fermentable DM and H₂S introduced into the system from ruminal fluid as described by May et al. (2010b).

**VFA Analyses.** Fluid samples taken from each 125-mL serum bottle from the gas production phase of the experiment were retained, and 500 µL of a 20% (vol/vol) H₂SO₄ solution were added to stop fermentation. These samples were frozen, and duplicate samples were analyzed by gas chromatography for VFA concentrations as described by May et al. (2010b). The average CV with duplicate samples for total VFA concentration was 3.40%, and when the CV exceeded 10%, samples were reanalyzed. Based on the molar proportions and total VFA concentrations, estimates of methane and CO₂ produced and hexose fermented were calculated as described by Wolin (1960).

**IVDMD.** For the IVDMD analysis (adapted from Galyean, 1997), 0.5 ± 0.05 g were weighed for each treatment in triplicate on each of the 2 separate runs and placed in 50-mL plastic centrifuge tubes. Incubation methods were as described by May et al. (2010b). Although the total volume was only 36 mL, the ruminal fluid-to-buffer ratio was the same as used in the gas production measurements. Three blanks were prepared for each run; blanks did not contain substrate but had the same quantities of ruminal fluid and buffer solution as cultures containing substrates. A 48-h acidified pepsin incubation followed the initial incubation, after which samples were filtered and dried (100°C overnight) to calculate IVDMD (May et al., 2010b).

**In Vitro Kinetics of Gas Production.** Twenty-four 250-mL gas pressure monitor modules (Ankom Technology) were used with each of the 7 treatments in triplicate, plus 3 blank flasks (no substrate) for each of 2 runs conducted on separate days. Each flask received approximately 1.4 ± 0.01 g of treatment substrate. Total culture volume was 100 mL, and the ruminal fluid collection and ruminal fluid:McDougall’s buffer ratio were as described for the IVDMD and gas production procedures. Other details of the procedure were described by May et al. (2010b).

**Statistical Analyses.** As noted previously, IVDMD, total gas and H₂S production, VFA proportions and total concentration, and gas production kinetics were replicated on 2 separate days. In each day, tubes, flasks, or serum bottles were incubated in triplicate to estimate sampling error. The MIXED procedure of SAS was used to analyze the data in a randomized complete block design. Within the model, day effect represented block and was considered random, whereas the 7 treatment substrates were the fixed effects. A nonlinear model (modified Gompertz; Schofield et al., 1994) was used to fit the data from the gas pressure system. The parameters of this model were lag time (h), asymptotic gas production (V), and rate of gas production (k). Fractional rate of gas production was calculated as k divided by V. The resulting model estimates were analyzed using the same mixed model described above for the other in vitro data. Preplanned orthogonal contrasts and the α levels were the same as in Exp. 1.

**RESULTS AND DISCUSSION**

**Exp. 1**

**Diet Composition.** Chemical composition data for the 7 diets (Table 1) generally agreed with values expected from formulation. Diets were formulated to contain 15 and 30% WDG, respectively; however, as shown in Table 1, actual values differed slightly from formulated values because diets were formulated based on the DM of a composite sample of the WDG taken before the start of the trial. After completing the trial, the formulation was corrected for the DM contents of ingredients used throughout the trial. Diets were formulated for equivalent ether extract concentrations; the resulting range among treatments was 5.23 to 6.09% ether extract (DM basis). As expected from the S concentration of WDG (Table 2), dietary S concentrations increased as WDG concentration increased, which was especially the case for the 30% WDG diets. These S concentrations were well below the 0.4% maximum tolerable value suggested by NRC (1996). More recently, NRC (2005) recommended a maximum tolerable concentration of 0.3% for S in high-concentrate diets, and our 30% WDG diets had S concentrations close to that value. Decreased ruminal ammonia concentrations have been observed when feeding DG-containing diets (Ham et al., 1994; May et al., 2009; Uwituze et al., 2010). Moreover, with SFC-based diets, Wagner et al. (2010) reported that including less than 7.4% DIP might limit feedlot performance, but increasing DIP above 8.4% resulted in little further improvement in performance; thus, our diets were formulated to contain 8% DIP. Our diets were not iso-nitrogenous, and the 30% WDG diets had appreciably more CP than the CON diet, reflecting the CP concentration of WDG (Table 2). The ADF concentration increased as WDG concentration increased, which also was expected from the ADF concentration of WDG (Table 2); however, ADF concentration was not consistently responsive to AH concentration, which presumably reflects variance associated
with sampling from feed bunks over the course of the study. In a survey of feedlot nutritionists, Vasconcelos and Galyean (2007) reported that the range of dietary roughage concentrations used by consultants was 4.50 to 13.50%, with a mean of 8.30% (DM basis). Thus, the dietary AH concentrations used in the current experiment are well within the range of roughage concentrations observed in US feedlot diets.

**Feedlot Performance.** For consistency of presentation across tables, simple-effect means for treatment responses are shown in the tables, and results will be presented and discussed in the context of the preplanned orthogonal contrasts. No significant WDG × AH concentration interactions ($P \geq 0.12$) were detected for feedlot performance or carcass characteristics. There were no differences among treatments in final BW, adjusted final BW, or ADG (d 0 to 105, d 0 to end; $P > 0.15$; Table 3). Our results for WDG concentrations are similar to those of Corrigan et al. (2009), who fed diets containing 0, 15, 27.5, or 40% wet corn DG with solubles in DRC-, HMC-, or SFC-based diets. For the SFC-based diets, Corrigan et al. (2009) observed quadratic effects on final BW, shrunk BW, and ADG, with the 40% wet corn DG with solubles diet resulting in decreased performance compared with other treatments. Depenbusch et al. (2009a) fed SFC-based diets and dried DG plus solubles in 15% increments up to 75%, and observed linear and quadratic effects of DG concentration on final BW, DMI, and ADG. When dried DG composed more than 30% of the diet, feedlot performance was decreased, but lesser concentrations resulted in similar or greater performance than the control.

There was a linear effect of AH on ADG from d 0 to 35 ($P = 0.045$) and from d 0 to 70 ($P = 0.023$), with diets containing less AH resulting in greater ADG. Similarly, Kreikemeier et al. (1990) fed 0, 5, 10, or 15% AH in steam-flaked wheat diets and observed that ADG responded quadratically, with maximal ADG between 5 and 10% AH. Complete removal of roughage when feeding WDG would not be recommended based on results of Depenbusch et al. (2009b), who fed diets containing

### Table 3. Effects of wet distillers grain with solubles (WDG; 15 or 30%) and alfalfa hay concentration (7.5, 10, or 12.5%) on performance by finishing beef steers in Exp. 1

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<td>Adjusted final BW, kg</td>
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<td>578</td>
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<td>ADG, kg</td>
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<tr>
<td>d 0 to 35</td>
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<td>d 0 to end</td>
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<td>Daily DMI, kg/steer</td>
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<td>d 0 to 35</td>
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<td>d 0 to end</td>
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<td>8.96</td>
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<td>G:F⁴</td>
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<td>d 0 to 35</td>
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<td>0.249</td>
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<td>0.218</td>
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<td>0.204</td>
<td>0.212</td>
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<td>0.198</td>
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<td>d 0 to end</td>
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<td>0.173</td>
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<td>0.0028</td>
<td>Linear*</td>
</tr>
<tr>
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<td>0.175</td>
<td>0.168</td>
<td>0.168</td>
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<td>0.163</td>
<td>0.167</td>
<td>0.0032</td>
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<td>2.10</td>
<td>2.05</td>
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<td>2.06</td>
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<td>1.43</td>
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<td>1.39</td>
<td>1.40</td>
<td>0.018</td>
<td>Linear*</td>
</tr>
<tr>
<td>NEₑ, Mcal/kg of DM</td>
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</tbody>
</table>

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¹CON = standard steam-flaked corn-based diet; DG15-L, DG15-M, and DG15-H = steam-flaked corn-based diets with 15% wet distillers grain and 7.5, 10, or 12.5% alfalfa hay, respectively; and DG30-L, DG30-M, and DG30-H = steam-flaked corn-based diets with 30% wet distillers grain and 7.5, 10, or 12.5% alfalfa hay, respectively.

²Pooled SE of treatment means, n = 8 pens/treatment.

³Orthogonal contrasts: DG = the average of the 15% WDG diets vs. the average of the WDG 30% diets; linear = linear effects of alfalfa hay concentration; Q = quadratic effects of alfalfa hay concentration. * $P \leq 0.05$; † $P \leq 0.05$ ≤ 0.10; NS = $P > 0.10$.

⁴The ADG data for d 0 to 35, d 0 to 70, and d 0 to 105 were not shrunk; however, a 4% shrink was applied to final BW and adjusted final BW for calculation of ADG from d 0 to end and adjusted, d 0 to end. No shrink factor was applied to initial BW data.

⁵Adjusted final BW equalled HCW divided by the average dressing percent of each shipment group (62.35, 62.28, and 62.68%, for the first, second, and third groups, respectively). Adjusted BW gain (d 0 to end) was calculated from the adjusted final BW and the initial BW, and adjusted G:F (d 0 to end) was calculated as the ratio of adjusted ADG to d 0 to end DMI.

⁶Cattle in the blocks 1 through 3, 4 through 6, and 7 and 8 were on feed for 176, 154, and 133 d, respectively.

⁷Dietary NE values were calculated from performance data using energy requirement equations for maintenance and shrunk BW gain from NRC (1996).
15% wet or dry sorghum DG with 0 or 6% AH and reported that removing roughage from the diet decreased final BW, DMI, and ADG.

There was a tendency for cattle fed 15 vs. 30% WDG to have greater ADG from d 0 to 35 (P = 0.093; Table 3). Associated with the ADG response, there was a tendency for cattle fed 15 vs. 30% WDG to have greater DMI from d 0 to 35 (P = 0.059), and DMI was greater with 15% WDG from d 0 to 70 (P = 0.049; Table 3); however, there was no effect (P > 0.17) of WDG concentration on DMI from d 0 to 105 or for the overall feeding period. For the overall feeding period, DMI tended (P = 0.079) to increase linearly as AH concentration increased in the diet (Table 3). Increased DMI with increasing dietary roughage concentrations agrees with observations by Kreikemeier et al. (1990), Defoor et al. (2002), and Miller et al. (2009), who fed 6 or 10% AH in SFC-based diets, observed increased DMI with 10% AH early in the feeding period (d 0 to 35 and d 0 to 70); however, roughage concentration did not have a significant effect on DMI for the overall feeding period. In the present study, increasing the percentage of AH decreased G:F in all periods (P < 0.041), and there were tendencies for linear (P = 0.068) and quadratic (P = 0.077) effects of AH on carcass-adjusted G:F (Table 3). Similar to the present results, May et al. (2010c) fed diets containing 25% dry corn DG with 5 or 15% corn silage and observed that decreasing roughage concentration decreased DMI; however, this response had no effect on ADG, thereby improving G:F. Our results contradict those of Parsons et al. (2007) and Miller et al. (2009). Miller et al. (2009) fed SFC-based diets with 25% dried DG and 3, 6, 9, 12, or 15% AH and observed no differences among treatments in G:F. Parsons et al. (2007) fed diets containing 40% wet corn gluten feed and 0, 4.5, or 9% AH, and observed that as AH increased, DMI and ADG also increased, such that G:F was not affected by AH concentration.

The improvements in G:F at lesser AH concentrations resulted in linear increases in dietary NE_m and NE_g concentrations calculated from performance data (P < 0.01). The tabular NE values for each ingredient were adjusted for the performance-based calculations. For example, performance-based NE values were approximately 96% of tabular values. Thus, the tabular values for all non-WDG ingredients were multiplied by this adjustment factor. These adjusted ingredient NE concentrations and diet formulations were then used to determine the contribution of the non-WDG ingredients to the dietary NE values. This contribution was subtracted from the performance-based NE concentration for each diet, with the difference divided by the percentage of WDG in the diet to calculate the NE concentration of WDG. Based on this approach, the NE concentration for WDG ranged from 92.2 to 105.1% (NE_m) and 88.2 to 105.1% (NE_g) of the performance-adjusted value for SFC. The least values were for the DG15-H treatment, and the greatest were for the DG30-L treatment. Our finding of greater (P < 0.01) calculated NE concentrations with decreased dietary roughage is similar to observations by Kreikemeier et al. (1990), who observed quadratic effects of roughage concentration on NE_m and NE_g, with values being greatest between 5 and 10% AH. In addition, Parsons et al. (2007) observed that as AH decreased in diets containing 40% wet corn gluten feed, there were linear increases in calculated dietary NE_m and NE_g concentrations.

Carcass Characteristics. Cattle fed 15 vs. 30% WDG had greater calculated yield grade (P = 0.014; Table 4), with tendencies for greater 12th-rib fat (P = 0.054) and marbling score (P = 0.053). Corrigan et al. (2009) observed a quadratic effect of wet corn DG with solubles concentration on yield grade, 12th-rib fat thickness, and marbling score in cattle fed SFC-based diets, with maximal responses at 15% wet corn DG with solubles. Increased yield grade and 12th-rib fat also agrees with observations of Benson et al. (2005), who fed 0, 15, 25, or 35% dried DG in DRC-based feedlot diets. Nonetheless, these authors also observed increased HCW with increasing DG concentration, which was not evident in our study. May et al. (2010c) reported an increased proportion of carcasses with yield grades of 4 or 5 when feeding 25% dried DG compared with controls. Similarly, Vasconcelos et al. (2007) observed greater calculated yield grades when the concentration of wet sorghum DG increased from 0 to 15%, with no effect on marbling score or 12th-rib fat.

There were no differences among treatments in HCW, dressing percent, LM area, KPH, proportions of cattle grading USDA Choice, and incidence of liver abscess (P > 0.15; Table 4). These results are similar to those of Depenbusch et al. (2009a) for diets containing up to 30% dried DG. Likewise, Uwituze et al. (2010) observed no differences in HCW, dressing percent, LM area, KPH, 12th-rib fat, or USDA quality grade in SFC-based diets containing AH or corn silage with 0 or 25% dried DG.

Exp. 2

Substrate Composition. Chemical composition data for the 7 in vitro substrates (Table 5) generally agreed with values expected from formulation. As noted previously, substrates were balanced to provide similar tabular DIP values (approximately 8% DIP) but not CP. Thus, substrates containing WDG had greater CP concentrations than the CON treatment. In addition, the CP content was greater for substrates containing 30 vs. 15% WDG. As expected, ADF and NDF concentrations were slightly greater in substrates containing 30% WDG. Moreover, as the AH concentration increased in substrates, ADF and NDF increased. This finding is somewhat in contrast to the results of Exp. 1, presumably reflecting sampling errors associated with weekly collections of mixed diets and compositing procedures used in Exp. 1 vs. compounding substrates in the laboratory. As in Exp. 1, substrate S and P concentrations increased as WDG increased, reflecting the P and S
contributed by WDG (Table 2). By design, the ether extract concentration of the substrates was similar across treatments (range of 5.71 to 6.19%).

**IVDMD and Gas Production.** There was greater \( (P = 0.007) \) total gas production per gram of substrate DM for CON than for WDG treatments (Table 6). In addition, increasing the concentration of WDG decreased \( (P < 0.001) \) total gas production per gram of substrate DM. There was a tendency \( (P = 0.073) \) for the treatments containing 15% WDG to have a greater IVDMD than those with 30% WDG. Leibovich et al. (2009) incubated 0 or 15% sorghum DG with substrates containing DRC or SFC and observed that IVDMD decreased when sorghum DG was added to the substrate. The NE concentrations calculated from performance data in Exp. 1 do not support the idea of major differences in energy concentration of the 15 vs. 30% WDG diets.

**In Vitro H\(_2\)S Production.** Substrates containing WDG had greater \( (P < 0.001) \) H\(_2\)S production per gram.
of fermentable DM than the CON substrate (Table 6). In addition, substrates containing 30% WDG had greater ($P < 0.001$) H$_2$S production than those with 15% WDG. These results are consistent with the substrate S concentrations: the CON substrate contained 0.16% S, whereas the 15 and 30% WDG treatments averaged 0.22 and 0.31% S, respectively (Table 4). May et al. (2010b) reported similar findings in which substrates containing wet corn DG with solubles or wet sorghum DG with solubles had greater H$_2$S production than the control treatment, and increasing WDG from 15 to 30% increased H$_2$S production. Uwituze et al. (2008) noted increased ruminal H$_2$S production in vivo when the dietary S concentration increased from 0.42 to 0.65% in diets containing 30% dry corn DG with solubles. As a consequence of greater dietary S, decreased DMI, ADG, and HCW were observed by Uwituze et al. (2008). In the current experiments, the S concentrations (Tables 1 and 5) were well below those fed by Uwituze et al. (2008). Benson et al. (2005) also observed increased H$_2$S production in manure taken from the pen surface as the concentration of dried DG increased (0, 15, 25, or 35% dried DG).

**In Vitro Gas Production Kinetics.** The fractional rate of gas production was greater ($P = 0.03$) for the CON substrate than WDG substrates (Table 6). Although this finding is not strongly supported by the present IVDMD data, it agrees with the IVDMD results of May et al. (2010b), in which control substrates had greater IVDMD than substrates containing corn or sorghum WDG. In addition, in the present study there was a tendency ($P = 0.063$) for the 30% WDG to have less fractional rates of gas production than the 15% WDG treatments. This finding is consistent with the IVDMD results discussed previously, in which there was a tendency for IVDMD to be less with 30% than with 15% WDG substrates. There were no differences in the lag time of gas production among treatments ($P > 0.16$), which is similar to the findings of Leibovich et al. (2009) and May et al. (2010b).

**VFA and Fermentation Balance Calculations.** There were no differences in the molar proportions of VFA, total VFA concentration, or acetate-to-propionate ratio among the treatment substrates ($P > 0.13$; Table 7). There was a tendency ($P = 0.091$) for substrates containing 30% WDG to have greater valerate proportions than 15% WDG substrates, but the biological importance of this response is questionable. There were also no differences in the calculated values of hexose fermented and CO$_2$ or methane produced ($P > 0.23$; Table 7). Thus, despite reasonably large differences in substrate fiber concentrations (Table 5), in vitro VFA profiles were not greatly affected by inclusion of WDG. These results are similar to those of May et al. (2010b), who found that wet corn DG with solubles or sorghum WDG inclusion in substrates had no effect on fermentation balance calculations, or on proportions of acetate, propionate, butyrate, and total VFA concentrations. In contrast, Corrigan et al. (2009) and Vander Pol et al. (2009) fed up to 40% wet corn DG with solubles in vivo and observed increased proportions of propionate and decreased acetate when wet corn DG with solubles was included in DRC or HMC diets.

Overall, our results suggest that replacing various dietary components in an SFC-based diet (e.g., portions of cottonseed meal, urea, SFC, supplemental fat, and all the molasses) with WDG did not affect feedlot performance or carcass characteristics of beef steers. Moreover, increasing the WDG concentration from 15 to 30% in SFC-based diets was not detrimental to feedlot performance. Feeding 7.5% AH in WDG diets improved G:F and calculated NE$_{em}$ and NE$_{g}$ concentrations compared with WDG diets containing 10 or 12.5% AH. Because WDG has a greater S concentration than the dietary components it replaces, increas-

### Table 6. Effects of wet distillers grain with solubles (WDG; 15 or 30%) and alfalfa hay concentration (7.5, 10, or 12.5%) on in vitro fermentation measurements in Exp. 2

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<td>4.6</td>
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<td>0.26</td>
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</table>

$^1$CON = standard steam-flaked corn-based substrate; DG15-L, DG15-M, and DG15-H = steam-flaked corn-based substrates with 15% wet distillers grain and 7.5, 10, or 12.5% alfalfa hay, respectively; and DG30-L, DG30-M, and DG30-H = steam-flaked corn-based substrates with 30% wet distillers grain and 7.5, 10, or 12.5% alfalfa hay, respectively.

$^2$Pooled SE of treatment means, $n = 3$ reps/treatment on 2 separate days.

$^3$Orthogonal contrasts: CON = control vs. the average of all other diets; DG = the average of the 15% WDG diets vs. the average of the WDG 30% diets. *$P < 0.05$; †$0.05 < P < 0.10$; NS = $P > 0.10$.

Parameters estimated by fitting to a modified Gompertz function, where $k =$ fractional rate of gas production and lag = duration of the lag phase.
Table 7. Effects of wet distillers grain with solubles (WDG; 15 or 30%) and alfalfa hay concentration (7.5, 10, or 12.5%) on molar proportions (mol/100 mol) of VFA, total VFA concentration (mM), and fermentation balance calculations in Exp. 2

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<td>60.6</td>
<td>60.4</td>
<td>60.5</td>
<td>60.8</td>
<td>60.9</td>
<td>0.30</td>
<td>NS</td>
</tr>
<tr>
<td>Hexose fermented</td>
<td>1.02</td>
<td>1.02</td>
<td>1.03</td>
<td>1.02</td>
<td>1.02</td>
<td>1.03</td>
<td>1.03</td>
<td>0.003</td>
<td>NS</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>0.38</td>
<td>0.37</td>
<td>0.38</td>
<td>0.38</td>
<td>0.38</td>
<td>0.37</td>
<td>0.37</td>
<td>0.010</td>
<td>NS</td>
</tr>
</tbody>
</table>

¹CON = standard steam-flaked corn-based substrate; DG15-L, DG15-M, and DG15-H = steam-flaked corn-based substrates with 15% wet distillers grain and 7.5, 10, or 12.5% alfalfa hay, respectively; and DG30-L, DG30-M, and DG30-H = steam-flaked corn-based substrates with 30% wet distillers grain and 7.5, 10, or 12.5% alfalfa hay, respectively.
²Pooled SE of treatment means, n = 3 reps/treatment on 2 separate days.
³Orthogonal contrasts: DG = the average of the 15% WDG diets vs. the average of the WDG 30% diets. †0.05 < P ≤ 0.10.
⁴Hexose fermented (mol/100 mol of VFA), and carbon dioxide and methane (mol/mol of hexose fermented) were calculated from molar proportions of VFA using the fermentation balance equations described by Wolin (1960).

ing WDG increased in vitro H2S production. Including WDG and increasing the concentration from 15 to 30% in substrates decreased total gas production and rate of fermentation. There was a tendency for WDG treatments to decrease IVDMD compared with the control substrate. Finally, AH concentration in substrates had no major effects on various measures of in vitro fermentation.

LITERATURE CITED


