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The effects of feeding a standardized mixture of essential oils vs monensin on growth performance, dietary energy and carcass characteristics of lambs fed a high-energy finishing diet

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ABSTRACT

Thirty-six Pelibuey × Katahdin crossbred intact male lambs (28.5 ± 3.5 kg) were used in a 56-d experiment in a randomized complete block design to evaluate the effects of a standardized mixture of essential oils (EO) versus monensin sodium (MON) on growth performance, dietary energy, and carcass characteristics. Lambs were fed a corn-based finishing diet (13.8 % CP and 2.14 Mcal NE_m/kg DM) supplemented with: 1) no additive (Control), 2) 30 mg MON/lamb, and 3) 150 mg EO/lamb. Water consumption of EO and Control lambs was not different. In contrast, lambs fed MON consumed 18.1 % less ($P < 0.01$) water than Controls and EO groups. Compared to Controls, EO improved ($P < 0.05$) gain efficiency, estimated dietary net energy (NE). Compared to MON, supplemental EO increased ($P < 0.05$) dry matter intake (DMI), average daily gain (ADG) and gain efficiency, and tended ($P = 0.09$) to increase estimated dietary NE. Compared to Controls, lambs fed MON decreased DMI and ADG but without showing difference on gain efficiency and estimated dietary NE. With the exception of carcass weight (lambs fed MON had lower hot carcass weight than Control and EO), there were no treatments effects on carcass composition. Compared with Controls, EO and MON supplementation decreased relative weights (as a proportion of empty body weight) of intestine and omental fat. Compared with MON, EO decreased relative weight of mesenteric fat. We conclude that compared with Control (non-supplemented) lambs, supplemental EO enhances feed efficiency, and dietary net energy. Compared with MON, supplemental EO enhances ADG. However, effects of MON and EO on feed efficiency and dietary net energy are not appreciable different. Supplemental EO did not negatively affect carcass characteristics or visceral organ mass. As such, supplemental EO is a viable alternative to the antibiotic monensin for enhancement of feed efficiency of finishing feedlot lambs.

1. Introduction

Since approval of the antibiotic monensin (MON) in the mid-1970's, ionophore supplementation (particularly MON) in growing-finishing diets has become the conventional feeding practice in several countries, with expectation of improved gain efficiency from 8 to 12 %. Improved energetic efficiency have been attributed to changes in VFA molar ratios, decreased methane production, and decreased ruminal degradation of dietary protein (Tedeschi and Gorocica-Buenfil, 2018; da Fonseca et al., 2019). In an earlier report, Baran et al. (1986) concluded that in lambs, the effect of MON is greater in diets of lesser energy density (high roughage diets). Spires et al. (1990) observed that as the energy density of the diet increases beyond 2.00 Mcal NE_m/kg, the magnitude of improvement in gain efficiency due to MON

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supplementation starts to decrease, and no improvement in feed efficiency would be expected with ionophore supplementation of a diet containing greater than 2.23 Mcal NE_m/kg. Their prediction equation was later verified by the meta-analysis performed by Duffield et al. (2012), noting that in the last 40 years, the impact of MON on feed efficiency has decreased from 8.1 to 3.5%. This change may be explained, in part, by increases in diet energy density in current finishing diet formulations for feedlots lambs (Leite et al., 2021) and cattle (Hales, 2019; Pinto and Millen, 2019). The basis of this effect is not fully understood. A popular explanation is that as ruminal starch digestion increases, as occurs with high-cereal diets, ruminal fermentation patterns shift to direct carbon and hydrogen away from methanogenesis and toward propionate production (Wang et al., 2018). Reduced methane energy loss has been put forth as the primary basis for ionophores effects on energetic efficiency (Gibb et al., 2001). Current interests in limiting the use of conventional antibiotics as feed additives in livestock production, has led to the search for "generally-recognized-as-safe" additive alternatives. Dietary supplementation with essential oil compounds (**EO**; such thymol, limonene, eugenol, piperine, among others) has exhibited ionophore-like characteristics with antimicrobial properties that may slow the rate of ruminal starch digestion, increase ruminal propionate: acetate molar ratios, and reduce extent of ruminal feed protein degradation. (Koyunco and Canbolat, 2010; Samii et al., 2016; Meschiatti et al., 2016). Supplemental essential oils (Smeti et al., 2015; Parvar et al., 2018) and MON (Safaei et al., 2014) have both enhanced growth performance in small ruminants fed finishing diets of moderate energy density (i.e. $<$ 2.0 Mcal NE_m/kg). To our knowledge, no information is available that evaluates the comparative effects of supplemental EO vs MON in finishing lambs fed high-energy finishing diets (i.e. $>$ 2.10 Mcal NE_m/kg DM); diets in which supplemental MON has shown modest effects. The objective of this experiment was to compare the influence of supplementation with a standardized mixture of essential oils (EO) vs monensin sodium (MON) on growth performance, dietary energetic, and carcass characteristics in lambs fed a corn-based high-energy finishing diet. A non-supplemented treatment was included as a negative control.

2. Material and methods

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. During the course of the experiment, air temperature averaged 20.9 °C (minimum and maximum of 15.5 and 26.3 °C, respectively) and relative humidity averaged 71.8 % (minimum and maximum of 58.4 and 85.2 %, respectively). All animal management procedures were conducted within the guidelines of locally-approved techniques (NOM-062-ZOO-1999) for animal use and care.

2.1. *Animal, diets, and samples analyses*

Thirty-six Pelibuey × Katahdin crossbred intact male lambs (165 ± 20 d age; 28.5 ± 3.5 kg initial weight) were used in a 56-d growth-performance experiment to compare the effects of supplementation of a mixture of essential oils (EO) vs sodium monensin (MON) on growth performance, dietary energetic, and carcass characteristics in lambs fed a corn-based high-energy finishing diet. Two weeks before initiation of the experiment the lambs were treated for parasites (Albendaphorte 10 %, Animal Health and Welfare, México City, México), injected with 1×10^6 IU vitamin A (Synt-ADE®, Fort Dodge, Animal Health, México City, México), and vaccinated for *Mannheimia haemolityca* (One shot Pfizer, México City, Mexico). Upon initiation of the experiment, lambs were weighed just prior to the morning meal (electronic scale; TORREY TIL/S: 107 2691, TORREY Electronics Inc., Houston TX, USA), blocked by initial weight and assigned within blocks to 18 pens, two lambs per pen. Dietary treatments were randomly assigned to pens within blocks, resulting in 6 replicates per treatment. Pens were 6 m^2 with overhead shade, automatic waterers and 1 m fence-line feed bunks. Lambs were fed with cracked corn-based finishing diet (Table 1) and 3 treatments were tested as follows: 1) non supplemented (**Control**), 2) a daily supplementation with 30 mg MON/lamb (**MON**; Rumensin 90, Elanco Animal Health, Indianapolis, IN), and 3) daily supplementation with150 mg EO/lamb (**EO**, CRINA-Ruminants, DSM Nutritional Products, Basel, Switzerland, containing a standardized mixture of essential oils including thymol, eugenol, vanillin, guaiac, and limonene). The daily dose of 150 mg EO was estimated based on a previous report where ingestion of 100–200 mg EO/day resulted in maximal enhancements in ruminal fermentation and feed efficiency in lactating ewes (Giannenas et al., 2011). The dosage of 30 mg MON/day is the average of the recommended daily dosage for finishing lambs of 20–40 mg MON (Elanco, AF1404). Lambs were weighed just prior to the morning feeding on days 1 and 56 (final day). Live weights (LW) on days 1 was converted to shrunk body weight (SBW) by multiplying LW by 0.96 to adjust for the gastrointestinal fill (Cannas et al., 2004). Lambs were fasted for 18 h before recording the final LW. Additives were premixed with ground rice hulls (Powder mixer, JETENGE-L, Mod 2002, Guadalajara, Jalisco, Mexico) to provide the desired dosage of MON (30 mg) or EO (150 mg) in 10 g of final premix. The respective premix treatments were hand-weighed using a precision balance (Ohaus, mod AS612, Pine Brook, NJ, USA) and premixed for 5 min with minor ingredients (urea, limestone and trace mineral salt) before incorporation into complete mixed diets using a 2.5 m^3 capacity paddle mixer (model 30910-7, Coyoacán, México). To avoid contamination, the mixer was thoroughly cleaned before elaboration of each dietary treatment. To ensure additive consumption, the total daily dosage per lamb was concentrate in 300 g of diet provided in the morning feeding (all lambs were fed the basal Control diet in the afternoon feeding). Thus, lambs were provided fresh feed twice daily at 0800 and 1400 h, in which morning feed was offered constant, while afternoon feed was offered ad libitum to allowing for a feed residual of refusal of ~50 g/kg daily feed offering. Residual feed was collected between 0740 and 0750 h each morning and weighed. Adjustment to either increase or decrease daily feed delivery, was provided at the afternoon feeding. Water consumption was measured daily at 0700 h by dipping a graduated rod into the tank drinker (one watering tank for each pen). Once the measure was taken, the remaining water was drained, and the tanks were refilled with fresh water.

Feed samples were taken from each elaborated batch, while feed refusal were collected daily and composited weekly for DM analysis

Table 1
Composition of basal diet fed to lambs (DM basis).[1]

Item	% DM
Ingredient	
Corn grain cracked	64.50
Soybean meal	10.50
Sudan grass hay	10.00
Molasses cane	9.00
Yellow grease	3.50
Urea	0.40
Minerals supplement[1]	2.10
Nutrient composition (DM basis)[2]	
Net energy (Mcal/kg)	
Maintenance	2.14
Gain	1.47
Crude protein (%)	13.80
NDF (%)	15.53
Ether extract (%)	6.43

[1] Minerals supplement contained (%): $CoSO_4$, 0.068; $CuSO_4$, 1.04; $FeSO_4$, 3.57; ZnO, 1.24; $MnSO_4$, 1.07; KI, 0.052; limestone, 56.96 %; urea, 18 %, and NaCl, 18 %.

[2] Based on tabular values for individual feed ingredients (NRC, 2007) with the exception of CP and NDF, which were determined in our laboratory.

(oven drying at 105 °C until no further weight loss; method 930.15, AOAC, 2000). Feed samples 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), and NDF [Van Soest et al., 1991, corrected for NDF-ash, incorporating heat stable α-amylase (Ankom Technology, Macedon, NY).

2.2. Calculations

Estimates of daily weight gain (ADG), and dietary net energy were based on shrunk body weight (SBW; 96 % of full live weight, Cannas et al., 2004). Average daily gain was computed by subtracting initial SBW from final SBW and dividing the result by the number of days on feed. Gain efficiency was computed as ADG/ daily DMI. One approach for evaluation of the efficiency of dietary energy utilization in growth-performance trials is the ratio of observed-to-expected DMI and observed-to-expected dietary NE. Based on diet NE concentration and measures of growth performance, there is an expected energy intake. This estimation of expected DMI is performed based on observed ADG, average SBW, and NE values of the diet (Table 1): expected DMI, kg/d = $(EM/NE_m) + (EG/NE_g)$, where EM (energy required for maintenance, Mcal/d) = $0.056 \times SBW^{0.75}$, EG (energy gain, Mcal/d) = $0.276 \times ADG \times SBW^{0.75}$, and NE_m and NE_g are corresponding NE values based on the ingredient composition of the experimental diet (Table 1, NRC, 2007). The coefficient (0.276) was taken from NRC (1985) assuming a mature weight of 113 kg for Pelibuey × Katahdin male lambs (Canton and Quintal, 2007). Observed dietary net energy was calculated using EM and EG values, and DMI observed during experiment by means of the quadratic formula: $x = (-b - \sqrt{b^2 - 4ac})/2c$, where $x = NE_m$ (Mcal/kg), $a = -0.41$ EM, $b = 0.877$ EM + 0.41 DMI + EG, and $c = -0.877$ DMI (Zinn et al., 2008).

2.3. Carcass characteristics and whole cuts

All lambs were harvested on the same day and were slaughtered by disgorging after they were stunned by mechanical procedure. After slaughter, lambs were bled and skinned, the gastrointestinal organs were separated and weighed, the omental and mesenteric fat were weighed, as well hot carcass weight (HCW) was registered. After carcasses (with kidneys and internal fat included) chilled in a cooler at −2 to 1 °C for 24 h, the following measurements were obtained: 1) cold carcass weight (CCW); 2) body wall thickness (distance between the 12th and 13th ribs beyond the ribeye, five inches from the midline of the carcass); 3) subcutaneous fat (fat thickness) was taken over the 12th to 13th thoracic vertebrae; 4) LM surface area, measure using a grid reading of the cross-sectional area of the *longissimus muscle* between 12th and 13th rib, and 5) kidney, pelvic and heart fat (KPH) was removed manually and afterward weighed and reported as a percentage of the cold carcass weight (USDA, 1982). Each carcass was split into two halves. The left side 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 from the hindsaddle. Weight of each cut was subsequently recorded. The tissue composition of shoulder was assessed using physical dissection by the procedure described by Luaces et al. (2008).

2.4. Visceral mass data

Components of the digestive tract (GIT), including tongue, esophagus, stomach (rumen, reticulum, omasum, and abomasum), pancreas, liver, gall bladder, small intestine (duodenum, jejunum, and ileum), and large intestine (caecum, colon, and rectum) were removed and weighed. The GIT was then washed, drained, and weighed to get empty weights. The difference between full and washed digesta-free GIT was subtracted from the SBW to determine empty body weight (EBW). All tissue weights are reported on a fresh tissue basis. Organ mass is expressed as grams of fresh tissue per kilogram of final EBW, where final EBW represents the final full live weight 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 analyses

Growth performance (ADG, DMI, gain efficiency), estimated dietary NE and DMI, and carcass data were analyzed as a randomized complete block design, using pen as the experimental unit (SAS, 2007) according to the statistical model: $Yij = \mu + Bi + Tj + \varepsilon ij$, in which μ is the common experimental effect, Bi represents initial BW block effect (df = 5), Tj represents dietary treatment effect (df = 2), and εij represents the residual error (df = 10). Water intake was analyzed as a completely randomized design using linear mixed model for analysis of repeated measures (SAS, 2007).

Visceral organ mass data was analyzed using the MIXED procedure (SAS, 2007), with treatment and pen as fixed effects and interaction treatment × pen and individual carcasses within pen by treatment subclasses as random effects. Treatment effects were considered significant when the P-value was ≤ 0.05, and tendencies were identified when the P-value was > 0.05 and ≤ 0.10.

3. Results

Dietary additive intakes averaged 4 mg/kg LW and 0.80 mg/kg LW for EO and MON, respectively.

3.1. Growth performance and dietary energy

Water consumption between EO and Control lambs was very similar. In contrast, lambs fed MON consumed 18.1 % less ($P < 0.01$) water than Controls and EO groups (Table 2).

Average daily gain was similar for Controls and EO supplemented lambs. However, supplemental EO tended ($P = 0.09$) to decrease DMI. Consequently, gain efficiency for EO supplemented lambs was greater (4.7 %, $P < 0.05$) than that of Control lambs.

Compared to MON, EO supplementation increased ($P < 0.05$) DMI (9.3 %), ADG (13.2 %) and gain efficiency (4.7 %, $P < 0.05$). Compared to Controls, MON supplementation decreased ($P < 0.05$) DMI (11.6 %) and ADG (11.7). However, gain efficiency was not different.

Compared with Control lambs, EO supplementation increased (4 %, $P < 0.05$) estimated dietary NE. Compared with MON, supplemental EO tended (2.2 %, P = 0.09) to improve dietary NE. Compared to Controls, differences in dietary NE due to MON supplementation was not appreciable ($P = 0.18$).

3.2. Carcass characteristics and visceral mass

With exception of carcass weight and weight of the intestine and visceral fat depots expressed as g/kg EBW, treatment effects on carcass characteristics were small and not appreciable (Tables 3 and 4). Consistent with slower ADG, lambs fed MON had lower (4.6 %, $P < 0.01$) HCW than lambs receiving EO, and tended ($P = 0.08$) to have lower HCW than Control lambs. Compared with Controls, EO and MON supplementation decreased ($P < 0.05$) relative weight of intestines (3.8 %) and omental fat (9.7 %). Relative weight of visceral fat was lower to EO than Controls (9.1 %, P < 0.05). EO supplemented lambs had lower relative weight of mesenteric fat than lambs receiving MON (21.7 %, $P < 0.05$).

Table 2
Treatments effect on growth performance in finishing lambs.

	Treatments[1]				P-value		
Item	Control	MON	EO	SEM	MON vs Control	EO vs Control	EO vs MON
Live weight (kg)[2]							
Initial	28.49	28.40	28.61	0.157	0.91	0.60	0.37
Final	44.74	42.74	45.12	0.458	0.02	0.57	0.01
Water consumption (L/d)	2.55	2.10	2.58	0.032	<0.01	0.99	<0.01
Daily gain (kg)	0.290	0.256	0.295	0.008	<0.01	0.62	<0.01
Dry matter intake (kg/d)	1.190	1.052	1.160	0.027	<0.01	0.09	0.02
Gain to feed (kg/kg)	0.244	0.244	0.256	0.002	0.98	<0.01	<0.01
Observed dietary NE (Mcal/kg)							
Maintenance	2.16	2.19	2.23	0.017	0.18	<0.01	0.09
Gain	1.48	1.51	1.55	0.015	0.18	<0.01	0.09
Observed to expected dietary NE							
Maintenance	1.01	1.02	1.04	0.007	0.19	<0.01	0.09
Gain	1.01	1.03	1.05	0.010	0.19	<0.01	0.09
Observed to expected DM intake	0.99	0.97	0.95	0.009	0.19	<0.01	0.09

[1] MON = Sodium monensin fed at dose of 30 mg/lamb/day (Rumensin 90, Elanco Animal Health, Indianapolis, IN); [2] EO = a mixture of essential oils (CRINA® Ruminants, DSM Nutritional Products, Basel, Switzerland) fed a dose of 150 mg/lamb/day.

[2] Live weights (LW) on days 1 was converted to shrunk body weight (SBW) by multiplying LW by 0.96 to adjust for the gastrointestinal fill (Cannas et al., 2004). All lambs were fasted (drinking water was not withdrawn) for 18 h before recording the final LW.

Table 3
Treatments effect on carcass characteristics and whole cuts of lambs.

	Treatments[1]				P-value		
Item	Control	MON	EO	SEM	MON vs Control	EO vs Control	EO vs MON
Hot carcass weight (kg)	26.71	25.97	27.23	0.26	0.08	0.19	<0.01
Dressing percentage	59.70	60.72	60.35	0.48	0.16	0.36	0.60
Cold carcass weight (kg)	26.37	25.63	27.00	0.24	0.06	0.09	<0.01
Longissimus muscle area (cm^2)	15.90	15.51	15.77	0.16	0.12	0.57	0.28
Kidney-pelvic-heart fat (%)	3.78	4.16	3.95	0.20	0.22	0.57	0.48
Back fat thickness (cm)	2.26	2.43	2.46	0.11	0.31	0.25	0.87
Wall thickness (mm)	11.60	12.64	12.68	0.42	0.12	0.11	0.94
Leg circumference (cm)	45.08	45.46	46.42	0.83	0.76	0.28	0.42
Shoulder composition (%)							
Muscle	63.59	64.04	64.50	0.80	0.71	0.44	0.69
Fat	15.13	15.83	15.53	0.85	0.57	0.75	0.81
Muscle to fat ratio	4.20	4.05	4.15	0.16	0.55	0.89	0.66
Whole cuts (as percentage of CCW)							
Forequarter IMPS202	39.71	39.10	39.42	0.23	0.11	0.41	0.36
Hindquarter IMPS230	35.53	35.70	35.31	0.25	0.63	0.54	0.29
Shoulder IMPS206	14.15	14.11	14.15	0.14	0.83	0.98	0.86
Shoulder IMPS207	8.27	7.92	7.97	0.19	0.23	0.29	0.88
Rack IMPS204	6.55	6.63	6.48	0.18	0.76	0.79	0.58
Breast IMPS209	3.75	3.45	3.55	0.20	0.32	0.50	0.72
Loin IMPS231	6.46	6.52	6.44	0.14	0.74	0.95	0.70
Flank IMPS232	5.41	5.43	5.43	0.15	0.92	0.92	0.99
Leg IMPS233	23.66	23.69	23.38	0.22	0.93	0.37	0.33

CCW = cold carcass weight.

[1] MON = Sodium monensin fed at dose of 30 mg/lamb/day (Rumensin 90, Elanco Animal Health, Indianapolis, IN); [2] EO = a mixture of essential oils (CRINA® Ruminants, DSM Nutritional Products, Basel, Switzerland) fed ay dose of 150 mg/lamb/day.

4. Discussion

The relative average ingestion of 3.5 mg EO/kg LW (same blended oils than we used in this experiment) resulted in improved feed efficiency in lactating ewes (Giannenas et al., 2011). It has been determined that the effects of essential oils on ruminal fermentation and growth performance are dose-dependent and that these compounds are more effective when administered at high doses than at low doses (Benchaar et al., 2006; Giannenas et al., 2011). The recommended daily dose of MON for increased feed efficiency in finishing lambs are between 20 y 40 mg MON (Elanco, AF1404). Therefore, the final doses ingested in both experiments should not represent a limiting factor for the responses evaluated.

Similarly to our results, it has been reported absence of effects on water intake in finishing feedlot cattle that daily received up to 20 mg eugenol or cinnamaldehyde/kg LW (Ornaghi et al., 2017). On the other hand, reduced water consumption with MON supplementation has been previously reported in non-ruminant species (EFSA, 2008). The basis for this effect is uncertain, and appears to be unrelated to differences on DMI. Water consumption per kg DMI averaged 2.00, 2.11 and 2.22 for MON, Control, and EO treatments, respectively.

The effects of supplemental essential oils on lamb growth performance have been inconsistent. Moura et al. (2017) observed that supplementation with 500 mg copaiba essential oils/kg DM (equivalent to 370 mg/lamb/day; terpene class, primarily caryophyllene and colavenol) did not affect DMI, but markedly increased ADG (14.7 %) and gain efficiency (3.4 %) compared to a non-supplemented group. In contrast, Chaves et al. (2008) reported that supplementing a high-energy diet for growing lambs with cinnamaldehyde or carvacrol (200 mg/kg DMI) had no effect on DMI, gain, feed efficiency. Likewise, Simitzis et al. (2014) observed that cinnamon oil supplementation (1 mL/kg diet DM) did not affect lamb growth performance or meat quality characteristics. Parvar

Table 4
Treatments effect on visceral mass characteristics of lambs.

	Treatments[1]				P-value		
Item	Control	MON	EO	SEM	MON vs Control	EO vs Control	EO vs MON
EBW (percentage of full weight)	90.82	91.13	90.29	0.77	0.78	0.64	0.46
Organs (g/kg of EBW)	59.70	60.72	60.35	0.48			
Stomach complex[2]	29.23	28.96	28.52	0.58	0.75	0.36	0.88
Intestines[3]	46.53	44.06	45.06	0.44	<0.01	0.04	0.15
Heart/lungs	24.45	23.73	24.99	0.62	0.43	0.55	0.18
Liver/spleen	20.08	20.17	20.48	0.58	0.91	0.64	0.71
Kidney	2.81	2.60	2.91	0.12	0.26	0.59	0.12
Omental fat	30.87	27.45	28.32	0.75	<0.01	0.04	0.43
Mesenteric fat	7.29	8.15	6.38	0.46	0.21	0.19	0.03
Visceral fat	38.16	35.60	34.70	1.00	0.11	0.04	0.54

EBW = empty body weight.
[1] MON = Sodium monensin fed at dose of 30 mg/lamb/day (Rumensin 90, Elanco Animal Health, Indianapolis, IN); [2] EO = a mixture of essential oils (CRINA® Ruminants, DSM Nutritional Products, Basel, Switzerland) fed ay dose of 150 mg/lamb/day.
[2] Stomach complex = (rumen + reticulum + omasum + abomasum), without digesta.
[3] Small and large intestines without digesta.

et al. (2018) observed that supplementation with essential oils (250–750 mg/kg DM) from *Ferulago angulata* (containing a mixture of α-pinene and α-ocimene) decreased DMI, ADG and diet digestibility. Although supplemental essential oils may be grouped together as a class, their chemical structure and composition vary (Dhifi et al., 2016). Consequently, their effects on DMI and animal performance may likewise vary. de Souza et al. (2019), evaluating 4 distinct EO blends in heifers, observed that in comparison with non-supplemented lambs, some EO blends (eugenol + thymol + vanillin + clove) supplemented at 4 g/heifers/day, enhanced ADG and gain efficiency, whereas others (eugenol + thymol + vanillin) only affected DM intake.

At the time of writing this report, there is no published research evaluating effects of the EO (CRINA-Ruminants) on performance and feed efficiency in finishing lambs. In lactating ewes, Giannenas et al. (2011) evaluated EO (comparable blend to that of the present study) at levels of 0, 50 or 150 mg/kg of concentrate (equivalent to 100 and 200 mg EO/day). Supplementation did not affect DMI, but enhanced feed efficiency. Lin et al. (2013) observed that supplementation with 500 mg EO/d (comparable blend to that of the present study) increased ruminal propionate and decrease protein degradation without detrimental effects on nutrient digestion in cannulated sheep.

Compared with a non-supplemented high energy finishing diet, supplementation with 2–8 mg EO/kg BW (comparable blend to that of the present study) did not affect DMI, but tended to increase (4 %) feed efficiency of feedlot cattle (Meyer et al., 2009). Supplementation of a finishing diet with 6 or 12 mg EO/kg BW (comparable blend to that of the present study) likewise did not affect DMI, but markedly enhanced 16 %) feed efficiency of Nellore heifers (de Souza et al., 2019). Benchaar et al. (2006) conducted two trials evaluating EO blend (comparable to that of the present study) supplemented at 0, 4.7, or 9.4 mg EO/day. In the first trial EO did not affect DMI. Whereas, in the second trial, EO blend increased DMI.

There is no published research that directly compares effects of the supplemental EO (CRINA-Ruminant) vs MON on growth performance of finishing lambs. Ribeiro et al. (2020) compared thyme essential oil (1.25, 2.50, or 3.75 g/kg DM) vs MON (25 mg/kg DM) in cannulated lambs fed with high-energy diet. Apparent total tract digestion, N metabolism, and ruminal fermentation were similar for the two additives. In a 56-d growth-performance study involving Dorper lambs (22 kg) fed a moderately low-energy finishing diet (forage:concentrate ratio of 53:47, 1.83 Mcal NE_m/kg DM), Moura et al. (2017) observed that compared with MON, supplementation with 500 mg copaiba essential oils/kg DM (equivalent to 370 mg/lamb/day) numerically increased (11 %) DMI, but markedly enhanced ADG (19 %), and feed efficiency (10.3 %). However, they observed that EO supplementation at 1000 or 1500 mg/kg DM (equivalent to 800 and 1240 mg EO/lamb/day, respectively) depressed lamb growth performance.

Several studies have been conducted comparing the effects of supplemental EO (similar to that of the present study) vs MON and feedlot cattle growth performance. Meyer et al. (2009), observed that compared with MON, supplementation of feedlot steers with 2.5 mg EO/kg LW numerically increased ADG (2.8 %) and gain efficiency (4 %). Meschiatti et al. (2019) observed that compared with MON, supplementation of feedlot bulls with 834 mg EO/d increased DMI and ADG (6.9 and % 5.7 %, respectively), although gain efficiency was not affected. In contrast, supplementation with 4000 mg EO/day vs MON did not affect growth performance of steers and heifers fed a low-energy silage-based diet (1.50 Mcal NE_m/kg). Araujo et al. (2019) did not detect differences in 208-day growth performance of feedlot steers fed corn-silage-based growing-finishing diet supplemented with 33 mg MON/kg diet DM vs 150 mg EO/kg diet DM (mixture of carvacrol + thymol + eugenol).

In as much as supplemental EO may enhance metabolizable protein supply to the small intestine (Samii et al., 2016; Soltan et al., 2018), variation in growth performance responses to supplemental EO may be due, in part, to adequacy of the basal diet in meeting the increased metabolizable protein requirements during the initial start-up phase. Compared with MON (there were no control group in their experiment), supplementation with EO (blend comparable to that of the present study) enhancements in DMI, ADG and/or gain efficiency were most apparent during the initial 19–30 days on feed (Meschiatti et al., 2016; Acedo et al., 2018).

Observed-to-expected dietary NE and the observed-to-expect DMI ratio for the lambs fed the control diet was 0.99 (DMI was consistent with expectations based on observed ADG and formulated NE value of the diet, Table 1). This close agreement is supportive of the practicality of prediction equations for the estimation of DMI in relation to SBW and ADG in feedlot lambs. A dietary NE ratio (observed-to-expected dietary NE) of 1.0 is indicative that daily weight gain was consistent with observed DMI and tabular NE value of the diet (NRC, 2007). If the ratio is greater than 1, the observed dietary NE (estimated dietary NE based on growth-performance) is greater than expected based on growth performance and diet formulation, indicative of enhanced metabolizable energy utilization for maintenance and gain (the reverse being the case when the ratio is less than 1). As stated above, compared with Control lambs, EO supplementation enhanced (4 %, $P < 0.05$) estimated dietary NE, and compared with MON, supplemental EO tended (2.2 %, $P = 0.09$) to enhance dietary NE. The basis for improved dietary energy utilization for growth due to supplemental EO is not clear, but could due to effects of supplemental EO toward decreased ruminal acetate:propionate molar ratio, and enhanced N and starch utilization (Lin et al., 2013; Khiaosa and Zabelli, 2013; Samii et al., 2016; Meschiatti et al., 2016). Accordingly the time length of the trial could affect the overall responses to EO supplementation. To our knowledge no information is available regarding the interaction of level and duration of EO supplementation in lamb performance, although as stated previously, the response to EO supplementation appears more pronounced during the early phase of supplementation (Meschiatti et al., 2016; Acedo et al., 2018).

Decreased on DMI and enhanced gain efficiency of feedlot cattle as a result of MON supplementation is well-documented (Duffield et al., 2012). Decreases on DMI in cattle fed MON has been attributed to taste preference (Erickson et al., 2004). Decrease in ADG observed in lambs fed MON is more directly related to decrease in DMI. The effect of supplemental MON on gain efficiency in feedlot cattle has been variable, ranging from nil to greater than 18 % (Barreras et al., 2013). In a meta-analysis, Duffield et al. (2012) observed that, during the past 40 years, the impact of MON on gain efficiency decreased from an average of 8.1–3.5 %. This change may be attributable to increases in NE value of the finishing diet. Accordingly, the effect of MON was optimal at energy levels under 1.37 Mcal NE_g/kg diet DM, becoming negligible at dietary energy densities of $\geq$ 1.55 Mcal NE_g/kg (Barreras et al., 2013). Considering the observed NE_g of the basal diet (1.48 Mcal NE_g/kg; Table 2), less appreciable gain efficiency response to supplemental was expected.

Lack of treatment effects on carcass cutout and tissue composition is consistent with previous studies (Salinas-Chavira et al., 2010; Koyunco and Canbolat, 2010; Moura et al., 2017; Parvar et al., 2018). The lower HCW observed to lambs fed MON is consistent with the decrease ADG resulted in lower final weight.

Increased FT with essential oils supplementation has been reported in lambs fed diets of moderate energy density (Soares et al., 2012; Moura et al., 2017). However, supplemental essential oils has not affected FT in feedlot lambs fed high-energy diets (Chaves et al., 2008; Biricik et al., 2016). Likewise, supplemental MON did not affect FT in either, Pelibuey lambs (Salinas-Chavira et al., 2005; daili ingestion of 22 mg MON) or Pelibuey x Dorper crossbreed (Salinas-Chavira et al., 2010; daily ingestion of 28 mg MON).

Both MON and EO supplementation decreased the proportion of intestine as a percentage of EBW. The basis for this is not certain, but may be attributable to antibiotic-like effects on epithelial thickness (Ghazanfari et al., 2015). The effects of supplemental EO on fat distribution among depots is uncertain. It has been proposed that supplemental EO may have potential as an energy "repartitioning" agent, affecting net fat deposition and distribution (Kuester, 2016).This can partially explained the changes promote in meat quality of lambs by EO supplementation (Parvar et al., 2018; García-Galicia et al., 2020). To the extent that EO reduces ruminal acetate:propionate ratio (Meyer et al., 2009; Koyunco and Canbolat, 2010; Wanapat et al., 2013), the associated increase in propionate production lends to decreased visceral fat deposition (Smith and Crouse, 1984).

5. Conclusions

We conclude that compared with Control (non-supplemented) lambs, supplemental EO (blend of thymol, eugenol, vanillin, guaiac, and limonene) enhances feed efficiency, and dietary net energy. Compared with MON, supplemental EO enhances ADG. However, effects of MON and EO on feed efficiency and dietary net energy are not appreciable different. Supplemental EO did not negatively affect carcass characteristics or visceral organ mass. As such, supplemental EO is a viable alternative to the antibiotic monensin for enhancement of feed efficiency of finishing feedlot lambs.

Declaration of Competing Interest

Author declare no conflict of interest.

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