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Corn Based-diets Containing Corn Dried Distillers Grains with Solubles on Performance, Ruminal Fermentation, *In vitro* Methane Emissions, Carcass and Meat Quality of Lambs

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Authors' contributions

This work was carried out in collaboration among all authors. Author KRC, as part of his doctoral research, prepared the research protocol and carried out the sampling in the experimental field. Author KRC wrote the draft including the results obtained in the laboratory and in the field. Author JRBG was responsible for directing the research, supervised the writing and wrote the discussion of the results together with the author KRC. Author DHS is a meat quality specialist and supervised the sampling and development of analysis of the meat quality variables. Author MMCG was responsible for the animal nutrition laboratory and supervised the analysis of food and experimental diets. Author JCEE supported the statistical analysis of the data obtained from all the variables evaluated in this work. Author EASG placed in the implementation of the technique used in the laboratory for the determination of biogas and methane from experimental diets. Author OCM was in charge of supervising the slaughter of animals according to the regulations approved by the Animal Care Committee of the Postgraduate College and supervised the data collection of the characteristics of the lamb channel. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The objective of this study was to evaluate the effect of Distillers Dried Grains with Solubles (DDGS) in diets of finishing lambs on ruminal fermentation, digestibility, *in vitro* gas emissions, growth performance, carcass characteristics and meat quality.
Background: Replacing cereal grains and oilseed meals with dried distillers grains can reduce feeding cost and utilise an abundant waste byproduct of the ethanol industry.
Methodology: Thirty native Mexican male lambs of four months old and 24 ± 2. 41 kg BW, were used in the experiment which lasted for 56-days using a complete randomized design (*n* = 10). Treatments were: 1) Control (0% DDGS); 2) (20% DDGS/DM basis) and 3) (40% DDGS/DM basis).
Results: DMI, ADG, final body weight (BW) and carcass characteristics were not different (P > 0.05) among the treatments. However, apparent digestibility (AD) of DM (ADDM), ADNDF, ADADF and *in vitro* digestibility of DM (IVDDM) after 9, 12 and 24 h of incubation showed a quadratic effect while increasing level of DDGS. Rumen fluid pH was greater and ruminal VFA concentration was lower for 20% DDGS treatment (quadratic effect *P* = 0.*05*). The proportion of acetate: propionate and concentration of ammonia nitrogen, were not different (*P* > 0.05) between treatments. Biogas production was maximal at 40% DDGS (linear effect, *P* = 0.03) while a quadratic effect on CO_2 (*P* = 0.016) and CH_4 (*P* = 0.023) were observed. No differences (*P* > 0.05) on the physicochemical composition and characteristics of the meat of lambs fed different levels of DDGS were found.
Conclusion: The 40% DM inclusion of corn DDGS in diets for growing Mexican native lambs maintains its productive performance without significantly affecting the ruminal fermentation, diet digestibility, carcass characteristics and meat quality. DDGS can partially replace grains, oilseed meals and forage due to its high protein content and energy level. If DDGS is low in cost compared to oilseed meals, it may be included in finishing lamb diets.

Keywords: Ethanol by-product; sheep; product quality; gas emissions.

1. INTRODUCTION

The constant search for inputs to develop lamb finishing diets has concentrated its efforts on the by-products generated by the biofuel industry that generates DDGS derived from different grains, with corn being the most popular. This by-product is a viable alternative for animal feed even to a lower production costs, taking into account that grains have had a rise in prices and ethanol production continues to increase (Renewable Fuels Association, 2017). DDGS, due to their high energy content, can replace most grains [1] and to a lesser extent forage [2], in the diet of ruminants.

Investigations on the use of DDGS have reported that the optimal level of inclusion in feedlot cattle diets ranges between 20 and 30% DM [3] and there is the possibility of using it at up to 40% to improve feed conversion [4]. For lambs, the inclusion of 20% DDGS is suggested since this does not affect voluntary intake [5] and improves daily weight gain [6]. These suggestions are based on DDGS containing higher concentrations of nutrients the raw materials used for ethanol production corn, for example, contains 9% CP, 4.3% EE and 9% NDF, whereas DDGS contain 29% CP, 10. 5% EE and 42% NDF [7]. Uwituze et al. [8] observed a significant decrease in ammonia concentration in the rumen and digestibility of dry matter when 25% of DDGS was included in the diet. Felix et al. [6] reported that the inclusion of DDGS at 40 and 60% in the diet of sheep decreased the digestibility of dry matter and fat, but were not affected with 20% of DDGS. Whitney and Braden [9] reported that by substituting DDGS for cottonseed meal as a source of protein in the diet of growing lambs, carcass characteristics were not affected. Crane et al. [10] reported that neither the characteristics of the carcass nor the productive performance of lambs led with a diet containing 30% of DDGS during finishing were affected, although, the excretion of sulfur was increased in urine, the health of the animals was not affected. Avila-Stagno et al. [11] reported that the concentration of VFA was reduced as the wheat DDGS increased in the diet, while the propionate had a quadratic behaviour, it was deduced that this behaviour could be due to decreased feed intake as DDGS increased in the diet. However, McKeown et al. [12] reported that the inclusion of 20% DDGS in a growth diet for lambs did not affect the total concentration of VFA, but increased the concentration of propionate.

Study of the effects of including different levels of DDGS in diets for fattening lambs on rumen

fermentation and digestibility of the diet is important as these parameters relate directly to growth performance, carcass characteristics and meat quality, but it is important too that these food strategies be friendly with the environment. Therefore, the objective of this trial was to evaluate the effect of including 0, 20 and 40% of corn DDGS in corn-based diets in growing native lambs on ruminal fermentation, digestibility, *in vitro* gas emissions, growth performance, carcass characteristics and meat quality.

2. MATERIALS AND METHODS

The study was conducted at the experimental farm and the Laboratories of Animal Nutrition and Rumen Microbiology of the Department of Livestock-Genetic and Productivity Resource, Postgraduate College, Campus Montecillo, Texcoco, México. All animal procedures used in this study were approved by the Animal Care Committee of the Postgraduate College and following the guidelines of Official Mexican Norm-Technique specifications for production, care and use of laboratory animals (NOM-062-ZOO-1999).

2.1 Animals, Experimental Design, and Dietary Treatments

Thirty native Mexican male lambs of four month old and initial body weight (BW) of 24 ± 2.41 kg) were used in the experiment which was based on a completely randomized design. Animals were placed in individual metabolic cages and randomly assigned to one of the following experimental diets (10 animals per treatment): 1) Control (0% DDGS); 2) (20% DDGS); and 3) (40% DDGS). Diets were formulated to meet nutritional requirements (7) for growing lambs with the same nitrogen content (Table 1), the chemical composition of the diets was determined using the methods of the AOAC [13]; dry matter (DM; method 930.15), ash (method 942.05), ether extract (EE; method 954.02) and crude protein (CP; method 984.13). The content of neutral detergent fibre (NDF) and acid detergent fibre (ADF) was determined using the method proposed by Van Soest et al. [14].

Diets were offered *ad libitum* twice a day (9:00 and 16:00 h), permitting 5 to 10% refusal in each feed bunk daily, and animals had free access to freshwater. Lambs were adapted to experimental diets over 12 d and the treatment period lasted 56 d. Lambs were dewormed (subcutaneous injection of Ivomec® Merial LLC, USA, Ivermectina at 1 mL/50 kg), treated with vitamins A, D and E (intramuscular injection of Vigantol®, Bayer SA, Mexico, 2 mL per lamb) and vaccinated with Bacterina (Bobact-8® MSD-Merck, USA, 2.5 mL per lamb by intramuscular injection) at the beginning of the experiment.

2.2 Bodyweight, Feed Intake and Carcass Characteristics

Lambs were weighed on two consecutive days before the morning feed at the beginning and the end of the feeding period and every 14 d throughout the experimental period. Dry matter intake (DMI), average daily gain (ADG), and feed conversion ratio were determined for each 14-d period and the total trial. Diet refusals were sampled weekly and analysed for DM by oven-drying at 55°C for 48 h. DMI was calculated daily by the difference between the feed offered and the refusal. The lambs were weighed before the meal in the morning and the ADG was determined by the difference in weight in each period of 14 d and gain to feed ratio was calculated as the ratio of DMI to ADG.

The backfat (BF) and loin eye area (LEA) were measured in each animal using a Sonovet 600 ultrasound (Universal Medical Systems, Inc.) with a 7.5 Mhz transducer; measurements were performed between the 12th and 13th rib two days before slaughter. At the end of the experiment, the 30 lambs were weighed (final BW) and then taken to the slaughterhouse and fasted for 12 h before slaughter. Lambs were weighed at the slaughter time (slaughter weight; SW), and blood, skin, legs, head, green and red viscera (full and empty) were also weighed for calculation of empty body weight (EBW).

Carcasses were weighed immediately to obtain the hot carcass weight (HCW) and then cooled to 5°C for 24 h and cold carcass weight (CCW) determined. Hot and cold carcass yield was calculated. The pH of each carcass was measured at the *longissimus muscle* (LM) in the intercostal space between the 12th and 13th rib using a portable pH meter (Model HI99163, Hanna Instruments) equipped with a pH probe plus stainless steel penetration blade.

2.3 Rumen Fermentation and Total Apparent Digestibility of DM, NDF and ADF

To determine rumen pH, ammonia nitrogen ($N\text{-}NH_3$) and volatile fatty acids (VFA), approximately 50 mL of rumen fluid was collected from each lamb before the morning feed and 5 d before slaughter. Rumen fluid was

filtered using a triple layer of guage and pH determined using a portable pH meter (Orion, model SA 210). Subsequently, 4 mL of filtered rumen fluid was placed in a test tube containing 1 mL of 25% metaphosphoric acid (v/v) to achieve a concentration of 4:1; the samples were frozen until analysis. To determine the concentration of VFA, the samples were thawed and a 1.5 mL aliquot was centrifuged at 20,817 x g for 10 min. The resulting supernatant was removed by micropipette and passed through GHP acrodiscs 13 (0.45 µm pore size filter) to clean the sample. After filtration, samples were placed in 1-mL glass vials and 1 µL was injected into a gas chromatograph (PerkinElmer® Clarus 500) with auto sampler and equipped with a FFAP capillary column (15-m length). Chromatography conditions were as follows: injector temperature 240°C, flame ionization detector (FID) temperature 250°C and oven temperature 140°C, with a gas flow of 40 mL/min (air) and 400 mL/min (hydrogen). Retention times were 1.3, 1.6 and 2.15 min for acetic acid, propionic acid and butyric acid, respectively. To determine the concentration of N-NH_3, the technique proposed by McCullough [15] was used. A 2-mL sample of ruminal fluid was thawed and centrifuged at 1257 x g for 10 min. The resulting supernatant was collected and 20 µL placed in 10 mL test tubes, adding 1 mL of phenol and 1 mL of sodium hypochlorite. Samples were incubated in a water bath at 37°C for 30 min, 5 mL of distilled water was added for sample dilution and the solution mixed using a vortex (Genie 2 Model G-560). Readings were performed using an ultraviolet-visible light spectrophotometer (VARIAN CARY 1-E) at a wavelength of 630 nm.

To determine the total apparent digestibility of dry matter (ADDM), the technique proposed by Van Keulen and Young [16] of acid-insoluble ash (AIA) was used using a concentration of 2 N HCl, samples of meal offered and feces for each lamb were used. The score was the same for all calculations. Corresponding formulae were used to calculate the percentage of AIA, ADDM, apparent digestibility of neutral detergent fibre (ADNDF) and apparent digestibility of acid detergent fibre (ADADF).

2.4 *In vitro* DM Degradability and *in vitro* Gas Emissions

The *in vitro* degradability of dry matter (IVDDM) of the diets was performed using an incubator Daisy II® ANKOM® D200 model, which content four incubation bottles. Ten samples of 0.5 g

Table 1. Ingredients and composition of experimental diets fed to lambs

Ingredients (g/kg DM)	DDGS of inclusion in the diets (%)		
	0	**20**	**40**
DDGS	0	200	400
Ground corn	473	396	300
Molasses cane	60	60	60
Soybean meal	128	68	0
Wheat bran	70	50	50
Corn stover	150	150	150
Corn gluten meal	70	40	15
Fat bypass	24	11	0
$CaCO_3$	10	10	10
Salt	5	5	5
Premix salt and vitamin[a]	10	10	10
Chemical composition (g/kg DM)			
Dry matter (g/kg wet basis)	943.9	952.1	942.5
Crude protein	185.2	180.9	187.5
Organic matter	937.2	934.4	955.2
Ether extract	32.0	37.8	44.8
Ash	62.8	65.6	63.8
Neutral detergent fibre	220.4	294.1	317.0
Acid detergent fibre	138.0	160.5	163.2

[a] *Includes Ca, 24%; Cl, 12%; Mg, 2%; P, 3%; K, 0.50%; Na, 8%; S, 0.50%; Cr, 5 mg/kg DM; Co, 60 mg/kg DM; I, 100 mg/kg DM; Fe, 2000 mg/kg DM; Mn, 4000 mg/kg DM; Se, 30 mg/kg DM; Zn, 5000 mg/kg DM; Lasolacid, 2000 mg/kg DM; vitamin A, 500 000 UI/kg; vitamin D, 150 000 UI/kg; vitamin E, 1000 UI/kg. DDGS, Dried distillers grains with solubles*

were used for each experimental diet and placed in polyester / polyethylene bags of 5 x 4 cm with a pore size of 25 µm (ANKOM® Technologies, Macedon, NY, USA). In this technique, a mixture of buffer solutions (solution A and B) in a ratio of 1:5 was used. Solution A contained 10 g KH_2PO_4, 0.5 g $MgSO_4.7H_2O$, 0.5 g NaCl, 0.1 g $CaCl_2.2H_2O$ and 0.5 g urea (reagent grade) in 1000 mL of distilled water. Solution B contained 15 g Na_2CO_3 and 1 g $Na_2S.9H_2O$ in 1000 mL of distilled water. Two runs were implemented and incubation durations were 3, 6, 9, 12, 24 and 48 h. To perform this test, three male sheep (58.2 ± 2.6 kg BW) were used, each with a permanent rumen cannula and adapted to the experimental treatments. The collection of ruminal fluid (400 mL) was performed five days after the end of the adaptation period to the experimental diets. A thermos flask (500 mL capacity) was used to transport rumen fluid to the laboratory. Samples were then filtered through four layers of gauze. To 2000-mL flasks, 1600 mL of the mixture of A and B solutions (pH = 6.8) was added plus 400 mL of ruminal fluid. The mixture was injecting constantly with CO_2 before the flask was sealed with a bousen valve. The flasks were then incubated in a water bath at 39°C. Gas production was quantified using the displacement method with a saturated saline solution, described by Cobos-Peralta et al. [17], with an incubation time of 72 h.

Production of CH_4 and CO_2 were determined using a gas chromatograph (Perkin-Elmer®). Gases (300 µL) were sampled from the headspace of each vial (n = 5) and injected into the gas chromatograph using the following conditions: gas flow 23 mL m^{-1} at 60 psi, oven temperature 80°C, packed column temperature 170°C and temperature of thermal conductivity detector 130°C. The retention times were 0.68 and 1.05 min for CH_4 and CO_2, respectively. Helium was used as a carrier gas. The CH_4:CO_2 ratio was calculated by determining the amount of CH_4 and CO_2 contained in the biogas. Data are reported under normal pressure and temperature conditions.

2.5 Meat Quality

Samples collected from the *Longissimus dorsi* muscle (LM) in the 30 lambs were collected at 24 h postmortem, placed in sealed polyethylene bags and stored at 4°C for further analysis. The chemical composition of the meat was determined using the methods of the AOAC (13): ash (method 942.05) and crude protein (CP; method 984.13).

The colour of the meat was measured using a Minolta colourimeter (Chroma Meter CR-200, Tokyo, Japan), using samples collected three days after slaughter (1 cm thick and 7 cm in diameter) which were free of fat, bubbles and blood. The readings from each sample were taken, recording values for *L, *a and *b, which represent lightness, redness and yellowness, respectively.

The sheer force value for raw meat was performed five days after slaughter, using a Warner-Bratzler V-shaped blade and a texture analyzer TA-XT2 (Texture Technologies Corp., Scarsdale, NY). Samples of meat (1 × 1 × 1 cm cubes) were cut, one per animal. The samples were placed on the texture analyzer with the muscle fibres positioned transversely to the knife-edge; the maximum force required cutting the sample.

The water retention capacity of the meat was performed. Samples (2 g) of meat were ground in a mortar, placed in a centrifuge tube and 8 mL of sodium chloride solution (0.6 M) added. The mixture was stirred with a glass rod for 1 min, allowed to stand in an ice bath for 30 min, stirred again for 1 min and then centrifuged for 15 min at 1257 x g. The supernatant was decanted and the volume measured was reported as the amount of water remaining.

2.6 Statistical Analysis

Data were analyzed according to a completely randomized design with three treatments (0, 20 and 40% DDGS DM in the diet; n = 10), taking as covariate the initial live body weight of lambs using the MIXED procedure [18]. Linear and quadratic contrasts were analyzed to examine the effect of dietary DDGS inclusion on dependent variables. The mean values for each treatment were compared with the Tukey's test ($P < 0.05$).

3. RESULTS AND DISCUSSION

There was no linear or quadratic effect ($P > 0.05$) on final body weight, feed intake, daily gain, feed conversion or carcass characteristics in lambs fed different levels of DDGS (Table 2).

However, quadratic effects were observed on apparent digestibility of DM (ADDM; $P < 0.0001$), ADNDF ($P = 0.01$), ADADF ($P = 0.007$). The greatest effects were observed in ADNDF and ADADF with the 20% DDGS treatment. The pH of rumen fluid showed a tendency to be higher with the 20% DDGS treatment. However, the

AGV concentration had a quadratic effect (P = 0.05), being lower in the same treatment although the proportion of acetate/propionate and concentration of acetate, propionate, butyrate or ammonia nitrogen showed no difference (P > 0.05) between treatments (Table 3).

The diet containing 20% DDGS showed a linear and quadratic effect on IVDDM with incubation for 9 h (P = 0.04; P = 0.008) and 12 h (P = 0.01; P = 0.02), respectively, and a quadratic effect with incubation for 24 h (P = 0.01). The total biogas emission showed a linear (P = 0.03) and quadratic (P = 0.02) effect, being higher with the 40% DDGS diet. CO_2 emission showed the same pattern but there were no significant effects on CH_4 emission (Table 4).

No differences (P > 0.05) in the Physico-chemical composition or meat characteristics of lambs fed different levels of DDGS were found (Table 5).

3.1 Feedlot Performance and Carcass Characteristics

Schauer et al. [5] and Van Emon et al. [19] reported that feed intake and daily gain of weight improved as the concentration of DDGS in the diet of lambs increased. However, these differences were not observed in the present study. Several factors could explain this. It could be due to the conditions in which the trials were conducted, the type of lambs and their handling, the quality of DDGS or perhaps because CP levels were maintained at a constant level among the treatments. Also, some authors report that, as DDGS increases in the diet, feed conversion decreased linearly [6,19]. Other authors report that it increases linearly [10,20]. In the present study, no differences were found, which agrees with the results reported by Crane et al. [21]. The results of the present study agree with those reported by Van Emon et al. [19] and Crane et al. [10], namely that the carcass characteristics of lambs fed with increasing levels

Table 2. Effect of increasing concentration of DDGS on lamb performance and carcass characteristics

Item	DDGS inclusion (%)			SEM	*P* -value		
	0	20	40		Treatments	Linear	Quadratic
Feedlot performance, Ten lambs per treatment							
Initial BW (kg)	23.78	24.17	24.06	0.833	0.94	081	0.81
Final BW (kg)	38.48	38.12	39.11	1.004	0.78	0.65	0.58
DMI (kg/d)	1.337	1.261	1.281	0.036	0.32	0.13	0.14
ADG (kg/d)	0.263	0.249	0.269	0.015	0.65	0.72	0.29
Feed conversion[a]	5.569	5.389	5.111	0.281	0.52	0.22	0.88
Slaughter weight	34.64	34.61	35.48	1.028	0.79	0.56	0.72
Empty body weight	31.15	30.94	31.21	0.857	0.97	0.96	0.82
Carcass characteristics							
Hot carcass weight (kg)	18.26	18.14	18.34	0.408	0.91	0.89	0.78
Cold carcass weight (kg)	17.82	17.79	17.60	0.429	0.87	0.96	0.71
Hot carcass yield (%)	52.78	52.52	51.81	0.648	0.56	0.30	0.78
Cold carcass yield (%)	51.51	50.91	50.26	0.605	0.36	0.15	0.97
Back fat $(mm)^2$	2.78	2.56	2.67	0.164	0.64	0.63	0.57
Loin eye area (mm^2)[b]	919.89	862.22	956.11	42.045	0.29	0.54	0.15
pH[C]	6.78	6.77	6.81	0.098	0.97	0.83	0.88
pH 24 h post-mortem[C]	6.22	6.12	6.27	0.132	0.71	0.79	0.44

[a] Calculated as DMI/ADG, [b]e backfat and loin eye area were measured using ultrasound between the 12th and 13th rib two days before slaughter, [C]The pH of each carcass was measured at the longissimus muscle (LM) in the intercostal space between the 12th and 13th rib

Means in the same row with no superscript letters after them or with a common superscript letter following them are not significantly different (P > 0.05). DDGS, Dried distillers grains with solubles; BW, Initial and final body weight; DMI, Dry matter intake; ADG, Average daily gain

of DDGS were not affected. However, those results differ from the results of Castro-Pérez et al. [20] who reported a linear behavior of hot and cold carcass weights as DDGS in the diet of Pelibuey lambs increase.

3.2 Rumen Fermentation and Total Apparent Digestibility (AD) of DM, NDF and ADF

Values for ADMS, ADFDN and ADFDA were higher (P > 0.05) with 20% DDGS than with the control or 40% DDGS treatments. The lambs to had a constant supply of energy for rumen microbial protein synthesis, together with a similar contribution of nitrogen in the diet, as the concentration of N-NH_3 was not different between treatments when soybean meal was partially replaced by DDGS. These effects possibly allowed the nutrient supply to the hindgut to be similar and, therefore, differences in lamb daily weight gain were not detected.

The DDGS have a lower DM degradation compared to other protein sources, such as sunflower seed meal and cottonseed meal. This may be due to part of the protein being resistant to ruminal degradation, perhaps as a result of the higher prolamin and glutelins content [22]. Cobos-Peralta et al. [17] reported lower DIVMS of DDGS compared to soybean meal, which explains the lowest DIVMS found with 40% DDGS in the diet. Treatment with 20% DDGS had the lowest concentration of VFA and better pH of ruminal fluid, which could improve the efficiency of the ruminal microorganisms in the use of substrates and this was reflected in greater degradation of the MS, NDF and FDA. The decreased ADDM treatment with 40% DDGS is consistent with that reported by Felix et al. [6], namely that with 40% DDGS digestibility decreased from 79.64 to 75.18%. This may be explained by the lower DM degradation with DDGS (81.8%) compared to corn grain (91.35%) [23]. The same authors reported that no differences were found between treatments in terms of NDF and ADF digestibility. This is different from the findings in this study where the diet containing 20% DDGS had higher (*P* > 0.05) ADFDN and ADFDA than the control diet, but similar to 40% DDGS, perhaps because of corn DDGS had higher NDF (79.36%) than the corn grain (44.90%).

McKeown et al. [12] reported that the total concentration of VFA was not affected when 20% DDGS was included in the diet of lambs, but the propionate concentration increased compared to the control diet. Contrary to this report, in this study there was no such increase in the concentration of propionate, perhaps influenced by the source of DDGS (i.e., an ethanol processing plant) and the difference in the type and carbohydrate content that was found between diets [23].

Table 3. Effect of increasing concentration of DDGS in the diet of lambs on total apparent digestibility of DM, NDF and ADF, and ruminal fermentation

Item	DDGS inclusion (%)			SEM	*P* -value		
	0	20	40		Treatments	Linear	Quadratic
Total apparent digestibility							
DM	73.810[a]	76.288[a]	70.141[b]	0.819	<0.0001	0.002	<.0001
NDF	43.338[b]	49.470[a]	45.144[ab]	1.641	0.04	0.44	0.01
ADF	37.225[b]	44.844[a]	40.414[ab]	1.672	0.01	0.19	0.007
Ruminal fermentation							
Rumen fluid pH	6.41	6.83	6.65	0.124	0.07	0.18	0.05
Total VFA (mmol/L)	52.51	41.18	47.46	3.633	0.11	0.33	0.05
VFA, % in total VFA							
Acetate (A)	59.19	59.81	60.58	1.335	0.76	0.46	0.96
Propionate (P)	30.38	27.52	27.44	1.543	0.32	0.18	0.46
Butyrate	10.43	12.67	11.98	0.965	0.26	0.26	0.22
A/P	2.01	2.22	2.29	0.154	0.39	0.19	0.73
N-NH_3 (mg/dL)	37.63	41.61	37.43	1.237	0.67	0.63	0.57

Means in the same row with no superscript letters after them or with a common superscript letter following them are not significantly different (P > 0.05). DDGS, Dried distillers grains with solubles; VFA, Volatile fatty acid; A/P, Acetate/Propionate ratio; N-NH_3, Ammonia nitrogen

Table 4. Effect of the increasing concentration of DDGS in the diet of lambs on *In vitro* digestibility (%) of the DM and *in vitro* gas emissions

Incubation time (h)	DDGS inclusion (%)			SEM	*P* -value		
	0	20	40		Treatments	Linear	Quadratic
***In vitro* digestibility**							
3	21.165	22.964	22.553	0.7087	0.204	0.18	0.22
6	25.938	26.885	27.216	0.8641	0.567	0.31	0.77
9	29.766^{B}	34.031^{A}	32.247^{AB}	0.8204	0.007	0.04	0.008
12	33.875^{B}	39.266^{A}	37.911^{A}	1.0708	0.007	0.01	0.02
24	50.579	55.193	50.568	1.4000	0.051	0.99	0.01
48	62.873	63.045	60.572	1.2270	0.310	0.20	0.39
***In vitro* biogas emissions (mL/g DM)[a]**							
Biogas production	62.274^{ab}	54.212^{b}	80.179^{a}	4.022	0.01	0.03	0.02
CH_4	14.047	11.474	13.562	0.491	0.063	0.64	0.023
CO_2	48.227^{b}	42.737^{b}	66.616^{a}	3.703	0.009	0.016	0.025

[a] *Reported under normal conditions of temperature and pressure. Means within a row with different superscripts are different (P < 0.05). DDGS, Dried distillers grains with solubles*

Table 5. Effect of increasing concentration of DDGS in the diet of lambs on composition and physical-chemical characteristics of the *Longissimus dorsi*

Item	DDGS inclusion (%)			SEM	*P* -value		
	0	20	40		Treatments	Linear	Quadratic
Moisture (%)	77.20	76.90	76.83	0.38	0.28	0.38	0.18
Crude protein (%)	21.19	21.63	21.93	0.11	0.13	0.06	0.43
Ash (%)	0.97	1.10	0.91	0.09	0.72	0.83	0.44
Meat colour							
L * (lightness)	38.37	40.82	39.96	0.43	0.06	0.12	0.06
a * (redness)	18.29	18.88	18.70	0.13	0.17	0.20	0.16
b * (yellowness)	3.94	4.90	4.44	0.21	0.18	0.33	0.11
Shear force value for row meat (kg/cm^2)	1.68	1.73	1.78	0.03	0.49	0.24	0.93
Water retention capacity (mL/100 g meat)	20.00	20.00	20.15	0.68	0.99	0.93	0.96

[1] *L*, Lightness (0 = black, 100 = white); a*, redness (0 = green, 100 = red); b*, yellowness (0 = blue, 100 = yellow. Means in the same row with no superscript letters after them or with a common superscript letter following them are not significantly different (P > 0.05). DDGS, Dried distillers grains with soluble*

There was no difference between treatments in the N-NH_3 concentration in the rumen. Martineau et al. [24] reported that rate of absorption of N-NH_3 from the rumen is affected by the pH; at pH 6.5 or higher, absorption is rapid, at pH 5.5 it is low and at 4.5 it drastically becomes slower, and that at a stable ruminal pH maintained within a range of 6.5–7.0, the protein fermentation by microorganisms in the rumen is efficient. In the present study, the rumen pH remained stable between treatments, which favoured the absorption of N-NH_3 from the rumen, so no differences in its concentration were observed.

The pH of ruminal fluid reported in this study is consistent with that observed by Neville et al. [25], who found no differences between treatments using 0, 20, 40 and 60% DDGS in the diet of growing lambs. The reported value falls within the range that is usually found in ruminal fluid pH, which is 6–7 [26].

3.3 *In vitro* Degradability and Gas Emissions

Avila-Stagno et al. [11] reported that IVDMD decreased (Linear P < 0.01) as more wheat DDGS was included in the diet of growing lambs, this is with an incubation time of 48 h. This behaviour is different when corn DDGS were used in this study; however, at 24 h we found a

quadratic response (P = 0.01), being the IVDMD higher in the diet containing 20% corn DDGS. McKeown et al. [12] reported no difference in IVDMD, when 20% corn DDGS was included in the diet of growing lambs with incubation times of 24 h. However, they reported that corn DDGS releases less biogas compared with wheat DDGS and triticale. Böttger and Südekum [27] reported that corn DDGS produces 45.2 mL of biogas per 200 mg of DM. However, in the present study, inclusion of 40% DDGS (Linear, *P* = 0.03) in the diet produced the highest biogas emission (80.17 mL/g DM) and 20% DDGS produced the least amount of biogas with a quadratic effect (*P* = 0.02).

The inclusion of corn DDGS also produced less CH_4 compared to wheat and triticale DDGS diets when they were used in bulls and heifers, and also showed a decreased in the amount of acetate and protozoa in the rumen [28]. Pecka-Kielb et al. [29] reported that 30% corn DDGS in the diet resulted in the lowest production of CH_4, and Avila-Stagno et al. [11] found no differences in CH_4 production by including wheat DDGS in the diet of lambs. It is known that the acetate is used by methanogenic archaea for methane production via acetoclastic methanogenesis [30] and, also, ruminal protozoa produce significant amounts of hydrogen and have a symbiotic relationship with methanogenic archaea [31].

Despite the results reported in the literature, it is observed that there is a certain consistency in the results that coincide with the fact that the production of methane is reduced when corn DDGS are used. The results of the present study are consistent with those that reported a reduction in methane production when corn DDGS is used in sheep diets.

3.4 Physical-chemical Characteristics of the Meat

Moisture (77.5%) and protein (20.8%) content of meat reported in this study was similar to that reported by Faria et al. [32] when they used lambs grazing clover, and also with results of Priolo et al. [33] who reported values of 77% and 21.9%, respectively. These findings suggest that the nutritional value of meat is difficult to modify with feed. Values for the color of meat indices were similar to those reported by Ekiz et al. [34] in Kivircik lambs when comparing different operating systems, obtaining values of L * = 40.12, a * = 13.52 and b * = 2.49 in intensive systems.

Although the color was not significantly different, the meat of lambs fed 20% DDGS had the highest brightness value (L * = 40.82), followed by the inclusion of 40% DDGS (39.96). These results are similar to those reported by Felix et al. [7], who found a linear effect on the brightness with inclusion of DDGS in the diet of growing lambs, obtaining the highest value with 60% with corn DDGS (L * = 41.14) and the lowest value for the control (L * = 39.92). The result reported by Teixeira et al. [35] regard the shear force value (1.62 kg cm^2) is similar to that obtained in the treatments (1.73 kg cm^2; average) in this research.

4. CONCLUSION

It is concluded that the inclusion up to 40% DM of corn DDGS in diets for growing Mexican native lambs maintains its productive performance without significantly affecting the ruminal fermentation, growth performance, diet digestibility or carcass characteristics and meat quality. If DDGS is low in cost compared to oilseed meals, it may be included in finishing lamb diets.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by the personal efforts of the authors.

ETHICAL APPROVAL

Animal ethic Committee approval has been collected and preserved by the author.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Klopfenstein TJ, Erickson GE, Bremer VR. BOARD-INVITED REVIEW: Use of distillers by-products in the beef cattle feeding industry. Journal of Animal Science. 2008;86:1223–1231.

2. Li YL, McAllister TA, Beauchemin KA, He ML, McKinnon JJ, Yang WZ. Substitution of wheat dried distillers grains with solubles for barley grain or barley silage in feedlot cattle diets: Intake, digestibility and ruminal fermentation. Journal of Animal Science. 2011;89:2491–2501.
3. Depenbusch BE, Coleman CM, Higgins JJ, Drouillard JS. Effects of increasing levels of dried corn distillers grains with solubles on growth performance, carcass characteristics and meat quality of yearling heifers. Journal of Animal Science. 2009;87:2653–2663.
4. Amat S, Hendrick S, McAllister TA, Block HC, McKinnon JJ. Effects of distillers' dried grains with solubles from corn, wheat or a 50:50 corn: Wheat blend on performance, carcass characteristics and serum sulphate levels of feedlot steers. Canadian Journal of Animal Science. 2012;92:343–351.
5. Schauer CS, Stamm MM, Maddock TD, Berg PB. Feeding of DDGS in lamb rations. Sheep & Goat Research Journal. 2008;23:15–19.
6. Felix TL, Zerby HN, Moeller SJ, Loerch SC. Effects of increasing dried distillers grains with solubles on performance, carcass characteristics and digestibility of feedlot lambs. Journal of Animal Science. 2012;90:1356–1363.
7. NRC. Nutrient Requirements of Small Ruminants: Sheep, Goats, Cervids, and New World Camelids. National Research Council (Washington, DC, USA); 2007.
8. Uwituze S, Parsons GL, Shelor MK, Depenbusch BE, Karges KK, Gibson ML, Reinhardt CD, Higgins JJ, Drouillard JS. Evaluation of dried distillers grains and roughage source in steam-flaked corn finishing diets. Journal of Animal Science. 2010;88:258–274.
9. Whitney TR, Braden KW. Substituting corn dried distillers grains for cottonseed meal in lamb finishing diets: Carcass characteristics, meat fatty acid profiles, and sensory panel traits. Sheep & Goat Research Journal. 2010;25:49–56.
10. Crane AR, Redden RR, Swanson KC, Howard BM, Frick TJ, Maddock-Carlin KR, Schauer CS. Effects of dried distiller's grains and lasalocid inclusion on feedlot lamb growth, carcass traits, nutrient digestibility, ruminal fluid volatile fatty acid concentrations and ruminal hydrogen sulfide concentration. Journal of Animal Science. 2017;95:3198–3205.
11. Avila-Stagno J, Chaves A V, He ML, McAllister TA. Increasing concentrations of wheat dry distillers' grains with solubles in iso-nitrogenous finishing diets reduce lamb performance. Small Ruminant Research. 2013;114:10–19.
12. McKeown LE, Chaves a V, Oba M, Dugan MER, Okine E, McAllister TA. Effects of corn-, wheat- or triticale dry distillers' grains with solubles on *in vitro* fermentation, growth performance and carcass traits of lambs. Canadian Journal of Animal Science. 2010;90:99–108.
13. AOAC. Association of Official Analytical Chemists Official Methods of Analysis' 18th edn. (Washington, DC, USA); 2005.
14. Van Soest PJ, Robertson JB, Lewis BA. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science. 1991;74:3583-3597.
15. McCullough H. The determination of ammonia in whole blood by a direct colorimetric method. Clinica Chimica Acta. 1967;17:297–304.
16. Van Keulen J and Young BA. Evaluation of acid-insoluble ash as a natural marker in ruminant digestibility studies. Journal of Animal Science. 1977;44:282–287.
17. Cobos-Peralta MA, Curzaynz-Leyva KR, Rivas-Martínez MI, Santillán-Gómez EA Bárcena JR. *In vitro* effect of diets for growing lambs supplemented with dried distillers grains on rumen fermentation and gas emissions. Agrociencia. 2018;52:203-215.
18. SAS Institute Inc. SAS/STAT ® 15.1 User's Guide (Business Analytics software). (Cary, NC, USA); 2010.
19. Van Emon ML, Vonnahme KA. Berg PT. Influence of level of dried distillers grains with solubles on feedlot performance, carcass characteristics, serum testosterone concentrations, and spermatozoa motility and concentration of growing rams. Journal of Animal Science. 2013;91:5821–5828.
20. Castro-Pérez BI, Estrada-Angulo A, Ríos FG, Dávila-Ramos H, Robles-Estrada JC, Contreras-Pérez G, Calderón-Cortés JF, López-Soto MA, Barreras A, Plascencia A. 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. Small Ruminant Research. 2014;119:8–15.

21. Crane A, Redden R, Crouse M, Kirsch J, Borowicz P, Held J, Swanson K, Schauer C. Influence of distiller's dried grains with solubles on ram lamb growth and reproductive traits. Journal of Animal Science. 2018;96:1484–1494.
22. Gao W, Chen A, Zhang B, Kong P, Liu C, Zhao J. Rumen degradability and post-ruminal digestion of dry matter, nitrogen and amino acids of three protein supplements. Asian-Australasian Journal of Animal Sciences. 2015;28:485–493.
23. Nuez Ortín WG, Yu P. Nutrient variation and availability of wheat DDGS, corn DDGS and blend DDGS from bioethanol plants. Journal of the Science of Food and Agriculture. 2009;89:1754–1761.
24. Martineau R, Sauvant D, Ouellet DR, Côrtes C, Vernet J, Ortigues-Marty I, Lapierre H. Relation of net portal flux of nitrogen compounds with dietary characteristics in ruminants: A meta-analysis approach. Journal of Dairy Science. 2011;94:2986–3001.
25. Neville BW, Lardy GP, Karges KK, Kirschten LA, Schauer CS. Sulfur Intake, Excretion and Ruminal hydrogen sulfide concentrations in lambs fed increasing concentrations of distillers dried grains with solubles. Sheep & Goat Research Journal. 2011;26:13–19.
26. Yokoyama MT, Johnson KA. Microbiology of the rumen and intestine in 'the ruminant animal: Digestive physiology and nutrition'. (Ed. D.C. Church) (Prentice Hall, New Jersey, USA).1993;125–144.
27. Böttger C, Südekum KH. Within plant variation of distillers dried grains with solubles (DDGS) produced from multiple raw materials in varying proportions: Chemical composition and *in vitro* evaluation of feeding value for ruminants. Animal Feed Science and Technology. 2017;229:79–90.
28. Hünerberg M, McGinn SM, Beauchemin KA, Okine EK, Harstad OM, McAllister TA. Effect of dried distillers' grains with solubles on enteric methane emissions and nitrogen excretion from finishing beef cattle. Canadian Journal of Animal Science. 2013;93:373–385.
29. Pecka-Kielb E, Zawadzki W, Zachwieja A, Michel O, Mazur M, Miśta D. *In vitro* study of the effect of corn dried distillers grains with solubles on rumen fermentation in sheep. Polish Journal of Veterinary Sciences. 2015;18:751–758.
30. Madigan MT, Martinko JM, Bender KS, Buckley DH and Stahl DA. 'Brock biology of microorganisms'14th Edn. (Pearson Educaction, Inc., Illinois, USA); 2014.
31. Ushida K. Symbiotic Methanogens and Rumen Ciliates In '(Endo) symbiotic Methanogenic Archaea'. (Ed. A. Steinbuchel) (Springer-Verlag, Germany). 2010;25–34.
32. Faria PB, Bressan MC, Vieira JO, Vicente-Neto J, Ferrão SPB, Rosa FC, Monteiro M, Cardoso MG, Gama LT. Meat quality and lipid profiles in crossbred lambs finished on clover-rich pastures. Meat Science. 2012; 90:733–738.
33. Priolo A, Lanza M, Biondi L, Pappalardo P, Young OA. Effect of partially replacing dietary barley with 20% carob pulp on post-weaning growth, and carcass and meat characteristics of Comisana lambs. Meat Science. 1998;50:355–363.
34. Ekiz B, Yilmaz A, Ozcan M, Kocak O. Effect of production system on carcass measurements and meat quality of Kivircik lambs. Meat Science. 2012;90:465–471.
35. Teixeira DL, Miranda-De La Lama GC, Villarroel M, Garcia-Belenguer S, Sañudo C, Maria GA. Effect of straw on lamb welfare, production performance and meat quality during the finishing phase of fattening. Meat Science. 2012;92:829–836.

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