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ARTICLE

Effect of dietary inclusion of safflower meal on ruminal fermentation, growth performance, carcass characteristics, and meat quality of lambs

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Abstract: This study examines the effect of including graded levels of safflower meal (SM) [0 (SM0), 150 (SM15), or 200 g kg^{-1} dry matter (SM20)] in diets of Katahdin–Pelibuey lambs on ruminal fermentation, growth performance, and meat quality. Experimental diets were randomly allocated to 24 lambs (29.25 ± 0.55 kg) in a 60 d feeding trial. On day 30, rumen fluid was collected from each sheep at 0, 3, and 6 h after morning feeding to measure pH, ammonia, and volatile fatty acids. Feed intake, nutrient digestibility, growth performance, carcass characteristics, and meat quality were also measured. Feed intake, ruminal volatile fatty acids concentration, dry matter, and crude protein digestibility were not affected ($P > 0.05$) by diets. Lambs fed on SM15 had higher ($P < 0.05$) ruminal pH at 3 and 6 h post feeding compared with those on SM0 and SM20. Inclusion of SM increased ($P < 0.05$) ruminal ammonia concentration at 3 and 6 h post feeding; however, daily gain decreased with increasing levels of SM. Diets did not affect ($P > 0.05$) carcass and meat quality traits. Feeding SM-containing diets resulted in similar feed utilization, carcass characteristics, and meat quality to the control diet while improving ruminal fermentation parameters.

Key words: sheep, carcass characteristics, growth performance, meat quality, ruminal fermentation, safflower meal.

Résumé : Cette étude évaluait les effets d'inclure différents niveaux de tourteau de carthame (SM – « safflower meal ») [0 (SM0), 150 (SM15) ou 200 g kg^{-1} matières sèches (SM20)] dans les diètes des agneaux Katahdin–Pelibuey sur la fermentation dans le rumen, la performance de croissance et la qualité de viande. Les diètes expérimentales ont été assignées aléatoirement à 24 agneaux (29,25 ± 0,55 kg) dans une étude d'alimentation de 60 j. Au jour 30, le liquide du rumen a été collecté à partir de chaque animal 0, 3 et 6 h après le repas du matin pour mesurer le pH, l'ammoniac et les acides gras volatils. La consommation, la digestibilité des éléments nutritifs, la performance de croissance, les caractéristiques de la carcasse et la qualité de viande ont aussi été mesurées. Il n'y a pas eu d'effet ($P > 0,05$) des diètes sur la consommation, la concentration d'acides gras volatils dans le rumen, la digestibilité des matières sèches et des protéines brutes. Les agneaux ayant reçu les diètes SM15 avaient un plus grand ($P < 0,05$) pH ruminal à 3 et 6 h après le repas par rapport aux animaux ayant reçu les diètes SM0 et SM20. L'ajout de SM a augmenté ($P < 0,05$) la concentration d'ammoniac dans le rumen à 3 et 6 h après le repas. Par contre, le gain quotidien a diminué avec les niveaux plus élevés de SM. Les diètes n'ont pas eu d'effet ($P > 0,05$) sur les caractéristiques de carcasse et de qualité de viande. Nourrir les animaux des diètes contenant du SM se soldait par une utilisation d'aliments, des caractéristiques de carcasse et une qualité de viande similaires à la diète témoin tout en améliorant les paramètres de fermentation du rumen. [Traduit par la Rédaction]

Mots-clés : mouton, caractéristiques de carcasse, performance de croissance, qualité de viande, fermentation dans le rumen, tourteau de carthame.

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Introduction

Feed accounts for about 60%–70% of costs in animal production. The most expensive feed ingredients are protein sources such as soybean meal due to low availability and high demand. There is, therefore, a need to identify and evaluate readily available, inexpensive, alternative protein sources of good quality for ruminants (Tufarelli et al. 2013). One of such alternative is safflower meal (SM), which has been evaluated for some livestock species. Safflower (*Carthamus tinctorius* L.) is primarily cultivated for its oil, with Mexico being one of the biggest producers in the world (3855 tons of seeds annually) (FAO 2016). The quality of the meal, a byproduct of oil extraction, varies greatly depending on the amount of hulls and residual oil. Its protein content varies between 20% and 25% in undecorticated seeds but can rise up to 40% in decorticated seeds. The fiber content varies between 40% in undecorticated meals and 10% in decorticated meals (Kohler et al. 1966).

Safflower meal can be incorporated in ruminant diets as a source of protein to replace conventional protein sources (Kohler et al. 1966). The high ether extract content in SM may increase the metabolic energy content of feed (Malakian et al. 2011). High levels of SM in ruminant diets have been reported to reduce animal performance (Walker 2006). However, in lambs fed hay-based diets, SM inclusion up to 250 g kg^{-1} dry matter (DM) improved feed intake, nutrient digestibility, feed efficiency, and body weight (BW) gain (Dessie et al. 2010). In addition, Dixon et al. (2003) also observed that when lambs on low quality grass hay or straw-based diets were offered supplementary SM, they had higher live weight gains compared with barley or urea supplements. It was, therefore, hypothesized that including safflower in the diets of male Katahdin–Pelibuey lambs would improve their rumen fermentation, growth performance, carcass characteristics, and meat quality.

Materials and Methods

Study site and animal care

The field experiment was conducted at the sheep production experimental unit of the National Center of Disciplinary Research in Physiology and Animal Improvement (CENIDFyMA), National Forest Research Institute, Agriculture, and Livestock (INIFAP), Ajuchitlán, Queretaro, Mexico. All procedures used for handling animals during the experimental period were according to the official Mexican standards of animal care (NOM-051-ZOO-1995).

Animals, housing and feeding

Twenty-four Katahdin–Pelibuey lambs (29.25 ± 0.55 kg initial BW) were individually housed in 1.5 m^2 pens with free access to water and randomly allocated to three experimental diets in a 60 d feeding trial. Each lamb was considered as an experimental unit. At the beginning of the experiment, lambs received Ivermectin (Ivomec®-F-1 1 mL 50 kg^{-1} BW, subcutaneous), bacterin (Covexin® 10 mL $animal^{-1}$; intramuscular), and vitamins A, D, and E (Vigantol® ADE 1 mL $animal^{-1}$, intramuscular). The three experimental diets were formulated by including graded levels of SM [0 g (SM0), 150 g (SM15), and 200 g kg^{-1} DM (SM20)] in a conventional sheep fattening diet in which the major protein source was soybean meal. The diets (Table 1) were formulated to meet the nutrient requirements of sheep according to NRC (2007) recommendations. Adjustments were made to the quantity of diets offered to ensure collection of orts. The first 15 d were considered as an adaptation period. Lambs were fed twice daily in two equal portions at 0700 and 1600. During the collection period, the amount of feed offered was recorded and orts collected and weighed for determination of daily feed intake by difference. Feed and orts samples were collected daily, bulked weekly, dried at 60 °C to constant weight and stored pending chemical analysis. A digestibility experiment was carried out to determine DM and crude protein (CP) digestibility by total fecal collection from day 45 to day 50 of the feeding trial. Feces were collected twice daily from each lamb at 0600 and 1500, according to the methodology proposed by Stock et al. (1987) and stored at −10 °C. A subsample of about 100 g kg^{-1} of the total feces collected from each lamb was taken daily and bulked before being dried, milled, and chemically analyzed.

Table 1. Ingredients and chemical composition [g kg^{-1} dry matter (DM)] of experimental diets fed to lambs.

	Diets[a]		
Items	SM0	SM15	SM20
Ingredients			
Safflower meal	0	150	200
Rolled corn grain	340	205	185
Ground sorghum grain	270	200	180
Soybean meal	130	70	40
Ground oat hay	100	100	100
Ground alfalfa hay	100	180	200
Molasses	30	60	60
Urea	10	15	15
Minerals and vitamins mixture[b]	20	20	20
Chemical composition			
Dry matter	983	982	985
Organic matter	993	992	991
Crude protein	191	193	195
Neutral detergent fiber	196	274	314
Acid detergent fiber	99	157	186

[a]Diets: Safflower meal added to lamb diets at 0 (SM0), 150 (SM15), and 200 g kg^{-1} DM (SM20).

[b]Minerals and vitamins mixture composed of 15 g phosphorus, 194 g calcium, 1 g magnesium, 68 g sodium, 10 g sulfur, 5.71 mg copper, 330.39 mg manganese, 208.47 mg zinc, 143.39 mg iron, and 0.04 mg selenium.

Chemical analysis

Dried feed, feed orts, and fecal samples were ground to pass through a 1 mm screen using a Wiley mill

(Arthur H. Thomas, Philadelphia, PA, USA) and analyzed for DM, nitrogen, and acid detergent fiber (No. 973·18) according to AOAC (1997), whereas neutral detergent fiber (NDF) was analyzed according to Van Soest et al. (1991).

Ruminal fermentation parameters

Rumen fluid was collected on day 30 of the experiment using an esophageal probe from the ventral sac of each sheep at 0, 3, and 6 h after morning feeding. The rumen fluid samples (approximately 50 mL per lamb) were filtered immediately through four layers of cheesecloth, strained and stored in 45 mL glass bottles. Ruminal fluid pH was then determined using a portable pH meter (Orion, model SA 210, USA). A 5 mL subsample of rumen fluid was acidified with 5 mL of 0.2 mol L^{-1} hydrochloric acid for ammonia determination using an ultraviolet light spectrophotometer (VARIAN CARY 1-E, CA, USA) set at 630 nm wavelength according to McCullough (1967). For volatile fatty acids (VFA) analysis, a 4 mL subsample of rumen fluid was mixed with 1 mL metaphosphoric acid (250 g L^{-1}) in a test tube and stored at –18 °C. Concentration of acetic, propionic, and butyric acids in rumen fluid was measured by gas–liquid chromatography (Hewlett Packard, Little Falls, DE, USA) using a capillary column (30 m length, 0·32 mm i.d., 0·25 mm film thickness; Elite-FFAP, Perkin Elmer Instruments, Shelton, WA, USA) according to Erwin et al. (1961). The injector temperature was set at 240 °C, flame ionization detector at 250 °C, and oven at 140 °C with hydrogen gas and air flows at 40 and 400 mL min^{-1}, respectively.

Growth performance

Daily weight gain of lambs was calculated by weighing animals at the beginning of the experiment and then weekly thereafter. The lambs were weighed before morning feeding at 0700 using a digital scale (Dibatec®, Acero, Mexico City, Mexico). Feed conversion ratio was calculated as a ratio of daily intake to daily weight gain.

Carcass characteristics

At the end of experiment, lambs were slaughtered, gutted, and skinned to determine hot carcass weight. The carcasses were then kept in a refrigeration chamber at 4 °C for 24 h before recording cold carcass weight. Cold carcass yield was determined as a ratio of cold carcass weight to slaughter weight. The cold carcass was suspended from the hocks, 12 cm apart, to allow for morphometric measurements using a tape-measure. The croup perimeter was measured at the level of the trochanters of both femurs, whereas the thorax perimeter was measured as the circumference at the existing maximum amplitude between the ribs. Using a zoometric stick, the croup width was measured as the maximum distance between the trochanter of both femurs, whereas the anterior thorax width was measured as the existing maximum amplitude between the ribs. The posterior thorax width was measured as the existing minimum amplitude between the ribs.

Subsequently, the carcass was divided longitudinally along the spine. Meat samples were obtained from the middle of the left carcass. The internal carcass length was measured as the maximum distance between the leading edge of the ischio-pubic symphysis and the edge of the first rib at its midpoint. Leg length was measured as the distance between the flow point of the perineum and the most distal point of the medial edge of the articular surface tarso-metatarsal. Thorax depth was measured as the maximum distance between the sternum and the back of the channel in the sixth thoracic vertebra.

After the morphological measurements of the carcass, a cut was made from the space between the 5th and 6th rib to the space between the 12th and 13th rib. Measurements were made on the *Longissimus dorsi* muscle with a ruler directly on the muscle surface space between the 12th and 13th rib. Muscle outline was drawn on an acetate paper with a fine-point pen, and then the surface was measured along the line with a digital planimeter (TAMAYA TECHNICS INC®, Planix 6, Tokyo, Japan).

Meat quality

Meat pH and muscle temperature were measured with a portable potentiometer (Hanna Instruments® HI 99163 Meat pH/temperature meter, Italy) with a penetrating electrode. The measurements were taken 24 h after slaughter on the *Longissimus dorsi* muscle between the 5th and 6th lumbar vertebra. An incision was made in the muscle, and the electrode was introduced at about 4 cm depth.

Color of muscle was measured 24 h post mortem at the *Longissimus dorsi* between the 6th and 7th rib. Meat was exposed to air for 30 min, and then color was measured using a spectrocolorimeter (MiniScan EZ® 4500L, HunterLab, Virginia, USA). Color of perirenal fat was also determined 24 h post mortem on the *Longissimus dors*i, by placing the spectrocolorimeter in the perirenal fat. Water-holding capacity (WHC) was determined by weighing 0.3 g of meat, which was placed on a filter paper (No. 54, 110 mm in diameter, Whatman) previously weighed and folded in half. The filter paper was placed between two glass plates, and the meat was subjected to compression with a weight of 2.25 kg for 5 min. Thereafter, the meat and filter paper were weighed, and WHC was calculated according to the formula proposed by Cañeque and Sañudo (2000). Protein and fat content of meat were determined according to AOAC (1997).

Statistical analysis

Statistical analyses were performed using PROC MIXED of SAS (2004). Data were analyzed using a completely randomized design and the model contained "lamb in treatment" as a random effect and "dietary treatment" as a

Table 2. Feed intake, nutrient digestibility, and rumen fluid parameters in lambs fed diets containing graded levels of safflower meal ($n = 8$ lambs per dietary treatment).

	Diets[a]				*P* value		
Parameters	SM0	SM15	SM20	SEM	SM0 vs. other	Linear	Quadratic
DMI (kg d^{-1})	1.59	1.53	1.75	0.077	0.125	0.156	0.148
DMD (g kg^{-1} DM)	655	648	639	18.8	0.836	0.556	0.978
CPD (g kg^{-1} DM)	638	670	667	17.0	0.391	0.260	0.413
Ruminal pH							
0 h	6.86	7.11	7.08	0.088	0.138	0.099	0.229
3 h	6.25	6.54	6.40	0.061	0.012	0.099	0.009
6 h	6.13	6.49	6.40	0.080	0.019	0.034	0.037
Ruminal ammonia (g L^{-1})							
0 h	5.67	9.77	9.74	1.104	0.020	0.014	0.123
3 h	5.85	16.60	25.58	3.125	0.001	0.001	0.821
6 h	7.12	15.32	26.53	2.213	<0.001	<0.001	0.589

Note: DM, dry matter; DMI, dry matter intake; DMD, dry matter digestibility; CPD, crude protein digestibility; SEM, standard error of the mean.

[a]Diets: Safflower meal added to lamb diets at 0 (SM0), 150 (SM15), and 200 g kg^{-1} DM (SM20).

fixed effect. Each lamb was the experimental unit, and all analyses were run according to the following model: $Y_{ij} = \mu + T_i + E_{ij}$, where Y_{ij} is every observation of the jth lamb assigned to ith treatment, μ is the overall mean, T_i is the dietary treatment effect, and E_{ij} is the residual error. To separate least square means, the probability of difference option was used. For all statistical tests, significance was declared at $P \leq 0.05$. The Tukey's test was used for the multiple comparisons of means, and polynomial (linear and quadratic) contrasts were used to examine the responses to increasing levels of SM in the diets.

Results

Feed intake, ruminal fermentation, and nutrient digestibility

Feed intake and the digestibility of DM and CP were not affected ($P > 0.05$) by experimental diets (Table 2). Feeding diets containing SM did not affect ($P > 0.05$) ruminal fluid pH soon after (0 h) feeding but higher pH was recorded when measured 3 ($P = 0.012$) and 6 h ($P = 0.019$) after feeding, with the highest value (quadratic effect, $P < 0.05$) being recorded for SM15 (Table 2). Ruminal ammonia concentration was higher ($P \leq 0.02$) for SM-containing diets compared with the control diet soon after feeding. Increasing the level of dietary SM linearly increased ($P \leq 0.001$) ammonia concentration at 3 and 6 h post feeding.

Safflower meal did not affect ($P > 0.05$) the concentration of total short-chain fatty acids, acetate, and propionate at 0, 3, and 6 h after feeding (Table 3). However, SM inclusion linearly ($P = 0.004$) decreased the concentration of butyrate 6 h after feeding ($P = 0.016$), but did not affect ($P > 0.05$) its concentration at 0 and 3 h after feeding. The proportion of ruminal acetate was higher in sheep fed with SM20, at 0 ($P = 0.044$) and 6 h ($P = 0.042$) after feeding, compared with those on the control diet.

Performance and carcass characteristics of lambs

There was a linear decrease ($P = 0.01$) in average daily gain as the level of SM increased (Table 4). Feed utilization expressed as feed conversion ratio also decreased linearly ($P < 0.05$) with increasing level of SM in experimental diets. Carcass characteristics and morphometry of lambs were not affected ($P > 0.05$) by diets.

Meat quality

Diets had no effect ($P > 0.05$) on carcass pH, carcass temperature, and color values [L^* (lightness), a^* (redness), and b^* (yellowness) of muscle and perirenal fat], but sheep on SM20 diet had a smaller ($P = 0.003$) diameter of *Longissimus dorsi* muscle (Table 5). However, diet did not affect ($P > 0.05$) the large diameter of *Longissimus dorsi* muscle. In addition, diets did not affect ($P > 0.05$) the dorsal fat depot area, cutlet area, WHC, shear strength, as well as protein and fat content of meat.

Discussion

Feed intake and nutrient digestibility

Although SM is slightly bitter and less palatable compared with other common protein sources, its inclusion in diets of lambs did not affect feed intake. Feed intake depends on factors such as palatability, concentration fiber fractions, and ruminal fermentation of fiber (Smith 1996). Thus, the level of SM inclusion in the diet is an important factor that may affect intake. In this study, lambs were fed SM at 150 and 200 g kg^{-1} of DM, which may have been low enough not to affect palatability, and thus, voluntary feed intake. This is in agreement with the findings of Kott et al. (2003) who also reported that the inclusion of SM at 150 g kg^{-1} DM in the diet of lambs had no effect on daily feed intake. Similarly, SM was found to be palatable in cows (Smith 1996). Tufarelli et al. (2013) also observed no reduction in feed

Table 3. Total short chain fatty acids (SCFA, mmol L^{-1}) and individual volatile fatty acids (mmol 100 $mmol^{-1}$ of SCFA) in rumen fluid from lambs fed diets containing graded levels of safflower meal ($n = 8$ lambs per dietary treatment).

	Diets[a]				*P* value		
Acids	SM0	SM15	SM20	SEM	SM0 vs. other	Linear	Quadratic
Total SCFA							
0 h	52.0	50.7	52.2	3.50	0.946	0.968	0.744
3 h	62.7	62.2	73.5	5.16	0.245	0.168	0.362
6 h	81.4	74.7	74.3	4.95	0.561	0.339	0.610
Acetate							
0 h	60.5	60.5	65.0	1.44	0.061	0.044	0.221
3 h	55.7	60.0	59.3	1.27	0.067	0.063	0.125
6 h	54.7	57.1	59.6	1.54	0.120	0.042	0.991
Propionate							
0 h	20.2	20.5	19.3	1.96	0.899	0.739	0.765
3 h	26.3	25.4	24.9	1.34	0.732	0.437	0.919
6 h	25.1	25.4	26.7	2.09	0.851	0.606	0.841
Butyrate							
0 h	19.3	19.0	15.7	1.66	0.272	0.158	0.470
3 h	18.0	14.6	15.8	1.73	0.401	0.392	0.282
6 h	20.2	17.5	13.7	2.86	0.269	0.113	0.871

Note: SEM, standard error of the mean.
[a]Diets: Safflower meal added to lamb diets at 0 (SM0), 150 (SM15), and 200 g kg^{-1} DM (SM20).

Table 4. Performance and carcass characteristics of lambs fed diets containing graded levels of safflower meal ($n = 8$ lambs per dietary treatment).

	Diets[a]				*P* value		
Parameters	SM0	SM15	SM20	SEM	SM0 vs. other	Linear	Quadratic
Performance							
Initial weight (kg)	29.7	29.2	30.1	2.22	0.931	0.721	0.925
Final weight (kg)	48.2	45.1	45.7	2.08	0.555	0.409	0.467
Average daily gain (kg d^{-1})	0.31	0.27	0.26	0.013	0.017	0.010	0.157
Feed conversion	5.21	5.76	6.74	0.436	0.011	0.003	0.818
Carcass characteristics							
Slaughter weight (kg)	50.8	49.0	47.8	1.45	0.323	0.138	0.868
Cold carcass weight (kg)	25.3	24.6	23.8	0.84	0.482	0.235	0.942
Cold carcass yield (%)	49.8	50.2	49.7	0.61	0.859	0.944	0.591
Backbone weight (g)	788	838	838	757	0.148	0.463	0.075
Croup perimeter (cm)	66.0	65.3	64.7	0.84	0.573	0.298	0.929
Croup width (cm)	18.8	20.0	19.1	0.48	0.217	0.632	0.092
Thorax perimeter (cm)	79.1	78.3	79.4	1.11	0.789	0.854	0.517
Anterior thorax width (cm)	23.9	22.8	23.2	0.53	0.417	0.400	0.295
Posterior thorax width (cm)	18.4	17.6	17.9	0.48	0.523	0.489	0.356
Internal carcass length (cm)	58.9	56.5	59.8	1.20	0.161	0.593	0.071
Leg length (cm)	43.4	42.8	42.9	0.63	0.829	0.653	0.672
Thorax depth (cm)	17.6	18.2	18.3	0.47	0.603	0.345	0.724

Note: SEM, standard error of the mean.
[a]Diets: Safflower meal added to lamb diets at 0 (SM0), 150 (SM15), and 200 g kg^{-1} DM (SM20).

intake when SM was included in place of corn, soybean meal, and wheat bran in lamb diets.

Similar DM and CP digestibility between the control and SM groups shows that SM can be included up to 200 g kg^{-1} DM in the diets of lambs without impairing feed digestion. Although fiber increased with increasing SM level, the fact that this did not depress feed digestibility and intake suggests that fiber content was not high enough to affect these parameters in lambs. Indeed, Meissner and Paulsmeier (1995) identified 600 g NDF kg^{-1}

Table 5. Meat quality traits in lambs fed diets containing graded levels of safflower meal ($n = 8$ lambs per dietary treatment).

	Diets[a]				*P* value		
Traits	SM0	SM15	SM20	SEM	SM0 vs. other	Linear	Quadratic
Carcass pH	5.67	5.60	5.62	0.05	0.584	0.439	0.477
Carcass temperature (°C)	13.4	14.8	12.7	0.73	0.162	0.562	0.074
L^* muscle	39.7	40.5	40.5	0.74	0.687	0.462	0.636
a^* muscle	22.2	22.2	22.5	0.31	0.816	0.613	0.722
b^* muscle	11.1	11.5	11.7	0.36	0.585	0.319	0.781
L^* perirenal fat	75.7	79.3	78.9	1.62	0.292	0.200	0.338
a^* perirenal fat	11.5	10.0	10.7	0.72	0.379	0.474	0.224
b^* perirenal fat	14.4	13.1	13.2	0.77	0.444	0.299	0.440
Large diameter of *Longissimus dorsi* (cm)	6.41	6.55	6.20	0.17	0.345	0.389	0.253
Smaller diameter of *Longissimus dorsi* (cm)	3.61	3.61	3.03	0.12	0.003	0.003	0.058
Dorsal fat depot area (cm)	3.36	4.00	2.88	0.41	0.180	0.434	0.099
Cutlet area (cm)	16.9	18.0	16.5	0.61	0.240	0.692	0.107
Water-holding capacity (%)	19.3	18.4	18.8	0.37	0.301	0.436	0.172
Shear strength (kg cm^{-2})	3.39	3.36	3.28	0.18	0.898	0.661	0.904
Shear strength (20%)	0.89	0.97	1.06	0.07	0.307	0.131	0.916
Shear strength (80%)	3.52	3.70	3.99	0.24	0.397	0.186	0.857
Shear strength (100%)	4.41	4.67	5.05	0.30	0.364	0.165	0.871
Total meat protein (%)	20.9	21.2	21.3	0.28	0.673	0.421	0.697
Total meat fat (%)	3.93	4.03	4.17	0.304	0.866	0.600	0.963

Note: L^*, lightness; a^*, redness; b^*, yellowness; SEM, standard error of the mean.
[a]Diets: Safflower meal added to lamb diets at 0 (SM0), 150 (SM15), and 200 g kg^{-1} DM (SM20).

DM as the threshold level at which fiber depresses feed intake and digestibility. None of the two SM-containing diets had NDF level close to this threshold.

Ruminal fermentation

Higher ruminal pH was observed in lambs offered SM-containing diets. The ruminal pH ranged between 6.13 and 7.11, which is considered acceptable for fiber digestion (Ørskov and Ryle 1990). Increased ruminal pH may be related to the increased fiber levels associated with higher inclusion levels of SM. Increasing dietary fiber level has been reported to increase ruminal pH due to slowing down of the rate of fermentation and increased chewing time and salivation rate (Olafadehan and Adebayo 2016).

Though the digestibility of CP was not affected, ruminal ammonia concentration increased with SM inclusion in lamb diets. The result suggests that SM protein is inherently highly degradable, in agreement with the findings of Olafadehan et al. (2016) who reported increased ruminal ammonical nitrogen (NH_3-N) and attributed that to rapid dietary protein degradation. In this study, ruminal ammonia concentration ranged between 5.67 and 26.53 g L^{-1}, which were above the 5 g ammonia L^{-1} considered to be sufficient for microbial protein synthesis. The concentration of ruminal ammonia depends on the balance between the rate of ammonia release in the rumen and its rate of uptake by ruminal microflora for microbial protein synthesis. Therefore, if bacterial population decreases, the usage of ammonia is reduced resulting in higher accumulation in the rumen. The linoleic acid in the SM may have reduced the bacterial population in the rumen (Oguz et al. 2014) causing the accumulation of ruminal ammonia in the rumen. The higher ruminal pH in lambs fed SM diets may be another cause of the increased NH_3-N as reported by Olafadehan and Adebayo (2016).

Feeding SM did not affect total and individual VFA; however, the ruminal acetate proportion was higher in SM20-fed lambs, which could be due to relatively higher fiber concentration of the diet. Elghandour et al. (2016) showed that increasing the level and digestibility of fiber is associated with higher ruminal acetate concentration. In addition, Lu et al. (2010) reported that increasing dietary fiber level within acceptable range in the diet enhances cellulolytic activity in the rumen and increases salivation during eating and ruminating.

Performance, carcass characteristics, and meat quality of lambs

The lower average daily gains observed in lambs fed SM-containing diets may be due to reduced feed conversion efficiency. Higher fiber levels in SM-containing diets may have reduced the density of the diet resulting in lower passage rates and, consequently, reduced average daily gains (Malakian et al. 2011). Kott et al. (2003) observed no differences in final BW of Rambouillet ram lambs fed a diet supplemented with safflower seed at 162 g kg^{-1} DM.

In this study, inclusion of SM in diets of lambs did not influence slaughter weight, cold carcass weight, cold carcass yield, backbone weight, croup perimeter, and all

other carcass parameters investigated. Kott et al. (2003) included SM in the diet of lambs at 150 g kg^{-1} DM and noted that dressing percent, *Longissimus dorsi* muscle area, and kidney fat weight were not affected, but the fat content of muscle tissue was high. Moreover, Ragni et al. (2015) showed that inclusion of SM in the diet of kids at 200 g kg^{-1} DM did not affect cold carcass dressing percentage.

Carcass pH, carcass temperature, color indexes, characteristics of *Longissimus dorsi* muscle, WHC, shear strength, and total protein and fat were not affected by the inclusion of SM in the diets of lambs. Carcass pH affects meat characteristics such as color, shelf life, taste, microbiological stability, yield, and texture (Devine et al. 1998). Carcass pH ranged between 5.60 and 5.67, which was within the range reported by Devine et al. (1998), who explained that pH value of meat should not exceed 5.8 because higher pH values are the cause of dark meat, which is undesirable. Ragni et al. (2015) showed that including SM at 200 g kg^{-1} DM in the diet of kids did not affect the pH of *Longissimus lumborum* and semimembranosus muscles at slaughter.

Meat color parameters including L^*, a^*, and b^* were unaffected by the inclusion of SM in the diets of lambs. Ragni et al. (2015) showed that including SM in the diet of kids at 200 g kg^{-1} DM increased the lightness of meat, whereas the other two color indices were unchanged. The values of color indices in this study are similar to the findings of Marichal et al. (2003) and Jambrenghi et al. (2007). The shear force, a good indicator of the quality of meat, ranged between 3.28 and 3.39 kg cm^{-2} showing that meat quality was not reduced by the dietary inclusion of SM. In contrast to our findings, Ragni et al. (2015) reported that dietary inclusion of SM increased peak shear force of muscle of kids. Protein and fat content of meat were unaffected by feeding SM-containing diets, in agreement with an earlier report (Tufarelli et al. 2013). In this study, meat fat content ranged from 3.93 to 4.17 g 100 g^{-1}, which is slightly lower than the fat content (5.25 g 100 g^{-1}) of muscle tissue from a typical feedlot lamb in the USA sheep industry.

Conclusion

Under the current experimental conditions, inclusion of SM in the diets of male Katahdin–Pelibuey lambs at 150 and 200 g kg^{-1} DM did not affect feed intake, nutrient digestibility, carcass characteristics, and meat quality. However, SM diets increased ruminal ammonia concentration and pH but decreased average daily gain. It can be concluded that SM can be used as a protein source in lamb diets without negatively affecting feed intake, carcass characteristics, and meat quality.

Conflict of Interest

The authors declare that there is no conflict of interest relating to this publication.

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