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Effects of replacing partially dry-rolled corn and soybean meal with different levels of dried distillers grains with solubles on growth performance, dietary energetics, and carcass characteristics in hairy lambs fed a finishing diet

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ABSTRACT

While there is very little empirical data with feedlot lambs, the current standards assigns the same energy value to distillers dry grain with solubles (DDGS) and corn. Since the basis of energy of corn is starch while in DDGS are the proteins and fat content, in the vast majority of the studies comparisons were made between in non-isoenergetic diets, situation that make it difficult to accurately determine the feeding value of DDGS included at high levels. For the latter, the objective of this experiment was to determine in isoenergetic diets the effects of replacing partially dry-rolled corn (DRC) and soybean meal (SBM) with different levels (0, 15, 30 and 45%) of dried distillers grains with solubles (DDGS) on growth performance, dietary energetics, carcass characteristics, and visceral mass in finishing hairy lambs. DDGS substitution improved (linear $P = 0.04$) final weight and average daily gain, but as a consequence of a tendency ($P = 0.06$) to increase dry matter intake (DMI) with DDGS substitution, there were no advantages ($P \geq 0.33$) on gain efficiency, dietary energetic or observed-to-expected DMI. DDGS substitution did not affect dressing percentage and backfat thickness, but increased (linear, $P \leq 0.03$) hot carcass weight and kidney, pelvic and heart fat (KPH) and decreased (linear, $P = 0.05$) longissimus muscle area (LM). There were not treatments effects on carcass composition, but increased DDGS level in substitution tended to linearly decrease, as a percentage of cold carcass weight, muscle ($P = 0.08$) and increase carcass fat (linear, $P = 0.10$). There were no effects of substitution with DDGS on wholesale cuts. Replacing corn and SBM with DDGS increased (linear $P = 0.03$) empty body weight (EBW, as percentage of full weight) but influence on organ weights as a proportion of EBW (g/kg EBW) were small. The feeding value of DDGS is similar to that of dry-rolled corn (~9.62 MJ EN_m/kg), this feeding value decreases as the inclusion level of DDGS increases beyond 30% because to the removal of starch instead NDF and the potential reduction of digestibility of fat. The drastically change of source of energy (fat and protein instead starch)

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can affect the deposition of body fat and the area of LM. Based on DMI and performance observed in the present study, DDGS is a suitable substitute for a portion of the dry-rolled corn and SBM in a finishing diet; however, at high levels of inclusion, it tends to decrease the LM area and increase the KPH.

1. Introduction

During the production process of distillers dry grain with solubles (DDGS), protein, minerals, fat and fiber are concentrated three-fold as co-products when compared with corn. Therefore, DDGS contains approximately 30% crude protein (73% ruminal undegradable intake protein, UIP), 40% neutral detergent fiber (NDF) and 11% fat (NRC, 2007), and often costs less than corn (USDA, 2012). The growing supply of DDGS is likely to lower the cost of the feed ingredient, making it more favorable for use as a protein and energy source in the livestock industry. The high potential of the nutritional value of DDGS can be useful for replacing grains (Klopfenstein et al., 2008) or grains plus protein sources (Depenbusch et al., 2008) in growing-finishing diets of beef cattle. However, it appears that the feed value of DDGS may vary by level of inclusion (Uwituze et al., 2010), as well as the strategy of ingredients that it replaces (Dicostanzo and Writhe, 2012). Historically, DDGS has primarily been feed to beef and dairy cattle, swine and poultry (Rosentrater, 2012). Even though DDGS should be appropriate as a feed ingredient for lambs, the feeding value of DDGS in finishing diets fed to lambs is well not defined because only a limited amount of research has evaluated the use of DDG in lamb diets (Huls et al., 2006; Schauer et al., 2008). Early efforts in evaluating DDGS as an ingredient for lambs were directed to evaluate DDGS as potential substitute for soybean meal (Waller et al., 1980). However, given the physicochemical properties of DDGS is being used in finishing diets for feedlot lambs to partially replace corn and soybean meal. Huls et al. (2006) reported, based on growth performance (DMI, gain and feed efficiency), that DDGS is similar to a mixture composed of 56% corn and 44% soybean meal (SBM) when 17.3% of corn and 100% of SBM were replaced by 22.9% of DDGS in the finishing diet which contained 72.2% and 10.2% corn and SBM, respectively. As result of source of forage used in these trials (soybean hulls), they argue the performance responses more for functional food aspects than for feed value of DDGS *per se*. More recently, Schauer et al. (2008) reported that lambs could be fed up to 60% DDGS (DM basis), to replace a 55% barley and 5% SBM, without affecting performance and carcass quality, which could indicates that the feeding value of DDGS was similar to the proportion of barley and soybean meal replaced in these diets. However, treatments were not formulated to be isocaloric or isonitrogenous and this could mask the real feeding value of DDGS in Schauer's study. Furthermore, it is known that inclusion levels above 25% may affect the nutritional value of DDGS (Vander Pol et al., 2005). Felix et al. (2012) reported a quadratic effect on average daily gain (ADG) in feedlot lambs when corn and soybean meal were replaced by DDGS, being maximal at 20% of inclusion. These researchers argue that the chemical composition of DDGS (high content of NDF and fat) is responsible for the decreases in the feeding value at high levels of inclusion. Because SBM were totally replaced in DDGS treatments in most of the experiments, the relative difference in protein concentration between control diets *vs.* diets supplemented with high levels of DDGS was up to 35%, the excess protein might decrease the available energy for growth by increasing the energy cost of certain organs that are responsible for dealing with excess protein (Gunn et al., 2009). In the same way, the diets were generally not isoenergetic when DDGS partially replaced grain and totally replaced SBM in diets. Both situations make it difficult to accurately determine the feeding value of DDGS included at high levels in these experiments. Therefore, the purpose of this study was to evaluate, in isoenergetic diets, the feeding value of DDGS included at high levels as a partial substitute of corn and SBM, and to test the hypothesis that this DDGS can partially replace corn and SBM in high concentrate diets for finishing hair lambs without affecting growth performance, carcass characteristics and visceral organ mass.

2. Materials and methods

2.1. Diets, animals and experimental design

This experiment was conducted at the Universidad Autónoma de Sinaloa Feedlot Lamb Research Unit, located in the Culiacán, México (24°46′13″ N and 107°21′14″ W). Culiacán is about 55 m above sea level, and has a tropical climate. All animal management procedures were conducted within the guidelines of locally approved techniques for animal use and care. Forty Pelibuey × Katahdin (17.27 ± 1.36 kg) crossbred intact male lambs were used in a growth-performance experiment to evaluate the effects of replacing partial soybean meal (SBM) and dry-rolled corn (DR) with different levels (0, 15, 30 and 45%) of dried distillers grains with solubles (DDGS) on growth performance, dietary energetics, carcass characteristics, and visceral organ mass. Three weeks before the experiment started, lambs were treated for endoparasites (Tasasel 5%®, Fort Dodge, Animal Health, México), and injected with 1×10^6 IU vitamin A (Synt-ADE®, Fort Dodge, Animal Health, México). Upon initiation of the experiment, lambs were weighed individually before the morning meal (electronic scale; TORREY TIL/S: 107 2691, TOR REY electronics Inc, Houston TX, USA) and were equally grouped by weight into five uniform weight groups and assigned to 5-pen blocks (two lambs per pen). The 20 pens used in the study were 6 m^2 with overhead shade, automatic waterers and 1 m fence-line feed bunks. During a 21-d adaptation period all lambs received the basal diet (no DDGS supplementation, Table 1). Dietary treatments consisted of the replacement of the total of DRC and SBM in basal diet by DDGS using the following proportions: (1) 0% for basal diet (DDGS0); (2) 15% DDGS level replacing 15% of corn and 30% of SBM (DDGS15); (3) 30% DDGS level replacing 30% corn and 60% SBM (DDGS30), and (4) 45% DDGS level replacing 45% corn and 90% SBM (DDGS45). Experimental diets and their chemical compositions are shown in Table 1. To maintain the proportion (>1.5) of Ca:P in diet, limestone was added, replacing molasses cane, at levels of 0.25, 0.50, and 0.75% in the diets DDGS15, DDGS30 and DDGS45, respectively. Diets were formulated to be isocaloric but not isonitrogenous, because the protein level increased as the level of DDGS replacing corn and SBM in the diet increased. The relative differences in protein concentration between the control diet and the high level DDGS diet was 2.46% (17.10 *vs.* 19.56% CP). It is well recognized that when the diet

Table 1
Ingredients and composition of experimental diets fed to lambs (% of dry matter).

Item	Dried distillers grains plus solubles level (%)			
	0	15	30	45
Ingredient composition (%)				
Dry-rolled corn	62.00	52.50	43.00	33.00
Dried distillers grains with solubles	0.00	15.00	30.00	45.00
Soybean meal	18.00	12.50	7.00	2.00
Sudan grass hay	10.00	10.00	10.00	10.00
Molasses cane	7.50	7.25	7.00	6.75
Limestone	0.00	0.25	0.50	0.75
Trace mineral salt[a]	2.50	2.50	2.50	2.50
Chemical composition[b], *(DM basis)*				
Crude protein (%)	17.10	17.74	18.70	19.56
Ether extract (%)	2.98	3.90	4.79	5.77
NDF (%)	15.98	19.90	23.76	27.22
Starch	44.02	39.46	32.44	26.68
Ca	0.79	0.89	1.01	1.12
P	0.38	0.50	0.62	0.72
Calculated net energy[c] *(MJ/kg)*				
Maintenance	8.36	8.36	8.36	8.33
Gain	5.65	5.65	5.65	5.64

[a] Mineral premix contained: CP, 50%; calcium, 28%; phosphorous, 0.55%; magnesium, 0.58%; potassium, 0.65%; NaCl, 15%; vitamin A, 1100 IU/kg; vitamin E, 11 IU/kg.

[b] Dietary composition was determined by analyzing subsamples collected and composited throughout the experiment. Accuracy was ensured by adequate replication with acceptance of mean values that were within 5% of each other.

[c] Based on tabular net energy (NE) values for individual feed ingredients (NRC, 1985) with the exception of supplemental fat, which was assigned NE_m and NE_g values of 25.1 and 19.87 MJ/kg, respectively (Zinn, 1988).

contains more than 8.28 MJ of NE_m/kg, increasing protein level above of 15% has no additional beneficial effects on the productive performance of finishing lambs, therefore it is expected that this difference on protein level between diets has not an impact on the measure of retained energy (Ríos-Rincón et al., 2014). White corn was used as a source of grain in the form of a commercial blend obtained from Mexico. Corn was prepared by passing whole corn through rollers (46 cm × 61 cm rolls, 5.5 corrugations/cm; Memco, Mills Rolls, Mill Engineering & Machinery Co., Oklahoma, CA) and machinery that had been adjusted so that the kernels were broken into an approximate bulk density of 0.52 kg/L. The source of the DDGS used was a corn DDGS named for its appearance (color) as "Golden" and was obtained in an ethanol production facility with a 0.8% maximal content of sulfur (Pinal Energy LLC, Maricopa, AZ). The soybean meal used was a standard US soybean meal obtained by solvent extraction (Ceres Commodities LCC, Newport, KY). The forage source of diet (sudangrass hay) was ground in a hammer mill (Bear Cat #1A-S, Westerns Land and Roller Co., Hastings, NE) with a 3.81 cm screen, before incorporation into complete mixed diets. Dietary treatments were randomly assigned to pens within blocks. The experiment lasted 112 days and lambs were weighed at the beginning of the trial and every 28 days thereafter. The initial BW was reduced by 4% to adjust for the gastrointestinal fill, and all lambs were fasted (food but not drinking water was withdrawing) for 18 h before recording the final BW. Lambs were allowed *ad libitum* access to dietary treatments. Daily feed allotments to each pen were adjusted to allow minimal (<5%) feed refusals in the feed bunk. The amounts of feed offered and feed refused were weighed daily. Lambs were provided fresh feed twice daily at 0800 and 1400 h in a 40:60 proportion (as feed basis). Feed bunks were visually assessed between 0740 and 0750 h each morning, refusals were collected and weighed and feed intake was determined. Adjustments, to either increase or decrease daily feed delivery, were provided at the afternoon feeding.

2.2. Sample analysis

The ingredients (DDGS, corn and soybean meal) and complete diets were subjected to the following analyses: DM (oven drying at 105 °C until no further weight loss; method 930.15; AOAC, 2000); CP (N × 6.25, method 984.13; AOAC, 2000); ash (method 942.05; AOAC, 2000); 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)]; ether extract (method 920.39; AOAC, 2000); starch (Zinn, 1990); calcium, (method 927.02; AOAC, 2000) and phosphorus (method 964.06; AOAC, 2000). Feed and refusal samples were collected daily for DM analysis, which involved oven-drying the samples at 105 °C until no further weight loss occurred (method 930.15; AOAC, 2000).

2.3. Calculations

The estimations of dietary energetic and expected DMI were performed based on the estimated initial shrunk body weight (SBW), to convert to a SBW basis is assuming that SBW is 96% of the full weight (Cannas et al., 2004), and final body weight. Average daily gains were computed by subtracting the initial BW from the final BW and dividing the result by the number of days on feed. The efficiency of BW gain was computed by dividing ADG by the daily DMI.

The estimation of expected DMI was performed based on observed ADG and average shrunk weight (SBW) according to the following equation: expected DMI, kg/d = $(EM/NE_m) + (EG/NE_g)$, where EM (energy required for maintenance, MJ/d) = $[4.184 \times (0.056 \times SBW^{0.75})]$ (NRC, 1985), EG (energy gain, MJ/d) = $[4.184 \times (0.276 \times ADG \times SBW^{0.75})]$ (NRC, 1985), NE_m and NE_g are 8.58 and 5.86 MJ/kg, respectively (derived from tabular values based on the ingredient composition of the experimental diet; NRC, 1985), and SBW represent full body weight × 0.96 (Cannas et al., 2004). The coefficient (0.276) was estimated assuming a mature weight of 113 kg for Pelibuey × Kathdin male lambs (Canton and Quintal, 2007). Dietary NE was estimated by means of the quadratic formula:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2c}$$

where $x = NE_m$, $a = -0.41EM$, $b = 0.877\ EM + 0.41\ DMI + EG$, and $c = -0.877\ DMI$ (Zinn et al., 2008); the results obtained were multiplied by 4.184 to convert to units of MJ.

The estimated net energy of DDGS was performed given that the NE_m values of DR corn and soybean meal are 2.24 and 2.06 Mcal/kg, respectively (NRC, 1985), so the comparative NE_m values for the DDGS in each supplemented diet were estimated as follows:

$$EN_m,\ Mcal/kg\ DDGS15 = \left(\frac{((0.775 \times 2.24) + (0.225 \times 2.06)) - ((1.97 - 2.00)/0.8) - ((0.65625 \times 2.24) + (0.15625 \times 2.06))}{0.1875}\right)$$

$$EN_m,\ Mcal/kg\ DDGS30 = \left(\frac{((0.775 \times 2.24) + (0.225 \times 2.06)) - ((1.97 - 2.01)/0.8) - ((0.5375 \times 2.24) + (0.0875 \times 2.06))}{0.375}\right)$$

$$EN_m,\ Mcal/kg\ DDGS45 = \left(\frac{((0.775 \times 2.24) + (0.225 \times 2.06)) - ((1.97 - 2.01)/0.8) - ((0.4125 \times 2.24) + (0.025 \times 2.06))}{0.5625}\right)$$

The constants 0.775 and 0.225 represent the proportion of DR corn and SBM in the total participation in basal diet, while the constants 2.24 and 2.06 represent the NE_m of corn and SBM replaced by DDGS; the constant 1.97 represents the EN_m observed to basal diet; the constant 0.80 represents the total percentage of corn and SBM in basal diet; the constants 0.1875, 0.375, and 0.5625 correspond to the proportion of DDGS which replaced corn and SBM in the basal diet; and finally, the constants 0.65625 and 0.15625; 0.5375 and 0.0875, and 0.4125 and 0.025 represent the proportion of corn and SBM in the DDGS replaced diets. The results obtained were multiplied by 4.184 to convert to units of MJ.

2.4. Carcass and visceral mass data

All lambs were harvested on the same day. After sacrifice, lambs were skinned, and the gastrointestinal organs were separated and weighed. After carcasses (with kidneys and internal fat included) were chilled in a cooler at −2 °C to 1 °C for 48 h, the following measurements were obtained: (1) carcass length (maximum distance between the edge of the ischio-pubic symphysis and anterior border of the first rib at its midpoint); (2) carcass depth (maximum distance between the sternum and the back of carcass, at level of sixth thoracic vertebra); (3) leg length (distance from the symphysis pubis to the tarsal-metatarsal joint); (4) body wall thickness (distance between the 12th and 13th ribs beyond the ribeye, five inches from the midline of the carcass); (5) fat thickness perpendicular to the *m. longissimus thoracis* (LM), measured over the center of the ribeye between the 12th and 13th rib; (6) LM surface area, measure using a grid reading of the cross sectional area of the ribeye between 12th and 13th rib, and (7) kidney, pelvic and heart fat (KPH). The KPH was removed manually from the carcass, and then weighed and reported as a percentage of the cold carcass weight (USDA, 1982). Each carcass was split along the vertebrae into two halves. The left side of each carcass was fabricated into wholesale cuts, without trimming, according to the North American Meat Processors Association guidelines (NAMP, 1997). Rack, breast, shoulder and foreshank were obtained from the foresaddle, and the loins; flank and leg were from the hindsaddle. The weights of each cut were subsequently recorded. The carcass composition was assessed using physical dissection by the procedure described by Luaces et al. (2008).

All tissue weights were reported on a fresh tissue basis. Previous data suggests that there is very little variation among fresh and dry weights for visceral organs (Neville et al., 2008). Organ mass was expressed as grams of fresh tissue per kilogram of final empty BW. Final EBW represents the final full BW minus the total digesta weight. Full visceral mass was calculated by the summation of all visceral components (stomach complex + small intestine + large intestine + liver + lungs + heart), including digesta. The stomach complex was calculated as the digesta-free sum of the weights of the rumen, reticulum, omasum and abomasum.

2.5. Statistical analysis

Performance (gain, gain efficiency, and dietary energetics) and carcass data were analyzed as a randomized complete block design. The experimental unit was the pen. The linear statistical model was $Y_{ij} = \mu + \tau_i + b_j + \varepsilon_{ij}$ $i = 1, 2, \ldots, t$; $j = 1, 2, \ldots, r$ where μ is the true mean effect, τ_i is the fixed treatment effect, b_j is the random pen effect with mean 0 and variance σ_b^2, and ε_{ij} is the random experimental error with mean 0 and variance σ^2. Under the mixed model an observation has expected value $E(Y_{ij}) = \mu + \tau_i$ and variance $\sigma^2 + \sigma_b^2$. The MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) was used to analyze the variables. Whole cuts data and carcass composition were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC). The linear statistical model was $Y_{ijk} = \mu + \tau_i + b_j + (\tau b)_{ij} + \beta(x_{ijk} - \bar{x}_{\ldots}) + \varepsilon_{ijk}$ $i = 1, 2, \ldots, t$; $j = 1, 2, \ldots, r$; $k = 1, 2, \ldots, u$ where μ is the general mean, τ_i is the fixed treatment effect, $b_j \sim$ iid $N(0, \sigma_b^2)$ denotes the pen effect, $(\tau b)_{ij} \sim$ iid $N(0, \sigma_{\tau b}^2)$ is treatment × pen interaction effect, β is the coefficient for the linear regression of Y_{ijk} on x_{ijk}, x_{ijk} is the final CCW as covariate, and ε_{ijk} is the individual carcasses within-pen by treatment subclasses effect ∼ iid $N(0, \sigma_e^2)$. When the covariate represented a non-significative ($P > 0.05$) source of variation was not included into the model. Visceral organ mass data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC). The linear statistical model was $Yi_{jk} = \mu + \tau_i + b_j + (\tau b)_{ij} + \varepsilon i_{jk}$ $i = 1, 2, \ldots, t$; $j = 1, 2, \ldots, r$; $k = 1, 2, \ldots, u$ where μ is the general mean, τ_i is the fixed treatment effect, $b_j \sim$ iid $N(0, \sigma_b^2)$ denotes the pen effect, $\varepsilon_{ijk} \sim$ iid $N(0, \sigma_e^2)$ is treatment × pen interaction effect, and ε_{ijk} is the individual carcasses within-pen by treatment subclasses effect ∼ iid $N(0, \sigma_e^2)$.

Treatment effects were tested for linear, quadratic and cubic components of the DDGS supplementation level. Contrasts were considered significant when the *P*-value was ≤0.05, and tendencies were identified when the *P*-value was >0.05 and ≤0.10.

Table 2
Composition and density of dried distillers grain with solubles (DDGS), dry-rolled corn (DRC) and soybean meal (SBM) determined by analyses.

Item	DDGS	DRC	SBM	Sudan hay
DM (%)	94.2	91.4	91.7	94.74
CP (%)	29.7	9.1	49.4	6.87
NDF (%)	33.2	10.3	12.1	60.42
Starch (%)	4.3	69.4	2.7	–
Ether extract (%)	9.8	3.6	2.8	1.88
Ash (%)	5.7	1.7	7.5	9.53
Ca	0.17	0.03	0.32	0.48
P	0.88	0.26	0.62	0.28
Density (g/L)	491	598	602	63

3. Results

Due to the chemical composition of DDGS, DRC and SBM (Table 2), the crude protein, NDF, and ether extract increased and starch declined as the level of DDGS replacing corn and SBM in the diet increased (Table 1). Growth performance, dietary energetic, carcass traits and visceral organ mass are shown in Tables 3–5. The DDGS substitution improved (linear $P = 0.04$) final weight and average daily gain, but, as a consequence of a tendency ($P = 0.06$) to increase dry matter intake (DMI) with DDGS substitution, there were no advantages ($P \geq 0.33$) on gain efficiency, dietary energetic or observed-to-expected DMI. DDGS substitution did not affect dressing percentage and backfat thickness, but increased hot carcass weight (HCW) and kidney, pelvic and heart fat (KPH) and decreased *longissimus* muscle area (LM). There were not treatment effects on carcass composition, but increased DDGS levels in the substitution tended to decrease as a percentage of cold carcass weight muscle ($P = 0.08$) and increase carcass fat ($P = 0.10$). There were no effects of substitution with DDGS on wholesale cuts. Replacing corn and SBM with DDGS increased (linear $P = 0.03$) empty body weight (EBW, as a percentage of full weight), but influences on organ weights as a proportion of EBW (g/kg EBW) were small. The estimated net energy of maintenance (MJ/kg) of DDGS was 9.79, 9.62 and 9.50 for DDGS15, DDGS30 and DDGS45, respectively.

4. Discussions

4.1. Physical and chemical characteristics of DDGS and replaced corn and soybean meal

The physicochemical composition of DDGS, corn and SBM used in the trial are shown in Table 2. The bulk density of DDGS and SBM obtained here corresponds closely to the reported previously (Molenda et al., 2002). While that bulk density of DR white corn was in close agreement with the targeted 0.57 kg/L, the density of DR corn in the present study was 24% greater than that reported by Plascencia et al. (2011); thus, there was greater coarse-processing of the corn used in the current study.

The nutrient composition of white corn and SBM used in the present experiment was consistent with previous reports (Foster et al., 2009; Plascencia et al., 2011). Compared to the values assigned to DDGS by the NRC (2007), the relative values of CP, NDF, and ash (as 100% of DM) were 0.98, 0.72, and 1.10, respectively. According to the NRC

Table 3
Treatment effects on growth performance and dietary energy in drylot hairy lambs fed different levels of dried distillers grain plus solubles (DDGS).

Item	DDGS level (%)				SEM	P[a] value		
	0	15	30	45		Linear	Quadratic	Cubic
Days on test	112	112	112	112				
Pen replicates	5	5	5	5				
Live weight (kg)[b]								
Initial	17.29	17.26	17.25	17.29	0.04	0.95	0.43	0.84
Final	44.28	44.31	46.47	47.47	1.09	0.03	0.57	0.61
Total gain (kg)	26.99	27.05	29.22	30.18	1.09	0.04	0.69	0.51
Average daily gain (kg)	0.241	0.242	0.261	0.270	0.009	0.04	0.69	0.51
Dry matter intake (g/d)	1.017	1.008	1.074	1.112	0.031	0.06	0.26	0.44
Gain to feed (kg/kg)	0.237	0.240	0.243	0.243	0.004	0.33	0.76	0.88
Observed dietary Net energy (MJ/kg)								
Maintenance	8.24	8.37	8.41	8.41	0.12	0.34	0.71	0.97
Gain	5.52	5.61	5.65	5.69	0.11	0.34	0.71	0.97
Observed to expected dietary Net energy ratio								
Maintenance	0.99	1.00	1.00	1.01	0.015	0.91	0.25	0.73
Gain	0.98	0.99	1.00	1.00	0.019	0.84	0.22	0.63
Observed to expected daily dry matter intake[c]	1.01	0.99	0.98	0.98	0.018	0.92	0.15	0.50

[a] *P*, observed significance level for linear, quadratic and cubic effect of supplementation level of DDGS.
[b] The initial body weight (BW) was reduced by 4% to adjust for the gastrointestinal fill, and all lambs were fasted (food but not drinking water was withdrawing) for 18 h before recording the final BW.
[c] Expected dry matter intake (DMI) was computed as follows: DMI, kg/d = (EM/NEm) + (EG/ENg), where EM, maintenance coefficient of 0.056 Mcal/LW $^{0.75}$ (NRC, 1985) and EG is the daily energy deposited (Mcal/d) estimated by equation: EG, ((0.276 × ADG) × shrunk body weight$^{0.75}$, NRC, 1985), where ADG, average daily gain (kg/d), SBW, shrunk body weight and represents 0.96 of live weight. The divisor NE_m and NE_g are the net energy of maintenance and gain of diet (calculated from tables of composition of feed; NRC, 1985).

Table 4
Treatment effects on dressing percentage and carcass characteristics.

Item	Dried distillers grains plus solubles level (%)				SEM	P[a] value		
	0	15	30	45		Linear	Quadratic	Cubic
Hot carcass weight (kg)	26.59	27.13	28.48	28.84	0.53	<0.01	0.86	0.47
Dressing percentage	60.12	61.23	60.31	60.75	0.56	0.71	0.56	0.21
Cold carcass weight (kg)	26.05	26.53	28.08	28.31	0.52	<0.01	0.81	0.42
LM[b] area (cm^2)	12.32	12.37	11.30	11.14	0.45	0.05	0.82	0.34
Fat thickness (cm)	0.24	0.21	0.22	0.22	0.015	0.50	0.33	0.64
Kidney pelvic fat (%)	2.17	2.04	2.48	3.10	0.29	0.03	0.22	0.76
Carcass composition (kg)								
Muscle	5.87	6.25	6.01	6.11	0.16	0.51	0.41	0.21
Fat	2.46	2.27	2.42	2.44	0.14	0.90	0.40	0.39
Bone + scraps	1.93	1.96	2.07	2.02	0.06	0.17	0.51	0.38
Carcass composition (%) of cold carcass weight								
Muscle	22.55	23.54	21.42	21.61	0.60	0.08	0.51	0.07
Fat	8.51	8.00	9.23	9.33	0.47	0.10	0.55	0.22
Bone + scraps	7.43	7.40	7.40	7.15	0.22	0.40	0.63	0.77
Muscle to bone ratio	3.03	3.18	2.92	3.02	0.09	0.46	0.83	0.08
Muscle to fat ratio	2.45	2.83	2.49	2.58	0.18	0.97	0.42	0.17

[a] *P*, observed significance level for linear, quadratic and cubic effect of supplementation level of dried distillers grains plus solubles level.
[b] LM, *m. longissimus thoracis*.

Table 5
Treatment effects on visceral organ weight.

Item	DDGS level (%)				SEM	P[a] value		
	0	15	30	45		Linear	Quadratic	Cubic
Full final weight (kg)	46.12	46.16	49.19	49.45	1.20	0.03	0.93	0.30
GIT fill (kg)	4.28	4.44	3.79	3.83	0.29	0.16	0.84	0.24
Empty body weight, kg	43.45	43.29	43.94	43.90	0.29	0.16	0.84	0.26
Empty body weight (% of full weight)	90.95	90.65	92.06	92.01	0.44	0.03	0.78	0.12
Full viscera (kg)	10.08	10.08	9.55	9.75	0.27	0.26	0.70	0.33
Organs (g/kg EBW)								
Stomach complex	33.69	32.69	31.92	31.73	0.82	0.09	0.62	0.92
Small intestine	18.80	19.69	18.35	18.62	0.45	0.37	0.51	0.08
Large intestine	34.49	33.05	36.00	36.66	1.37	0.12	0.43	0.29
Liver	20.40	19.05	19.52	20.11	0.51	0.62	0.09	0.64
Heart/lungs	23.49	22.74	23.00	24.01	0.69	0.50	0.19	0.95
Visceral fat	22.01	19.96	22.83	24.57	1.99	0.25	0.34	0.50

[a] *P*, observed significance level for linear, quadratic and cubic effect of supplementation level of DDGS.

(2007), the main constituent is the NDF, followed by the CP, although this proportion can be changed by the quantity of solubles added during the process (Kim et al., 2008). As a result, much of the variation in the composition of DDGS can be attributed to plant-to-plant differences in the proportions of distillers solubles added during processing (Kim et al., 2008). The average ash content was very similar to the results obtained by Belyea et al. (2004).

4.2. Dry matter intake, growth performance and dietary energetic

Previous studies evaluating DDGS substitution for corn and SBM did not report an effect on feed intake when DDGS was included from levels of 20% (Huls et al., 2006) to 60% (Felix et al., 2012) in finishing diets with soybean hulls as a forage source. Similarly, feeding 40% DDGS to lambs that received 10% alfalfa hay did not affect the DMI in growing lambs when compared with a corn-based diet (Lodge et al., 1997). However, in barley-based diets, Schauer et al. (2008) noted increases in DMI as the DDGS increased in the diet. The DMI of finishing diets varies with NDF (Galyean and Defoor, 2003) and net energy (NE) content of the diet (NRC, 2007). DDGS is a source of readily digestible non-forage fiber (Ham et al., 1994; Castro-Pérez et al., 2013) and its fiber particles are very small, meaning that rumen microbes can degrade easily (Bhadra et al., 2007). Thus, in most of the cases, the differences in NDF content of the control diet and DDGS diets have not had an important impact on DMI in both lambs (Huls et al., 2006; Felix et al., 2012) and in feedlot cattle (Depenbusch et al., 2008; Uwituze et al., 2010). In the present experiment, the differences of NDF concentration between control diet and the diet which contained high level of DDGS was almost twice (15.98 *vs.* 27.22%). this corroborated the DDGS is a source of highly digestibility of NDF, so it is unlikely that NDF contribute significantly to the decline feed intake when high levels of DDGS are included in diets.

In prior studies involving lambs (Lodge et al., 1997; Schauer et al., 2008), the substitution of DDGS for DRC and SBM, at levels from 20 to 60% of diet DM did not affect the overall ADG or gain efficiency. However, there are some aspects that should be considered when determine the value of DDGS compared with ingredients that replaces. Given the nature of the treatments used in some studies, the results obtained for the nutritional value of DDGS may be largely masked by functional aspects (source of fiber in diets, Huls et al., 2006), by the method of substitution (replacing important quantities of starch by increases on fiber, Lodge et al., 1997), by the inclusion levels used (treatments were not formulated to be isocaloric or isonitrogenous, Schauer et al., 2008), or by chemical composition constraints of DDGS at high levels of inclusion (high content of NDF and fat, Vander Pol et al., 2005; Felix et al., 2012; Carrasco et al., 2013).

In the present experiment, the NE content of the DDGS was estimated based on performance and their energetic relations in lambs that were fed with isoenergetic diets with different DDGS levels inclusion, the total grain in diets did not greater than 62% and the relative differences in protein concentration between the control diet and the high level DDGS diet was only of 2.46% (17.10 *vs.* 19.56% CP). Even still, it is well recognized that when the diet contains more than 8.28 MJ of NE_m/kg, increasing protein level above of 15% has no additional beneficial effects on the productive performance of finishing lambs (Ríos-Rincón et al., 2014), therefore it is expected that this difference on protein level between diets had not an impact on the measure of retained energy.

The estimated NE of DDGS for 15, 30 and 45% levels contained 102, 100 and 98% of the relative NE value of corn, respectively. The average NE_m and NE_g values of DDGS were in close agreement with tabular (NRC, 2007) NE_m and NE_g values of 9.62 and 6.7 MJ/kg. Mathematically, based on fat content, DDGS could account for 9% more energy than corn (Larson et al., 1993); however, the NE value of fat is dynamic, largely depending on the level of supplementation (Zinn and Plascencia, 2007). Thus, the comparative feeding value of DDGS can be affected by level of inclusion. Vander Pol et al. (2005) summarized feeding trials that evaluated the performance of cattle fed corn distillers grains and concluded that the energy content of wet distillers grains was higher than that of DRC, but that this difference declined with increasing levels of distillers grains in the diet. The estimated NE (MJ/kg) value for DDGS in the DDGS15 treatment (9.92 MJ) was declined (4.2%) in the DDGS45 treatment. According to Plascencia et al. (2003), the NE value of fat is 100% of the tabular value (NRC, 2007) when fat intake does not exceed 1.2 g of fat/kg of BW and declines by 1.5 percentage units for each 0.1 g of fat intake/kg of BW under the limit of 1.2 g/kg BW. Estimated fat intake of lambs that were fed with DDGS45 treatment was 1.7 g/kg BW and according to Plascencia et al. (2003), the diminished of estimated NE value of DDGS45 treatment correspond closely to fat intake at this supplementation level. This effect would be the most important to placing upper constraints on levels of DDGS supplementation without affect its feeding value.

4.3. Carcass traits and visceral organ mass

The effects of inclusion of DDGS in diets fed to lambs are contradictory. Similar to our results, increases in HCW without any effect on dressing percentage was reported when DDGS was included up to a level of 60% in finishing diets (Schauer et al., 2008). In contrast, Felix et al. (2012) noted an increase (quadratic effect) of HCW and found dressing percentage to be at its maximum at a 20% level of inclusion. The Back fat thickness (BFT) was increased only in one (Huls et al., 2006) of four reports; the rest of the reports, similar to our results, stated that BFT was unaffected by DDGS supplementation. Generally, the LM area remains unchanged when lambs are fed diets that contain DDGS (Schauer et al., 2008; Felix et al., 2012); however, a decrease of 4.6% was observed in lambs when 22.9% of DDGS replaced DR corn and SBM (Huls et al., 2006). In contrast, no effects on carcass characteristics in Rambouillet wethers were noted with the inclusion of up to 20% of DDGS in place of cottonseed meal in a sorghum-based finishing diet (Whitney and Braden, 2010). Typically, increases intakes of dietary fat increased KPH (Zinn, 1988; Plascencia et al., 1999); thus, increases of KPH in cattle fed diets with high levels of DDGS are expected. In agreement with the above, a positive linear effect was observed for the amount of KPH in correlation with the DDGS level in the present experiment. However, Felix et al. (2012) reported a quadratic effect ($P = 0.03$) of dietary DDGS inclusion on KPH. Lambs fed 20% DDGS had the greatest amount of KPH, while lambs fed 60% DDGS showed lower values for KPH than controls (2.62 *vs.* 3.07). Excluding the present experiment and the report of Felix et al. (2012), no data of KPH in lambs fed diets supplemented with DDGS are available. In feedlot cattle, a linear increase in the KPH value was observed from the level of inclusion of 30% DDGS (Gordon et al., 2002). While, Corrigan et al. (2009) observed that KPH increased quadratically in steers fed a steam-flaked corn-based diet as the WDGS level increased and greater responses were observed when 15 and 25.7% WGDS was fed. However, the inclusion of up to 40% DDGS did not show an impact on KPH (Depenbusch et al., 2008; Leupp et al., 2009).

Similar to our results, previous reports shown that the total percentage of fat in carcass linearly increased as DDG increased in the diet when lambs were fed a finishing sorghum-based diet (Whitney and Braden, 2010). In contrast, in lambs fed a DRC-based diet, the LM fat decreased linearly with increasing DDGS inclusion in the diet (Felix et al., 2012). The reason for the inconsistent responses in carcass composition is not clear but appears to be related to energy and protein levels among the control and DDGS diets. The diets were isoenergetic and isoproteic in the experiment of Whitney and Braden (2010), while in the experiment of Felix et al. (2012) they were not. Apparently, calories from DDGS differently affected the energy partitioning and site of fat deposition, as a result of the level of inclusion as well as the strategy of ingredients that are replaced. Until recently, the effect of DDGS in finishing lambs on yield of wholesale cuts has been limited and published research in this area scarce. Nevertheless, similar to our results, Felix et al. (2012) did not observe any effect on the trimmed cuts in lambs when comparing the control diet with other DDGS diets (data not shown).

In lambs, there are very limited information related to the effect of supplementation of DDGS on organ weights, but similar to our results, the liver weight (gram and gram per kilogram of BW) of steers did not differ when DDGS was included up to a level of 50% in a finishing diet (Salim, 2011). It appears that liver weight responds mainly to energy-yielding nutrients and amino acids (Sainz and Bentley, 1997), in contrast, the total mass of the forestomach responded to diet type rather than intake, increasing with dietary fiber content (Sun et al., 1994), and the main factor influencing intestinal weight seemed to be dietary fiber (Sainz and Bentley, 1997) and protein intake (Johnson et al., 1990). As mentioned previously, DDGS is a source of readily digestible non-forage fiber (Ham et al., 1994; Castro-Pérez et al., 2013) and its fiber particles are very small, which favors a rapid passage rate. The diets of the present experiment were formulated to be isoenergetic, while the maximum differences in protein concentrations among diets were 2.46% (17.10 *vs.* 19.56% to control *vs.* 45% DDGS diet, Table 1).

5. Conclusions

Under the conditions of the current experiment, it was concluded that in finishing diets for lambs, the feeding value of DDGS is similar to that of dry-rolled corn (~9.62 MJ/kg EN_m); thus, the NE of DDGS is congruent with the reported in current standards (NRC, 2007). This feeding value decreases as the inclusion level of DDGS increases beyond 30% because to the removal of starch instead NDF and the potential reduction of digestibility of fat. The drastically change of source of energy (fat and protein instead starch) can affect the deposition of body fat and the area of LM. At high levels of inclusion, it tends to decrease the LM area and increase the KPH. Based on DMI and performance observed in the present study, DDGS is a suitable substitute, at moderated levels, for a portion of the dry-rolled corn and SBM in a finishing diet. An additional consideration is that the use of DDGS as an alternative feed for fattening lambs depends on the relative price of DDGS, corn and protein supplements. For example, at the moment that the experiment was carried, the price of DDGS, corn and soybean meal was 363, 324 and 541 dollar/metric ton; thus, the replacement of corn and SBM by DDGS at 30% of level of inclusion, saves 12.17 dollars per ton.

Conflict of interest

None.

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