Research Article

Evaluation of Ruminal Degradation Characteristics of Dehulled Moringa Seed Cake and its Influence on Performance of Lactating Damascus Goats

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Abstract | Moringa seed cake is a protein-rich source that can be utilized as a feed supplement or a cheaper protein feed ingredient. This study aimed to: (1) assess the ruminal degradation features of machine-dehulled moringa seed cake (DMSC); and (2) examine the effect of supplementing lactating Damascus goats' diets with DMSC on milk production. Three cannulated rams (50.60± 3.05 kg, body weight) were used to assess the ruminal degradability of DM, NDF, and ADF for DMSC using *in sacco* technique. Fifteen lactating Damascus goats (averaging 45.4± 0.5 kg, body weight and averaging milk yield 900±65 g/head/day) were randomly assigned to one of three treatments for 6 weeks to study DMSC's effect on blood metabolites and quality and quantity of the produced milk. Treatment groups were provided either a control diet or control diet with 40 g/head/day (DMSC40) or 80 g/head/day (DMSC80) of DMSC. DMSC was high in protein (39.6% CP on DM) and low in fibre. DMSC DM was thought to be highly digestible due to its high ruminally degradable fraction (76.1%). Increasing supplementation amount of DMSC in goats' diets reduced their blood cholesterol (linear; $P = 0.012$). However, total protein, albumin, globulin, urea-N, glucose, and liver enzymes showed no significant changes. DMSC supplementation increased milk energy content (MJ/kg), milk total solids, non-fat solids, protein, and lactose (g/kg) (linear; $P < 0.05$). In conclusion, supplementing lactating goats' diets with a low level of DMSC might enhance the produced milk (quality and quantity) without any adverse effects.

Keywords | Dehulled Moringa seed cake, Rumen degradation, Milk production, Damascus, Goats

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INTRODUCTION

Moringa oleifera is an Indian native versatile tree with high economical and commercial importance that has adapted to grow in tropical climates (Lins et al., 2019; Valdivié-Navarro et al., 2020). Every part of moringa tree can be utilized for industrial, alimental and medicinal purposes (Rayan and Embaby, 2016). In intensive livestock systems, 60–70% of overall production costs are attributed to feed cost. In addition, global feed production, processing, and transport are responsible for 45% of the greenhouse gas emissions produced by the livestock (Makkar, 2018; Salami et al., 2019).

Producers in developing countries are looking for cheaper alternatives to traditional and costly feeds. Both the seeds and leaves of the moringa plant can be used as a cheaper substitute for the expensive imported feeds (Blache et al., 2008; Hansen et al., 2020). A single moringa tree annually produces up to 50 - 70 kg of fruits (pods) with an average yield of 12 to 13 tons of seeds per hectare each year (Bridgemohan et al., 2014). It is worth mentioning that, depending on the cultivar and origin, the nutritional value of different parts of moringa tree may differ (Oyeyinka and Oyeyinka, 2018).

In the last two decades, the moringa tree have intensive studies concerning with utilization of its parts and its by-products as animal feed (Abdel-Rahman et al., 2019; Aboamer et al., 2020; Makkar et al., 2007). Moringa seed cake (MSC) is a by-product of oil extraction that has a high protein content (61.4% to 70.3% CP on DM basis) and may be used as a protein supplement (Hansen et al., 2020; Makkar et al., 2007). Moringa seed cake might be utilized as an alternative protein source to cotton seed meal in the diets of male Damascus goats at levels of 25% and 50% (Abdel-Rahman et al., 2019; Makkar et al., 2007).

Moringa seed cake has been demonstrated to improve post-rumen protein availability by lowering dietary protein breakdown in an *in vitro* rumen simulation studies (Hoffmann et al., 2003; Makkar et al., 2007). Several researchers indicated that moringa seeds have antibacterial properties against gram-negative and gram-positive bacteria, and antifungal properties (Lins et al., 2019). Moreover, it was reported that mustard seed cakes and moringa seed press cakes had the capacity to reduce CH_4 emission without affecting rumen fermentation *in vitro* (Salami et al., 2019). Extensive *in vitro* studies were conducted to determine the optimal inclusion levels of moringa seed cakes in ruminants' diets regarding digestibility, methane production, and volatile fatty acid fractions (Aboamer et al., 2020; de Morais et al., 2015; Ebeid et al., 2020; Hansen et al., 2020; Hoffmann et al., 2003; Melesse et al., 2013). Hansen et al. (2020) reported that, inclusion of moringa whole seed cake at or above 7.5% of the total diet DM decreased methane production, showing its potential to increase dietary energy efficiency. Substitution levels below 5% of total DM had no effect on the digestibility of DM and fiber, whereas inclusion levels over 5% significantly reduced their digestibility compared to control, with the largest significant loss of dDM (digestible dry matter) (13%) occurring at 12.5% MSC (Hansen et al., 2020).

A linear reduction in methane generation was reported when moringa seeds were introduced to the animals at 20% or 40% of concentrated dry matter (Lins et al., 2019). However, this decline coincided with a marked decrease in the degradability of the diet. Thus, raw moringa seeds do not appear as a feasible feed supplement to decrease CH_4, but they can be incorporated into the diet DM at up to 100g/kg as a protein-rich feed source with no harmful effect on rumen fermentation or microbial production (Lins et al., 2019).

Most published research has used moringa seed meal produced by milling the seeds after removing the outer shell, or seed extracts (Hansen et al., 2020). Removal of the hulls from moringa seeds has traditionally been done by hand, which is a time-consuming and labor-intensive process. However, the producers will save time and money by switching to dehulling machines (Ikubanni et al., 2017). The dehulling machine for moringa seed processing is powered by an electric motor, pulleys, belts, shafts, and bearings (Ikubanni et al., 2017). The fiber content was found to be significantly reduced after dehulling the moringa seeds due to the obvious high concentration of fiber in the seed hull (Rayan and Embaby, 2016). Dehulling considerably lowered tannin levels by 57.8 percent, showing that the majority of tannins in moringa seeds are located in the hull (Rayan and Embaby, 2016). However, after dehulling, phytic acid levels increased by 7.4%, indicating that phytic acid is present in moringa seed kernels (Rayan and Embaby, 2016).

The dehulling performance was found to be affected by the moisture content of seeds, and the machine's overall efficiency was estimated to be 65.9% while dry and decreased to 52.5% when wet (Ikubanni et al., 2017). This means that machine-dehulled moringa seed cake will retain bits of pods and shell. The residual cake after oil extraction is the richest in protein content, ranging from 23-43% for hulled or de-hulled and defatted seed (Aboamer et al., 2020; Bridgemohan et al., 2014; Hansen et al., 2020).

Studies on the effect of feeding moringa seed cake on milk production and composition are rare. In addition, the type and level of seed cake utilized varied across studies. The objectives of this study were to: (1) estimate the ruminal degradation characteristics of machine-dehulled moringa seed cake using *in situ* (*in sacco*) nylon bag technique; and (2) examine the effect of supplementing the diets of lactating Damascus goats with machine-dehulled moringa seed cake on milk production.

MATERIALS & METHODS

Machinery-dehulled moringa seed cake

The residual machine-dehulled moringa seed cake after oil extraction was obtained from Moringa Production Unit, National Research Centre, Egypt.

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In sacco trial (Nylon bags)

Degradability coefficients of machine-dehulled moringa seed cake was measured using *in sacco* method where feed samples were placed in porous polyester or nylon bags and suspended in the rumen of fistulated animals, then the rate of loss of DM, N, and other components were measured (Orskov and Mcdonald, 1979). Moringa cake was ground through a Wiley mill 1 mm screen and dried at 60°C for 48 hours in a forced air oven before being incubated in three cannulated rams (50.60±3.05 kg, body weight) as replicates. Rams were fed at maintenance level of 40:60 concentrate to roughage. Ankom *in situ* bags (SKU: R510) with a pore size of 50±10 µm were used. About 5.0 g was placed in a previously weighted, clean, dry, and numbered bag. The bags were incubated one hour after offering the morning meal. The incubation times were 2, 6, 8, 24, 48 hours. After incubation, the bags with residues were taken out of the rumen, dipped immediately into cold water to stop microbial activity, and then washed under running cold water until the water was clear. After that the bags were drained, dried for 72 h at 60°C, cooled in a desiccator, and weighed. The residues were removed and then analyzed for nitrogen content using Kjeldahl method (AOAC, 2005); NDF and ADF (Van Soest et al., 1991). The solubility was defined as weight loss after soaking the bags with the substrate for 1 h in water at 38°C, then washed and dried in a similar way. When determining the degradation rate for NDF and ADF, the 0 h is omitted from the calculation. The ruminal disappearance rate of tested feed at each individual incubation time was calculated as the difference between the contents in the initial samples and the residues remaining after incubation in the rumen and expressed as a percentage of the content of the initial sample. Data of ruminal disappearance characteristics of DM was fitted to the exponential equation following the procedure described by Orskov and Mcdonald (1979): $y = a + b(1 - \exp(-k_d t))$, where: y = DM disappearance in rumen at time t, a = soluble fraction, b = slowly degradable fraction, k_d = constant rate of degradation of b (%/h) to determine the degradability coefficients. However, data of ruminal disappearance characteristics of fiber fractions (NDF and ADF) were fitted to the following equation $y = b(1 - \exp(-k_d t))$. Then ruminally degraded (RD) can be calculated as: $RD = a + b(k_d/(k_d + k_p))$, where k_p is the fractional outflow rate of solids from the rumen. In this study, the rumen outflow rate was assumed to be 0.05 h^{-1}.

Lactation study

The study was carried out at the experimental farm of Animal Production Research Institute, Gemazza, Egypt. The analysis for feed, blood, and milk samples were performed at Animal Milk Production Lab., Dairy Science Department, National Research Centre, Egypt. This experiment was conducted according to the guidelines of the Institutional Committee, National Research Centre, and Giza, Egypt.

Management of animal:

Fifteen multiparous lactating Damascus goats in 2nd and 3rd parity with average body weight of 45.4±0.5 kg and producing 900±65 of energy corrected milk (ECM/d) were allocated into three equal groups (five goats of each) using complete randomized design for 6 weeks experimental period. Goats were fed twice daily at 7.30AM and 4.00PM according to recommendations of NRC (2007), while drinking water was available for 24 hours.

Experimental ration:

The control ration contained Egyptian clover (*Trifolium alexandrinum*) and a commercial concentrate feed mixture (CFM) in a 40:60 R:C ratio. The commercial CFM included: 25% undecorticated cotton seed meal, 35% wheat bran, 30% corn, 3% rice bran, 3% molasses, 2% limestone, 1% urea, and 1% salt. The control group was fed control diet, while treatment groups T1 and T2 were fed control diet plus dehulled moringa seed cake (DMSC) at level 40g/head/d (T1; DMSC40) and 80g/head/day (T2; DMSC80), respectively. Moringa seed cake was analyzed for dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE), and ash content as described by AOAC (2005). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined according to Van Soest et al. (1991). Table (1) presents the proximate analysis of berseem clover; a commercial concentrate feed mixture (CFM), and machinery-dehulled moringa seed cake.

Sampling and analysis:

Daily feed intake was measured by weighing the feed and orts from the day before. Feed and orts samples were ground through a 1-mm screen using a Wiley mill (Arthur H. Thomas, Philadelphia, PA, USA), and analyzed for DM, OM, CP, EE and ash content as described by AOAC (2005), and NDF and ADF were determined according to Van Soest et al. (1991).

After 4 h of morning feeding, blood samples (10 mL) were withdrawn from the jugular vein of each goat into a tube with Heparin anticoagulants at the end of the 2nd, 4th, and 6th weeks of the experimental period. Blood samples were centrifuged for 15 minutes at 4000 g. Plasma was extracted into a 2-mL vial and kept frozen until analysis at -20 °C. Blood plasma was tested for total protein, albumin, urea-N, glutamate-oxaloacetate transaminase, glutamate-pyruvate transaminase, glucose, and cholesterol concentrations using UV spectrophotometry according to manufacturer instructions (Stanbio Laboratory, Boerne, Texas, USA). The concentration of globulin was estimated by subtracting albumin values from total protein values.

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Table 1: Proximate analysis of ingredients and basal diet fed to lactating Damascus goats(g/kg DM)

Items	Machine-dehulled moringa seed cake	Concentrate feed mixture	Berseem clover	Basal diet (Control)
Chemical composition (g/kg) DM				
Dry Matter	945.3	910.0	147.0	604.8
Organic Matter	952.6	894.9	894.0	894.5
Crude protein	396.0	149.0	160.6	153.6
Ether extract	107.0	39.0	18.4	30. 8
Neutral detergent fiber	460.3	265.0	541.9	375.8
Acid detergent fiber	338.8	141.0	403.4	187.6
Mineral content				
N, %	0.44			
P, %	0.79			
K, %	1.15			
Ca, %	0.47			
Mg, %	0.51			
S, %	146.1			
Fe, ppm	143			
Mn, ppm	13			
Zn, ppm	199			
Cu, ppm	3			

Table (2): *In situ* DM, NDF and ADF degradability of dehulled moringa seed cake.

	Nutrients degradability*		
Time (h)	**DM**	**NDF**	**ADF**
0	47.1	0	0
2	68.7	55.6	46.0
6	72.7	58.3	49.5
8	76.5	64.2	56.2
24	79.5	68.0	61.5
48	80.8	69.6	66.0
Fractions, %**			
a	47.6	-	-
b	30.7	65.2	58.9
c	69.3	34.8	41.1
K_d, fraction/h	0.4902	0.9325	0.6945
Fractions, %			
RD	75.5	61.9	55.0
RU	24.5	38.1	45.0

*DM: dry matter; NDF: neutral detergent fiber; ADF: Acid detergent fiber

**a=soluble fraction, b=potentially degradable fraction; c=undegradable fraction; K_d=ruminal degradation rate (fraction/h); RD =Ruminally degraded, calculated a + b (K_d/(K_d + K_p)) where K_p =ruminal passage rates of .05/h.; RU =Ruminally undegradable, calculated (1 - RD).

Similarly, milk yield was recorded in 3 times throughout the whole experiment at the end of the 2th, 4th, and 6th weeks. Milk samples were collected from each goat (milked by hand twice daily at morning and evening) to measure milk composition by using infrared spectrophotometry (Milkotester LM2, Belovo, Bulgaria). Milk samples were analyzed for total solids, fat, total protein, and lactose. The fat corrected milk, energy corrected milk, the gross energy content (MJ/kg), and the milk energy output (MJ/d) in milk were calculated as follows:

4% FCM = 0.4 (milk yield, g) + 15 (fat yield, g) ………… (Gaines, 1927)

ECM= 0:327*Milk yield (kg) +12:95*Fat yield (kg) + 7:20*Protein (kg) ….(Tyrrell and Reid, 1965).

Gross energy content in milk was calculated as follow:

Milk energy content (MJ/kg) = 4·184 × 2·204 × [(41·63 × fat (g/100 g)+ 24·13 × protein (g/100 g) + 21·60 × lactose (g/100 g) −11·72)/1000]. ….(Tyrrell and Reid, 1965).

Milk energy output (MJ/d) = milk energy (MJ/kg) × milk yield (kg/d). ….(Tyrrell and Reid, 1965).

Statistical Analysis

The DM, NDF, and ADF degradation data were analyzed using the nonlinear procedure (NLIN) of SAS (2018) and fitted to the model of estimates of degradation fractions and degradation rates of DM, NDF, or ADF were analyzed using nonlinear procedure of SAS (2018). Data from *in vivo* experiment were subjected to analysis of variance using GLM procedure of SAS (2018) using the following model; $Y_{ij} = \mu + T_i + e_{ij}$. Where; Y_{ij} is performance trait of i^{th} goat with j^{th} group, μ is the overall mean, T_i is the effect of treatment, e_{ij} is the experimental error. Moreover, data of milk production (milk yield parameters) as well as blood metabolite parameters were also statistically analyzed two orthogonal contrasts including all treatments in linear effect of treatment dose and quadratic effect of treatment. Treatment effects were declared significant at $p < 0.05$ and trends were discussed at $0.05 \leq p < 0.1$ to compare the treatment means by using Duncan's multiple range tests (Duncan, 1955).

RESULTS & DISCUSSION

In situ degradability

Table 1 shows the proximate analysis of berseem clover, a commercial concentrate feed mixture (CFM) and mineral content of the machinery-dehulled moringa seed cake. The machinery-dehulled moringa seed cake is rich in protein content (39.6% CP on a DM basis) and has less fiber content than the un-dehulled moringa seed cake used in our previous work (Aboamer et al., 2020; Ebeid et al., 2020). This is due to the high fiber content of the seed hull (Rayan and Embaby, 2016). Also, Makkar et al. (2007) reported that moringa seed hulls contained low CP content (99 g/kg) but very high fiber fraction (NDF, ADF, and ADL: 842, 805, and 452 g/kg, respectively).

The *in sacco* DM, NDF, and ADF degradability of machinery-dehulled moringa seed cake at different incubation hours are presented in Table (2). The amount of feed digested in the rumen is a balance between the inherent digestion rate and the passage rate of undigested feed from the rumen. In this study, the ruminally degraded fraction (RD) was estimated at ruminal passage rates of $0.05h^{-1}$. As shown in Table (2), the DMSC DM had high ruminal degradability. The fraction that represents non-structural carbohydrates, which are often water soluble, was about 47.6%. The fraction (a) of DMSC DM was higher than that reported for moringa whole seeds, defatted moringa seeds, and partially defatted moringa seeds (Ebeid et al., 2020). While the (b) fraction that represents slowly degradable structural carbohydrates (cellulose and hemicellulose) represents 30.7% with a remarkably fast degradation rate (K_d) of $0.4902h^{-1}$. Ebeid et al. (2020) reported that moringa whole seeds DM had a higher (b) fraction (53.2%) than defatted or partially defatted moringa seeds. Also, the observed degradation rate of DMSC DM was higher than that reported by Ebeid et al. (2020). In addition, for ruminal outflow fate of ($0.05h^{-1}$), the estimated ruminally degraded (RD) and ruminal undegradable (RU) fraction of DMSC DM were 75.5% and 23.9%, respectively.

For fiber fractions (NDF and ADF) of DMSC, the ruminally undegradable fractions (RU) were 38.1 and 45.0%, respectively. The degradable fraction (b) of NDF was 65.2% with a high rate of degradation (K_d) of 0.9325 fraction/h. While the DMSC ADF was less degradable than NDF, being 58.9% with a slower rate of degradation (K_d) (0.6945, fraction/h).

Blood metabolites

Results of blood metabolites in Table (3) showed a significant reduction (linear; P = 0.012) in cholesterol concentration with increasing DMSC level in goats' rations. However, no significant effects were observed on the plasma concentrations of total protein, albumin, globulin, urea-N, glucose, and liver enzymes (GPT and GOT).

Furthermore, all blood metabolite results in the current study were within normal concentrations with no adverse effects. In our previous work, Aboamer et al. (2020) studied the effect of feeding moringa seed cake (MSC) on lactating ewes and observed similar results for total protein, urea- N, cholesterol, GPT, and GOT concentrations. In another study conducted by Abdel-Rahman et al. (2019) they noticed that the values of serum glucose, total cholesterol, and triglyceride concentrations were gradually decreased in both groups fed 25 and 50% moringa seed meal compared to the control group in male Damascus goat rations, while total proteins and globulins were markedly (P < 0.05) increased in both groups fed moringa seed meal. Furthermore, EL-Hedainy et al. (2020) added moringa seed meal to fattening lambs' diets and reported a significant increase in serum total protein concentrations, while no differences in all blood serum constituents (albumin, urea, glucose, cholesterol, triglycerides, GPT, and GOT) between the control group and lambs fed moringa

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Table 3: Blood plasma metabolites of lactating Damascus goats receiving two levels of dehulled moringa seed cake.

Items*	Diets**			SEM	P value***		
	Control	DMSC40	DMSC80		TRT	L	Q
Total proteins, mg/dl	6.70	6.69	6.79	0.056	0.742	0.406	0.584
Albumin, mg/dl	3.73	3.84	3.89	0.101	0.823	0.594	0.901
Globulin, mg/dl	2.96	2.85	2.90	0.108	0.919	0.849	0.774
Albumin/globulin	1.35	1.49	1.66	0.126	0.612	0.378	0.971
Urea-N, mg/dl	34.16	32.14	32.38	0.541	0.256	0.250	0.394
Glucose, mg/dl	81.74	76.63	76.64	1.079	0.088	0.157	0.397
GPT (Units/l)	17.62	16.46	16.13	0.310	0.120	0.027	0.435
GOT (Units/l)	39.88	41.59	43.73	1.437	0.558	0.087	0.906
Cholesterol, ml/dl	134.73^{a}	120.52^{b}	123.95^{b}	2.378	0.033	0.012	0.425

*GPT= Glutamate-pyruvate transaminase (Units/l); GOT= Glutamate-oxaloacetate transaminase, Units/l.
** Control= basal diet; DMSC40= 40 g/head/day machine-dehulled moringa seed cake; DMSC80= 80 g/head/day machine-dehulled moringa seed cake.
*** TRT= treatment; L= linear; Q= quadratic.

Table 4: Actual milk yield, FCM, ECM, milk energy content and output, and milk composition of lactating Damascus goats receiving two levels of moringa seed cake.

Items	Diets*			SEM	P values**		
	Control	DMC40	DMC80		TRT	L	Q
Yield (g/d, unless stated otherwise)							
Actual Milk	1329	1219	1006	71.7	0.150	0.061	0.728
Fat corrected milk (FCM)	969	1098	807	68.4	0.256	0.316	0.185
Energy corrected milk (ECM)	1123	1266	963	75.5	0.307	0.376	0.208
Milk energy content (MJ/kg)	2.43^{b}	3.13^{a}	2.98^{ab}	0.129	0.045	0.044	0.092
Milk energy output (MJ/d)	3.22	3.87	2.98	0.235	0.357	0.670	0.180
Fat	29.15	40.68	26.99	3.19	0.218	0.762	0.094
Protein	43.14	47.31	39.46	2.59	0.540	0.576	0.348
Lactose	64.79	69.32	59.19	3.63	0.589	0.547	0.416
Milk composition (g/kg)							
Total solids	11.09^{b}	13.56^{a}	13.47^{a}	0.489	0.035	0.022	0.152
Solids not fat	8.88^{b}	10.29^{a}	10.76^{a}	0.330	0.020	0.007	0.388
Fat	2.21	3.27	2.71	0.204	0.106	0.249	0.068
Protein	3.25^{b}	3.86^{a}	3.92^{a}	0.129	0.030	0.015	0.230
Lactose	4.88^{b}	5.64^{a}	5.92^{a}	0.177	0.024	0.005	0.387
Ash	0.75	0.78	0.91	0.032	0.064	0.027	0.457

* Control= basal diet; DMSC40= 40 g/head/day machine-dehulled moringa seed cake; DMSC80= 80 g/head/day machine-dehulled moringa seed cake.
** TRT= treatment; L= linear; Q= quadratic.

seed meal. Ben Salem and Makkar, (2009) also reported non-significant effects on plasma protein concentrations for supplementation of lambs' diets with defatted moringa seed meal, but plasma glucose concentrations were significantly higher in lambs fed defatted moringa seed meal at 4g/head/day.

Despite limited previous studies on the effect of moringa seed meal on blood metabolites and the different forms of moringa seed meal used (kernel cake, whole seed cake, and defatted seed cake) most reports concluded that the addition of moringa seed cake had no adverse effect on blood metabolites. Furthermore, moringa seed is enriched in fatty acids of C18:1, C18:2 and C18:3 which can control cholesterol concentration in the blood (Abdel-Rahman et al., 2019; Ebeid et al., 2020). Moreover, moringa seed cake could be described as its functional effect of phytochemicals such as carotenoids, flavonoids, chlorophyll, phenolics, xanthins, cytokines, and alkaloids that play a role in reducing cholesterol concentration in blood and then in the milk of lactating animals (Babiker et al., 2017). Furthermore, moringa seed cake contains phytosterols such as β-sitosterol, which may play a good bioactive agent role in hypolipidaemic activities like cholesterol and triglycerides by up-regulating lipolytic enzyme activities or by stimulating fecal bile acid excretion, which may be the cause of the improved lipid profile in this study (Emmanuel, 2016; Pop et al., 2018).

Also, the content of anti-nutritional compounds in moringa cake such as alkaloids, glucosinolates, isothiocyanates, tannins, and saponins could be attributed to the reduction of degradable protein in the rumen (Basha et al., 2015), which could be due to protecting the protein from degradation in the rumen. Moreover, another report by Ben Salem and Makkar (2009) suggested that MSC has bioactive moieties that are known cationic proteins having antibacterial properties, and it is possible that MSC response is similar to that of monensin and other antibiotic additives and could be used to positively manipulate rumen fermentation. Also, possibly due to the interaction of cationic proteins in defatted moringa meal with the rumen microbes, thereby making them available in the intestine (Hoffmann et al., 2003; Makkar et al., 2007). The present results suggest that future work should discover the positive effects of moringa seed cake as cationic proteins and phytosterols have antibacterial properties on ruminal microbial diversity that might have a role in improving health status.

Milk yields and composition

Data in Table (4) presents the effect of supplementation of DMSC at two levels on milk yield and composition. There were insignificant differences between DMSC supplementation and control in actual milk yield, fat corrected milk (FCM), energy corrected milk (ECM), milk energy output (MJ/d), and milk component yields (g/d). However, milk energy content (MJ/kg) was significantly increased ($P = 0.045$) in groups fed on DMSC compared to control. For milk composition (g/kg), DMSC supplementation led to a significant increase in milk total solids, solids not fat, protein, and lactose. There was a significant linear relationship between the level of DMSC supplementation and the increase in milk protein, lactose, and solids not fat concentrations ($P < 0.05$). However, fat content was numerically increased ($P = 0.106$) in DMSC40 compared to the control group.

The effect of supplementation with moringa seed cake on milk production performance has not been extensively studied. This was studied in our previous work (Aboamer et al., 2020). It was found that feeding lactating ewes on whole moringa seed cake at a low level (2.5% of the concentrated diet) significantly increased milk composition and FCM yield. Moreover, other studies focused on fattening and growing lambs and goats report that using of moringa seed cake as a protein source in TMR rations improved nutrient digestibility and daily gain (Aboamer et al., 2020; Ben Salem and Makkar, 2009; EL-Hedainy et al., 2020).

Additionally, the improvement of milk composition could be due to the balanced composition of the amino acids, and high protein content (23-56%) in MSC that has low ruminal degradability, which could increase the by-pass proteins for the small intestine and improve amino acid absorption, which then goes to the udder to synthesize milk protein (Ebeid et al., 2020). Furthermore, the MSC is rich in cationic proteins and has high natural antioxidant content alongside antioxidant activity, which enhances the performance of milk yield and composition of sheep and goats (Babiker et al., 2017).

Moreover, moringa seeds have bioactive agents like riseofulvin, dechlorogriseofulvin, 8-dihydroramulosin, and mullein that have antifungal and antibacterial activity against pathogenic fungi and bacteria, and this helps the activity of favourable ruminal microbes, as a consequence, enhancing the efficiency of ruminal fermentation, digestibility, and the overall animal performance (Babiker et al., 2017; Soltan et al., 2017).

Also, feeding on MSC could reduce energy loss through bio-active components that play antibiotic feed additives like monensin to inhibit methanogenesis and then methane production (Hansen et al., 2020; Soltan et al., 2017), and this could support our findings for improving milk energy content and output.

CONCLUSION

Using moringa feed cake as a supplement at a low level might increase milk production, as indicated by the findings of this study and other published data. However, further studies are needed to uncover the optimal inclusion amount of different un-hulled and dehulled moringa seed cakes and their effect on milk production.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

NOVELTY STATEMENT

Machine-dehulled moringa seed cake, which has been processed to remove the hulls by machine, is high in protein while low in fiber. It might be included in lactating goats' diets at a low level as a feed supplement or as a cheaper protein source without any adverse effects.

AUTHORS CONTRIBUTION

All authors participated in designing the experimental plan and collecting the data. Abu Eella A.A. and Matloup O.H. participated in feeding the animals and collecting samples. Khattab I.M. and Aboamer A.A. participated in conducting and calculating in situ degradability. Ebeid, H.M, Aboamer A.A. and Hadhoud, Fatma I. participated in analyzing the samples, evaluating the results, and writing the manuscript. Aboamer, A.A. and Ebeid, H.M. participated in conducting the statistical analysis and publication of this paper. All authors contributed to reviewing this manuscript.

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