Spanish Journal of Agricultural Research
22 (1), e0602, 12 pages (2024)
eISSN: 2171-9292
https://doi.org/10.5424/sjar/2024221-20274
INIA-CSIC

RESEARCH ARTICLE

OPEN ACCESS

Feeding formaldehyde-treated sesame meal to lactating Murciano-Granadina goats: implications on milk yield and composition, digestibility, rumen fermentation, and blood metabolites

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Abstract

Aim of study: To investigate the effect of substituting sesame meal (SM) treated with different levels of formaldehyde instead of soybean meal (SBM) on rumen fermentation, milk composition, and hemato-chemical parameters in lactating goats.

Area of study: Kerman, Iran.

Material and methods: Forty Murciano-Granadina goats in mid-lactation were allocated to four groups as a completely randomized design for 56 d. They were fed with diets containing: 1) SBM (control), 2) 12.5% untreated SM, 3) 12.5% treated SM with 0.8 g formaldehyde/100g crude protein (CP), and 4) 12.5% treated SM with 1.2 g formaldehyde/100g CP.

Main results: The goats fed diet containing SM treated with 1.2 g of formaldehyde had greater ($p < 0.01$) intake of dry matter, CP and metabolizable energy (ME) than other groups. Milk yield and milk protein in goats fed diets containing 1.2 g formaldehyde-treated SM were greater than others ($p < 0.01$). Fat-corrected milk and total solids in groups fed diets containing formaldehyde-treated and untreated SM were greater than those in control ($p < 0.01$). Goats fed control diet showed a greater proportion of saturated fatty acids (SFA), and short and medium-chain FA in their milk compared to other groups ($p < 0.01$). Partial replacement of SBM with formaldehyde-treated or untreated SM increased milk unsaturated FA and long-chain FA ($p < 0.01$). Goats fed formaldehyde-treated SM had lower acetate production ($p < 0.01$).

Research highlights: Partial replacement of SBM with formaldehyde-treated SM can be suggested to increase lactating goats' performance without adverse effects on their health.

Additional keywords: lactating goat; milk protein; propionate; saturated fatty acids

Abbreviations used: AA (amino acid); AC (antioxidant capacity); ALT (Alanine transaminase); AST (Aspartate transaminase); BUN (blood urea nitrogen); BW (body weight); CP (crude protein); DM (dry matter); ECM (energy corrected milk); EE (ether extract); FA (fatty acid); FCM (4% fat corrected milk); GC (gas chromatography); HDL (high-density lipoprotein); LCFA (long-chain fatty acid); LDL (low-density lipoprotein); MCFA (medium-chain fatty acid); MDA (malondialdehyde); ME (metabolizable energy); MUFA (mono unsaturated fatty acid); NDF (neutral detergent fiber); OM (organic matter); PUFA (poly unsaturated fatty acid); RDP (rumen degradable protein); RUP (rumen undegradable protein); SBM (soybean meal); SCFA (short-chain fatty acid); SFA (saturated fatty acid); SM (sesame meal); TSCM (total solids corrected milk); UFA (unsaturated fatty acid); VFA (volatile fatty acid); VLDL (very-low-density lipoprotein).

Citation: Firozi, F; Dayani, O; Tahmasbi, R; Dadvar, P (2024). Feeding formaldehyde-treated sesame meal to lactating Murciano-Granadina goats: implications on milk yield and composition, digestibility, rumen fermentation, and blood metabolites. Spanish Journal of Agricultural Research, Volume 22, Issue 1, e0602. https://doi.org/10.5424/sjar/2024221-20274

Received: 23 Feb 2023. **Accepted**: 19 Jan 2024. **Published**: 30 Jan 2024.

Introduction

Soybean meal (SBM) is one of the most common protein supplements used in livestock diets. It contains high level of lysine, but low in methionine, valine, and isoleucine, which are the first, second, and third limiting amino acids (AA), respectively in dairy cows (Schingoethe, 1996). Also, the use of SBM in animal diets increases the cost of livestock production because it is considered as an imported product in most countries and is expensive. Sesame meal (SM), a by-product of sesame oil extraction, can replace SBM at a lower cost with a positive effect on milk production and nutrient digestibility (Abo Omar, 2002; Obeidat et al., 2019). The amounts of dry matter (DM), crude protein (CP), ash, ether extract (EE), nitrogen free extract and crude fiber in SM are about 83-96%, 23-46%, 7.5-17%, 1.4-27%, 25-32% and 5-12%, respectively (FAO, 1990). As a fat source, SM is valued for its high levels of unsaturated fatty acids (UFA), especially linolenic acid and linoleic acid, which can modify some bioactive components in milk, such as conjugated linoleic acid and omega-3 fatty acids (Medeiros et al., 2014).

Decreasing the degradability of protein in the rumen has the potential to improve milk production by providing more AAs for absorption in the small intestine. Many measures are taken to protect feed against degradation in the rumen (Haryanto, 2014). Among these, treatment with formaldehyde is the most common, efficient and least expensive method (Walli, 2005). Formaldehyde toxicity has been studied in rats, rabbits, and dogs after oral feeding, and the LD_{50} 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, has not been generally shown as a cause of 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 (Sanjukta & Rai, 2016). There are few reports on the effects of formaldehyde-treated SM on dairy. However, a positive effect of feeding formaldehyde-treated SBM or canola meal on nutrient intake, milk production and composition was observed in cattle, goats and sheep (Tajaddini et al., 2021). Thus, the objective of current study was to evaluate the effect of substitution of SBM by treated or untreated SM in the diet of Murciano-Granadina dairy goats on feed intake, nutrient digestibility, milk yield, milk fatty acid (FA) profile, blood metabolites, and rumen fermentation characteristics.

Material and methods

Sesame meal processing

The formaldehyde was diluted with water (37%) and sprayed on SM samples (resulting in a final concentration of 0.8 and 1.2 g formaldehyde/100 g CP of SM), mixed homogenously for 15 minutes, and kept in nylon bags for 48 h. Then, the bags were opened and the SM was allowed to dry in the shade for three days before being introduced into the experimental diets (Hadjipanayiotou, 1992).

Animals and experimental diets

The Animal Care and Use Committee of Shahid Bahonar University of Kerman approved all animal handling protocols in compliance with EU standards (EC, 2010). This experiment was carried out on a herd of Murciano-Granadina dairy goats in Kerman, Iran (30º 150 N latitude and 57º 010 E longitude). At the 16th week of lactation, forty multiparous Murciano-Granadina dairy goats (42.8 ± 3.3 kg of BW and 1.95 ± 0.31 kg/d average milk yield) were allocated to four groups (n = 10 per group) as a completely randomized design. They were fed with diets containing: 1) SBM (control), 2) untreated SM, 3) treated SM with 0.8 g formaldehyde/100 g CP and 4) treated SM with 1.2 g formaldehyde/100g CP (Table 1). The level of SM in diets 2, 3 and 4 was 12.5%. During a 56-d experimental period (including 14 d for animal's adaptation to the experimental diet and 42 d for data collection), goats were housed individually in pens (1.5 × 1.5 m). The experimental diets were formulated to be iso-energetic and iso-nitrogenous based on nutrient requirements of dairy goats according to NRC (2007). The diets had a forage-to-concentrate ratio 62:38 (on DM basis) and animals were fed a total mixed ration twice daily ad libitum at 08:00 and 16:00. Fresh water was provided freely throughout the experiment.

Milk yield and composition

Daily milk yield of goats during the experiment was recorded twice a day through an automatic device. On the last five day of the experiment, approximately 50-mL milk samples were collected in tubes containing potassium dichromate (as a preservative) and stored at 4°C until analysis for milk composition, including fat, protein, lactose, total solids and solids-not-fat contents using a Milko scan apparatus (FOSS Electric, Hillerod, Denmark).

The production of 4% fat-corrected milk (FCM), energy-corrected milk (ECM), and total solids-corrected milk (TSCM) were calculated according to NRC (2001), Sjaunja et al. (1991), and Tyrrell & Reid (1965), respectively.

Another milk subsample was used for determining FA profile using fat extracts generated by trans-esterification to form methyl esters as described by Bouattour et al. (2008). The FA in the milk sample extracts were then measured using a gas chromatography (GC; 3400 Varian Star; Varian Inc., Palo Alto, CA, USA) and a fused silica capillary column (CP-SIL-88- 0.25 mm × 60 m). The column temperature used for the fatty acid quantification ranged from 50 to 190 °C (hold 1 min at 50 °C; increase 4 °C/min to 190 °C; hold 10 min). Helium gas was used as the carrier gas.

Table 1. Ingredients and chemical composition of the experimental diets

	Control	Untreated SM[1]	0.8 g formaldehyde treated SM	1.2 g Formaldehyde treated SM
Ingredients (% dry matter)				
Alfalfa hay, chopped	16.0	16.0	16.0	16.0
Corn silage	16.3	16.3	16.3	16.3
Wheat straw, chopped	2.00	2.00	2.00	2.00
Corn grain, ground	16.0	16.0	16.0	16.0
Barley grain, ground	11.0	11.0	11.0	11.0
Soybean meal	18.8	7.50	7.50	7.50
Sesame meal	0.00	12.5	12.5	12.5
Beet pulp	4.00	4.00	4.00	4.00
Wheat bran	12.7	11.5	11.5	11.5
Sodium bicarbonate	1.40	1.40	1.40	1.40
Calcium carbonate	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 dry matter)				
Dry matter	615	616	613	613
Organic matter	921	919	918	918
Metabolizable energy (Mcal/kg)	2.61	2.61	2.61	2.61
Crude protein (CP)	166	167	167	167
Rumen undegradable protein (% CP)	48.0	48.0	36.2	66.0
Rumen degradable protein (% CP)	118	119	63.8	101
Ether extract (EE)	26.4	27.2	27.2	27.2
Neutral detergent fiber	280	280	280	280
Acid detergent fiber	200	200	200	200
Non-fiber carbohydrates[3]	408	407	407	407

[1] Sesame meal. [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).

Digestibility

Daily samples of feed offered and refused were collected and after grounding through a 1-mm screen Wiley mill were kept at –20°C for subsequent analysis. In order to determine nutrient digestibility, individual faecal samples (50 g) were collected for all goats at last five experimental days. Acid-insoluble ash was used as an internal indicator (Liu, 2022). The samples of SM, treated SM, feed, and feces were analyzed for DM (method 930.15), organic matter (OM; method 942.05), CP (method 990.03), and EE (method 920.39) according to AOAC (2000). Neutral detergent fiber (NDF) was determined according to Van Soest et al. (1991).

Rumen fermentation variables

On last day of the experiment, about 40-50 mL of rumen content was collected via a stomach tube 3 h post-feeding. The rumen fluid was filtered through four layers of cheesecloth. The pH was determined immediately using a pH meter (Sentron, model A102-003). For determination of NH_3-N, about 5 mL of filtered rumen fluid was acidified with 1 mL of 0.2 N HCl to stop fermentation and frozen at -20°C. For volatile fatty acids (VFA) analysis, 1 mL of strained rumen fluid was mixed with 0.25 mL of an acid solution containing 200 mL/L of orthophosphoric acid and 20 mmol 2-ethyl-butyric acid and frozen at -20°C. The total VFA and its components (acetic, propionic, isobutyric, butyric, isovaleric and valeric acids) were determined by GC using ethyl butyric acid as an internal standard. Total numbers and generic composition of rumen protozoa were determined according to the method of Dehority (2003).

Blood variables

On the last day of the experiment, blood samples were collected via jugular venipuncture through vacuumed tubes containing lithium heparin at 3 h after feeding. Plasma was harvested after centrifuging at 3000 rpm for 15 min, partitioned into aliquots and stored at -20°C until further analysis. Plasma glucose, cholesterol, triglyceride, blood urea nitrogen (BUN), albumin, total protein, high-density lipoprotein (HDL), low-density lipoprotein (LDL), very-low-density lipoprotein (VLDL), aspartate transaminase (AST) and alanine transaminase (ALT) were determined with a spectrophotometer using commercial kits (Pars Azmoon Diagnostics, Tehran, Iran).

In order to assess the total antioxidant capacity (AC) and malondialdehyde (MDA) in plasma and milk, samples were stored at -70°C until the analysis. The thiobarbituric acid technique was used to measure the amount of MDA in plasma and milk (Moore & Roberts, 1998). Milk and blood AC were determined using the ferric reduction in antioxidant power technique (Benzie & Strain, 1996). All measurements were conducted in five replicates and in compliance with the manufacturer's recommendations.

Statistical analysis

All data were analyzed as a completely randomized design using GLM procedure (except for the milk yield data which was analyzed by MIXED procedure) of SAS (version 9.1.3, SAS Institute, Cary, NC, USA). All data were analyzed by the model: $Y_{ij} = \mu + a_i + e_{ij}$, where Y_{ij}, μ, a_i, and e_{ij} represent the dependent variable, the overall mean, the fixed effect of dietary treatment, and the experimental error, respectively. The Tukey test was used to examine the differences among treatments mean. The results were considered significantly different when $p \leq 0.05$ or $p \leq 0.01$.

Results

Nutrients intake and digestibility

The experimental diets had no effect ($p > 0.05$) on DM or nutrient digestibility (Table 2). Goats fed diet containing formaldehyde-treated SM had greater ($p < 0.01$) DM, OM, CP, and ME intakes than those fed untreated SM and SBM. Feeding formaldehyde-treated SM diets resulted in greater ($p < 0.01$) NDF intake compared to diets containing SBM. The apparent digestibility of any of the nutrients was not affected by the experimental diets.

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

Item	Control	Untreated SM[1]	0.8 g formaldehyde treated SM	1.2 g formaldehyde treated SM	SEM[2]	p-value
Intake (g/d)						
Dry matter	1629^{c}	1683^{bc}	1748^{ab}	1777^{a}	23	0.004
Organic matter	1514^{c}	1565^{bc}	1625^{ab}	1662^{a}	22	0.004
Crude protein	270^{c}	278^{bc}	289^{ab}	294^{a}	3.62	0.003
Neutral detergent fiber	458^{b}	469^{ab}	486^{a}	489^{a}	6.42	0.006
Metabolizable energy (Mcal/kg)	4.19^{b}	4.36^{b}	4.54^{a}	4.59^{a}	0.06	0.003
Digestibility (%)						
Dry matter	68.4	68.5	71.2	70.8	0.95	0.090
Organic matter	69.4	69.9	72.3	71.8	0.87	0.070
Crude protein	73.5	74.1	74.6	76.8	1.07	0.100
Neutral detergent fiber	53.8	54.1	55.2	55.4	0.64	0.210

[1] Sesame meal. [2] SEM: Standard error of mean. [a,b] Means within row with different superscripts differ ($p < 0.05$).

Table 3. Milk yield and composition in lactating goats fed experimental diets

Item	Control	Untreated SM[1]	0.8 g formaldehyde treated SM	1.2 g formaldehyde treated SM	SEM[2]	p-value
Yield (g/day)						
Milk	1922[c]	2152[b]	2288[ab]	2358[a]	57	<0.001
FCM 4%[3]	2139[b]	2429[a]	2523[a]	2588[a]	49	0.003
ECM[4]	2034[b]	2298[a]	2409[a]	2473[a]	61	0.001>
TSCM[5]	1921[b]	2171[a]	2273[a]	2328[a]	58	0.007
Efficiency						
Milk yield/DMI[6]	1.18[c]	1.28[b]	1.31[a]	1.32[a]	0.03	0.036
FCM 4%/DMI	1.31	1.44	1.45	1.46	0.03	0.063
Milk composition (%)						
Fat	4.75	4.87	4.68	4.65	0.09	0.350
Protein	3.21[b]	3.20[b]	3.26[ab]	3.32[a]	0.03	0.048
Lactose	4.27	4.22	4.24	4.16	0.04	0.070
Total solids	12.3	12.2	12.2	12.1	0.11	0.750
Solids-not-fat	7.48	7.42	7.51	7.48	0.04	0.520

[1] Sesame meal. [2] SEM: 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 solid corrected milk (g/day) = (12.3×g of fat) + (6.56×g of nonfat solids) - (0.0752×g of milk). [6] DMI: Dry matter intake. [a,b] Means within row with different superscripts differ ($p < 0.05$).

Milk yield, milk composition and fatty acids

The diet containing 1.2 g formaldehyde-treated SM resulted in a greater ($p < 0.01$) milk yield than diet containing untreated SM or SBM (Table 3). The lowest amount of FCM, ECM and TSCM was observed in goats fed with diet containing SBM ($p < 0.01$), while there was no difference between treatments containing treated and untreated SM. Milk yield efficiency (g milk yield/g DM intake) in goats fed with formaldehyde-treated SM was greater than that in other groups ($p < 0.05$), but efficiency of FCM was not affected by experimental treatments. Furthermore, milk contents of fat, lactose, total solids and solids not fat were not affected by experimental treatments, but milk protein was higher ($p < 0.05$) in goats fed diet containing 1.2 g formaldehyde-treated SM than the other groups.

The concentrations of C18:1-cis and C18:3-cis in the milk of goats fed SBM diet were lower ($p < 0.01$) than those in goats fed formaldehyde-treated SM diets (Table 4). The saturated FA (SFA), short-chain FA (SCFA), and medium-chain FA (MCFA) were higher and unsaturated FA (UFA), UFA/SFA, monounsaturated FA (MUFA), poly unsaturated FA (PUFA), and long-chain FA (LCFA) were lower in the milk of goats fed a diet containing SBM compared to other groups ($p < 0.01$).

Rumen fermentation variables

As shown in Table 5, the lowest pH values and NH_3-N concentration and the highest total VFA concentration were observed in the rumen fluid of goats fed formaldehyde-treated SM diet than others ($p < 0.01$). Additionally, the concentration of acetate was lowest and propionate was highest in these goats ($p < 0.01$). The acetate/propionate ratio in the rumen fluid of goats fed formaldehyde-treated SM diet was also lower than that in other groups ($p < 0.01$). The protozoa population was not affected by the experimental treatments at 3 h after feeding.

Blood parameters

The results of the present study showed that the concentration of hemato-chemical parameters including glucose, triglyceride, cholesterol, HDL, LDL, VLDL, total protein, albumin, BUN, AST, and ALT, was not affected by the experimental treatments (Table 6).

Antioxidant indices in blood and milk

Experimental treatments did not affect any of the antioxidant indices including superoxide dismutase, glutathione

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

Fatty acids	Control	Untreated SM[1]	0.8 g formaldehyde treated SM	1.2 g formaldehyde treated SM	SEM[2]	p-value
C16:0	30.7	27.3	28.5	27.5	1.19	0.190
C16:1-cis	1.29	1.41	1.47	1.43	0.05	0.120
C16:1-trans	0.43	0.44	0.45	0.46	0.03	0.910
C18:0	9.33	10.3	9.71	9.90	0.46	0.480
C18:1-cis	15.2[b]	19.1[a]	19.7[a]	19.8[a]	0.51	0.001
C18:1-trans	2.52	2.41	2.41	2.29	0.06	0.110
C18:2-cis	3.14	3.28	3.41	3.38	0.09	0.180
C18:2-trans	0.31	0.35	0.29	0.28	0.02	0.110
C18:3-cis	0.85[b]	0.93[b]	1.21[a]	1.15[a]	0.04	0.001
C18:3-trans	0.02	0.02	0.01	0.01	0.002	0.190
SFA[3]	72.6[a]	68.3[b]	67.3[b]	67.5[b]	0.66	0.001
UFA[4]	27.4[b]	31.7[a]	32.7[a]	32.5[a]	0.66	0.001
UFA/SFA	0.38[b]	0.47[a]	0.49[a]	0.48[a]	0.01	0.001
MUFA[5]	23.1[b]	27.1[a]	27.8[a]	27.7[a]	0.62	0.001
PUFA[6]	4.32[c]	4.58[bc]	4.92[a]	4.82[ab]	0.11	0.001
SCFA[7]	14.5[a]	13.7[b]	12.8[b]	13.2[b]	0.35	0.010
MCFA[8]	52.9[a]	48.7[b]	49.2[b]	48.8[b]	0.95	0.010
LCFA[9]	32.6[b]	37.6[a]	37.9[a]	38.0[a]	1.03	0.002

[1] Sesame meal. [2] Standard error of mean. [3] Saturated fatty acids. [4] Unsaturated fatty acids. [5] Monounsaturated 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). [a,b] Means within row with different superscripts differ ($p < 0.05$).

peroxidase in blood, MDA and AC in blood and milk of goats (Table 7).

Discussion

Today's ongoing global challenge is to optimize the use of protein and fat supplements in various production systems, which is mostly focused on the quality of produced milk/meat in developed countries, rather than raising the quantity of production in developing countries (Gulati et al., 2005). The results of the current study demonstrated that goats fed diets containing formaldehyde-treated SM, especially those with higher levels of formaldehyde, had grater DM, OM, CP, and ME intakes than those fed diets containing untreated SM or SBM. This may be due to the processing with formaldehyde since this processing decreases protein solubility in the rumen and enhances the number of peptides and essential AAs available in the intestine and increases animal feed intake (Sanjukta & Rai, 2016). In other words, preventing the degradation of dietary CP by rumen microorganisms, increases the flow of by-pass protein and AAs to the small intestine, which helps balance of absorbed AAs and thus stimulates feed intake (Baker et al., 1996). Similar to our results, Tajaddini et al. (2021) reported that DMI increases when goats are fed with formaldehyde-treated canola meal, which can be mainly attributed to higher dietary rumen undegradable protein (RUP) content of diets by using formaldehyde-treated canola meal, leading to an improved balance of amino acids post-ruminally (Forbes, 1995). Furthermore, increased milk production in goats fed a diet containing treated SM (Table 3) leads to a rise in nutrient requirements, especially energy, requiring higher nutrient consumption (Baker et al., 1996). It is evident that the goats with higher milk production will consume more DM and ME. Furthermore, substitution of SBM with formaldehyde-treated SM increased RUP content of diet and RUP intake of the goats compared to control. Our results agree with previous researchers' findings who fed formaldehyde-treated canola meal or SBM to dairy goats and cows (Baker et al., 1996; Tajaddini et al., 2021). However, Sirohi et al. (2013) reported no effect on feeding formaldehyde-treated mustard cake to lactating crossbred cows.

Table 5. Ruminal fermentation characteristics in lactating goats fed experimental diets

Item	Control	Untreated SM[1]	0.8 g formaldehyde treated SM	1.2 g formaldehyde treated SM	SEM[2]	p-value
pH	6.42[a]	6.38[a]	6.19[b]	6.17[b]	0.03	<0.001
NH_3-N (mg/dL)	28.30[a]	27.50[a]	25.40[b]	25.10[b]	0.36	<0.001
Total VFA[3] (mmol/L)	71.30[b]	73.50[b]	76.50[a]	77.80[a]	0.95	0.002
Individual VFA (mol/100 mol)						
Acetate	62.50[a]	63.10[a]	59.10[b]	59.90[b]	0.47	0.001
Propionate	20.90[b]	20.50[b]	23.90[a]	23.60[a]	0.44	0.002
Butyrate	8.03	8.15	8.27	8.11	0.19	0.840
Isobutyrate	5.49	5.36	5.42	5.24	0.16	0.750
Valerate	1.25	1.14	1.35	1.21	0.11	0.580
Isovalerate	1.81	1.76	1.88	1.85	0.14	0.940
Acetate/propionate	2.99[a]	3.07[a]	2.48[b]	2.55[b]	0.07	0.001>
Protozoa population ($\times 10^5$/mL)						
Total protozoa	6.23	6.04	6.22	6.27	0.15	0.740
Entodiniinae	3.81	3.49	3.91	3.87	0.14	0.190
Diplodiniinae	0.72	0.76	0.67	0.74	0.03	0.170
Isotrichiae	0.72	0.76	0.74	0.69	0.03	0.330
Epidiniumae	0.96	1.02	0.89	0.97	0.04	0.260

[1] Sesame meal. [2] Standard error of mean. [3] Volatile fatty acids. [a,b] Means within row with different superscripts differ ($p < 0.05$).

Table 6. Hemato-chemical parameters of lactating goats fed experimental diets

Item	Control	Untreated SM[1]	0.8 g formaldehyde treated SM	1.2 g formaldehyde treated SM	SEM[2]	p-value
Glucose (mg/dL)	53.90	55.60	54.00	52.90	2.77	0.920
Triglyceride (mg/dL)	16.80	20.60	17.10	21.60	1.48	0.070
Cholesterol (mg/dL)	84.90	88.30	85.00	90.40	7.55	0.940
HDL[3] (mg/dL)	41.10	40.30	41.10	45.00	4.29	0.860
LDL[4] (mg/dL)	40.50	43.90	40.50	41.10	9.35	0.990
VLDL[5] (mg/dL)	3.36	4.12	3.42	4.32	0.31	0.070
Total protein (g/dL)	7.36	6.87	7.89	7.35	0.27	0.100
Albumin (g/dL)	4.06	3.81	4.15	4.01	0.16	0.520
BUN[6] (mg/dL)	47.60	41.10	43.30	42.30	2.82	0.410
AST[7] (U/L)	116	111	108	97	7.22	0.320
ALT[8] (U/L)	20.20	18.10	17.60	16.90	1.26	0.310

[1] Sesame meal. [2] Standard error of mean. [3] High-density lipoprotein. [4] Low-density lipoprotein. [5] Very-low-density lipoprotein. [6] Blood urea nitrogen. [7] Aspartate transaminase. [8] Alanine transaminase. [a,b] Means within row with different superscripts differ ($p < 0.05$).

Table 7. Antioxidant activity of milk and blood in lactating dairy goats fed experimental diets

Item	Control	Untreated SM[1]	0.8 g formaldehyde treated SM	1.2 g formaldehyde treated SM	SEM[2]	p-value
Blood						
SOD[3] (U/gHb)	1547	1476	1494	1475	89.90	0.930
GPX[4] (U/gHb)	69.70	60.60	68.30	69.10	3.04	0.080
MDA[5] (nmol/mL)	2.24	2.11	1.89	1.93	0.18	0.490
AC[6] (mmol Fe^{2+}/L)	0.40	0.46	0.43	0.40	0.02	0.230
Milk						
MDA (nmol/mL)	0.78	0.74	0.75	0.74	0.03	0.790
AC (mmol Fe^{2+}/L)	1.45	1.61	1.55	1.57	0.05	0.150

[1] Sesame meal. [2] Standard error of mean. [3] Superoxide dismutase. [4] Glutathione peroxidase. [5] Malone dialdehyde. [6] Antioxidant capacity. [a,b] Means within row with different superscripts differ ($p < 0.05$).

Partial substitution of SBM with either untreated or treated SM with different levels of formaldehyde had no effect on nutrient digestibility. These findings might be attributed to the similarities in chemical composition of four dietary groups as mentioned by Mahmoud & Bendary (2014). This result support those obtained by Obeidat et al.'s study (2009) in which addition of different levels of SM (0, 8, and 16%) to the diet of fattening lambs have no significant effect on nutrient digestibility. Furthermore, our results are consistent with findings of Mahmoud & Ghoneem (2014). Throat et al. (2016) also reported that the formaldehyde-treated rapeseed meal do not affect feed digestibility in high-yielding dairy cows. Furthermore, Obeidat et al. (2019) reported that there is no significant difference in nutrient digestibility when SBM was replaced by SM in the diet of Awassi sheep.

Goats fed diets containing formaldehyde-treated SM had higher milk production than other groups. This may be due to the fact that when dietary protein is treated with formaldehyde, it leads to increased absorption of essential AAs and metabolizable proteins from the duodenum (Yörük et al., 2006), and hence providing the limiting AAs for milk synthesis to the mammary gland. Increased milk production in goats fed with formaldehyde-treated SM, which were fed diets with higher contents of protected protein, may be a direct result of more postruminal supply of those amino acids involved in limiting milk production (Tajaddini et al., 2021). In addition, increased milk production in response to formaldehyde-treated SM might be attributed to an increase in protein available for digestion in the intestines increasing milk precursors (Mishra et al., 2006). As previously stated, an increase in DM, CP and ME intake in goats fed the formaldehyde-treated SM diets could explain their increased milk production because higher ME intake is responsible for higher milk production (Tajaddini et al., 2021). In accordance with our findings, Petit (2003) demonstrated that adding formaldehyde-treated flaxseed and sunflower seeds to the diet of dairy cows increases milk production up to 2.7 kg/day when compared to untreated flaxseed and sunflower seeds. Tajaddini et al. (2021) also reported that giving 1.2% formaldehyde-treated canola meal to lactating goats increased their milk, FCM, ECM and TSCM production. Similar findings were also obtained in cows, buffalos, and goats by feeding rapeseed meal treated with formaldehyde (Sherasia et al., 2010), formaldehyde-treated mustard and groundnut cakes (Shelke et al., 2012b), formaldehyde-treated SBM (Dosky et al., 2012), and formaldehyde-treated sesame cake (Bugalia & Chaudhary, 2010). Throat et al. (2016) reported that lactating cows supplemented with formaldehyde-treated rapeseed meal on iso-nitrogenous rations have higher daily milk yield and FCM, and improved production efficiency. However, our findings are inconsistent with those of Ashes et al. (1992), who found no change in milk production in response to formaldehyde-treated canola seeds. Substitution of 15% SM in the diets of lactating dairy cows decreases milk yield and feed efficiency than control diet (Shirzadegan & Jafari, 2014). Variations in the type and quantity of protein, as well as the animals' stage of lactation, may cause different outcomes.

Goats fed diets containing SM (either treated or untreated) had higher milk fat content than those fed control diet. The results of present study agree with Hejazi & Abo Omar (2009), who found that Anglo-Nubian goats fed diets containing 10 and 15% sesame oil cake have significantly higher milk fat than goats fed basal ration. The increasing in milk protein content in goats fed diets containing formaldehyde-treated SM may be due to increased RUP levels through treatment with formaldehyde, which is then optimally utilized in milk protein synthesis. In line with the results of the present study, Ababakri et al. (2021b) indicated that higher levels of dietary RUP (40%) has beneficial effects on ewes' milk protein contents, but did not affect milk production.

Addition of untreated and formaldehyde-treated SM to the diet of lactating goats decreased SFA, SCFA and MCFA in milk, while UFA, MUFA, LCFA, and PUFA contents as well as UFA/SFA ratio significantly increased. Since the mammary gland's epithelial cells primarily produce SCFA from *de novo*, their synthesis can be prevented by raising the concentration of specific LCFA (Grummer, 1991). Indeed, the high amount of C18:1 (oleic acid) and C18:2 (linoleic acid) in SM causes an inhibition in the expression of genes involved in the *de novo* synthesis of milk SCFA and MCFA (acetyl-Co A carboxylase alpha and fatty acid synthase) (Thakur et al., 2018) and reduces milk SCFA and MCFA contents. On the other hand, it is possible that due to the high concentration of PUFA in SM, these FAs escape rumen degradation and enter the blood and increase the milk UFA content. It is also possible that the decrease in ruminal degradation in goats fed formaldehyde-treated SM diet, led to the escape of fatty acids from rumen biohydrogenation and absorbed in the small intestine and entered the milk, and as a result, LCFA is higher in the milk of these goats. Similar to our results, Kim et al. (2013) found that the ratio of UFA/SFA is higher in steers fed the diet containing SM. Also, Liu et al. (2008) also showed a reduction in SCFA and MCFA concentrations in milk when cows are fed diets containing SM. Given that MCFA constitutes the hypercholesterolemic component of milk fat; therefore, reducing MCFA may be recommended as a potential to improve milk's FAs profile from the perspective of human health (Shingfield et al., 2013).

Replacement of formaldehyde-treated SM in the dairy goats' diet reduced ruminal pH, NH_3-N concentration, acetate production as well as acetate/propionate ratio while increasing total VFA and propionate production as compared with SBM and untreated SM. The decrease in rumen pH in goats fed formaldehyde-treated SM is influenced by the increase in total VFAs and especially the increase in propionate production in the rumen. Previous studies showed that formaldehyde-treated SBM (Yörük et al., 2006) and formaldehyde-treated canola meal (Tajaddini et al., 2021) have no effect on sheep's ruminal pH, but significantly decrease rumen NH_3-N concentration. The reduction of ruminal NH_3-N in goats fed formaldehyde-treated SM diets was predictable because treating with formaldehyde protects the protein from microbial degradation. Previous results on feeding formaldehyde-treated oilseed protein meals were reported by Shelke et al. (2012a) who indicated that rumen protected protein supplements save more energy, which could be wasted through urea synthesis in the liver. Similar to our findings, Wright et al. (2005) found a decrease in ruminal NH_3-N production when lactating cows were provided heat and lignosulfonate-treated canola meal.

Increased production of VFA in goats fed formaldehyde-treated SM diets could be attributed to higher DM intake (McDonald et al., 2011). Our findings are consistent with those of Bhatt & Sahoo (2019), reporting that feeding formaldehyde-treated SBM to lambs increases the production of rumen VFAs and propionate. On the other hand, reduced acetate production in rumen of goats fed formaldehyde-treated SM is mainly due to lower ruminal pH which in turn diminishes rumen cellulolytic activity and lowers ruminal acetate concentration (Purdie et al., 2008). Moreover, an increase in ruminal acetate production of goats fed untreated-SM and SBM diets may be due to the fact that feeding more rumen degradable protein (RDP) may enhance the deamination of AA in the rumen and the supply of branched-chain VFAs, which may promote fiber digestion and lead to an increase in ruminal acetate production in these goats (Misra & Thakur, 2001).

In the present study, experimental diets had no significant effect on hemato-chemical parameters of lactating goats. The concentration of blood triglyceride and cholesterol is an indicator of an animal's energy state and equivalent amounts of these two parameters among different dietary groups suggest animals with comparable energy status. Our results agree with those reported by previous studies (Shirzadegan & Jafari, 2014; Ashjae et al., 2021) in which the substituting SM with SBM in the diet of dairy cows have no significant effect on blood glucose, cholesterol, or calcium levels. However, our findings contradicted those of Ababakri et al. (2021a), who found that sheep given extruded flaxseed containing high levels of RUP have higher blood glucose and cholesterol concentrations.

Similar to our results, Mahima et al. (2017) found no significant changes in serum creatinine, total protein, albumin, and globulin levels among heifers fed different levels of formaldehyde-treated mustard oil cake. Estimation of blood AST and ALT activity is an important factor for evaluating liver health. When the liver is damaged, these enzymes are released in high proportions into the blood, resulting in hepatopathy (Venukumar & Latha, 2004). The ineffectiveness of the experimental treatments on liver enzymes (ALT and AST) suggested that either formaldehyde-treated or untreated SM consumption had no adverse effects on the liver.

The BUN content is commonly used to assess nitrogen balance in ruminants. High BUN levels are associated with increased dietary RDP, which is degraded into NH_3-N and absorbed from the rumen to the blood (Wanapat & Pimpa, 1999). In the present study, goats fed formaldehyde-treated SM showed lower ruminal NH_3-N concentration, but their BUN concentration was similar to other groups. Perhaps the reason for this difference is related to other factors such as the energy in the rumen that affected the BUN concentration. Our findings contradicted the study of Shelke et al. (2012b), in which BUN content is reduced in buffalos fed diets containing formaldehyde-protected mustard and peanut meals.

Experimental treatments did not influence antioxidant activity of milk and blood in lactating dairy goats. Sesamin is one of the most important lignan furfuran compounds, which has various vital roles and is found in sesame seeds, oil, and meal. Some properties of sesamin include its antioxidant capacity (Jin et al., 2005) improving immune system function and anticancer activity (Hristov & Giallongo, 2014) as well as reducing blood pressure and serum lipid content (Ordway et al., 2009). Tsiplakou et al. (2021) reported that feeding goats a diet rich in SM, selenium and vitamin E improves their health and their milk oxidative status. Additionally, Mitsiopoulou et al. (2021) found that supplementing the diet with a high level of sesame seed (10% vs. 5%) increased blood antioxidant activity and milk oxidative stability in goats.

In conclusion, partial substitution of costly conventional protein sources like SBM with less expensive ones like formaldehyde-treated SM in the diet of lactating Murciano-Granadina goats improved their nutrients intake, milk yield and composition, and rumen fermentation characteristics. Furthermore, the addition of formaldehyde-treated SM (1.2 g formaldehyde/ 100 g CP) to the diet of dairy goats led to an increase in PUFA and a decrease in milk SFA, which could be beneficial to human health.

Data availability: Not applicable.

Competing interests: All authors declare that there are no actual or potential conflicts of interest between the authors and other people or organizations that could inappropriately bias their work.

Authors' contributions: **Fateme Firozi:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Project administration, Writing – original draft. **Omid Dayani:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Reza Tahmasbi:** Validation, Writing – original draft, Writing – review & editing. **Poorya Dadvar:** Formal analysis, Writing – original draft, Writing – review & editing.

Funding: The authors received no specific funding for this work.

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