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Influence of level of dried distillers grains plus solubles substitution for steam-flaked corn on characteristics of growth performance, and dietary energetics of calf-fed Holstein steers during the initial 16-week growing phase: metabolizable protein versus metabolizable amino acids

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ABSTRACT

This study evaluates the partial replacement of steam-flaked corn (SFC) with increasing dried distillers grains plus solubles (DDGS) levels in growing-finishing diets for calf-fed Holstein steers. Two experiments were conducted. In trial 1, 100 Holstein calves (136 ± 7 kg) were used to evaluate the effect of DDGS as a metabolizable protein source on cattle growth performance, and dietary energetics of calf-fed Holstein steers during the initial 111 d growing phase. Four dietary levels of DDGS were evaluated (10, 15, 20, and 25%, dry matter basis), replacing SFC (flake density, 0.31 kg/L). In trial 2, four Holstein steers (368 ± 20 kg) with cannulas in the rumen and proximal duodenum were used to evaluate treatment effects on characteristics of ruminal and total tract digestion of organic matter (OM), neutral detergent fiber, nitrogen (N), and indispensable amino acid supply to the small intestine. The increasing level of DDGS did not affect ($P \geq 0.13$) average daily gain, gain efficiency, and estimated dietary net energy values. Replacement of SFC with increasing levels of DDGS decreased (linear; $P = 0.01$) ruminal OM digestion. There was no treatment effect on the flow of microbial nitrogen to the small intestine ($P = 0.34$) and ruminal microbial efficiency ($P = 0.79$). However, increasing levels of DDGS in the diet increased (linear; $P \leq 0.04$) flow of methionine, histidine, phenylalanine, threonine, leucine, isoleucine, and valine but did not affect ($P = 0.74$) intestinal supply of lysine. Increasing DDGS in the diet increased (linear, $P < 0.01$) flow of N to the small intestine but decreased (linear; $P < 0.01$) ruminal N efficiency. Replacing SFC with DDGS increased intake and amino acid leaving the abomasum. Still, this effect was not sufficient to increase the growth performance of calf-fed Holstein during the first 111 d on feed.

Key words: distillers grains, Holstein, digestion, performance, amino acids

INTRODUCTION

Although numerous studies have been conducted that evaluate the comparative feeding value of distillers' dried grains plus soluble (DDGS) as a partial replacement for corn in finishing diets for feedlot cattle (Klopfenstein et al., 2008), most of the comparisons have involved yearling cattle (>300 kg initial body weight (BW); Al-Suwaiegh et al., 2002; Gunn et al., 2009; Leupp et al., 2009b; Uwituze et al., 2010; Wierenga et al., 2010) where the extra-caloric effect of increased metabolizable protein intake due to DDGS substitution is less likely to be observed.

However, very little information is available in the literature regarding the comparative feeding value of DDGS on the growth performance of cattle placed into the feedlot as calves, where growth performance and efficiency responses to DDGS protein contribution may be observed. Indeed, the value of DDGS as a protein source for feedlot cattle remains uncertain. Prior estimates of undegradable intake protein (UIP) for DDGS have ranged from 40% to 70% (Brake et al., 2010; Cao et al., 2009; Islas and Soto-Navarro, 2011; Leupp et al., 2009a). The tabular UIP value for DDGS (52%), as put forth by NASEM (2000), represents the mean of six highly variable observations (SD = 20), with 95% confidence limits of 31 and 75%.

We hypothesized that the comparative feeding value of DDGS may be increased in calf-fed Holsteins steers consistent with its contribution to metabolizable protein requirements during the initial growing phase. The objective of this study was to evaluate the comparative feeding value of DDGS as a partial replacement for steam-flaked (SF) corn in growing-finishing diets for calf-fed Holstein steers.

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MATERIALS AND METHODS

All animal care, handling, and surgical techniques followed protocols approved by the University of California, Davis, Animal Use and Care Committee (protocol # 22363, 22271).

Experiment 1

Animal processing, housing, and feeding. One hundred Holstein steers (average live weight, 136 ± 7 kg) were used to evaluate the influence of the level of DDGS substitution for SF corn on characteristics of growth performance, and dietary energetics of calf-fed Holstein steers during the initial 111 d growing phase. Processing on arrival included vaccination for clostridials (Ultra Choice 8, Zoetis, Kalamazoo, MI), IBR (Bovi-Shield Gold One Shot, Zoetis, Kalamazoo, MI), and gram-negative septicemic diseases caused by E.coli, Salmonella, and Pasteurella (Endovac-Beef; IMMVAC, Inc. Columbia, MO), and injected with 1,000,000 IU vitamin A (Vitamin AD, Huvepharma, Inc., St. Joseph, MO). Calves were treated for internal and external parasites (3 mL SC, Dectomax, Zoetis, Kalamazoo, MI) and received 4 mL of Draxxin (400 mg Tulathromycin, Zoetis, Kalamazoo, MI). On d 28, calves received booster vaccinations (Endovac-Beef and Ultra Choice 8). Steers were blocked by weight into five blocks and assigned within blocks to 20 pens (5 steers/pen). Pens were 5.48 × 9.14 m with 26.7 m^2 shade and equipped with automatic waterers and fence-line feed bunks (4.27 m in length). Steer full BW was recorded every 28 d until the end of the experiment to monitor live weight changes. Steers were not denied feed or water before weighing. In determining average daily gain (ADG), interim and final weights were reduced by 4% to account for digestive tract fill.

Four dietary treatments were evaluated: 1) 10% DDGS; 2) 15% DDGS; 3) 20% DDGS; and 4) 25% DDGS, replacing steam-flaked corn (SFC) as a source of carbohydrate and amino acid (AA) and urea as a source of Nitrogen (N), making the isoenergetic diets and supply similar amount of N on rumen (SFC; flake density, 0.31 kg/L; Table 1). Flaked corn was allowed to air-dry before incorporation into complete mixed diets. Diets were prepared weekly and stored in plywood boxes in front of each pen. Steers were allowed ad libitum access to dietary treatments. Fresh feed was provided twice daily. Estimates of steer performance were based on pen means.

Estimation of dietary NE and metabolizable amino acids. Daily energy gain (EG; Mcal/d) was calculated by the equation: $EG = ADG^{1.097}\ 0.0557W^{0.75}$, where W is the mean shrunk BW (kg; NASEM, 1984). Maintenance energy (EM) was calculated by the equation: $EM = 0.084W^{0.75}$ (Garrett, 1971). Dietary NE_g was derived from NE_m by the equation: $NE_g = 0.877\ NE_m - 0.41$ (Zinn, 1987). Dry matter intake is related to energy requirements and dietary NE_m according to the equation: $DMI = EG/(0.877NE_m - 0.41)$, and can be resolved for estimation of dietary NE using the quadratic formula: $x = (-b - \sqrt{b^2-4ac})/2c$, where $a = -0.41EM$, $b = 0.877EM + 0.41DMI + EG$, and $c = -0.877DMI$, and $NEg = 0.877\ NEm - 0.41$ (Zinn and Shen, 1998).

The intestinal supply of indispensable amino acids for steers was estimated based on the indispensable amino acid supply observed in experiment 2, assuming proportionality of amino acid supply and DMI (Zinn and Owens, 1983; Zinn and Shen, 1987). The DMI for steers in experiments 1 and 2 averaged 2.7 and 1.9% of BW, respectively. Zinn and Borquez (1993) observed that within the range in DMI of 1.9% to 2.9% BW, the flow of nonammonia N to the small intestine of Holstein steers was directly proportional to DMI. Amino acid requirements were determined according to NASEM (2000; level 1).

For calculating steer performance, the initial BW is the off-truck arrival weight. Final BW was reduced by 4% to account for digestive tract fill. Pens were used as experimental units. Experimental data were analyzed as a randomized complete block design according to the following statistical model: $Y_{ij} = \mu + B_i + T_j + \varepsilon_{ij}$, where μ is the common experimental effect, B_i represents the initial weight block effect (df = 4), T_j represents dietary treatment effect (df = 3), and ε_{ij} represents the residual error (df = 12). Treatment effects were tested using orthogonal polynomials (Statistix 10, Analytical Software, Tallahassee, FL).

Experiment 2

Animals, diets, and sampling. Four Holstein steers (average live weight, 368 ± 20 kg) with cannulas in the rumen and proximal duodenum (Zinn and Plascencia, 1993) were used in a 4 × 4 Latin square experiment to evaluate the influence of supplemental DDGS level in substitution by SF corn on characteristics of digestive function. Treatments were the same

Table 1. Composition of experimental diets (DM basis)

	DDGS inclusion, DM basis			
Item	10%	15%	20%	25%
Ingredient composition, % DM				
Sudangrass hay	8.00	8.00	8.00	8.00
Alfalfa hay	4.00	4.00	4.00	4.00
Tallow	2.50	2.50	2.50	2.50
Molasses, cane	4.00	4.00	4.00	4.00
Distillers Grains w/solubles	10.00	15.00	20.00	25.00
Steam-flaked corn	68.41	63.660	58.91	54.11
Urea	1.10	0.850	0.60	0.40
Limestone	1.60	1.60	1.60	1.60
Magnesium oxide	0.090	0.090	0.090	0.090
TM Salt[1]	0.30	0.30	0.30	0.30
Rumensin	0.018	0.018	0.018	0.018
Nutrient composition, DM basis (NASEM, 2000)				
Dry matter, %	89.1	89.2	89.2	89.2
NEm, Mcal/kg	2.21	2.21	2.21	2.20
NEg, Mcal/kg	1.54	1.54	1.54	1.53
Crude protein, %	14.2	14.5	14.9	15.3
Rumen DIP, %	8.85	8.76	8.72	8.74
Rumen UIP, %	5.35	5.74	6.18	6.56
Ether extract, %	6.71	7.02	7.33	7.64
Ash, %	5.53	5.68	5.84	5.99
Nonstructural carbohydrates, %	58.25	55.5	52.8	50.0
Neutral detergent fiber, %	17.7	19.6	21.5	23.3
Calcium, %	0.76	0.77	0.79	0.80
Phosphorus, %	0.33	0.36	0.39	0.41
Potassium, %	0.77	0.81	0.84	0.88
Magnesium, %	0.25	0.26	0.27	0.28
Sulfur, %	0.18	0.19	0.21	0.22

[1]Trace mineral salt contained: CoSO4, 0.068%; CuSO4, 1.04%; FeSO4, 3.57%; ZnO, 0.75%; MnSO4, 1.07%; KI, 0.052%; and NaCl, 93.4%.

as those in experiment 1 (Table 1). Chromic oxide (0.3%) was added to diets to estimate nutrient digestion. Steers were maintained in individual pens (3.9 m^2) with access to water at libitum. Diets were fed at 0800 and 2,000 daily. Dry matter intake was restricted to 1.9 % of the BW. Experimental periods consisted of a 10-d diet adjustment period followed by a 4-d collection period. During the collection period, duodenal and fecal samples were taken from all steers twice daily as follows: d 1, 0750 and 1,350; d 2, 0900 and 1,500; d 3, 1,050 and 1,650; and d 4, 1,200 and 1,800. Individual samples consisted of 750 mL duodenal chyme and 200 g (wet basis) fecal material. Samples from each steer and within each collection period were composited for analysis. Upon completion of the trial, ruminal fluid was obtained from all steers and composited for the isolation of ruminal bacteria via differential centrifugation (Bergen et al., 1968).

Sample analysis and calculations. Feed, duodenal, and fecal samples were subjected to the following analysis: DM (oven drying at 105 °C until no further weight loss; method 930.15; AOAC, 2000); ash (method 942.05, AOAC, 2000), Kjeldahl N (method 984.13; AOAC, 2000); neutral detergent fiber (NDF) (Van Soest et al., 1991; corrected for NDF-ash) incorporating heat stable α-amylase (Ankom Technology, Macedon, NY) at 1 mL per 100 mL of NDF solution (Midland Scientific, Omaha, NE); amino acid (method 982.30 E; AOAC, 2006); and chromic oxide (Hill and Anderson, 1958). Ammonia N (method 941.04; AOAC, 2000) and purines (Zinn and Owens, 1986) were determined in ruminal and duodenal samples. Microbial organic matter (OM) and N leaving the abomasum were calculated using purines as microbial markers (Zinn and Owens, 1986). OM fermented in the rumen was considered equal to OM intake minus the difference between total OM reaching the duodenum and microbial OM reaching the duodenum. Feed N escape to the small intestine was considered equal to total N leaving the abomasum minus ammonia-N and microbial N and, thus, includes any endogenous contributions.

Statistical design and analysis. The effects of DDGS level on characteristics of digestion in cattle were analyzed as a 4 × 4 Latin square design according to the following statistical model for the trial as follows: $Y_{ijk} = \mu + S_i + P_j + T_k + E_{ijk}$, where: Y_{ijk} is the response variable, μ is the common experimental effect, S_i is the steer effect, P_j is the period effect, T_k is the treatment effect, and E_{ijk} is the residual error. Treatment effects were tested by means of orthogonal polynomials (Statistix 10, Analytical Software, Tallahassee, FL).

RESULTS AND DISCUSSION

The composition of corn DDGS and SFC corn are shown in Table 2. The crude protein (CP), neutral detergent fiber (NDF), and ash composition of DDGS were 97, 70, and 89%, respectively, of corresponding tabular values (NASEM, 2000). Much of the variation in the composition of DDGS can be attributed to plant-to-plant differences in the proportions of distillers solubles added back in the process (Kim et al., 2008; Spiehs et al., 2002). Whereas it is the starch component of corn that is extracted in the fermentation process, and average corn grain contains 71.8% starch, 9.2% CP, 10.0% NDF, and 3.9% ether extract (29,595 observations, DM basis; Owens and Soderlund, 2010), the removal of 98% of the starch during fermentation would yield a residue containing 31% CP, 34% NDF, and 13% ether extract which it is left as DDGS. Consistent with previous studies (Almeida et al., 2011; Guthrie et al., 2004; Stein and Shurson, 2009), the amino acid composition of DDGS as a function of total CP was similar to that of corn grain. But values for DDGS and corn were generally greater than current tabular estimates (reported as % of UIP; NASEM, 2000).

Experiment 1

Treatment effects on growth performance and dietary NE values for calves during the 111-d initial growing phase are shown in Table 3. Consistent with previous studies evaluating

Table 2. Composition of dried distillers grains plus solubles (DDGS) and steam-flaked corn (SFC), and corresponding tabular values (NASEM, 2000)

Item	DDGS	SFC	DDGS (NRC, 2000)	SFC (NRC, 2000)
			%	
DM	89.6	88.7	91.0	86.0
CP, % DM	29.4	8.6	30.4	9.8
NDF[1], % DM	31.9[a]	7.7[a]	46.0	9.0
Ether extract, % DM	11.4	4.1	10.7	3.9
Ash, % DM	4.63	1.36	5.2	1.6
Amino acids, % of CP				
Arg	4.93	4.13	4.15	1.82
His	2.56	2.38	1.82	2.06
Ile	4.13	3.25	2.78	2.69
Leu	11.58	11.26	9.07	10.73
Lys	2.96	2.63	2.06	1.65
Met	2.00	2.00	1.20	1.12
Phe	5.05	4.63	4.20	3.65
Thr	3.81	3.63	3.12	2.80
Val	5.49	4.50	5.24	3.75

[1]Ash-free NDF.

Table 3. Level of DDGS supplementation and growth performance of calf-fed Holstein steers during the initial 16-week growing phase (experiment 1)

	DDGS inclusion, DM basis					*P* value	
	10%	15%	20%	25%	SEM	L	Q
MP, % req[1]	93	96	98	100			
mLys, % req[2]	87	88	90	91			
Weight, kg							
Initial	136.1	136.0	135.9	134.7	0.75	0.25	0.47
111 d	294.8	294.5	292.7	295.8	3.6	0.93	0.65
ADG, kg	1.43	1.43	1.41	1.45	0.031	0.73	0.53
DMI, kg/d	5.97	5.76	5.82	5.85	0.085	0.43	0.19
ADG/DMI	0.240	0.248	0.243	0.248	0.003	0.13	0.63
NEm, Mcal.kg	1.97	2.03	1.99	2.02	0.018	0.17	0.42
NEg, Mcal/kg	1.32	1.37	1.34	1.36	0.016	0.17	0.42
Observe to expected dietary NE ratio							
Maintenance	0.89	0.92	0.91	0.92	0.008	0.09	0.43
Gain	0.86	0.89	0.88	0.89	0.010	0.09	0.43

[1]MP: Metabolizable protein predicted supply versus requirements based on observed ADG, DMI, and diet formulation (NASEM, 2000).
[2]mLys: Metabolizable lysine predicted supply versus requirements based on observed ADG, DMI, and diet formulation (NASEM, 2000).

Table 4. Treatment effects on estimated metabolizable indispensable amino acid supply to the small intestine as a percentage of requirement (experiment 1)[1]

	DDGS in diet			
Item	10%	15%	20%	25%
D 1 to 111				
Methionine	79.8	83.5	83.9	87.3
Lysine	84.5	89.5	83.8	88.5
Histidine	67.0	69.8	71.3	82.0
Phenylalanine	125.2	130.1	131.5	148.9
Threonine	100.3	105.2	103.0	111.2
Leucine	124.3	131.9	135.5	145.3
Isoleucine	145.4	149.7	146.8	164.5
Valine	110.2	111.8	109.6	123.6
Arginine	104.3	110.5	106.7	117.6

[1]Based on amino acid supply to the small intestine per unit DMI in trial 1, adjusting for corresponding DMI in Exp.
[2](assuming 80% of amino acid flow to the small intestine is metabolizable; NASEM, 2000). Metabolizable indispensable amino acid requirements based on NASEM (2000).

DDGS substitution for SFC corn in crossbred beef breeds (Gordon et al., 2002; Quinn et al., 2011; Uwituze et al., 2010), there were no treatment effects ($P \geq 0.19$) on DMI. During this initial 111-d period, when metabolizable amino acid supply was expected to be most limiting (NASEM, 2000), increasing the level of DDGS did not affect ($P \geq 0.13$) ADG, gain efficiency, and estimated dietary NE but tended (linear effect, $P = 0.09$) to slightly increase the observed versus expected dietary NE. Regressing estimated dietary NE on DDGS:SFC ratio, the NEm and NEg value of DDGS were 2.13 and 1.46 Mcal/kg, respectively. These NE values are in reasonably good agreement with the tabular values (2.18 and 1.50 Mcal/kg, respectively; NASEM, 2000).

Calf-fed Holstein steers are typically fed a single SFC-based diet throughout the growing-finishing period in southwestern feedlots (Carvalho et al., 2022; Latack et al., 2021). Similar to the 0% DDGS diet shown in Table 1, this single diet formulation usually contains between 12 and 13% CP, with urea as the sole source of supplemental N (Zinn et al., 2005). Although this diet meets the theoretical (NASEM, 2000; Level 1) metabolizable amino acid requirements across the overall feedlot feeding period (usually least from 320 to 350 d), it does not meet the metabolizable amino acid requirements of calves during the initial growing phase (112 to 140 d; Zinn and Shen, 1998; Zinn et al., 2007). In the current experiment, only the treatment with 25% DDGS in the diet were in theory meeting metabolizable protein requirements (111 d). However, they did not meet limiting amino acid requirements (i.e., Lysine).

Estimates of indispensable amino acid supply to the small intestine in experiment 1 as a percentage of requirement (NASEM, 2000) are shown in Table 4. Regardless of DDGS treatment, supplies of metabolizable methionine, lysine, and histidine were providing on average 83.3%, 83.6%, and

Table 5. Influence of supplementation level of dried distillers grains plus solubles (DDGS) on characteristics of apparent ruminal and total tract digestion in Holstein steers (experiment 2)

	DDGS in diet (% of diet DM)					Contrast *P*-value	
Item	10%	15%	20%	25%	SEM	Linear	Quadratic
Steer replicates	4	4	4	4			
Intake							
DM, g/d	7,570	7,568	7,567	7,566			
OM, g/d	7,209	7,194	7,179	7,164			
NDF, g/d	1,255	1,354	1,454	1,552			
N, g/d	158	163	168	174			
Flow to duodenum, g/d							
OM	3,517	3,587	3,522	3,675	47	0.10	0.42
NDF	863	840	891	881	31	0.48	0.85
Starch	4,187	4,261	4,164	4,354	59	0.18	0.36
N	164	173	171	183	4.5	0.04	0.76
Ammonia N	5.83	6.03	6.13	6.03	0.27	0.59	0.59
Nonammonia N	159	167	165	177	4.7	0.05	0.74
Microbial N	80.6	82.8	69.3	79.9	3.4	0.37	0.23
Feed N	61.8	68.9	79.5	80.7	3.2	<0.01	0.39
Ruminal digestion, %							
OM	62.4	61.5	60.6	59.9	0.58	0.02	0.93
NDF	31.2	37.9	38.7	43.2	2.2	0.01	0.64
Feed N	60.9	57.7	52.5	53.6	1.9	0.02	0.33
MN efficiency[1]	18.0	18.7	15.9	18.8	0.78	0.91	0.20
N efficiency[2]	1.01	1.03	0.99	1.02	0.03	0.96	0.88
Postruminal digestion, % leaving abomasums							
OM	56.5	60.7	57.1	57.6	1.7	0.97	0.30
NDF	0.5	1.9	0.8	1.9	0.7	0.39	0.81
N	73.3	77.2	75.1	76.3	1.1	0.19	0.25
Fecal excretion, g/d							
DM	1,781	1,631	1,745	1,812	58	0.45	0.11
OM	1,533	1,404	1,515	1,558	53	0.46	0.16
NDF	858	825	883	865	27	0.55	0.79
N	44.2	39.5	42.5	43.3	1.9	0.98	0.21
Total-tract digestion, %							
DM	76.5	78.4	76.9	76.1	0.76	0.44	0.11
OM	78.7	80.5	78.9	78.3	0.7	0.39	0.16
NDF	31.6	39.1	39.2	44.3	1.9	<0.01	0.54
N	72.0	75.8	74.6	75.1	1.2	0.19	0.23

[1] Duodenal microbial N, g kg^{-1} OM fermented in the rumen.
[2]Duodenal nonammonia N, g g^{-1} N intake.

72.5% of theoretical requirements, respectively. Thereafter, metabolizable methionine and histidine were the limiting amino acid in cattle receiving this diet. In previous studies involving calf-fed Holstein steers (Zinn et al., 2000, 2007), deficiencies in metabolizable amino acid supply were reflected in decreased ADG and energetic efficiency (observed vs. expected dietary NE).

Moreover, in previous studies involving crossbred yearling beef cattle (Depenbusch, 2008a; May et al., 2007; Uwituze et al., 2010), the substitution of DDGS for SFC corn at levels of up to 25% of diet DM did not affect overall ADG or gain efficiency. In contrast, partial substitution of SFC-based finishing diets with wet distillers grains slightly reduced ADG and feed efficiency in crossbreed yearling cattle (Daubert et al., 2005; Depenbusch et al., 2008b; May et al., 2010). The variable response in cattle growth performance as DDGS is included in cattle diet may be explained by the variation in nutrient composition of this byproduct which may be related to the source and method of processing (Gunn et al., 2009; Hersom et al., 2010).

Experiment 2

Treatment effects on characteristics of ruminal and total tract digestion are summarized in Table 5. Ruminal NDF digestion increased (linear effect, $P = 0.01$) with DDGS substitution.

Table 6. Supply of indispensable amino acids (g/d) to the small intestine of Holstein steers as influenced by the level of dried distillers grains plus solubles supplementation (experiment 2)

	DDGS in diet (% of diet DM)					Contrast *P*-value	
Item	10%	15%	20%	25%	SEM	Linear	Quadratic
Steer replicates	4	4	4	4			
Amino acids							
Methionine							
Intake, g/d	15.4	17.3	19.1	20.9			
Leaving abomasum, g/d	17.2	18.8	18.7	20.0	0.25	<0.01	0.57
Lysine							
Intake, g/d	22.2	26.3	30.4	34.4			
Leaving abomasum, g/d	58.6	64.3	59.6	64.9	0.88	0.01	0.83
Histidine							
Intake, g/d	19.6	22.4	25.1	27.8			
Leaving abomasum, g/d	18.0	20.5	19.9	22.2	0.27	<0.01	0.68
Phenylalanine							
Intake, g/d	38.9	44.3	49.7	55.0			
Leaving abomasum, g/d	47.3	51.1	51.2	56.2	0.68	<0.01	0.44
Threonine							
Intake, g/d	27.4	31.3	35.1	38.9			
Leaving abomasum, g/d	42.3	46.0	44.6	47.9	0.61	<0.01	0.76
Leucine							
Intake, g/d	81.3	92.5	103.5	114.5			
Leaving abomasum, g/d	90.0	99.3	101.2	111.5	1.3	<0.01	0.71
Isoleucine							
Intake, g/d	29.0	33.2	37.2	41.3			
Leaving abomasum, g/d	46.1	49.4	47.9	52.7	0.67	<0.01	0.33
Tyrosine							
Intake, g/d	21.9	25.7	29.5	33.3			
Leaving abomasum, g/d	41.0	44.3	44.1	47.5	0.59	<0.01	0.98
Valine							
Intake, g/d	36.1	41.1	46.1	50.9			
Leaving abomasum, g/d	48.9	52.8	51.2	56.6	0.71	<0.01	0.32
Cystine							
Intake, g/d	13.8	14.7	15.5	16.3			
Leaving abomasum, g/d	15.5	17.0	17.1	19.2	0.23	<0.01	0.29
Glycine							
Intake, g/d	29.9	33.6	37.3	40.9			
Leaving abomasum, g/d	47.7	49.0	45.8	53.9	0.69	<0.01	<0.01
Proline							
Intake, g/d	60.1	67.7	75.1	82.5			
Leaving abomasum, g/d	53.6	57.9	59.9	64.9	0.76	<0.01	0.73
Glutamate							
Intake, g/d	119	133	146	159			
Leaving abomasum, g/d	137	153	152	169	2.0	<0.01	0.99
Serine							
Intake, g/d	32.9	37.2	41.5	45.8			
Leaving abomasum, g/d	40.2	43.5	42.9	47.5	0.58	<0.01	0.31
Alanine							
Intake, g/d	49.9	55.9	61.9	67.9			
Leaving abomasum, g/d	63.6	68.2	67.5	74.0	0.91	<0.01	0.31
Aspartic acid							
Intake, g/d	52.1	58.7	65.1	71.5			
Leaving abomasum, g/d	84.6	91.6	87.5	94.5	1.2	<0.01	0.99
Arginine							
Intake, g/d	32.4	37.1	41.8	46.4			
Leaving abomasum, g/d	38.1	43.0	41.2	44.4	0.57	<0.01	0.18

However, the replacement of SFC with increasing levels of DDGS decreased (linear effect, $P = 0.02$) ruminal digestion of OM. Previous research has reported similar results. The decrease in ruminal OM digestion with the increased inclusion of DDGS in the diet is expected due to the greater NDF and fat content of DDGS versus SFC (May et al., 2009).

There was no treatment effect ($P \geq 0.37$) on the flow of microbial N (MN) to the small intestine and ruminal microbial efficiency (flow of microbial N to the small intestine as a proportion of OM fermented; Table 5). Substitution of SFC corn with DDGS increased (linear effect, $P < 0.04$) flow of N to the small intestine. However, there were no effect ($P = 0.96$) of DDGS inclusion in the diet on ruminal N efficiency (flow of nonammonia N to the small intestine as a proportion of N intake).

Ruminal digestion of feed N decreased (linear effect, $P = 0.02$) with an increasing level of DDGS substitution for SFC (Table 5). Regressing feed N entering the small intestine on DDGS:SFC ratio, the ruminal UIP value of DDGS was 47.6%. This value is in good agreement with the tabular value (52%; NASEM, 2000). However, the NASEM (2000) value represents the mean of six highly variable observations (SD = 20). The 95% confidence limits for the current tabular UIP value are 31 and 75%. Prior estimates of UIP for DDGS have ranged from 40% to 70% (Brake et al., 2010; Cao et al., 2009; Islas and Soto-Navarro, 2011; Leupp et al., 2009a; NASEM, 2000) and were observed to be as low as 13% UIP (Gilbery et al., 2006). High variation in DDGS' UIP values may be related to the source and method of processing (Gunn et al., 2009; Hersom et al., 2010) and the proportion of soluble returned to grain solids residues in the DDGS mixture (Cao et al., 2009).

There were no treatment effects on postruminal digestion of NDF ($P \geq 0.19$; Table 5). Dried distillers grains plus solubles supplementation tended to increase (linear effect, $P < 0.01$) total tract NDF digestion with no major effect ($P \geq 0.19$) on other DM, OM, and N total-tract digestibility. However, Corrigan et al. (2009), reported that the level of DDGS substitution for SFC decreased (linear effect, $P < 0.01$) total tract OM digestion. Moreover, Leupp et al. (2009a) and Brake et al. (2010), observed that total tract apparent N digestion increased (linear effect, $P = 0.04$) with the level of DDGS substitution. However, this effect may be more a function of the increased N content of the diet by replacing SFC with DDGS (Holter and Reid, 1959). As previously mentioned, the inconsistency of DDGS processing methods might be the reason for the differences between the current results and previous research.

The indispensable AA supply to the small intestine is shown in Table 6. Increasing the level of substitution of DDGS for SFC increased (linear effect, $P < 0.01$) the flow of methionine, histidine, phenylalanine, threonine, leucine, isoleucine, and valine. This is in good agreement with authors hypothesis that increasing levels of DDGS in the diet would increase postruminal flow of amino acids. However, this increase could not impact animal performance.

In conclusion, the NEm and NEg values for DDGS in SFC-based growing-finishing diets are consistent with current tabular standards (2.18 and 1.50 Mcal/kg, respectively). The first 111-d growth performance was not enhanced with increasing DDGS substitution for SFC. Methionine and Histidine were the first co-limiting amino acids, averaging 91.5 and 81.78% of theoretical requirements. Whereas increasing DDGS concentration in the diet increased metabolizable protein supply to the small intestine, it did not appreciably increase metabolizable lysine.

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