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Production efficiency and milk composition of Murciano-Granadina dairy goats fed with treated sesame meal instead of soybean meal at different levels of dietary crude protein

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Abstract This study examined the impact of replacing soybean meal (SBM) for treated and untreated sesame meal (SM) with varying amounts of crude protein (CP) on nutrient intake and digestibility, milk composition, and ruminal parameters in lactating goats. Forty mid-lactation Murciano-Granadina goats were randomly allocated to four diets including (1) SBM (16.5% CP; CON); (2) untreated SM (USM; 16.5% CP). (3) formaldehyde-treated SM (FTSM; 16.5% CP), and (4) FTSM containing 14.5% CP (LPFT). FTSM goats had higher dry matter (DM) and nutrient intake than CON and LPFT, as observed for milk fat ($P<0.001$) and total solids (TS; $P=0.001$) yield. Milk fat content was higher with USM than LPFT ($P<0.05$). In general, the sum of milk saturated fatty acids (SFA) decreased, and milk unsaturated FA (UFA), monounsaturated FA (MUFA), polyunsaturated FA (PUFA), and long-chain FA (LCFA) increased by the inclusion of USM, and FTSM in the diet. Incorporation of FTSM in the diet decreased ruminal pH, ammonia nitrogen, and acetate molar proportion compared to CON and USM as observed with LPFT. Also, this inclusion increased total volatile FAs production and propionate proportion compared to CON and USM ($P<0.001$). In conclusion, substitution of SBM for FTSM in the diet of dairy goats can improve milk and milk component yield as well as health-promoting alterations in milk FAs profile. Furthermore, reducing dietary CP level along with FTSM inclusion in the diet may be considered as a proper tool in compensating the adverse effects of dietary CP deficiency and optimizing the productive performance of dairy goats utilizing lower amounts of nitrogen sources.

Keywords: formaldehyde treatment, lactating goat, sesame meal, soybean meal

Introduction

Goat milk and its products are vital sources of protein for people who are allergic to dairy products from other animals, especially for those who live in areas where cow milk accessibility is limited (Bouattour et al., 2008). However, dairy farmers are faced with severe challenges. One of the most critical challenges is providing sufficient feed at a reasonable price to meet the nutritional requirements of dairy goats because feed cost accounts for more than 70% of the total cost of any livestock production. Sesame meal (SM) contains fibers and chemical compounds such as phenolic antioxidants as well as a proper balance of amino acids (AA), especially sulfur containing AA such as methionine with concentrations being higher than that in SBM (Dosky, 2012). Sesame oil is reported to have high contents of unsaturated fatty acids (Medeiros et al., 2014), especially linoleic and linolenic acids which can alter the concentration of milk bioactive components such as conjugated linoleic acid (CLA) by several times (Griinari and Bauman, 1999).

Consumption of feedstuffs with high rumen-degradable protein content leads to the rapid degradation of CP and production of large amounts of ammonia in the rumen that is lost through urine after conversion to urea by the liver. Furthermore, protection of oil seeds meal against microbial degradation in the rumen can affect the rate and site of digestion, leading to more efficient utilization (McKinnon et al., 1995). Various methods were evaluated for protecting proteins against ruminal degradation and increasing the amount of feed-based protein reaching the post-ruminal tract; however, due to the high cost of physical and mechanical methods, more effective chemical methods are needed to enhance the nutritional quality of meals for ruminants. Formaldehyde treatment is an effective chemical method that is environmentally safe and can reduce dietary protein degradation in the rumen (Kumar et al., 2015). Formaldehyde toxicity was studied in rats, rabbits, and dogs after oral feeding, and the LD50 was 800, 270, and 550 mg/kg of body weight (BW), respectively (NCBI, 2023), indicating the low toxicity of formaldehyde. Wales et al. (2010) concluded that formaldehyde, when applied as an antimicrobial feed additive, did not cause adverse responses in animals. Formaldehyde significantly reduces the solubility of protein and makes it very resistant to microbial attack in the rumen without affecting its digestibility in the small intestine (Coombe, 1985; Sanjukta and Rai, 2016).

Increases in dry matter intake (DMI), and milk yield and components have been previously reported by feeding formaldehyde-treated canola (Tajaddini et al., 2021) or soybean meals (Dosky, 2012) to dairy goats. Furthermore, reducing the level of protein supplements in the diet by improving the efficiency of dietary protein utilization without adverse effects on productive performance is both economically and environmentally advisable (Rotz et al., 1999). Therefore, this study aimed to compare the diet containing SBM, as the most common protein supplement, with the diets containing formaldehyde-treated SM on the nutrient intake, digestibility, ruminal parameters, and milk production and composition in Murciano-Granadina dairy goats.

Materials and methods

The experiment was conducted on a Murciano-Granadina dairy goat herd in Kerman, Iran (30◦150 N latitude and 57◦010 E longitude). All procedures of animal handling were approved by the Animal Care and Use Committee of Shahid Bahonar University of Kerman in accordance to EU standards (Directive 2010/63/EU of the European Parliament and of the Council).

Animals, diets and experimental design

At week 16th of lactation, forty multiparous Murciano-Granadina dairy goats were randomly assigned to one of four treatments. The experimental diets were: (1) SBM (16.5% CP; CON); (2) untreated SM (USM; 16.5% CP). (3) formaldehyde- treated SM (FTSM, 0.8 g formaldehyde/100g CP); 16.5% CP), and (4) FTSM containing 14.5% CP (LPFT). Goats (CON, 43.4 ± 2.3 kg; USM, 43.7 ± 2.6 kg; FT, 42.8 ± 2.2 kg; LPFT, 43.5 ± 2.8 kg of BW and 1.95 ± 0.31 kg/d average initial milk production) were housed in individual pens (1.5 × 2.0 m) for 70 days, including a 14 day of adaptation followed by a 56 days of data collection. The experimental diets (Table 1) were isocaloric and formulated to meet the nutrient requirements of dairy goats according to NRC (2007). The concentrate: forage ratio was 62:38 (DM basis) and the TMR diets were offered twice daily (at 0800 and 1600h) at *ad libitum* access; fresh water was provided freely throughout the experiment.

Sesame meal processing and feed analyses

To treat the SM with formaldehyde, formaldehyde was diluted with water and sprayed on the meal (0.8% of SM crude protein), mixed thoroughly for 15 minutes, and stored in nylon bags for 48 hours. Then, the bags were opened and FTSM was dried in the shade for three days before being incorporated into the experimental diets (Tajaddini et al., 2021).

Samples of feed offered and refused were collected daily, sub-sampled representatively after grounding to pass through a 1-mm screen in a Wiley mill and kept at –20 °C until further analysis. For determination of the dry matter (DM) content, feed samples were oven-dried at 105 °C for 48 hours. Samples of feces were oven-dried at 60 °C for 24 h and ground. Organic matter (OM) was measured as the difference between DM and ash content. The ether extract (EE) content was determined by weight loss of the DM on extraction with diethyl ether in a Soxhlet extractor. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were measured as described by Van Soest et al. (1991) procedure. The nitrogen content (N) was determined by the Kjeldahl procedure, using CuSO4 and K_2SO_4 as catalysts, and the CP was calculated as 6.25 × N.

Digestibility

For determination of apparent nutrients digestibility, feed and fecal samples were collected daily during the last five consecutive days of the data collection period. A 10% sub-sample of the total fecal output was collected, dried at 60 °C and passed through 1-mm sieve for analysis. The apparent digestibility of the nutrients was calculated by acid insoluble ash (AIA) technique (Van

Keulen and Young, 1977) according to the following equation:

$$\text{Apparent nutrient digestibility (\%)} = 100 - \left(100 \times \frac{\%\,AIA\ in\ feed}{\%\,AIA\ in\ feces} \times \frac{\%\,Nutrient\ in\ feces}{\%\,Nutrient\ in\ feed}\right)$$

Milk production and chemical analysis

The goats were milked twice daily with a fully automatic machine and the milk yield was recorded. The two samples (morning and afternoon), collected on the same day. were pooled. For determination of the milk composition [fat, protein, TS and solid not fat (SNF)], milk samples were collected in tubes containing potassium dichromate preservative and stored at 4 °C for further analysis using a Milko scan set (FOSS Electric, Hillerod, Denmark). The total fat, protein and lactose yield was calculated by multiplying the daily milk production by the concentrations of each component.

Another set of milk samples was stored at −20 °C for determination of milk FAs profile. For this purpose, milk fat was extracted according to the method described by Bouattour et al. (2008), and after methylation, milk FAs profile was determined using gas chromatography (GC; 3400 Varian Star; Varian Inc., Palo Alto, CA) equipped with capillary column (CP-SIL-88- 0.25 mm × 60 m). Helium gas was used as the carrier gas. The temperature of the column was initially 50 °C for 1 minute and then gradually increased (4 °C per minute) to 190 °C. The injector temperature was 280 °C and the detector temperature was 300 °C.

Table 1. Ingredients and chemical composition of the experimental diets fed to lactating goats

	Experimental diets[1]			
	CON	USM	FTSM	LPFT
Ingredients (% DM)				
Alfalfa hay, chopped	16.00	16.00	16.00	16.00
Corn silage	16.30	16.30	16.30	16.30
Wheat straw, chopped	2.00	2.00	2.00	2.00
Corn grain, ground	16.00	16.00	16.00	17.00
Barley grain, ground	11.00	11.00	11.00	12.00
Soybean meal	18.80	7.50	7.50	2.00
Sesame meal	0.00	12.50	12.50	12.50
Beet pulp	4.00	4.00	4.00	4.00
Wheat bran	12.70	11.50	11.50	15.00
Sodium bicarbonate	1.40	1.40	1.40	1.40
Calcium carbonate ($CaCO_3$)	0.30	0.30	0.30	0.30
Mineral-vitamin premix[2]	1.20	1.20	1.20	1.20
Salt	0.30	0.30	0.30	0.30
Chemical composition (g/kg DM)				
Metabolizable energy (Mcal/kg DM)	2.61	2.61	2.61	2.61
Crude protein (CP)	166	167	167	146
Rumen undegradable protein (% CP)	28.7	28.6	36.2	34.6
Rumen degradable protein (% CP)	71.3	71.4	63.8	65.4
Dry matter (DM)	615	616	613	616
Organic matter (OM)	921	919	918	919
Ether extract (EE)	26.40	27.20	27.20	28.50
Neutral detergent fiber (NDF)	280	280	280	285
Acid detergent fiber (ADF)	200	200	200	200
Non-fiber carbohydrates (NFC)[3]	408	407	407	417

[1] CON= diet with 16.5% CP containing SBM; USM= diet with 16.5% CP containing untreated SM; FTSM= diet with 16.5% CP containing SM treated with 0.8 g formaldehyde/100g CP); LPFT= diet with 14.5% CP containing SM treated with 0.8 g formaldehyde/100g CP.

[2] Each kg of the premix contained (DM basis): 500000 IU vitamin A, 100000 IU vitamin D, 2000 IU vitamin E, 190000 mg Ca, 25000 mg P, 40000 mg Na, 30000 mg Mg, 5000 mg Zn, 3500 mg Mn, 2500 mg Fe, 400 mg Cu, 35 mg Co, 90 mg I, 40 mg Se.

[3] NFC = 1000 - (NDF + CP + EE + Ash).

Rumen fermentation parameters

On the last day of the experimental period, ruminal fluid was collected via a stomach tube at 3 hours after morning feeding. Immediately after sampling, the pH of ruminal fluid was determined using a digital pH meter (model AZ8686). About 10 mL of ruminal liquid sample were strained through 4 layers of cheesecloth, mixed with 0.5 mL of 7.2 N sulfuric acid, centrifuged and prepared for ammonia nitrogen (NH_3-N) determinations with a spectrophotometer using the phenol-hypochlorite method (Broderick and Kang, 1980). Volatile FA (VFA) composition of the samples was analyzed using gas chromatography (GC) equipped with a split injector and flame ionization detection (FID) system described by Filípek and Dvořák (2009). An FFAP capillary column was used (length: 30 m × inner diameter: 0.25 mm × film thickness: 0.25 μm). The initial oven temperature was 40 °C (held for 2 min), and increased to 150 °C at a rate of 10 °C/min, held for 1 min. The injector and detector temperatures were set at 250 °C and 300 °C, respectively. A sample (1 μL) was injected at a split ratio of 10:1 and the column temperature of 40 °C. Helium was used as a carrier gas for the system at 3.0 mL/min, 16.793 psi. Based on the retention time, all VFA peaks were identified. The VFA concentration was determined by plotting the width area against the calibration curve of each acid (acetic, propionic, butyric, isobutyric, valeric and isovaleric). Total protozoa and subfamilies were enumerated according to Dehority (2003) using a light microscope (Olympus CH-2). For this purpose, 1 mL of the ruminal fluid was mixed with 4 mL of methyl-green formalin saline solution and stored in a dark place for further protozoal identification.

Statistical analysis

The data were analyzed as a completely randomized design using GLM procedure of SAS v. 9.1. The statistical model used as follows:

$Y_{ij} = \mu + T_i + A_j + e_{ij}$,

where Y_{ij}, μ, T_i, A_j and e_{ij} were the dependent variable, the overall mean, the fixed effect of treatment, the random effect of animal, and the random residual error, respectively. Daily measures for parameters such as milk yield, milk components, and DMI were averaged into weekly data for analysis. The mean of recorded measurements in each experimental unit was considered in the statistical analysis. Differences among treatment means were tested by the Tukey-Kramer's test. The results were expressed as the least squares mean (LSM) ± standard error of the mean (SEM). Significance was declared at $P \leq 0.01$.

Results

Nutrient intake and digestibility

Daily intakes of DM, OM, CP, NDF and metabolizable energy (ME) and nutrient digestibility were higher in the FTSM diet than in the CON and LPFT diets (P<0.05), and CP intake was lower in LPFT compared to CON (P<0.001). Nutrients digestibility was not affected by dietary treatments although the DM digestibility tended to be higher (P=0.07) in FTSM diet.

Table 2. Nutrients intake and digestibility in the lactating goats fed the experimental diets

	Experimental diets[1]					
Item	CON	USM	FTSM	LPFT	SEM[2]	*P*-value
Intake (g/d)						
Dry matter	1629^{b}	1683^{ab}	1749^{a}	1641^{b}	19.1	0.005
Organic matter	1514^{b}	1565^{ab}	1625^{a}	1531^{b}	17.9	0.010
Crude protein	270^{b}	278^{ab}	289^{a}	238^{c}	3.03	<0.001
Neutral detergent fiber	458	469	486	475	5.86	0.030
Metabolizable energy (Mcal/kg)	4.19^{b}	4.36^{ab}	4.54^{a}	4.26^{b}	0.05	0.004
Digestibility (%)						
Dry matter	68.40	68.50	71.20	68.20	1.06	0.070
Organic matter	69.40	69.90	72.40	69.40	0.98	0.120
Crude protein	73.50	74.10	74.20	76.40	0.93	0.160
Neutral detergent fiber	53.80	54.10	55.20	53.70	0.68	0.380

[a,b]Within rows, mean values with common superscript (s) are not different (P>0.05; Tukey's test).

[1]CON= diet with 16.5% CP containing SBM; USM= diet with 16.5% CP containing untreated SM; FTSM= diet with 16.5% CP containing SM treated with 0.8 g formaldehyde/100g CP); LPFT= diet with 14.5% CP containing SM treated with 0.8 g formaldehyde/100g CP.

[2] Standard error of mean.

Milk composition and fatty acids

Milk protein, lactose, TS and SNF contents were not affected by dietary treatments but the USM goats had higher milk fat percentage than the LPFT goats (P<0.01). Moreover, daily yields of milk fat, protein, lactose and SNF (P<0.01) were higher for USM and FTSM than for LPFT goats (Table 3).

Substitution of SBM by USM and/or FTSM significantly (P<0.01) lowered the milk total contents of the saturated FA (SFA), short-chain FA (SCFA) and medium-chain FA (MCFA); this substitution also led to an increase (P<0.003) in UFA, mono-unsaturated FA (MUFA), poly-unsaturated FA (PUFA), long-chain FA (LCFA) and UFA/SFA ratio in milk (Table 4). The highest and lowest percentages of PUFA were found in LPFT and CON groups, respectively (P<0.001) while the highest and lowest percentages of SCFA were measured in CON and LPFT diets, respectively (P<0.001).

Rumen fermentation parameters

At 3 h post-feeding, the total protozoa population and subfamilies were not affected by the treatments but higher ruminal pH and NH_3-N observed in CON and USM goats (P<0.001) as compared with the FTSM and LPFT ones (Table 5). The highest ruminal NH_3-N concentration, at 3 h post-feeding, was found in CON and USM goats followed by FTSM and LPFT (P<0.001). Incorporation of FTSM (both FTSM and LPFT) in the diet decreased ruminal acetate and increased propionate proportion and acetate/propionate ratio (P<0.001). Furthermore, the highest total VFA concentration in the rumen (P<0.001) was observed in FTSM goats followed by CON and USM, with LPFT goats recording the lowest values (Table 5).

Table 3. Milk composition in the lactating goats fed the experimental diets

	Experimental diets[1]					
Item	CON	USM	FTSM	LPFT	SEM[2]	*P*-value
Milk composition (%)						
Fat	4.75^{ab}	4.87^{a}	4.68^{ab}	4.54^{b}	0.08	0.010
Protein	3.21	3.20	3.26	3.24	0.04	0.590
Lactose	4.27	4.22	4.24	4.22	0.04	0.770
Total solids	12.3	12.3	12.2	12.0	0.09	0.200
Solids not fat	7.48	7.42	7.51	7.47	0.04	0.530
Milk component yield (g/day)						
Fat	91.30^{b}	105^{a}	107^{a}	75.70^{b}	3.02	<0.001
Protein	61.70^{ab}	68.80^{a}	74.60^{a}	54.40^{b}	4.34	0.010
Lactose	82.10^{ab}	90.80^{a}	96.90^{a}	70.80^{b}	5.27	0.009
Total solids	236^{bc}	262^{ab}	279^{a}	210^{c}	9.73	0.001
Solids not fat	144^{ab}	160^{a}	172^{a}	125^{b}	9.57	0.010

[a,b]: Within rows, mean values with common superscript (s) are not different (P>0.05; Tukey's test).

[1] CON= diet with 16.5% CP containing SBM; USM= diet with 16.5% CP containing untreated SM; FTSM= diet with 16.5% CP containing SM treated with 0.8 g formaldehyde/100g CP); LPFT= diet with 14.5% CP containing SM treated with 0.8 g formaldehyde/100g CP.

[2] Standard error of mean.

[3] Fat corrected milk (g/day) = 0.4 Milk yield (kg/d) + 15 Fat yield (kg/d)

[4] Energy corrected milk (g/day) = milk production (g/day) × [38.3×fat (g/kg) + 24.2×protein (g/kg) + 16.54×lactose (g/kg) + 20.7] /3140

[5] Total solids-corrected milk (g/day) = (12.3×g of fat) + (6.56×g of nonfat solids) - (0.0752×g of milk)

Table 4. Milk fatty acids profile (g/100 g of total fatty acids) in the lactating goats fed the experimental diets

	Experimental diets[1]					
Fatty acids	CON	USM	FTSM	LPFT	SEM[2]	*P*-value
SFA[3]	72.60^{a}	68.30^{b}	67.30^{b}	66.70^{b}	0.75	<0.001
UFA[4]	27.40^{b}	31.70^{a}	32.70^{a}	33.30^{a}	0.75	<0.001
UFA / SFA	0.38^{b}	0.47^{a}	0.49^{a}	0.50^{a}	0.01	<0.001
MUFA[5]	23.10^{b}	27.10^{a}	27.80^{a}	28.10^{a}	0.67	<0.001
PUFA[6]	4.32^{c}	4.58^{bc}	4.92^{ab}	5.13^{a}	0.13	0.001
SCFA[7]	14.50^{a}	13.70^{ab}	12.80^{bc}	11.80^{c}	0.41	<0.001
MCFA[8]	52.90^{a}	48.70^{b}	48.70^{b}	49.60^{b}	0.99	0.020
LCFA[9]	32.60^{b}	37.60^{a}	37.90^{a}	38.60^{a}	1.14	0.003

[a,b] Within rows, mean values with common superscript (s) are not different (P>0.05; Tukey's test).

[1] CON= diet with 16.5% CP containing SBM; USM= diet with 16.5% CP containing untreated SM; FTSM= diet with 16.5% CP containing SM treated with 0.8 g formaldehyde/100g CP); LPFT= diet with 14.5% CP containing SM treated with 0.8 g formaldehyde/100g CP.

[2] Standard error of mean, [3] Saturated fatty acids, [4] Unsaturated fatty acids, [5] Monounsaturated fatty acids.6 PUFA: Polyunsaturated fatty acids, [6] Polyunsaturated fatty acids, [7] Short-chain fatty acids (sum of C4:0 – C10:1 fatty acids), [8] Medium-chain fatty acids (sum of C12:0 – C17:1 fatty acids), [9] Long-chain fatty acids (sum of C ≥ 18 fatty acids).

Table 5. Ruminal fermentation characteristics in the lactating goats fed the experimental diets at 3 hours after morning feeding

	Experimental diets[1]					
Item	CON	USM	FTSM	LPFT	SEM[2]	*P*-value
pH	6.42^{a}	6.38^{a}	6.17^{b}	6.15^{b}	0.02	<0.001
NH_3-N (mg/dL)	28.30^{a}	27.50^{a}	25.40^{b}	21.50^{c}	0.34	<0.001
Total VFA (mmol/L)	71.30^{bc}	73.50^{b}	76.50^{a}	69.10^{c}	0.85	<0.001
Individual VFA (mol/100 mol)						
Acetate	62.50^{a}	63.10^{a}	59.10^{b}	56.90^{c}	0.37	<0.001
Propionate	20.90^{c}	20.50^{c}	23.90^{b}	26.40^{a}	0.41	<0.001
Butyrate	8.03	8.15	8.27	8.42	0.19	0.520
Isobutyrate	5.49	5.36	5.42	5.20	0.17	0.660
Valerate	1.25	1.14	1.35	1.19	0.11	0.410
Isovalerate	1.81	1.76	1.88	1.92	0.14	0.860
Acetate/propionate	2.99^{a}	3.07^{a}	2.48^{b}	2.16^{c}	0.07	<0.001
Total protozoa (× 10^5/mL digesta)	6.23	6.04	6.20	6.01	0.15	0.630
Entodiniinae	3.81	3.49	3.91	3.74	0.13	0.180
Diplodiniinae	0.72	0.76	0.67	0.71	0.03	0.160
Isotrichiae	0.72	0.76	0.74	0.70	0.02	0.560
Epidiniumae	0.96	1.02	0.89	0.85	0.05	0.120

[a,b] Within rows, mean values with common superscript (s) are not different (P>0.05; Tukey's test).

[1] CON= diet with 16.5% CP containing SBM; USM= diet with 16.5% CP containing untreated SM; FTSM= diet with 16.5% CP containing SM treated with 0.8 g formaldehyde/100g CP); LPFT= diet with 14.5% CP containing SM treated with 0.8 g formaldehyde/100g CP.

[2] Standard error of mean.

Discussion

In the present study, partial replacement of SBM with either USM or FTSM did not impact on the apparent total tract digestibility of DM, OM, CP and NDF. Similar to our results, addition of USM in the diet of fattening lambs had no effect on the nutrients digestibility (Obeidat et al., 2009). Also, Throat et al. (2016) observed no effects on feed digestibility when high-yielding dairy cows were fed formaldehyde-treated rapeseed meal. Incorporation of FTSM in the diet with 16.5% CP enhanced the nutrients intake compared with other treatments. Treating oilseed meals in order to protect the proteins from ruminal degradation by microorganisms increase the dietary bypass protein and enhanced the flow of peptides and essential AA for absorption through the small intestine which help the balance of absorbed AA and subsequently promote the feed intake and immune response (Baker et al., 1996). Furthermore, the increase in milk production in goats fed treated SM led to an increase in nutrient requirements especially energy, which in turn dictates higher nutrient consumption in animals (Baker et al., 1996). Similar to our results, Tajaddini et al. (2021) reported that DMI increased when goats were fed with formaldehyde-treated canola meal, which can be mainly attributed to higher dietary rumen undegradable protein (RUP) content in the diet by using formaldehyde-treated canola meal, leading to an improved balance of AA post-ruminally (Forbes, 1995). As expected, the nutrient intake of CON and LPFT goats was similar except for CP intake which was higher for CON that is clearly due to the lower dietary CP in LPFT diet. However, Tajaddini et al. (2021) reported an increase in DM intake (DMI) when lactating goats were fed formaldehyde treated canola meal with reduced dietary CP level (12.5%).

The milk of LPFT goats contained the lowest fat percentage among all dietary treatments. The reduction of dietary CP was primarily responsible for this observation which may adversely affect the activity of ruminal cellulolytic bacteria, thus reducing the production of acetic acid as the main precursor of de novo FA synthesis in the mammary gland (Purdie et al., 2008). Contrary to the results of the present study, Ababakri et al. (2021) observed that raising the dietary RUP caused a negative impact on the ewe milk fat contents beside an increase in milk production. Goats fed USM and FT diets had higher daily milk fat, protein, lactose and SNF yields compared to CON and LPFT due to more daily milk production which is in agreement with the earlier results of Tajaddini et al. (2021) and Wright et al. (2005). When compared to goats fed with SBM, the diets containing either treated or untreated SM led to lower contents of milk SFA, SCFA and MCFA, and higher contents of UFA, MUFA, PUFA and LCFA. Also, substitution of SBM by treated or untreated SM enhanced the UFA: SFA ratio. Similar to our results, Kim et al. (2013) also found remarkably higher ratio of UFA: SFA in steers fed SM. Additionally, PUFA derived from C18:2 n-6 and C18:3 n-3 seem to have protective effects in lowering the risk of cardiovascular diseases development (Scollan et al., 2001), also preventing cancerous tumors, reducing heart disease, and controlling blood pressure, which are crucial factors in maintaining human health.

In comparison to USM and CON, diets containing FTSM had lower ruminal pH and NH3-N concentrations. Ruminal pH is an important factor in both microbial protein synthesis and dietary protein degradation. Lower ruminal pH is associated with increased fermentation of available OM, which promotes microbial protein synthesis (Hoover and Stokes, 1991). The lower ruminal pH observed in FTSM fed goats suggests that formaldehyde-treated SM is degraded less than SBM or untreated SM in the rumen. A lower proportion of dietary nitrogen is also converted to NH3-N in the rumen as a result of consuming FTSM than SBM and USM, which reduces the ruminal pH as a result of the buffering nature exhibited by NH3-N. In contrast to our findings, Yörük et al. (2006) showed that treatment of SBM with formaldehyde (increased RUP) had no effect on the sheep ruminal pH but significantly reduced the NH3-N concentration.

Microorganisms break down RDP into peptides, AA, NH3-N and branched-chain FAs. A decrease in NH3-N was anticipated in goats consuming the formaldehyde-treated SM which lowers the RDP and protects the proteins against microbial degradation. Wright et al. (2005) found a similar reduction in ruminal NH3-N production when lactating cows were provided heat- and/or lignosulfonate-treated canola meal. Tajaddini et al. (2021) also noted that goats fed only formaldehyde-treated canola meal or with decreased dietary CP level had significantly lower ruminal NH3-N concentrations. Inclusion of formaldehyde-treated SM in the diet with high CP level resulted in the highest total VFA production in the rumen. This might be attributed to higher intake of DM and OM compared with CON and LPFT goats, which could lead to increases in fermentable DM and OM available for VFA production in the rumen (McDonald et al., 2011).

The ruminal production of acetic acid and total VFA was lower in LPFT than other goats. As the FA profile of SM showed high unsaturated long chain FA content, this can be attributed to toxic effects of free polyunsaturated FA (Palmquist and Jenkins, 1980) on rumen microbes, or low efficacy of the method used for protecting the polyunsaturated FA (Kitessa et al., 2003) which consequently interferes with cell wall digestion and rumen fermentation. Also, reducing the dietary CP level in goats fed with LPFT increased the ruminal concentration of propionic acid and decreased the acetic to propionic ratio. Similar to the results of Bhatt and Sahoo (2019), it is mainly attributed to feeding proteins with lower ruminal degradation rates can better synchronize the capture of released nitrogen by microbes leading to improved balance of carbon: nitrogen ratio for better microbial efficiency. Contrary to our results, Tajaddini et al. (2021) reported that total VFA concentration increased in dairy goats when formaldehyde-treated canola meal was supplemented to a low-protein diet. Incorporation of FTSM in the diet lowered ruminal acetate proportion compared to USM and CON. This might be due to the lower dietary CP level (specifically from the RDP source) and the extent of ruminal degradation which subsequently lower the ruminal pH and diminish the activity of the cellulolytic bacteria, in turn resulting in decreased acetate production (Purdie et al., 2008). Therefore, the increase in acetate production of CON and USM goats was mainly due to more RDP provided in the rumen raising the deamination activity and supply of NH3-N, consequently promoting the fiber digestion and acetate production (Misra and Thakur, 2001). In addition, increased ruminal NH3-N concentration in CON and USM goats is responsible for higher ruminal pH which in turn stimulates cellulolytic bacteria activity. In the present study, dietary treatments had no effect the molar proportions of branched chain VFAs. Branched-chain VFAs are produced from oxidative deamination and decarboxylation of branched AA including valine, isoleucine, and leucine which are provided in the rumen from dietary origin (Hobson and Stewart, 1997). These AA are accounted for about 17.08% and 17.86% of the SBM and SM amino acid profile, respectively (NRC, 2001; Fasuan et al., 2018). Thus, similar molar proportions of branched-chain VFAs amongst different treatments was likely due to the similar content of branched-chain AA in SBM and SM.

Conclusions

In conclusion, substitution of SBM by FTSM (about 65%) in the diet of lactating Murciano-Granadina goats improved the DMI and milk productive performance. In addition, the FTSM diet led to increased milk PUFA, decreased SFA and a higher UFA/SFA ratio. Moreover, regarding the same results for most of studied parameters in CON and LPFT goats, inclusion of FTSM in low CP diet might be used as a cost-effective strategy to reduce feed costs as well as environmental pollution resulting from greater nitrogen emissions in dairy farms rather than feeding SBM. Also, evaluation of different levels of formaldehyde for processing of SM is recommended for future studies.

Declaration of competing interest

The authors declare that there are no real or perceived conflicts of interest.

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