The effects of diets containing two corn stubble levels and three non-hydrogenated lipids sources on fattening performance, carcass, and meat quality of male hair-lambs

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ABSTRACT
Research regarding the association of fatty acids (FA) with corn stubble in feedlot lambs is limited. FA dietary supplements can reduce the digestibility of neutral detergent fibre (NDF). However, it is not known if the NDF amount added with corn stubble and FA source in the diet can influence the content of polyunsaturated fatty acids (PUFA) and the conjugated linoleic acid (CLA), all of which are related to meat quality. In this study, 96 male-lambs (29 ± 4.9 kg) were assigned in two dietary NDF levels (25% (NDF-25) and 29% (NDF-29)) and four supplemental fat treatments [no supplemental (C), 3% CLA-60, 3% Safflower oil (SAF) and 3% linseed oil (LIN)] evaluated in a 2 × 4 factorial arrangement of treatments. Compared with CLA diets, diets supplemented with SAF and LIN contained more C18:2. Dietary forage level did not affect average daily gain, feed efficiency, or carcass characteristics (p = .56). With NDF-29 increased meat protein content (2%, p < .05). Meat chromatic b* values were greater (p = .02) with NDF-25. Control vs. supplemental lipids (SL) MUFA and PUFA increased in the muscle with SL. The endogenous level of CLA in muscle improved (p < .05) in the muscle with SL. Juiciness meat increased with both NDF levels and lipid supplements (p = .06). In conclusion, protein content and juiciness in the meat improve with NDF-29 (as corn stubble) on a diet. Similarly, SAF and LIN increase the content of PUFA and CLA in meat.

HIGHLIGHTS
1. A slight increase of NDF from 25% to 29% added with corn stubble within an iso-energetic diet, change the colour and some sensory variables of the lamb meat.
2. Safflower and linseed oils included in the diet at 3% improve the content of conjugated linoleic acid in lamb meat.
3. The General Quality index in the meat sensory analysis is not affected by inclusion levels of fibre (NDF 25 vs. 29) and lipids (3%) in the diet of hair lambs.

Introduction
Meat per-capita consumption and the total amount of meat consumed are rising, driven by increasing average individual incomes and by population growth (Godfray et al. 2018) raises the relevance and importance of high-quality meat supply for human consumption. Therefore, intensive ruminants fattening units require an adequate balance of ingredients for good quality meat production. In this case, the National Research Council (NRC 2007) recommended that a four-month-old (30 kg) growing lamb (early maturing) with a daily gain of 200 or 250 g, requires 2.4 – 2.8 Mcal of Metabolisable energy/kg of dry matter (DM) and 0.75 – 1.07 Mcal of Net Energy for gain,
respectively. Dietary ingredients must provide energy and protein to cover the requirements in lambs. Consequently, the maximum level of neutral detergent fibre (NDF) that the diet can reach is from 25% to 35%, and the supplemented fatty acids (FA) must be of low cost, improve energy density, and provide a reasonable quantity of polyunsaturated fatty acids (PUFA) into the diet.

Endogenous sources of lipids are provided by forages and concentrates in the diet, unsaturated FA predominate (Ferlay et al. 2017). Mainly, forages provide galacto-, sulfo- and phospholipids, while concentrates provide triacylglycerides. However, the content of FA can be increased with lipid supplements included in the diet. Ingested lipids are hydrolysed and non-esterified FAs are released in the rumen, the biohydrogenation process occurs mainly in 18:3 n-3, 18:2 n-6 and cis-9 18:1, becoming FA saturated (Harfoot and Hazlewood 1997); Although during BH, several intermediate FAs are also formed, such as the conjugated linoleic acid (CLA) isomer (Kott et al. 2003; Francisco et al. 2019), the trans-11-18:1 FA, vaccenic acid (Griinari et al. 2000). On the other hand, various PUFAs cause selective toxicity towards rumen microorganisms (Maia et al. 2010), possibly causing damage to the lipid bilayer of the bacterial cell membrane, caused by double bonds of AF (Maia et al. 2007). Bacteria are known to be mainly responsible for rumen biohydrogenation, the genera of Butyrivibrio Lactobacillus spp., Dialister spp. and Blifidobacterium spp. have been identified as the most important biohydrogenating bacteria (Dewankele et al. 2020). Various strategies of feeding forages, supplying vegetable oils or oilseeds, marine products or fat sources have been used to improve the lipid content in meat (Scollan et al. 2003). The use of unsaturated oilseeds, linseed, soybean and sunflower oils increase trans-18:1 FA, being more evident with linseed and sunflower (Glasser et al. 2008). Sunflower and soybean oils improve the amounts of CLA in meat (Mir et al. 2003).

Additionally, diets must contain sufficient forages to provide enough fibre to maintain a stable ruminal environment. As a product, meat from pasture-finished ruminants has higher levels of n3 FA and also has the added benefit of having elevated quantities of CLA (Daley et al. 2010); both lipids have been shown to lower the risk of obesity and heart diseases in humans (den-Hartigh 2019). However, grain-finished ruminants had faster conformation and more acceptable meat-fat flavour (brothy and buttery) compared with pasture-finished animals (O’Quinn et al. 2016). This concept is not so simple, and few studies have evaluated the effects of forage species on FA content in livestock products (Haddad and Ata 2009). For example, poor quality forages are very common in underdeveloped countries, usually as by-products of oats, barley, or corn grain production. Corn stubble is highly available and used exclusively in the feeding of equines and ruminants; it has a low nutritional value and interesting enough to be used as a source of fibre in high-grain diets.

Interactions of dietary FA with poor quality forages in lamb diets have seen limited research. Dietary FA supplements can reduce NDF digestibility. However, there is no information to show if the amount of NDF can influence the rate of BH, the PUFA profile, and to quantify the synthesis of CLA that reaches the intestine and subsequently stored in inter-muscular fat tissue. The FA profile of chime entering the small intestine of feedlot lambs may be influenced through the manipulation of dietary forage fibre, to the extent where it affects the intestinal passage rate (Glasser et al. 2008) and decreasing the magnitude of BH on FAs flowing to the small intestine (Galley and Defoor 2003).

Therefore, the objective of this study was to evaluate the effects of two levels of NDF with four treatments, considering the control group and three dietary lipids sources (two vegetable oil sources, and one form of CLA). Supplemental CLA was considered a positive control group, because the hypothesis of the study considers that safflower and linseed oils are better sources available at a commercial and biological level; therefore, their additions in the rations improve the content of CLA in intramuscular fat.

Material and methods

Management distribution and performance of animals

Animal care was under the Mexican Council on Animal Care guidelines (NOM-062-ZOO 1999) and handling procedures were approved by the ethics committee on animal use of Colegio de Postgraduados, protocol Folio 08/2017. Ninety-six crossbred Pelibuey × Katahdin male-lambs were received at the Montecillo Postgraduate College research unit. Upon arrival, lambs were vaccinated for the prevention of clostridia diseases (Ultrabac 8®, SmithKlineBeechman), and treated for the elimination of parasites (Ivomec Plus® Merck, Rahawy, NJ). Lambs were adapted to the basal finishing diet for 14 days before initiation of the trial. They were blocked by weight (29 ± 4.9 kg average in...
each treatment) into eight blocks of 12 lambs each and housed in 96 individual cages (1.5 × 0.9 m) equipped with feeder and drinker.

Two dietary NDF levels (25% (NDF-25) and 29% (NDF-29)) and four supplemental fat treatments [no supplemental (C), 3% conjugated linoleic acid (CLA 60, ConLinco®) (CLA), 3% Safflower oil (SAF) and 3% linseed oil (LIN)] were evaluated in a 2 × 4 factorial arrangement of treatments. The composition of dietary treatments is shown in Table 1. Diets were formulated to meet nutritional requirements for growing lambs based on tabular values for individual feed ingredients (NRC 2007).

Lambs were weighed (electronic scale; Torrey Til/s: 107 2691, Houston TX, USA) once at the beginning and at the end of the trial (after a fasting period of 14 h). Diets were prepared weekly and stored in plywood boxes. The total feed was offered in two meals, in the morning (40%) and in the afternoon (60%); feed refusal (target was 5% ors) was collected before each morning delivery to calculate animal intake. The amount of feed offered to each animal was adjusted in dry matter basis per day to get the dry matter intake (DMI). Average daily gain (ADG) was obtained by the difference in final and initial weight divided between the 60 d that the experiment lasted. Feed efficiency was estimated with DMI/ADG.

### Carcase characteristics, retail and measurements

Slaughtering started when the lambs reached 40 kg BW (~60d of the fattening period). On the day of slaughter, the lambs were weighed (Live weight in the slaughterhouse (LWS)), and they were stunned and exsanguinated. All lambs killed were harvested an equal number for each treatment on a given slaughter day at the local commercial slaughterhouse (Puebla city) (NOM-2006). Hot carcase weight, including kidneys and testicles (HCW), was recorded. Carcases were cooled at 4 °C for 24 h. Subsequently, cold carcase weight (CCW) was obtained. Commercial dressing percentage was calculated according to the following formulae: Commercial dressing percentage (CDP) = HCW/LWS × 100.

The pH was measured in the Longissimus thoracis (between the 11–13th thoracic vertebra) 1 and 24-h post-mortem using a portable pH-meter (H199161-Hanna, Instruments. India) with a glass electrode standardised for pH 4.0 and 7.0. Fat depth (FD) was measured at the intercostal cavity of the 12th rib, 4 cm from the spine (NOM-2006). After 36 h, carcases were ribbed between the 12th and 13th ribs, and the Longissimus lumborum and Biceps femoris of each animal were removed from the cold carcases and packaged in a vacuum-sealed bag and transported to the Meat Science laboratory at the Metropolitan

### Table 1. Ingredient composition of experimental diets in hair-lambs fed with two levels of neutral detergent fibre (NDF) as corn stubble and oils in the diets.

| Ingredients, % (DM) | C   | CLA | SAF | LIN | C   | CLA | SAF | LIN |
|---------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Barley grain        | 35.82 | 37.17 | 37.17 | 37.17 | 24.00 | 23.57 | 23.57 | 23.57 |
| Wheat grain         | 29.00 | 24.68 | 24.68 | 24.68 | 24.45 | 24.72 | 24.72 | 24.72 |
| Corn stubble (CS)   | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 | 16.00 |
| Soybean meal        | 5.40  | 5.43  | 5.43  | 5.43  | 5.43  | 5.43  | 5.43  | 5.43  |
| Conjugated linoleic acid (CLA) | –     | 3.00  | –    | –    | –    | 3.00  | –    | –    |
| Safflower oil (SAF) | –    | –    | –    | –    | –    | 3.00  | –    | –    |
| Linseed oil (LIN)   | –    | –    | 3.00  | –    | –    | –    | –    | 3.00  |
| Molasses            | 11.18 | 11.23 | 11.23 | 11.23 | 16.02 | 13.03 | 13.03 | 13.03 |
| Limestone           | 1.20  | 1.03  | 1.03  | 1.03  | 1.02  | 1.03  | 1.03  | 1.03  |
| Urea                | 1.00  | 1.06  | 1.06  | 1.06  | 1.19  | 1.33  | 1.33  | 1.33  |
| Minerals trace*     | 0.40  | 0.40  | 0.40  | 0.40  | 0.40  | 0.40  | 0.40  | 0.40  |

Note: C = No supplemental lipids. Lipids: CLA, SAF, LIN.

*Trace mineral salt contained: CoSO4: 0.068, CuSO4: 0.09%, FeSO4: 3.5%, ZnO:1.2, MnSO4: 1.04, KI: 0.06, Na2SeO3: 0.06, NaCl: 93.9%.

NDFa = Provided by the ingredients of the ration, not including CS. NDFb = Provided by all ingredients of the ration.
University, Mexico. Samples were maintained at 
–35 °C until analysis.

**Sensory analysis**
From each treatment, carcases from seven lambs were randomly selected, and the right hind quarter of each lamb carcase was thawed at 4 °C before being used. *Biceps femoris* were cut into five slices of 1.5 cm thickness and cooked in a contact grill pre-heated to 200 °C until the internal temperature of the muscle reached 71 °C, as measured by a thermocouple inserted into the approximate centre of the muscle (AMSA 2015). After cooking, the slices of lean (excluding external fat and connective tissue) were cut into two pieces and each piece was wrapped in aluminium foil, coded and placed in a heater to minimise heat loss until they were presented to the taste panel. A panel of 56 students (from 19 to 24 years old) of the Metropolitan University-Mexico with previous experience of sensorial analysis was used (AMSA 2015). Each panellist chewed or tasted the meat of each of the eight treatments. Meat samples were given to each student at random. The panel members were situated in distinct areas at 12 Post Meridiem (4 h after breakfast). Afterward, panellists were asked to assess each meat sample for the following sensory attributes: General quality, flavour intensity (associated with the animal species or cooked lamb meat) odour intensity (odour animal species or cooked lamb meat), hardness (the force needed to chew) and juiciness (water perceived during mastication). Panellist used a non-structured 1–12 rating scale, representing at the extremes the minimum (0 – absence of the sensation) and the maximum (12 – sensation extremely intense). Unsalted crackers and water were served to panellists to freshen their mouths before and between each assessment samples.

**Laboratory analysis**

**Chemical analyses in food samples:** At the end of the trial, frozen samples of experimental diets were thawed overnight at room temperature and analysed for DM by drying in an oven at 65 °C for 48 h (AOAC 2002). Dried food samples were ground through a 1-mm screen using a Christy-Norris mill (Christy and Norris Ltd., Chelmsford, UK). Ground food samples were pooled per treatment and analysed for: Analytical DM content of the oven-dried samples was determined by drying at 105 °C for 5 h. Ash was determined by combustion of DM food sample at 550 °C for 5 h. Nitrogen (N) content was determined by the Kjeldahl method (AOAC 2002). Samples for NDF analyses were first rinsed with 50 mL of hot-ethanol to withdraw the fat from the residues, followed by soaking in urea solution (30 mL of 8 M) with 0.2 mL of α-amylase (Sigma Chem. Co. St Louis, MO) leaving it to rest overnight before the NDF solution was added (Weizhong and Udén 1998).

**Chemical analyses and measurements in meat samples:** *Longissimus lumborum* samples were selected to quantify the following analyses. Moisture was evaluated by drying the meat samples in an oven at 105 °C until the sample reaches a constant weight by releasing moisture. The meat samples were cooled in the desiccator before reweighing. After, moisture content was calculated by the difference in wet and dry weight. Protein was calculated on the basis of total N content, with the Kjeldahl method. N content was multiplied by 6.25 to give the total protein content of meat. Ash was calculated when meat samples were dried in a muffle furnace at 550 °C, water and volatile substances present in meat samples were vaporised (AOAC 2002; NOM 2006).

The colour of the *Longissimus lumborum* muscle was measured after the fascia covering was removed, the colour was measured at two locations randomly selected to obtain a mean value with a representative reading of surface colour. Chroma metre (Hunter Lab, Chromameter CR-410, Konica Minolta Sensing, Inc. Japan) was used to determine the colour, and chromatic values were reported as L*, a*, b*; where: L* = Value designates lightness, ranging from 0 for black to 100 for ideal white. a* and b* = Colour coordinates (+a* = redness, –a* = green, +b* = yellow, –b* = blue). The metre was calibrated using a Minolta calibration tile: L* = 93.8, a* = 0.313, b* = 319. Extra meat samples were cut into rectangular pieces of 1 × 1 × 1.5 cm along the muscle fibre direction. Shear force values were determined on raw meat using a Warner-Bratzler shear in a TA-XT2 texture analyser (Texture Technologies Corp., Scarsdale, NY), at 5 mm test speed and 5 mm/g backing speed, being applied 0.981 N force (Ishihara et al. 2013). Water activity was measured by aw metre (WA: 4TE, Acua Lab. Pullman, USA).

**Fatty acid analysis in food and meat samples:** FA analysis in food and meat were involved by three principal steps: (a) Extraction of lipids, (b) Composition of FA methyl ester (FAME); and (c) Analysis with gas chromatography (GC) analysis (ÓFallon et al. 2007). For FA profile analysis, lipids were extracted in 1 g of the food or meat with CHCL3: MeOH (2:1, vol/vol) containing 1 mL of internal standard (0.5 mg of C13:0/ml of Me OH). The extraction mixture was filtered
through a sintered glass filter, and replicated aliquots were pipette into a 16 × 125 mm screw cap Pyrex culture tube. The organic phase was separated with NaCl (200 μl 0.9%/mL), and the solvent was subsequently removed under N at 55°C. One millilitre of hexane was added, 100 μl of rate KOH in MeOH, and the tube was vortex with CLA. As expected, CLA had greater content of unsaturated FAs in muscle. Correlations coefficients were obtained using CORR variable (SPSS 22 2013) and this were considered significant at p ≤ 0.05.

### Results

#### Dietary fatty acid profiles

The FA profile of dietary treatments is shown in Table 2. Total FA levels of control diets averaged ~2 mg/g DM, whereas the total FA content of lipid supplemented diets averaged ~5 mg/g DM. Lipid supplementation increased the concentration (mg/g DM) of C17:0 (0.15), C17: 1 (0.08), C18: 1 (0.36), C18: 2 (1.42) and C18: 3 (0.32). Particularly, diets supplemented with SAF and LIN increased C18: 2 (0.91) in comparison with CLA. As expected, CLA had greater content (0.44) of C18:2 and CLA-isomers than the SAF and LIN treatments.

#### Animal production performance and carcase characteristics

Treatment effects on 60-d lamb growth performance and carcase dressing percentage are shown in Table 3. Dietary forage level did not affect ADG (p = .91) or feed efficiency (p = .56). DMI variables average were: 1.14 kg, ADG: 0.249 kg and FE: 5.03. There were no forage levels by supplemental lipid treatment interactions (p > .10). Although, dry matter intake tended to be greater (7.3%, p = .07) for NDF-29 than NDF-25. Carcase characteristics did not have a significant difference (p > .05) with supplemental lipids and two levels of NDF. The mean for variables was: Dressing hot and cold, 54.3 and 52.9%. Similarly, fat thickness and both measures of carcase pH post-slaughter did not have

### Table 2. Fatty acid profile of experimental diets in hair-lambs fed with two levels of neutral detergent fibre (NDF) as corn stubble and lipids in the diets.

| Fatty acid | C | CLA | SAF | LIN | SEM | C | CLA | SAF | LIN | SEM |
|------------|---|-----|-----|-----|-----|---|-----|-----|-----|-----|-----|
| 16:0       | 0.22 | 0.71 | 0.80 | 0.61 | 0.04 | 0.27 | 0.57 | 0.50 | 0.56 | 0.04 |
| 16:1       | 0.09 | 0.19 | 0.07 | 0.16 | 0.03 | 0.14 | 0.30 | 0.29 | 0.26 | 0.01 |
| 17:0       | 0.12 | 0.26 | 0.37 | 0.31 | 0.02 | 0.12 | 0.21 | 0.22 | 0.27 | 0.02 |
| 17:1       | 0.12 | 0.16 | 0.26 | 0.28 | 0.03 | 0.12 | 0.16 | 0.16 | 0.15 | 0.02 |
| 18:0       | 0.06 | 0.06 | 0.09 | 0.09 | 0.02 | 0.04 | 0.08 | 0.07 | 0.08 | 0.01 |
| 18:1       | 0.32 | 0.84 | 0.75 | 0.85 | 0.02 | 0.33 | 0.68 | 0.48 | 0.48 | 0.03 |
| 18:2       | 0.54 | 1.37 | 2.42 | 2.08 | 0.09 | 0.47 | 1.26 | 2.35 | 2.02 | 0.11 |
| 18:3       | 0.19 | 0.41 | 0.39 | 0.69 | 0.06 | 0.21 | 0.51 | 0.57 | 0.58 | 0.07 |
| 18:2 CLA   | 0.04 | 0.81 | 0.04 | 0.17 | 0.06 | 0.05 | 0.77 | 0.12 | 0.25 | 0.06 |
| 22:0       | 0.04 | 0.04 | 0.05 | 0.05 | 0.02 | 0.05 | 0.06 | 0.06 | 0.06 | 0.01 |
| 20:4n-6    | 0.00 | 0.00 | 0.00 | 0.05 | 0.01 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 |
| Others     | 0.16 | 0.42 | 0.44 | 0.48 | 0.05 | 0.16 | 0.42 | 0.38 | 0.41 | 0.06 |

Total Fatty acids mg/g dry matter: 2.01a 5.28b 5.67b 5.83b 0.87 1.95a 5.03b 5.19b 5.17b 0.98

C = No supplemental lipids. Supplemental lipids: Conjugated linoleic acid (CLA), Safflower oil (SAF), Linseed oil (LIN). SEM: Standard Error Mean. Means with different letters indicate significant differences (p < 0.05).
Table 3. Performance, carcass characteristics, non-carcass components and wholesale cuts in hair-lambs fed with two levels of neutral detergent fibre (NDF) as corn stubble and oils in the diets.

| NDF-25%     | NDF-29%     | P effects (P =<) |
|-------------|-------------|------------------|
| C           | CLA         | SAF             | LIN | C | CLA | SAF | LIN | SEM | C vs. | CLA vs. | SAF vs. | LIN | NDF-25 | C vs. | NDF-29 | C vs. | NDF-29 vs. 25 |
| Initial weight, kg | 28.62 | 29.77 | 29.90 | 29.92 | 29.92 | 29.87 | 29.90 | 29.95 | 1.85 | 0.34 | 0.89 | 0.75 | 0.84 | 0.77 |
| DMI kg d−1 | 1.15 | 1.12 | 1.04 | 1.09 | 1.19 | 1.23 | 1.18 | 1.14 | 0.09 | 0.29 | 0.71 | 0.17 | 0.19 | 0.07 |
| ADG kg d−1 | 0.219 | 0.224 | 0.221 | 0.226 | 0.216 | 0.210 | 0.231 | 0.207 | 0.04 | 0.18 | 0.69 | 0.11 | 0.13 | 0.91 |
| DMI/ADG | 5.50 | 5.01 | 4.75 | 4.90 | 5.95 | 5.90 | 4.90 | 5.20 | 0.99 | 0.12 | 0.59 | 0.10 | 0.10 | 0.56 |
| Dressing hot, % | 33.1 | 52.94 | 54.79 | 53.31 | 54.23 | 53.69 | 53.72 | 56.19 | 1.70 | 0.14 | 0.86 | 0.13 | 0.34 | 0.24 |
| Dressing cold, % | 52.83 | 51.42 | 53.53 | 52.83 | 51.71 | 53.65 | 52.25 | 55.25 | 1.30 | 0.25 | 0.46 | 0.32 | 0.44 | 0.24 |
| Fat thickness | 1.20 | 1.13 | 1.40 | 1.20 | 1.04 | 1.26 | 1.23 | 1.42 | 0.19 | 0.63 | 0.21 | 0.86 | 0.74 | 0.99 |
| pH1h post-slaughter | 5.99 | 6.29 | 5.98 | 6.22 | 6.10 | 5.72 | 5.88 | 6.13 | 0.16 | 0.67 | 0.19 | 0.95 | 0.16 | 0.23 |
| pH24h post-slaughter | 5.37 | 5.67 | 5.29 | 5.39 | 5.34 | 5.34 | 5.43 | 5.41 | 0.14 | 0.42 | 0.31 | 0.51 | 0.57 | 0.30 |

C = No supplemental lipids. Supplemental lipids: Conjugated linoleic acid (CLA), Safflower oil (SAF), Linseed oil (LIN).

DMI: Dry matter intake; ADG: Average daily gain; SEM: Standard Error Mean.

significant differences (p > .05). Average for fat thickness, 1.2; pH1h = 6.03 and pH24h = 5.4.

Meat physicochemical analysis

Table 4 shows the values of meat physicochemical analysis. The moisture and ash were not affected (p > .05) by the FA supplement or the NDF level in the diets; the mean for variables was 71.4 and 4.15%, respectively. Meat protein content only improved by 2% with NDF-29 (p < .05). Chroma L* and a* had no significant differences between treatments, meaning 29.22 and 7.53, respectively. In contrast, b* value was greater (5.72 vs. 6.57; p = .02) in meat with NDF-29, indicating an increase in yellow colour. RMH and Wa were not significant differences, with a mean difference of 2.358 and 0.97, respectively.

Fatty acid profiles in muscle

Table 5 shows the FA profile (% of total FA) in Longissimus lumborum muscle. The results are described by section:

Control vs. supplemental lipids (SL): The content of C14: 0 decreased (C: 6.12 vs. SL: 3.8; p < .05) with SL. Consequently, the content of ∑SFA was also lower (C: 47.48 vs. SL: 39.4; p < .05) with SL. On the other hand, unsaturated FAs increased with SL. The content of C 18: 1n9 (C: 30.75 vs. SL: 35.39) and ∑MUFA (C: 39.94 vs. SL: 44.66%) increased (p < .05) in the muscle with SL. The PUFAs, C 18: 2n6 (C: 4.35 vs. SL: 5.62), C 18: 3n6 (C: 0.35 vs. SL: 0.45) and ∑PUFA (C: 8.42 vs. SL: 9.85) also increased (p < .05) in the muscle with SL. The endogenous levels of CLA in the muscle formed as C 18: 1 t11 (C: 3.16 vs. SL: 4.88) and C18: 2-CLA (C: 0.90 vs. SL: 1.22) improved (p < .05) in the muscle with SL.

CLA vs. SAF and LIN: CLA only was improved (p < .05) in C15:1n5 (0.12 vs. 0.07), C 18:3n6 (0.62 vs. 0.42) and C 20: 2n6 (0.56 vs. 0.43).

NDF-25: C vs. Supplemental lipids: SL decreased (p < .05) in the following FA: C14: 0 (6.45 vs. 3.92), C20: 0 (1.05 vs. 0.06), C22: 0 (0.98 vs. 0.32) and ∑SFA (46.41 vs. 38.63). In unsaturated acids there was only a decrease in C14: 1n5 (0.80 vs. 0.41; p < .05), while in C16: 1n7 (2.96 vs. 3.74), C18: 1n9 (30.2 vs. 35.23), ∑MUFA (39.9 vs. 45.1) had a decreased (p < .05) with SL.

NDF-29: C vs. Supplemental lipids: SL decreased (p < .05) the content of the following saturated lipids in the muscle: C 12: 0 (0.42 vs. 0.31), C 14: 0 (5.78 vs. 3.68), C 16: 0 (26.8 vs. 23.13), C 20: 0 (1.06 vs. 0.06), C 22: 0 (0.89 vs. 0.32), ∑SFA (48.47 vs. 40.17). Unsaturated FAs and CLA content in the muscle decreased (p < .05) in the following FA: C 18: 1n9 (31.3 vs. 35.54), ∑MUFA (39.97 vs. 44.24), C 18: 3n3 (0.29 vs. 0.40), C 20: 2n6 (0.26 vs. 0.41), ∑PUFA (7.38 vs. 9.24), C 18: 1 t11 (3.2 vs. 4.90).

NDF-25 vs. NDF-29: The amount of ∑PUFA decreased (p < .05) in the muscle with the highest NDF content (10.21 vs. 8.77). The other AF had no significant differences (p > .05).

Sensorial analysis

Table 6 shows the variables of sensorial analysis. Overall quality, colour, and hardness did not have significant differences among treatments (p > .1). The other variables such as odour intensity (C: 9.61 vs. NDF-25: 7.04, p = .09) and flavour (C: 8.4 vs. NDF-25: 7.3%, p = .09) tended to decrease with only NDF-25 when lipids were supplemented in the diets, while the juiciness increased with both NDF levels and the lipids...
supplements in the diets (C: 6.04 vs. NDF-25: 7.0, \( p = .08 \), and C: 6.4 vs. NDF-29: 8.2, \( p = .06 \)).

**Correlation of dietary fatty acid and fatty acids in muscle**

Table 7 shows the Pearson correlation coefficients between total dietary FA and the FA profiles in the lipids of meat lamb. There were no significant correlations between the total values of saturated and unsaturated FAs. Only, differences were observed in the CLA profile in the muscle; the diet with supplemental CLA was significantly correlated with C18: 2 CLA (0.71, \( p < .05 \)), and the diets supplemented with LIN and total lipids had a correlation trend also with C18: 2 CLA (0.53 and 0.62, \( p < .1 \)).

**Discussion**

*Animal production performance and carcass characteristics*

The amount and type of lipids added to ruminants are important in the production variables. Likewise, it is known that an excess of lipids in the diet causes a decrease in the digestion of fibre and lipids (Zinn 1992). In this study, lambs received an adequate level of lipids in the diet and consequently there was no reduction in total dry matter intake, although the higher level of NDF in the diet tended to slightly increase DMI. Lamb growth and feed efficiency did not show changes, other studies (Haddad and Younis 2004; Bessa et al. 2005; Ferreira et al. 2014) reported a reduced feed intake when protected fat or soybean oil was included at levels of 5 and 10% in diets, respectively. Despite the decrease in intake, the daily average body gain did not change. Although, Dutta et al. (2008) suggest including palm oil in the diet to improve daily weight gain in animals. Apparently, the differences depend on the fattening time and the initial weight of the lambs. Castro et al. (2005) and Manso et al. (2009) included 4% hydrogenated palm oil or sunflower oil in the concentrate and there were no changes in the productive variables and the carcass characteristics.

In the study, there were no differences in the characteristics of the carcass between the evaluated treatments. Likewise, Kott et al. (2003) did not observe differences in renal and subcutaneous fat in lambs supplemented with 6% sunflower oil. Although, Bessa et al. (2005) reported higher intramuscular fat deposition and lower proportion of muscle when lambs were fed 10% soybean oil. In general, the lipids included in the rations increase the fat content of the

Table 4. Meat psychochemical analysis in Longissimus lumborum muscle in hair-lambs fed with two levels of neutral detergent fibre (NDF) as corn stubble and lipids in the diets.

| Item               | Moisture | Protein | Ash     | C15 (Lightness) | a’ (Redness) | b’ (Yellowness) | Raw meat shear force | Water activity |
|--------------------|----------|---------|---------|-----------------|--------------|-----------------|---------------------|---------------|
| C                  | 72.31    | 21.11   | 4.31    | 27.58           | 7.59         | 5.82            | 2152.99             | 0.97          |
| NDF-25%            | 72.30    | 21.12   | 4.15    | 27.48           | 7.79         | 5.95            | 2592.22             | 0.98          |
| C vs. NDF-25%      | 0.21     | 0.19    | 0.28    | 0.14            | 0.21         | 0.23            | 0.08                | 0.06          |
| NDF-29%            | 70.54    | 21.01   | 3.91    | 30.74           | 8.31         | 5.44            | 2338.09             | 0.97          |
| C vs. NDF-29%      | 0.20     | 0.21    | 0.20    | 0.18            | 0.23         | 0.24            | 0.15                | 0.06          |
| C vs. Lipids       | 0.21     | 0.19    | 0.19    | 0.14            | 0.14         | 0.14            | 0.14                | 0.06          |
| NDF-25% vs. Lipids | 0.37     | 0.32    | 0.37    | 0.37            | 0.37         | 0.37            | 0.37                | 0.37          |
| NDF-29% vs. Lipids | 0.37     | 0.32    | 0.37    | 0.37            | 0.37         | 0.37            | 0.37                | 0.37          |

SEM = Standard Error Mean.

C = No supplemental lipids. Supplemental lipids: Conjugated linoleic acid (CLA), Safflower oil (SAF), Linseed oil (LIN).
carcase (Zinn 1992). Regarding the amount of forage in the diet, Matsuba et al (2019) reported a negative influence of coconut oil and soybean (4% in the ration) on fibre digestion, indicating a limitation in the efficient use of the feed, while this effect has not been observed with supplemented palm oil. The mean values in the carcase dressing were 54%, considered within the range cited in the bibliography of lambs fattened in similar systems (Hernández et al. 2009).

### Meat chemical composition and physicochemical

NDF-25 increased by 2% the protein content in meat, and there are reports that silage forage increases dietary energy density. This had a positive effect on both grade fat and muscle scores and protein content in dairy cull cows (Lee et al. 2009; Minchin et al. 2009). This result was not expected because the nutritional value of protein and energy is lower in high corn
stubble; this response can be with the availability of microbial protein when the diet was included with fat (Zinn 1989). Regarding the quality of the meat, no changes were found attributable to the raw meat force and water activity, there is no information indicating a change with the lipid supplement or the level of fibre in the diet used for feedlot. In general, differences in meat colour are associated with fat content or pH (Priolo et al. 2001). In this study, the values for b* were higher in meat with NDF-25, indicating an increased yellow meat colour, maybe some chromogens in the corn stubble are linked to being stored in adipocytes and caused by differences by pigment deposition or composition of FAs (Wood et al. 2008). In general, the indices obtained in the quality of meat were attributable as adequate according to the Mexican Norm of Classification (NOM 2006).

Fatty acid profiles in muscle

The amount of lipids in the muscle is increased by the inclusion of oilseeds or lipids in the diet of the lambs. In this study, SFAs predominated in meat: C 16: 0, C18: 0 and C 14: 0; MUFA: C 18: 1n9 and C 18: 1n7 and PUFA C: 20 4n6, coinciding with what has been published by other authors (Tshabalala et al. 2003; Costa et al. 2018). Higher content of MUFA (45%) and PUFA (10%) was presented in diets supplemented with lipids, considering that the higher content of unsaturated FAs is associated with protective capacity against cardiovascular diseases in humans. Thus, oleic acids (C18: 1) linoleic (C18: 2 n-6) and α-linolenic (C18: 3 n-3) improved with the lipid supplement, although C18: 1 gives an endogenous synthesis of C18: 0 by the enzyme complex Δ9-desaturase (stearyl-CoA desaturase (Piccinin et al. 2019). It has also been found that the proportion of some minor MUFA isomers (c7-16: 1 and c14-18: 1) is influenced by the type of forage (Kong et al. 2010) and the effects of feeding as pasture or mixed diet (Luo et al. 2019); these findings were attributed, in part, to differences in predominant ruminal microbes or to ruminal and duodenal flow rates among types of forages (Lee et al. 2003; Kong et al. 2010). The highest concentration of PUFA was in diets with NDF-25 content in the ration. This effect could be associated with a reduction in ruminal lipolysis and lower BH of lipids supplemented through a change in the ruminal microbial population (Huws et al. 2010), and a possible increase in the passage rate in the rumen (Ndlovu and Buchanan-Smith 1985) provided by NDF-25.

Previous research has shown that feeding high-oil to beef steers fed finishing diets decreased the oleic acid and increased the BH rates of linoleic (C18:2) and arachidonic acid (C20:4) (Duckett et al. 2002); this increased intestinal supply of linoleic acid could be from reduced ruminal BH of FA. To increase the amount of meat-PUFA is necessary to include a source of PUFA and create optimal conditions in the rumen, which favour the passage rate of PUFA and decrease the BH rate (Freitas et al. 2018). Several studies reported that feeding ruminants with lipids or oilseeds rich in FA with 18 carbons increased the accumulation of PUFA and CLA in tissues (Van Wagoner and Boles 2003; Petri et al. 2014). As is known, endogenous CLA is formed by isomerisation and intermediate hydrogenation, forming c9, t11-18: 2 and t11-18: 1 (trans-vaccenic acid), respectively Butyrivibrio fibrisolvens isomerises the cis-PUFA double bonds to form conjugated double c/t bonds, due to the action of the enzymes linoleate-isomerase and CLA-reductase (Mir et al. 2000). The final AF is trans-vaccenic acid (t11-18: 1); at the same time, it is hydrogenated to t10-18:1 acid (Singh and Sachan 2011; Shingfield and Wallace 2014). There is a close relationship between the digestive function of the rumen and the CLA content in tissue lipids (Shingfield and Wallace 2014), only a small portion of CLA is absorbed directly into the rumen mucosa and small intestine (Knight et al. 2003). In this study, the increase in the meat-PUFA was given

| Muscle fat       | No lipids supplement | Conjugated linoleic acid (CLA) | Supplemental | Safflower oil | Linseed oil | Total lipids |
|------------------|----------------------|-------------------------------|--------------|---------------|-------------|--------------|
| ∑SFA             | 0.12                 | −0.15                         | 0.18         | −0.19         | −0.15       |
| ∑MUFA            | 0.39                 | 0.54                          | 0.34         | 0.41          | 0.44        |
| ∑PUFA            | 0.11                 | 0.12                          | 0.09         | 0.08          | 0.11        |
| C 18:1 t11       | 0.29                 | 0.61                          | 0.45         | 0.54          | 0.52        |
| C18:2 CLA        | 0.31                 | 0.71**                        | 0.47         | 0.53*         | 0.62*       |

SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polinsaturated fatty acids. Total lipids: A correlation analysis was run with the three sources of lipids in the diets. **p < .05, *p < .1.
only with the CLA and SAF supplements; the main PUFA that marked these differences was C18:2-6 and C18:3-6. Therefore, the encapsulation of CLA with calcium salts should be decreased the BH of the FA and there was better availability of the PUFA to accumulate in the meat. The use of sunflower and flaxseed added in the diets (Bolte et al. 2002; Kott et al. 2003; Santos-Silva et al. 2003; Demirel et al. 2004; Boles et al. 2005) have increased the content of CLA in the muscles and fat of lambs. As mentioned early, the proportion of isomer t-18:1 was higher in both lipids supplemented groups and these differences are attributed to the formation of CLA in the diets with supplemental lipids, without differences between the two levels of NDF. Concerning the treatment with LIN likely had the highest rate of BH and decreased the accumulation of PUFA in meat. The PUFA/SFA ratio indicates the nutritional value of the meat and the balance of the FA of the n-6 and n-3 series (Russo 2009). The World Health Organisation recommends a PUFA/SFA ratio higher than 0.45; however, ruminant meat has a low ratio, due to the biohydrogenating action of rumen microorganisms. In this study, the PUFA/SFA (0.25) ratio was improved with the supplementation of lipids in the diet. The lack of differences in CLA levels in the meat of animals fed with two levels of NDF not altering the deposition in the muscle. CLA directly in the diet was not the appropriate route to enhance the meat with this CLA, because it is less available than SAF and LIN.

The CLA profile in the FA of ruminant meat is positively correlated with the content of CLA in the diet (Aurousseau et al. 2004; Raes et al. 2004) and the formation of trans FA by rumen microbes (Lawson et al. 2001). In this study, supplemental CLA in the diet was correlated with the level of CLA measured in muscle fat. On the other hand, some authors also cite that higher CLA content in meat of grazed lambs was associated with higher PUFA content found in the grass (Lawson et al. 2001). This response, however, was not observed in this study due to the differences in the types of diet. Lambs fed with energetic diets are limited in the quantity and quality of PUFA. However, oilseed supplements in feedlot-fed ruminant diets increase the CLA content in muscle lipids, with differences between the supplemented seeds or oils. Casutt et al. (2000) observed in steers that the feed added with sunflower seeds was positively correlated with the CLA content of the subcutaneous fat (7.8 mg/g of FAME), while the group of steers supplemented with linseed was lower (5.5 mg/g FAME). In contrast, lambs supplemented with flaxseed oil showed a correlation with the CLA of muscle fat (Demirel et al. 2004). Similarity in this study, lambs supplemented with LIN tended to improve the CLA level in muscle fat.

**Sensorial analysis**

The flavour intensity decreased with the lipids supplement and NDF-25, and there was also a tendency to improve the juiciness with the lipids supplement and both levels of NDF (Table 6). Conversely, the increase in the intensity of flavour and juiciness of bovine meat may be related to the intramuscular proportions of PUFA n-3 and n-6 (Vahmani et al. 2015) since the oxidation induced thermally of PUFA, when the meat is cooked, produces volatile compounds that can contribute to the taste of desirable or undesirable meat (Elmore et al. 1999). Another author (Melton 1990) has reported that lamb meat enriched with linoleic acid or a high content of sunflower seed has been evaluated as unattractive. Additionally, the addition of CLA in the diet increased hue and yellowness, whereas the inclusion of linseed decreased these values (Barahona et al. 2016). The influence on odour and flavour of the meat is due to lipid supplements; less than 4% in the diet had an adequate flavour (Jaworska et al. 2016) according to the results of this study.

Other research had shown that although the inclusion of flax seeds in the diet increased the formation of some volatile compounds in cooked lamb, this response was less dramatic when the lambs were fed with fish oil (Elmore et al. 2000). According to this work, the inclusion of 3% of lipids in the diet of hair lambs did not affect the variables in the sensory quality of the meat; the present findings were consistent with another study in lambs fed with saturated fat and protected linseed oil (Gravador et al. 2020). Intramuscular fat is an essential variable for determining meat quality in some markets of Asia and North America, and it is associated with proper sensorial evaluation. In most European and Latin American countries, excessive intramuscular fat can negatively influence consumers (Bessa et al. 2015). In general, most Latin American consumers prefer a light meat odour.

**Conclusions**

In this study, no evident differences were using two levels of NDF in the ration over the productive parameters and characteristics of the carcase and cuts. The data on protein content and juiciness in the meat was higher with NDF-29 on a diet. SAF and LIN were
adequate to improve the content of PUFA and CLA, and there were no interactions between the level of NDF and sources of dietary lipids. The reason for using protected CLA was to evaluate its efficiency to be deposited in meat, but its low disability did not justify its use in lambs.

**Ethical approval**

The protocol followed in this study was reviewed and approved by the Colegio de Postgraduados, Mexico (Ethics Reference No: 08/2017).

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**Disclosure statement**

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