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Effects of Adding MIN-AD to Steam-Flaked Corn-Based Diets With or Without Wet Corn Distillers Grain Plus Solubles on Performance by Beef Cattle During Receiving and Finishing Phases

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ABSTRACT

Effects of wet corn distillers grain (WCDG) and MIN-AD (MIN-AD Inc., Amarillo, TX), a commercial source of calcium-magnesium carbonate, on cattle performance and carcass measurements were evaluated in a 42-d receiving phase (220 steers; initial BW = 279.3 kg) and a subsequent finishing phase (192 steers). Both phases were arranged as a 2 × 2 factorial using steam-flaked corn-based diets. Factors were MIN-AD (0 or 0.75% of dietary DM) and WCDG (0 or 15% of dietary DM). Few MIN-AD × WCDG interactions were detected in either phase. Neither MIN-AD nor WCDG affected ADG, DMI, G:F, or 42-d BW ($P > 0.129$) during the receiving period. Compared with control steers, cattle fed WCDG in the finishing phase had greater ($P < 0.01$) ADG, DMI, final BW, and hot carcass weight (HCW). Fecal pH of cattle fed 15% WCDG was less than that of control steers ($P < 0.05$). Feeding WCDG had no effect ($P \geq 0.19$) on dressing percentage, LM area, 12th-rib fat, KPH, YG, marbling score, QG, or incidence of liver abscesses. Supplementing diets with MIN-AD increased LM area ($P = 0.031$), but ADG, DMI, G:F, final BW, HCW, dressing percentage, 12th-rib fat, KPH percentage, YG, marbling score, QG, and incidence of liver abscesses were not affected ($P \geq 0.063$) by MIN-AD. Results suggest that feeding 15% WCDG in a steam-flaked corn-based diet did not affect cattle performance during the receiving period, but it increased DMI, ADG, final BW, and HCW during the finishing period. Supplementing MIN-AD in combination with WCDG did not affect performance.

Key words: MIN-AD, beef cattle, wet distillers grains plus solubles

INTRODUCTION

Including wet corn distillers grains (**WCDG**) in feedlot diets based on steam-flaked corn has sometimes resulted in slightly decreased performance compared with diets based on dry-rolled corn, for which positive responses have generally been reported. Klopfenstein et al. (2008) summarized the evidence for an interaction between grain processing method and concentration of WCDG in their review of research on the use of distillers grains in feedlot diets. Reasons for the interaction are not known; however, most studies that have been conducted to date using WCDG as a partial replacement for steam-flaked corn have involved cattle that were

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already adapted to a finishing diet before WCDG was fed. In a metabolism study, May et al. (2008) reported that feeding 25% dry corn distillers grains with solubles increased ruminal lactate concentrations regardless of grain processing method. Increases in ruminal lactate early in the feeding period might lead to decreased or erratic intake or losses in performance until animals are fully adapted to distillers grains.

Calcium and Mg are both minerals needed by ruminant animals; one commercial feed supplement available to meet these requirements is MIN-AD (MIN-AD Inc., Amarillo, TX), which contains 21% Ca and 11% Mg. This feed supplement is used in partial replacement of MgO and $CaCO_3$, and is considered to have buffering properties in the digestive tract. Crawford et al. (2008) found no adverse effects on ruminal metabolism or feedlot performance when limestone and MgO were replaced with MIN-AD. If feeding WCDG alters the acid load in the rumen or other parts of the digestive tract, the potential buffering properties of MIN-AD might interact with the feeding of WCDG in diets based on steam-flaked corn. Thus, our objective was to measure performance and carcass characteristics of beef steers in diets with or without WCDG and MIN-AD. Fecal pH and gas production also were measured to assess potential effects of these factors on acidity in the digestive tract.

MATERIALS AND METHODS

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

Experimental Design

The experiment was conducted in 2 phases: a 42-d receiving phase and a subsequent finishing phase. Both phases were analyzed as a randomized complete block design, with a 2 × 2 factorial arrangement of treatments. In the receiving phase, 24 soil-surfaced pens with 9 to 10 animals/pen were used, whereas 48 concrete-surfaced pens with 4 animals/pen were used in the finishing phase. Treatment factors, which were the same in the receiving and finishing phases, included steam-flaked corn-based diets that contained: 1) 0 or 0.75% MIN-AD (DM basis; MIN-AD Inc.), and 2) 0 or 15% (DM basis) WCDG. Ingredient composition of the diets used during the receiving (65, 75, and 85% concentrate) and finishing (90% concentrate) phases is shown in Table 1. Vitamins, minerals, Rumensin (33 mg/kg, DM basis; Elanco Animal Health, Indianapolis, IN), and Tylan (11 mg/kg, DM basis; Elanco Animal Health) were provided in a loose-meal premix (Table 1). Magnesium was added to the diets that did not contain MIN-AD by means of a premix that also supplied Ca (from limestone) to equal the concentration supplied by MIN-AD but that had a lower Mg concentration than MIN-AD (5.5% Mg from MgO vs. 11.5% Mg in MIN-AD). The lower Mg concentration reflected the standard practice at the Texas Tech University Burnett Center. The WCDG (Quality Distillers Grains, Hereford, TX), which included solubles, used during the experiment was stored in a plastic silage bag for the duration of the experiment.

Management, Feeding, and Weighing Procedures

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 24 pens of cattle during the receiving phase and 48 pens during the finishing phase. Once the cattle were consuming feed ad libitum, adjustments to the feed delivery for each pen were made with a target of 0 to 0.45 kg of residual feed in the bunk when it was checked in the morning. The feeding order for treatments was established at the beginning of the experiment and was as follows: 1) no WCDG without MIN-AD; 2) no WCDG with MIN-AD; 3) WCDG without MIN-AD; and 4) WCDG with MIN-AD. Diets were mixed in a 1.27-m^3-capacity paddle mixer (Marion Mixers Inc., Marion, IA) and transferred by a drag-chain conveyor to a tractor-pulled mixer-delivery unit (Rotomix 84-8, Dodge City, KS; scale readability of ±0.454 kg), which was used to deliver feed to each pen. Diet samples were taken weekly from the delivery unit to determine the DM content (dried in a forced-air oven at 100°C for approximately 24 h). Weights for DM determination were taken on an Ohaus (Pine Brook, NJ) electronic balance (readability of ±0.1 g). Dried diet samples were subsequently composited by treatment within concentrate level across weeks of the experiment and sent to SDK Laboratories (Hutchinson, KS) for chemical analyses.

Receiving Phase

In March 2008, beef steers were purchased from auction barns in Southwest Missouri and transported to the Texas Tech University Burnett Center. After arrival, steers were weighed individually in a squeeze chute (Cummings and Sons, Garden City, KS) that was set on 4 load cells (Rice Lake Weighing Systems, Rice Lake, WI); scales were calibrated with 454 kg of certified weights before use. Steers were then tagged in the ear with an individual identification tag, vaccinated (subcutaneous injection) with 7-way clostridial and infectious bovine rhinotracheitis, parainfluenza-3, bovine respiratory syncytial virus, bovine viral diarrhea preparations (Vision 7 with SPUR and Vista 5 SQ, respectively; Intervet/Schering-Plough Animal Health, Millsboro, DE), and dewormed with Cydectin (Fort Dodge Animal Health, Overland Park, KS). Every group of 4 animals was sorted randomly to 1 of 4 sorting pens. When each sorting pen contained 9 steers, the cattle in these 4 sorting pens were moved to 4 contiguous soil-surfaced pens (4.9 m wide × 30.5 m in length; 4.9 m of bunk space). Each group of 4 contiguous pens represented a block that accounted for

Table 1. Composition and analyzed nutrient content (DM basis) of receiving, transition, and finishing diets fed during the receiving and finishing phases[1]

	65% Concentrate				75% Concentrate				85% Concentrate				90% Concentrate			
Item	C−	C+	DG−	DG+	C−	C+	DG−	DG+	C−	C+	DG−	DG+	C−	C+	DG−	DG+
Ingredient																
Steam-flaked corn	47.19	47.18	46.06	46.05	56.46	56.46	55.59	55.59	68.76	68.76	64.42	64.43	73.19	73.20	69.49	69.50
WCDG[2]	—	—	14.66	14.65	—	—	14.82	14.82	—	—	15.75	15.75	—	—	15.08	15.09
Alfalfa hay, ground	15.18	15.17	15.26	15.26	10.12	10.12	10.19	10.19	7.43	7.43	7.38	7.38	5.14	5.14	5.14	5.14
Cottonseed hulls	19.79	19.79	19.90	19.90	14.94	14.94	15.03	15.04	7.61	7.62	7.56	7.56	5.13	5.13	5.12	5.12
Cottonseed meal	8.10	8.10	—	—	8.15	8.16	—	—	5.19	5.19	—	—	5.51	5.51	—	—
Urea	0.55	0.55	0.41	0.41	0.71	0.71	0.40	0.40	0.92	0.92	0.41	0.41	0.91	0.91	0.51	0.51
Fat	2.10	2.10	0.50	0.50	2.13	2.12	0.45	0.45	2.54	2.54	0.86	0.86	2.52	2.51	0.90	0.90
Molasses	4.02	4.02	—	—	4.19	4.19	—	—	4.07	4.07	—	—	4.03	4.03	—	—
Limestone	0.35	0.35	0.50	0.50	0.55	0.55	0.75	0.75	0.70	0.70	0.86	0.86	0.80	0.80	0.99	0.99
MIN-AD[3]	—	0.75	—	0.75	—	0.75	—	0.75	—	0.75	—	0.75	—	0.76	—	0.75
Ca-Mg supplement[3]	0.73	—	0.73	—	0.75	—	0.76	—	0.76	—	0.76	—	0.76	—	0.77	—
Supplement[4,5]	1.99	1.99	1.98	1.98	2.00	2.00	2.01	2.01	2.02	2.02	2.00	2.00	2.01	2.01	2.00	2.00
Analyzed composition, %																
DM	83.8	84.0	69.1	69.6	82.2	82.4	66.4	66.1	82.5	81.5	67.6	66.3	82.4	82.3	67.6	67.7
CP	12.5	12.2	14.4	13.3	13.0	13.3	14.1	14.2	12.5	11.9	14.8	13.7	12.8	13.0	13.8	13.5
ADF	23.6	24.6	23.2	26.4	18.9	19.4	19.7	21.3	12.8	15.7	14.6	15.9	10.4	9.7	10.3	10.7
Ether extract	4.3	4.1	4.2	3.8	5.0	4.7	4.6	4.5	4.5	4.3	5.5	5.0	4.5	5.2	4.9	4.9
Ca	0.56	0.62	0.59	0.53	0.43	0.59	0.60	0.45	0.49	0.43	0.67	0.54	0.43	0.62	0.63	0.49
P	0.26	0.28	0.30	0.28	0.27	0.27	0.30	0.31	0.28	0.26	0.39	0.36	0.30	0.30	0.33	0.32
K	1.23	1.13	1.21	1.22	1.00	1.00	0.96	0.95	0.86	0.96	0.88	0.81	0.73	0.79	0.77	0.72
S	0.21	0.19	0.23	0.20	0.19	0.20	0.21	0.21	0.19	0.17	0.23	0.19	0.17	0.19	0.18	0.18
Mg	0.24	0.26	0.21	0.24	0.23	0.25	0.21	0.20	0.17	0.19	0.24	0.20	0.15	0.23	0.15	0.18

[1]C− = standard steam-flaked corn-based diet without supplemental MIN-AD (MIN-AD Inc., Amarillo, TX), C+ = standard steam-flaked corn-based diet with supplemental MIN-AD; DG− = steam-flaked corn-based diet with 15% (DM basis) wet corn distillers grain (WCDG) plus solubles without supplemental MIN-AD, DG+ = steam-flaked corn-based diet with 15% (DM basis) WCDG with supplemental MIN-AD.

[2]The average DM of WCDG (Quality Distillers Grains, Hereford, TX) during the experiment was 31.34% (SD = 1.28) during the 42-d receiving phase and 31.25% (SD = 1.49) during the finishing phase.

[3]MIN-AD = a commercially available source of Ca-Mg carbonate that contained 21% Ca and 11% Mg; Ca-Mg supplement = a mixture of limestone, MgO, and ground corn (61, 7.5, and 31.5%, respectively, DM basis), formulated to contain 21% Ca and 5.5% Mg.

[4]Supplement for the C− and C+ diets contained (DM basis): 66.383% cottonseed meal; 0.500% Endox (Kemin Industries, Des Moines, IA), 0.648% dicalcium phosphate; 10% potassium chloride; 4.167% ammonium sulfate; 15.000% salt, 0.002% cobalt carbonate, 0.196% copper sulfate; 0.083% iron sulfate; 0.003% ethylenediamine dihydroiodide; 0.333% manganese oxide, 0.125% selenium premix (0.2% Se), 0.986% zinc sulfate; 0.010% vitamin A (1,000,000 IU/g); 0.157% vitamin E (500 IU/g); 0.844% Rumensin (176.4 mg/kg; Elanco Animal Health, Indianapolis, IN); and 0.563% Tylan (88.2 mg/kg, Elanco Animal Health). Concentrations in parentheses for vitamins, Rumensin, and Tylan are expressed on a 90% DM basis.

[5]Supplement for the DG− and DG+ diets contained (DM basis): 54.790% cottonseed meal; 0.500% Endox (Kemin Industries), 0.648% dicalcium phosphate; 22% potassium chloride, 3.760% urea, 15.000% salt; 0.002% cobalt carbonate, 0.196% copper sulfate, 0.083% iron sulfate; 0.003% ethylenediamine dihydroiodide; 0.333% manganese oxide; 0.125% selenium premix (0.2% Se); 0.986% zinc sulfate; 0.010% vitamin A (1,000,000 IU/g); 0.157% vitamin E (500 IU/g); 0.844% Rumensin (176.4 mg/kg, Elanco Animal Health); and 0.563% Tylan (88.2 mg/kg, Elanco Animal Health). Concentrations in parentheses for vitamins, Rumensin, and Tylan are expressed on a 90% DM basis.

location of the pen in the feedlot and processing order of the cattle. After processing and sorting, all cattle were offered a 65% concentrate receiving diet. The 42-d receiving phase began the next day, at which time each animal was weighed individually and assigned randomly to 1 of the 4 pens within the location-processing order block in which the cattle had been housed on the previous day. Treatments were assigned randomly within the 4 contiguous pens in each block, and 65% concentrate treatment diets (Table 1) were fed. When the cattle were weighed individually for the d-14 BW measurement, each steer was implanted with Ralgro (36 mg of zeranol: Intervet/Schering-Plough Animal Health). The diet was increased to 75% concentrate (Table 1) on d 21 of the receiving phase and increased to 85% concentrate on d 35. With each change in dietary concentrate level, the quantity of DM offered to each pen was decreased slightly (approximately 92% of the previous day's intake) to provide a constant intake of NE_g, after which the intake of the new diet was gradually increased each day.

All cattle were monitored daily for morbidity, and those with symptoms of respiratory disease were removed from their pen for a more thorough evaluation. If the rectal temperature was ≥39.7°C, the animals were administered antimicrobial therapy (florfenicol, Intervet/Schering-Plough Animal Health, or tilmicosin phosphate, Elanco Animal Health) according to the instructions of the manufacturer and then returned to the pen. Only 3 animals were treated during the receiving phase. The receiving phase concluded with the 42-d individual BW measurement.

Finishing Phase

For the finishing phase, the 42-d BW data were sorted within treatment from lightest to heaviest BW. Within each of the 4 treatments, 6 to 7 steers were designated as extra cattle and were not used in the finishing phase. The extra cattle were chosen from the cattle with the heaviest and lightest BW within each treatment in an effort to balance BW across the 4 treatments. In addition, 3 steers with Brahman influence were designated as extra cattle. The d-42 BW data for the remaining 48 steers in each treatment were sorted from lightest to heaviest, and groups of 4 steers were assigned to 12 blocks, beginning with the lightest 4 steers in the first block and continuing through the heaviest 4 steers in the last block. Groups of 4 contiguous concrete, partially slotted-floor pens (2.9 m wide × 5.6 m in length; 2.9 m of linear bunk space) were assigned to blocks. Treatments were then assigned randomly to pens within blocks. The steers were sorted to their assigned pens 2 d after the conclusion of the receiving period and fed the same 85% concentrate treatment diets they had been fed during the receiving phase of the experiment. Seven days after the cattle moved to their assigned pens, the diet was switched to 90% concentrate, with feed delivery restricted to 96% of the previous day's delivery to allow for an approximately constant intake of NE_g. After another 5 d, all cattle were taken through the Burnett Center working facilities to obtain an individual BW to begin the finishing phase. At this time, each steer was implanted with Revalor-S (120 mg of trenbolone-acetate and 24 mg of estradiol; Intervet/Schering-Plough Animal Health). The cattle remained in their assigned pens and were fed the 90% concentrate diets until the completion of the experiment. Body weight measurements were obtained on a pen basis on d 35, 70, and 105 of the finishing phase. Cattle in various blocks were shipped to slaughter based on visual appraisal of body condition and BW, resulting in blocks 1 through 4, 5 through 8, and 9 through 12 being fed during the finishing phase for 167, 139, and 125 d, respectively (average = 143.7 d on feed). An individual BW measurement was collected on the morning before the cattle were shipped to slaughter.

Carcass Evaluation

Carcass data were obtained from each of the 3 slaughter groups at the Cargill Beef slaughter facility in Plainview, Texas. Carcass measurements included hot carcass weight (**HCW**), LM area, KPH, 12th-rib fat, and calculated USDA YG. Quality grade factors assessed were marbling score of the LM, skeletal maturity score, lean maturity score, overall maturity score, and final USDA QG. Livers were classified as either not condemned or as A−, A, or A+ for the presence of abscesses similar to the method of Brown et al. (1975). Hot carcass weights and dressing percentage data for cattle that were taken out of sequence and noted as having excessive carcass trim were excluded from analysis. For KPH, 15 observations were not collected; therefore, to calculate USDA YG, the average KPH of all cattle for which data were collected was used in the calculation of YG for these 15 carcasses. The HCW was divided by the average dressing percentage (62.31%) and multiplied by 0.96 to calculate an adjusted final BW. This value, along with initial BW for the finishing phase and days on feed, was used to calculate adjusted ADG and G:F values.

Net Energy Calculations and Statistical Analyses

Dietary NE_m and NE_g concentrations were calculated on a pen basis via a quadratic solution of NRC (1996) NE equations by using methods described by Vasconcelos and Galyean (2008). The calculated NE values along with performance and carcass data (pen basis) were analyzed using the MIXED procedure (SAS Institute Inc., Cary, NC) for a randomized complete block design. The effects of MIN-AD supplementation, WCDG addition, MIN-AD supplementation × WCDG addition, and block were included in the model, with block as a random effect. Initial BW (for the receiving or finishing phase data as appropriate) was included as a covariate in the models for performance and carcass data, and it was retained in the model only when determined to be significant ($P < 0.05$). Carcass QG (proportion of cattle in the pen grading USDA Choice or greater) and liver abscess data (proportion of cattle in the pen with abscessed livers) were analyzed as a binomial proportion using the GLIMMIX procedure of SAS. The same model was used for performance data.

Fecal pH and Gas Production

On d 70 and 105 during the finishing phase, fecal pH and in vitro gas production using a fecal inoculum were determined with freshly excreted fecal grab samples collected from the pen surface as the cattle were moved out of the pen to be weighed. On each of the 2 sampling days, fecal samples were collected from the pens in blocks 9, 10, and 11 (12 pens total: 1 pens/treatment). Samples were stored in plastic Ziploc bags in a Styrofoam cooler and transported to the laboratory for analysis of pH and gas production. Fecal pH was determined on the pen fecal composite sample by placing a combination electrode (Fisher Accumet pH meter, Fisher Scientific, Pittsburgh, PA) directly in the fecal sample. For gas production, approximately 700 mg of corn starch (as-is basis) was weighed to the nearest 0.1 mg and placed in a 125-mL serum vial (Wheaton Science Products, Millville, NJ). An inoculum was created by adding 40 g (wet basis) of each composite pen fecal sample to 160 mL of McDougall's buffer (prewarmed to 39°C, pH 7.0) for a 20% (wt/vol) solution (McDougall, 1948). The mixture was then homogenized in a standard blender for 30 s. Fifty milliliters of blended inoculum was added to each serum vial, after which the vial was flushed with CO_2 and closed with butyl rubber stoppers and a crimp seal. The vials were then incubated for 24 h at 39°C under constant agitation (100 rpm; Lab Line Environ-Shaker, Lab-Line Instruments Inc., Melrose Park, IL). After incubation, the volume of total gas produced was measured via water displacement by puncturing the butyl rubber stopper with a 14-gauge needle connected to a 250-mL inverted burette. Each pen fecal composite was evaluated in duplicate serum vials on each of the 2 sampling days.

For the fecal pH and gas production data, the statistical model included the fixed effects of replicate in time (d 70 and 105), MIN-AD supplementation, WCDG addition, MIN-AD supplementation × WCDG addition, and replicate in time × MIN-AD supplementation × WCDG addition. Block nested within replicate in time was a random effect in the model.

RESULTS AND DISCUSSION

Diet Chemical Composition

Analyzed chemical composition data for the various treatment diets are shown in Table 1. Values were generally in agreement with expectations from formulation. Because our methods involved compositing dried samples of the mixed diets, for which it was somewhat difficult to obtain a representative sample of fine, dense material, we sometimes observed more variation in analyses for minerals that were added directly or were in the supplement (e.g., Ca, K, and Mg) than for minerals that arose primarily from dietary ingredients (e.g., P). Our diet composition values were within the ranges or similar to the mean values described by Vasconcelos and Galyean (2007) for CP, Ca, P, K, S, Mg, ether extract, roughage level, and inclusion of WCDG.

Body Weight, Average Daily Gain, Dry Matter Intake, and Gain Efficiency

Cattle assigned to a particular treatment during the receiving phase remained on the same treatment during the finishing phase. Nonetheless, elimination of some cattle from the study after the receiving phase, resorting, and blocking the cattle by BW during the finishing phase necessitated separate statistical analyses of the 2 phases, as well as the use of initial BW as a potential covariate in statistical models. Thus, the results for the 2 phases are described separately.

Receiving Phase. Interactions between MIN-AD supplementation and WCDG addition were generally not evident ($P \geq 0.21$) during the receiving phase; however, the interaction approached significance ($P = 0.08$) for DMI from d 0 to 28 (Table 2). Neither initial BW nor d-12 BW differed ($P \geq 0.13$) because of MIN-AD supplementation or WCDG addition ($P \geq 0.29$), although initial BW was a significant ($P < 0.001$) covariate for d-12 BW. As expected with no differences in BW, ADG for different segments of the receiving phase did not differ ($P > 0.14$) within the main-effect treatments. The relatively high ADG during the receiving phase presumably reflected the fact that the initial BW was likely less affected by gut fill than were subsequent BW measurements. Nonetheless, comparatively high ADG would be expected with the overall excellent health of the cattle and high DMI (2.6% of BW for the 12-d period). Daily DMI did not differ within main-effect comparisons ($P \geq 0.22$) during the receiving phase, with the exception of DMI from d 0 to 14, which was less ($P = 0.004$) for cattle supplemented with MIN-AD than for those that did not receive MIN-AD (6.51 vs. 6.57 kg/d). This very small difference is not practically important because it is less than the measurement error of our feeding system, and it reflects a chance difference associated with the fact that intake was less than ad libitum for the first few days of the receiving phase, resulting in very low variation in DMI during this period (e.g., compare the SE for DMI from d 0 to 14 with the SE in other periods). Given the lack of major differences in ADG and DMI, it is not surprising that G:F ratio was not affected ($P \geq 0.17$) by the main-effect treatments. Similar to our findings, Loy et al. (2008), who supplemented the diets of growing heifers that had ad libitum access to hay with dry-rolled corn, dry distillers grains, or a combination of dry-rolled corn and corn gluten meal at 0.21 or 0.81% of BW daily or 3 times per week, found that DMI, ADG, or G:F did not differ within the frequency or supplementation among treatments.

Finishing Phase. Initial BW during the finishing phase was a significant ($P \leq 0.05$) covariate for several variables, including final BW and all DMI and G:F measurements. Thus, the least squares means for these variables were adjusted for differences in initial BW. With the exception of initial BW ($P = 0.026$), G:F from d 0 to 105 ($P = 0.013$), and NE_m and NE_g concentrations calculated from performance data ($P = 0.011$), no MIN-AD

Table 2. Effects of MIN-AD supplementation and addition of wet corn distillers grains (WCDG) plus solubles[1] to the diet on performance by beef steers during a 42-d receiving period

	MIN-AD supplementation			WCDG addition			
Item	0	+	*P*-value[2]	0	+	*P*-value	SE[3]
Initial BW, kg	280 4	278.1	0 479	278 1	280 4	0 475	2 55
d 42 BW,[4] kg	376 0	372.9	0.129	375 5	373 4	0.290	1 54
ADG, kg							
d 0 to 14	2.38	2.35	0 694	2.34	2 39	0.633	0 068
d 0 to 28	2 24	2.24	0.857	2.24	2 24	0.898	0 039
d 0 to 42	2 30	2 23	0.140	2 29	2 24	0 251	0 035
Daily DMI, kg/steer							
d 0 to 14	6.57	6.54	0 001	6 56	6 55	0 286	0 014
d 0 to 28	7.97	7.97	0 901	7.94	8.01	0 223	0.058
d 0 to 42	8.65	8.62	0 559	8 65	8.62	0 581	0.071
G:F							
d 0 to 14	0.363	0.359	0 769	0.358	0.364	0.614	0 0100
d 0 to 28	0 282	0 281	0 853	0.282	0.280	0 831	0 0042
d 0 to 42	0.266	0 259	0 167	0.265	0 260	0 293	0 0034

[1]MIN-AD supplementation = no supplemental MIN-AD (0; MIN-AD Inc , Amarillo, TX) or MIN-AD supplemented at 0.75% of the dietary DM (+); WCDG addition = WCDG added to the diet at either 0 or 15% (+) of dietary DM. With the exception of a tendency (*P* = 0 076) for DMI from d 0 to 28, no MIN-AD supplementation × WCDG addition interactions were detected ($P \geq 0.21$).

[2]Observed significance levels for MIN-AD supplementation and WCDG addition main-effect comparisons

[3]Pooled SE of main-effect means, n = 12 pens/main-effect mean.

[4]Initial BW was a significant ($P \leq 0.001$) covariate in the statistical analysis for d 42 BW.

supplementation × WCDG addition interactions ($P \geq 0.10$) were detected during the finishing phase. Thus, as with receiving phase data, main-effect means are reported (Table 3).

Main-effect means for initial BW shown in Table 3 indicate a lower ($P = 0.001$) initial BW for the finishing phase for cattle that received supplemental MIN-AD and a lower ($P = 0.009$) initial BW for cattle fed diets that did not contain WCDG. Because of the MIN-AD supplementation × WCDG addition interaction for initial BW noted previously, main-effect means should be viewed with caution. Simple-effect means for initial BW were 393.1, 381.6, 391.0, and 391.5 kg (SE = 8.12) for the no WCDG without MIN-AD, no WCDG with MIN-AD, WCDG without MIN-AD, and WCDG with MIN-AD treatments, respectively, with a lower ($P < 0.01$) initial BW for the no WCDG with MIN-AD cattle than for cattle in the other 3 treatment groups. This difference among treatments reflects, in part, nonsignificant differences in initial BW and ADG during the receiving phase, and it could possibly reflect effects associated with removal of some cattle before the start of the finishing phase. After covariance adjustment for the effects of initial BW, final shrunk BW tended to be less ($P = 0.06$) for cattle supplemented with MIN-AD and was greater ($P = 0.001$) for cattle fed diets with added WCDG than for those fed diets without WCDG. Using HCW and the average dressing percentage to calculate adjusted final BW resulted in no difference in final BW ($P = 0.10$) because of MIN-AD supplementation; however, a greater adjusted final BW was evident ($P = 0.009$) for cattle fed WCDG diets compared with diets that did not contain WCDG.

No differences ($P \geq 0.13$) in ADG were detected because of MIN-AD supplementation for any of the cumulative periods during the finishing phase. Present results are similar to those of Crawford et al. (2008), in which cattle performance was not affected when MIN-AD was supplemented as a partial replacement of limestone and MgO during the finishing period.

In contrast to results with MIN-AD, differences or strong trends were noted for greater ADG with the addition of WCDG to the diet for d 0 to 35 ($P = 0.01$), d 0 to 70 ($P = 0.02$), d 0 to 105 ($P = 0.06$), overall shrunk ADG ($P = 0.01$), and carcass-adjusted ADG ($P = 0.07$). These results are similar to those reported by Al-Suwaiegh et al. (2002) and Lodge et al. (1993), in which addition of distillers grains to the diet increased ADG; however, in these studies, dry-rolled corn was the basal grain source, as opposed to steam-flaked corn in the present study.

As with ADG, daily DMI did not differ ($P \geq 0.52$) in response to supplemental MIN-AD during the finishing phase; however, DMI was consistently greater ($P \leq 0.001$) with addition of WCDG to the diet. As would be expected from the lack of differences in ADG and DMI, no differences were detected in G:F (*P*

Table 3. Effects of MIN-AD supplementation and addition of wet corn distillers grains (WCDG) plus solubles[1] to the diet on performance by finishing beef steers

	MIN-AD supplementation			WCDG addition			
Item	0	+	*P*-value[2]	0	+	*P*-value	SE[3]
Initial BW, kg	393.5	386.5	0.001	387.3	392.7	0.009	8.00
Final BW,[4,5] kg	597.5	589.0	0.063	585.4	601.0	0.001	3.29
Adjusted final BW,[6] kg	597.5	588.8	0.103	585.9	600.4	0.009	3.66
ADG,[5] kg							
d 0 to 35	2.07	2.03	0.489	1.99	2.11	0.036	0.041
d 0 to 70	1.90	1.83	0.132	1.81	1.92	0.019	0.031
d 0 to 105	1.69	1.64	0.181	1.63	1.70	0.060	0.027
d 0 to end7	1.42	1.41	0.457	1.37	1.46	0.009	0.020
Adjusted,[6] d 0 to end	1.42	1.41	0.725	1.38	1.45	0.072	0.026
Daily DMI,[4] kg/steer							
d 0 to 35	9.31	9.22	0.537	8.97	9.56	<0.001	0.099
d 0 to 70	9.60	9.51	0.521	9.24	9.86	<0.001	0.105
d 0 to 105	9.56	9.47	0.526	9.24	9.79	0.001	0.108
d 0 to end[6]	9.65	9.56	0.546	9.31	9.89	0.001	0.105
G:F[4]							
d 0 to 35	0.223	0.222	0.839	0.222	0.222	0.937	0.0034
d 0 to 70	0.198	0.193	0.191	0.196	0.195	0.705	0.0024
d 0 to 105	0.177	0.174	0.158	0.176	0.174	0.374	0.0021
d 0 to end[7]	0.148	0.147	0.748	0.148	0.148	0.973	0.0018
Adjusted,[4,6] d 0 to end	0.148	0.147	0.909	0.148	0.147	0.633	0.0022
Calculated NE values[8]							
NE_m, Mcal/kg of DM	2.03	2.03	0.825	2.05	2.01	0.043	0.014
NE_g, Mcal/kg of DM	1.37	1.37	0.819	1.39	1.35	0.043	0.012

[1]MIN-AD supplementation = no supplemental MIN-AD (0; MIN-AD Inc., Amarillo, TX) or MIN-AD supplemented at 0.75% of the dietary DM (+); WCDG addition = wet corn distillers grains added to the diet at either 0 or 15% (+) of dietary DM. With the exception of initial BW ($P = 0.026$), d 0 to 105 G:F ($P = 0.043$), and calculated NE_m and NE_g concentrations ($P = 0.044$), no MIN-AD supplementation × WCDG addition interactions were detected ($P \geq 0.10$).

[2]Observed significance levels for MIN-AD supplementation and WCDG addition main-effect comparisons.

[3]Pooled SE of main-effect means. n = 24 pens/main-effect mean.

[4]Initial BW was a significant ($P \leq 0.05$) covariate in the statistical analysis of final BW, all DMI data, and all G:F data.

[5]The 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 in any calculations.

[6]Adjusted final BW equaled hot carcass weight divided by the average dressing percentage (62.31%). Adjusted gain (d 0 to end) was calculated from the adjusted final BW minus the initial BW divided by days on feed, and adjusted G:F (d 0 to end) was calculated as the ratio of adjusted ADG to d 0 to end DMI.

[7]Cattle in the blocks through 1 through 4, 5 through 8, and 9 through 12 were on feed for 167, 139, and 125 d, respectively, resulting in an average of 143.7 d on feed.

[8]Dietary NE values calculated from performance data using energy requirement equations for maintenance and shrunk weight gain from NRC (1996).

> 0.16) because of supplemental MIN-AD. For G:F from d 0 to 105, a MIN-AD supplementation × WCDG addition interaction ($P = 0.013$) was noted, and simple-effect means were 0.176, 0.177, 0.178, and 0.170 (SE = 0.0027) for the no WCDG without MIN-AD, no WCDG with MIN-AD, WCDG without MIN-AD, and WCDG with MIN-AD treatments, respectively. The G:F for the WCDG with MIN-AD treatment was less ($P < 0.02$) than the no WCDG with MIN-AD and WCDG without MIN-AD treatments, but was not different from the no WCDG without MIN-AD treatment. Both ADG and DMI increased when WCDG was added to the diet; G:F did not differ ($P > 0.371$) with addition of WCDG to the diet. Depenbusch et al. (2008b) fed dry corn distillers grains derived from traditional dry-grind or partial fractionation dry-grind processes (approximately 13% of the diet on a DM basis) in steam-flaked corn diets and reported that DMI, ADG, and G:F

did not differ ($P > 0.48$) from values observed with a control diet. With respect to supplementation of MIN-AD, present results agree with those of Crawford et al. (2008), who reported no differences ($P \geq 0.13$) in ADG, DMI, and G:F in cattle fed steam-flaked corn-based diets supplemented with 0, 0.75, or 1.5% MIN-AD.

In a meta-analysis of 9 experiments with cattle fed dry-rolled or high-moisture corn-based diets, Klopfenstein et al. (2008) reported increased ADG with the addition of WCDG to diets; however, DMI responded linearly and quadratically to the level of wet distillers grains, with slightly increased DMI when the level of wet distillers grains was 10 to 20% of dietary DM, but with decreased DMI as the inclusion level of wet distillers grains increased. In addition, these authors noted that the feeding value of distillers grains seemed to be affected by the grain processing method, with better performance when dry-rolled or high-moisture grain was used as the grain source compared with steam-flaked corn. Leibovich et al. (2009) fed 0 or 15% sorghum wet distillers grains in diets (balanced for fat) composed of dry-rolled corn or steam-flaked corn. Average daily gain, DMI (d 0 to 35 and 0 to 70), final BW, HCW, and G:F were decreased with the addition of distillers grains, regardless of the grain processing method. Similarly, Vasconcelos et al. (2007), who fed sorghum wet distillers grains at 0, 5, 10, and 15% of diet DM in steam-flaked corn-based diets, noted linear decreases in ADG, DMI (d 0 to 28, d 0 to 56, and d 0 to 81), and G:F as the percentage of distillers grains in the diet increased. In both these studies, the first time cattle received distillers grains was the first day of the finishing period. Possible negative effects of distillers grains on DMI early in the feeding period might result in decreased performance until cattle are fully adapted to distillers grains. May et al. (2008) and Uwituze et al. (2008) reported an increase in ruminal lactate when feeding 25% dry distillers grains with solubles in cattle that were allowed to adapt to the distillers grains for 11 and 17 d, respectively. Increased ruminal lactate could be one possible reason for decreased DMI early in the feeding period when wet distillers grain is added to the diet of cattle that are already adapted to a finishing diet. Depending on the length of the feeding period, cattle fed distillers grains might not have sufficient time to compensate for this initial decrease in DMI. In the present experiment, perhaps the fact that cattle received diets containing WCDG during an extending receiving phase allowed them to adapt in some way to the effects of WCDG in the diet, such that DMI was not affected negatively, and was actually increased by addition of WCDG. Research is needed to test the hypothesis that cattle need an adaptation period to use diets containing WCDG more effectively.

The main effect of MIN-AD supplementation was not significant ($P \geq 0.82$) for dietary NE_m and NE_g concentrations calculated from performance data; however, calculated dietary NE values were less ($P = 0.01$) for diets that contained WCDG versus diets without WCDG (Table 3). Our findings of decreased NE_m and NE_g concentrations with addition of distillers grains to the diet are consistent with results observed by Vasconcelos et al. (2007), Depenbusch et al. (2008a), and Leibovich et al. (2009). As noted previously, a MIN-AD supplementation × WCDG addition interaction was detected for calculated NE values. Simple-effect means for NE_m concentration (Mcal/kg of DM) were 2.03, 2.07, 2.03, and 1.99 (SE = 0.020) for the no WCDG without MIN-AD, no WCDG with MIN-AD, WCDG without MIN-AD, and WCDG with MIN-AD treatments, respectively. The NE_m concentration for the no WCDG with MIN-AD treatment differed ($P < 0.01$) from that noted for the WCDG with MIN-AD treatment, but neither of these treatments differed from the remaining 2 treatments. Similarly, simple-effect means for calculated NE_g concentrations were 1.37, 1.41, 1.37, and 1.31 Mcal/kg of DM (SE = 0.017) for the no WCDG without MIN-AD, no WCDG with MIN-AD, WCDG without MIN-AD, and WCDG with MIN-AD treatments, respectively. The pattern of significant ($P < 0.01$) differences among the treatments was the same as for dietary NE_m concentration. Thus, these data suggest that the effects of MIN-AD supplementation on performance-based dietary NE values depend on the addition of WCDG, but the reasons for this interaction are not readily apparent.

Carcass Characteristics

No MIN-AD supplementation × WCDG addition interactions ($P \geq 0.13$) were noted for carcass data. Initial BW was a significant ($P = 0.02$) covariate for dressing percentage, but not for any other carcass measurements.

With the exception of LM area, for which supplementation of MIN-AD resulted in a greater ($P = 0.03$) LM area than for diets without MIN-AD, no effects ($P \geq 0.10$) of supplemental MIN-AD were detected in the various carcass measurements, percentage of carcasses grading USDA Choice or greater, and percentage of cattle with abscessed livers (Table 4). Similarly, Crawford et al. (2008) did not detect effects of MIN-AD supplementation on carcass measurements in cattle fed steam-flaked corn-based diets. For the main effect of WCDG addition, with the exception of an increased ($P = 0.01$) HCW for cattle that were fed WCDG diets, no effects ($P > 0.19$) of WCDG were noted for carcass data. Increases in HCW would be similar to results of several studies in which distillers grains have been added to dry-rolled corn-based diets (Klopfenstein et al., 2008), but contradict much of the research that has been done to this point in which distillers grains have been added to steam-flaked corn-based diets (Vasconcelos et al., 2007; Depenbusch et al., 2008a; Leibovich et al., 2009).

Fecal pH and Gas Production

No interactions ($P > 0.20$) between MIN-AD supplementation and

Table 4. Effects of MIN-AD supplementation and addition of wet corn distillers grains (WCDG) plus solubles[1] to the diet on carcass characteristics of finishing beef steers

	MIN-AD supplementation			WCDG addition			
Item	0	+	*P*-value[2]	0	+	*P*-value	SE[3]
Hot carcass weight, kg	387.8	382.2	0.103	380.3	389.7	0.009	2.37
Dressing percentage[4]	62.25	62.37	0.666	62.45	62.17	0.324	0.193
LM area, cm^2	81.16	83.16	0.031	81.74	82.64	0.325	0.806
12th-rib fat, cm	0.84	0.84	0.611	0.81	0.86	0.514	0.038
KPH, %	2.45	2.45	0.941	2.46	2.44	0.917	0.113
YG	3.03	2.92	0.237	2.95	3.01	0.511	0.083
Marbling score[5]	405.8	405.4	0.967	399.3	411.8	0.187	0.658
Choice or greater, %	53.47	50.00	0.546	50.69	52.78	0.748	—
Select or less, %	46.53	50.00	0.546	49.31	47.22	0.748	—
Abscessed livers,[6] %	5.21	4.51	0.769	4.51	5.21	0.809	—

[1]MIN-AD supplementation = no supplemental MIN-AD (0; MIN-AD Inc., Amarillo, TX) or MIN-AD supplemented at 0.75% of the dietary DM (+), WCDG addition = wet corn distillers grain added to the diet at either 0 or 15% (+) of dietary DM. No MIN-AD supplementation × WCDG addition interactions were detected ($P \geq 0.13$).

[2]Observed significance levels for MIN-AD supplementation and WCDG addition main-effect comparisons.

[3]Pooled SE of main-effect means, n = 24 pens/main-effect mean.

[4]Initial BW was a significant ($P = 0.024$) covariate in the statistical analysis of dressing percentage.

[5]Marbling score. 300 = Slight^0; 400 = Small^0, 500 = Modest^0

[6]Sum of A−, A, and A+ liver abscess scores.

WCDG addition were detected for fecal pH and gas production. Supplemental MIN-AD did not affect fecal pH ($P = 0.25$) or fecal gas production ($P = 0.50$), although values were numerically greater for both variables with added MIN-AD (Table 5). Despite the lack of significance for the increased fecal pH with supplemental MIN-AD, the change is in the direction expected if MIN-AD buffers the intestinal contents, suggesting that further research in this area might be warranted. Goetsch and Owens (1985) compared Ca source (no supplement, $CaCl_2$-$2H_2O$, and $CaCO_3$) and concentration and noted that as the dietary Ca concentration increased, fecal pH tended to increase, with no effect on ruminal pH.

Fecal pH was decreased ($P = 0.05$) and fecal gas production tended ($P = 0.07$) to be increased with the addition of WCDG to the diet (Table 5). Decreased fecal pH presumably reflects lower postruminal buffering properties of the diet or an increased concentration of fermentable substrate in the lower small intestine and large intestine. Similarly, increased fecal gas production might reflect a more active microbial population in the lower gut or greater fermentable substrate in the fecal inoculum. Perhaps fiber escaping ruminal and intestinal fermentation provided the substrate for greater fecal gas production with diets containing WCDG. Future studies should include an inoculum "blank" to adjust for the baseline gas production from the inoculum alone.

Table 5. Effects of MIN-AD supplementation and addition of wet corn distillers grains (WCDG) plus solubles[1] to the diet on fecal pH and gas production using a fecal inoculum with a corn starch substrate

	MIN-AD supplementation			WCDG addition			
Item	0	+	*P*-value[2]	0	+	*P*-value	SE[3]
Fecal pH	6.06	6.22	0.251	6.29	5.99	0.049	0.095
Fecal gas production, mL/g of starch	177.9	180.8	0.496	175.2	183.5	0.070	4.00

[1]MIN-AD supplementation = no supplemental MIN-AD (0, MIN-AD Inc., Amarillo, TX) or MIN-AD supplemented at 0.75% of the dietary DM (+), WCDG addition = wet corn distillers grain added to the diet at either 0 or 15% (+) of dietary DM. No MIN-AD supplementation × WCDG addition interactions were detected ($P \geq 0.20$).

[2]Observed significance levels for MIN-AD supplementation and WCDG addition main-effect comparisons

[3]Pooled SE of main-effect means, n = 12 block × replication in time combinations/main-effect mean.

IMPLICATIONS

Supplemental MIN-AD did not affect performance and did not interact with the addition of 15% (DM basis) WCDG in steam-flaked corn-based diets. Neither MIN-AD nor 15% WCDG affected cattle performance during a 12-d receiving period. During the finishing period, cattle fed WCDG had increased ADG and DMI, with no effect on G:F. Additional research is needed to evaluate the effects of supplemental MIN-AD and WCDG on fecal pH and microbial activity in the lower small intestine and large intestine of beef cattle. Moreover, further research is warranted to evaluate whether adapting cattle to WCDG (e.g., adding WCDG to receiving and step-up diets) improves the utilization of WCDG in finishing diets.

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