The Effects of Replacing Dry Forage With Corn Silage on Milk Yield, Composition and Fatty Acids' Profiles, Blood Metabolites, Nitrogen Balance, and Rumen Fermentation Parameters in Mahabadi Lactating Goats

Shohre Tarverdi Sarabi

Islamic Azad University

Amir Fattah (✉ Amirfattah1357@gmail.com)

Islamic Azad University <https://orcid.org/0000-0003-3141-7098>

Nader Papi

Animal Science Research Institute

Seyyed Roohollah Ebrahimi Mahmoudabad

Islamic Azad University

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Abstract

The present study was performed with the aim of investigating the effects of replacing dry forage with corn silage on performance, milk yield, composition and fatty acids' profiles, blood metabolites, nitrogen balance, and rumen fermentation parameters in Mahabadi lactating goats. For this purpose, a total of 20 lactating goats aged between 2 and 5 years old and with body weight of 45.3 ± 7.20 (DS) kg were categorized into two groups, each one containing ten goats. Experimental treatments consisted of controlling diet and dietary substitution of forage part with corn silage at 20% of dry matter. The obtained data were analyzed by the mixed model for a randomized completed design using statistical packages of SAS (2002). The replacement of dry forage with corn silage did not affect the dry matter intake (DMI), live body weight, and milk yield. Feeding corn silage, rather than dry forage, had no significant effect on milk unsaturated fatty acids, monounsaturated fatty acids, $C_{18}:1C_9$ percentages, and non-esterified fatty acids concentration, and it caused a decline in milk polyunsaturated fatty acids percentage. As well, dietary inclusion of corn silage significantly decreased plasma urea nitrogen content in goats ($P < 0.05$). Furthermore, feeding corn silage led to a significant increase in antioxidant capacity of rumen liquor ($P < 0.05$), plasma ($P < 0.01$), and milk ($P < 0.01$) of lactating goats. Of note, the dietary addition of corn silage caused no significant effects on microbial nitrogen and nitrogen balance in lactating goats. Feeding corn silage did not affect the ruminal total volatile fatty acids, acetic acid, propionic acid, and butyric acid at both periods before and after feeding. In general, results indicated that replacing dry forage with corn silage could consequently improve the antioxidant status in Mahabadi lactating goats.

1. Introduction

The provision of foodstuffs in the ruminant's industry leads farmers to incur a high cost due to the high foodstuffs' prices (USDA-ERS 2010). So, using cheaper foodstuffs is very important to modulate the foodstuffs' price (Shi et al. 2015). On the other hand, ruminants need to consume forage to maintain the optimum production and health via the ruminal environment stability. It is noteworthy that about 40 to 90% of livestock requirements in ruminant production systems are provided by forage intake (Mahanna and Chase 2003). Therefore, the decreased fibrous feedstuffs intake, especially NDF amount, in ruminants leads to the lower ruminal pH level, consequently resulting in the digestive ineffectiveness. In this regard, this then causes the decreased dry matter intake, milk yield and fat contents, and fiber digestibility (Plaizier et al. 2008). While feeding diets containing forage are necessary to maintain the maximum health and production of ruminants, dietary inclusion of fiber-rich roughage also increases methane emissions (van Gastelen et al. 2015). So, feeding starch-rich forage is recommended to reduce methane production and emissions (Hassanat et al. 2013).

Although alfalfa hay and corn silage are the two main forages used in dairy diets (NRC 2007), in developing countries, the inconsistency of forage quality as well as the shortage of high quality-forage limit the developments in the agriculture industries, particularly ruminant's industry (Khaing et al. 2015). In this regard, feeding conserved forage like ensiling is an important strategy used to overcome the inconsistent quality of forage (Khaing et al. 2015). Corn silage is considered as a major forage

component used in most dietary rations of ruminants (Khan et al. 2012). Because it is rich in starch (between 25 and 35% DM basis; NRC 2007), it provides a remarkable amount of fermentable energy to the ruminal microbial population resulting in the rises in feed intake, milk yield, and milk protein (Khaing et al. 2015), and it can also reduce methane emissions (Khan et al. 2012; Wattiaux and Karg 2004). Similarly, corn silage, which is rich in polyunsaturated fatty acids (PUFA), especially n-3 and n-6 types, has been used to alter and modulate milk fatty acid components (Dewhurst et al. 2006). Furthermore, corn silage relative to other forages is readily mechanized, stored, and finally mixed with diets (Charmley 2001; Neylon and Kung 2003). Nevertheless, the nutritive value of corn silage mostly relies on corn density, degree of maturity, hybrid, different growing conditions, the moisture level, and ensiling conditions (Satter and Reis 2012). Many factors, including aerobic deterioration, moisture content, forage composition, and the elevated silage pH level can affect corn silage quality due to the produced mycotoxins concentration leading to the abortion in dairy herds (González-Pereyra et al. 2008; Schmidt et al. 2015).

In regard to the low facilities used to dry corn hay as well as the high cost related to the produced dry forage and its storage in Iran, it seems that using silo technology is an efficient strategy. Furthermore, in the present study, we hypothesized that feeding corn silage, which is high in anthocyanin content, could improve the antioxidant status in milk of Mahabadi lactating goats. So, this study was performed to evaluate the effects of replacing dry forage with corn silage on feed intake, milk yield, composition and fatty acids profiles, blood metabolites, nitrogen balance, antioxidant capacity, and rumen fermentation parameters in Mahabadi lactating goats.

2. Materials And Methods

2.1. Animals and treatments

The present study was conducted in the Small Ruminant Station of Agricultural Research, Education and Extension Organization, Animal Science Research Institute of Iran, Karaj, Iran. Moreover, all the protocols were approved by the Agricultural Research, Education and Extension Organization, Animal Science Research Institute of Iran, and Karaj Care and Use Committee. A total of 20 lactating goats aged between 2 and 5 years old with body weight of 45.3 ± 7.20 (SD) kg were selected and then divided into two groups, each one containing ten goats in terms of their age and body weight. Thereafter, every 10 goats were randomly housed into two boxes (3m × 10m) each one containing 3 goats and one box containing 4 goats during a 56-day period. The experimental treatments were controlling diet and dietary substitution of forage part with corn silage at 20% of dry matter. Accordingly, the experimental diets were prepared in TMR ration, and formulated using the exact values obtained in terms of NRC (2007), in order to meet all the nutritional requirements of small ruminants at lactation time (Table 1). As well, the studied goats were fed with experimental diets as TMR twice, once at 8:00 AM and once at 20:00 PM, *ad libitum*. The amounts of offered feeds and orts were weighed daily. Additionally, each individual's feed intake was recorded by subtracting daily weight of offered feed from refused quantities for each group containing 3 or 4 animals. Next, it was divided by 3 or 4. Of note, all these goats had free access to water during the

experiment. As well, they were individually weighed on both days 0 and 56 at 8:00 AM after 16h deprivation. Body weight gain for goats was calculated by the final body weight minus the initial body weight.

Table 1
Ingredients and chemical composition of diets

Item	Experimental period	
	Control	Silage
<i>Ingredients (g/kg DM)</i>		
Dry alfalfa	130.00	80.00
Wheat straw	300.00	150.00
Corn silage	0.00	200.00
Barley	110.00	110.00
Corn	201.00	201.00
Wheat bran	173.00	173.00
Soybean meal	70.00	70.00
Vitamin and mineral premix [†]	5.00	5.00
Salt	3.00	3.00
Calcium carbonate	8.00	8.00
Chemical composition (%)		
Dry matter	92.44	78.70
Crude protein	11.70	11.70
Ash	6.20	6.70
NDF	39.70	30.5
Crude fat	1.69	2.18
Non fibrous carbohydrate	41.10	49.00
Metabolizable energy (MJ/kg DM)	10.70	10.70
Calcium	8.31	8.17
Phosphorous	3.59	3.80
[†] Vitamin and mineral premix provided the following per kilogram of diet: vitamin A (from vitamin A acetate), 750000 IU; cholecalciferol, 200000 IU; vitamin E (from dl- α -tocopherol acetate), 4000 IU. Mg, 20 g; Na, 50 g; Mn, 12 g; Zn, 17 g; Fe, 6 g; Cu, 3.5 g; Ca, 18 g; I [from Ca (IO ₃) ₂ •H ₂ O], 150 mg; Co, 50 mg, and Se, 10 mg.		

2.2. Laboratory analysis

The chemical compositions, including dry matter, crude protein, calcium and phosphorous of forage parts, and concentrates used in this trial were determined using the AOAC methods (AOAC 2006). Afterward, the diet samples were oven-dried for 48 h at 70 °C, ground using 2 mm sieve, and finally analyzed for dry matter (DM, method 930.15), ash (method 924.05), calcium (method 927.02), and phosphorus (method 965.17) using AOAC (2006). Nitrogen (N) was measured by the Kjeldahl procedure with a Kjeltec-UDK 126A and then, the amount of N was multiplied by 6.25, in order to calculate CP (984.13) (AOAC 2006). Moreover, the aNDF was measured using heat-resistant α -amylase without adding any sodium sulfite (Van Soest et al. 1991). Metabolizable energy values of the diets were also calculated based on the feed composition tables of the National Research Council (NRC 2007).

2.3. Milk yield and composition

Goats were handily milked twice daily, once at 06:00 and once at 18:00 h. Thereafter, Milk samples (50 ml) were collected from the sequential a.m. and p.m. The milking process was performed every two weeks after parturition during the experiment using prelabeled plastic vials treated with preservative (potassium dichromate, Merck) and the samples were then stored at 4°C. Subsequently, these milk samples were analyzed in terms of pH, somatic cell counts, fat, crude protein, solids, solids non-fat, and lactose by infrared spectroscopy (Milk Oscan, 134 BN Foss Electric, Hillerød, Denmark; AOAC 2006). Furthermore, *De novo* fatty acids, mixed fatty acids, and free fatty acids were evaluated as g/100g of milk using Fourier transform infrared spectroscopy (FTIR) of CombiScope FTIR 600 HP (Delta Instruments, Drachten, The Netherlands) based on the partial least squares prediction models, as explained in a study by Woolpert et al. (2016). In addition, as previously described by Bach et al. (2019), *de novo* relative percentages were assessed by calculating the proportions of *de novo* fatty acids to total milk comprising of *de novo*, mixed, and preformed fatty acids. Next, Milk urea nitrogen content was assessed using a differential pH technique (Luzzana and Giardino 1999). As well, Lipids were extracted from the obtained milk samples using the method explained in a previous study by Folch et al. (1957). Notably, fatty acids profiles were determined according to a study by Feng et al. (2004). Finally, the levels of beta hydroxyl butyrate, non-esterified fatty acids, and acetone were measured using a clinical autoanalyzer (Hitachi 7020, Tokyo, Japan).

2.4. Plasma metabolites

To determine some biochemical plasma parameters, five goats from each treatment group were randomly selected at 7:30 AM and then bled from jugular vein, at the end of the trial period. Thereafter, the obtained blood samples were centrifuged (Sigma-16-P-Germany) at 3000 × g for 20 min at 4°C and the plasma samples were kept at -20°C. The concentrations of triglyceride, cholesterol, glucose, total protein, albumin, and urea nitrogen were measured using commercial assay kits attained from Farasamed Diagnostics (Tehran, Iran) via a spectrophotometer (Genova; Jenway, Barloworld Scientific Ltd., Dunmow, Essex, UK).

2.5. Ruminal parameters

At the end of the trial, by passing 56 days from kidding, five goats were randomly selected and then rumen liquors (about 50 ml) were taken from the esophageal tube once before and once 3 h after the feeding time in the morning. Subsequently, the rumen pH level was measured using a mobile pH meter (Rocky Mount NC 27894-USA). To determine the ammonia nitrogen concentration, 5 ml of each one of the rumen fluid samples was mixed with 5 ml of 0.2N HCL, and then centrifuged (Sigma-2-16-Germany). Finally, the filtered ruminal fluid was kept at -20°C, and Ammonia nitrogen concentration was also measured by micro kjeldahl apparatus, as explained earlier by Nasserian (1996).

To measure volatile fatty acid concentration, 5 ml of the filtered ruminal fluid was mixed with 1 ml of 20% of meta-phosphoric acid, and then centrifuged at 4000 × g for 10 min. Afterward, 2-ethylbutyric acid was added to approximately 2 ml of the supernatant and stored at -20°C. As previously described in a study by Bhandari et al. (2007), the concentrations of volatile fatty acids, acetic acid, propionic acid, butyric acid, valeric acid, and iso valeric acid were determined through gas chromatography (Agilent 6890 Silica Capillary Column BPX-70).

2.6. Antioxidant capacity

At this stage, the rumen liquor, blood plasma, and milk samples were collected to evaluate the total antioxidant capacity using the ferric reducing antioxidant power method (Benzie and Strain, 1996). Accordingly, this was done via the reduced ferric tripyridyltriazine (Fe^{3+} -TPTZ) complex to ferrous (Fe^{2+}) form, which consequently produced an intense blue color with an absorbance rate of 593nm using a spectrophotometer (Genova; Jenway, Barloworld Scientific Ltd., Dunmow, Essex, UK).

2.7. Microbial N synthesis and N retention

In this phase, five goats from each treatment group were randomly selected and then housed in individual metabolic cages (0.6m × 1.2m) during 21 days (14 days for being adapted and 7 days for sample collection) at the end of the trial period (started from day 57). From each animal, feces and urine samples were separately collected daily for one week. The feces collected from each animal were completely mixed and a sample weighing 100 g was obtained at last, which was kept in the freezer. The urine sample of each animal was collected daily in containers with 100 ml of 10% sulfuric acid during a 7-day period. The urine was weighed daily and 10% of the urine amount was then taken and diluted 4 folds (ratio of urine to water: 1:4) in order to prevent purine derivatives (e.g. uric acid) sedimentation. Finally, all these feces and urine samples were mixed and one sample per each goat was used for the chemical analyses.

Total purine derivatives excreted in the urine, including allantoin, uric acid, xanthine, and hypoxanthine, were evaluated using a spectrophotometer. As well, the urinary allantoin content was assessed at an absorbance rate of 522nm after conversion to phenyl hydrazine. Uric acid concentration was also determined in the optical density on 293nm after performing degradation of uric acid to allantoin via uricase (Product No. U-9375, Sigma-Aldrich, Darmstadt, Germany). Moreover, Xanthine and hypoxanthine contents were evaluated at an absorbance of 293 nm after conversion to uric acid via xanthine oxidase enzyme (Product No. X-1875, Sigma-Aldrich, Darmstadt, Germany). As explained in a study by Chen and

Gomes (Chen and Gomes 1995), the amount of the absorbed exogenous purines was assessed by the excreted urinary purine derivatives using the following equation:

$$X = (Y - 0.385 W^{0.75}) / 0.85$$

Where X is the absorbed exogenous purine, Y stands for the excreted purine derivatives, and W is the live weight.

The microbial protein synthesis was calculated by determining the urinary excreted and the absorbed purine derivatives by the following equation (Chen and Gomes 1995):

$$Y = 0.84X + (0.15W^{0.75}e^{-0.25X})$$

Where Y stands for the excreted purine derivatives, X shows the absorbed purine derivatives, $(0.15W^{0.75}e^{-0.25X})$ shows purine derivatives with internal origin, and W is metabolic weight.

The nitrogen balance was also calculated as the differences between total nitrogen intake and the excreted nitrogen in both urine and feces samples (Philips and Rao 2001). The concentrations of nitrogen in feed, feces, and urine samples were measured by a micro kjeldahl apparatus (AOAC 2006).

2.8. Statistical analysis

All the obtained data were analyzed as a mixed model using the statistical package of SAS (2002) for completing the randomized design. The statistical significance level was set at $p \leq 0.05$. The statistical model for data analyses was as follows:

$$Y_{ijk} = \mu + T_i + A_j + W_k + e_{ijk}$$

Where Y_{ij} is observation, μ is the general mean, T_i is the effect of treatment, A_j is the effect of age, W_k is the effect of body weight, and e_{ijkl} is the standard error of the mean.

3. Results

The effects of the dietary addition of corn silage on feed intake, milk yield, and milk composition analyses in Mahabadi goats during lactation phase are presented in Table 2. The dietary inclusion of corn silage caused no significant effects on feed intake, milk yield, fat, protein, lactose, solids, solids non-fat, total cell numbers, de novo relative fats, the mixed relative fats, performed relative fats percentages, and free fatty acids.

Table 2
the effects of replacing dry forage with corn silage on performance, milk yield, and milk composition of Mahabadi lactating goats

Item	Treatments		SEM	P-value level
	Control	Corn silage		
Initial body weight (kg)	45.2	44.8	2.20	0.90
Final body weight (kg)	46.8	45.0	2.24	0.58
Dry matter intake (kg DM/day)	1706.7	1832.3	107.96	0.50
Milk yield (g/day)	795.1	876.8	109.5	0.60
Fat (%)	4.57	4.27	0.14	0.19
Protein (%)	4.58	4.49	0.11	0.54
Fat to protein ratio	1.13	1.20	0.04	0.19
Lactose (%)	4.57	4.61	0.04	0.56
Solids (%)	15.29	15.37	0.29	0.84
Solids non-fat (%)	10.02	9.97	0.09	0.69
Total cell numbers ($\times 10^3$ cell/ml)	1040.20	671.93	242.48	0.31
Urea nitrogen (mg/100 g)	15.48 ^a	13.96 ^b	0.45	0.03
<i>De novo</i> relative fats (%)	42.93	41.58	0.63	0.16
Mixed relative fats (%)	23.40	24.27	0.61	0.33
Preformed relative fats (%)	33.67	34.15	0.96	0.73
Free fatty acids (meq/100 g fat)	0.92	1.01	0.05	0.26
^{a-b} Means with no common superscript within each column are significantly (P<0.05) different.				

The inclusion of corn silage in diet, instead of dry alfalfa/straw, significantly (P<0.03) decreased the milk urea nitrogen concentration in lactation goats (Table 2).

In the present study, milk fat percentage by passing four weeks from the time of lactation significantly (P<0.01) decreased in goats fed with a diet containing corn silage compared to those fed with diet without any corn silage (as shown in supplementary Table 1 as shown in Online Resource).

As indicated in Table 3, although feeding with a diet containing corn silage had no significant effects on milk C_{16:0}, and C_{18:0} percentages, as well as beta hydroxy butyrate, and acetone concentrations during the present trial, it significantly caused the decreased saturated fatty acids, and PUFA (P=0.05) percentages,

as well as the increased monounsaturated fatty acids, C₁₈:1C₉, and non-esterified fatty acids contents (P<0.05) in milk within six weeks after lactation (supplementary Table 2 as shown in Online Resource).

Table 3
the effects of replacing dry forage with corn silage milk fatty acids profile and serum ketone bodies in Mahabadi lactating goats

Item	Treatments		SEM	P-value level
	Control	Corn silage		
Saturated fatty acids (% total fatty acids)	79.51	78.37	2.08	0.54
Unsaturated fatty acids (%total fatty acids)	20.49	21.63	1.42	0.34
Monounsaturated fatty acids (%)	13.12	14.41	1.26	0.26
Polyunsaturated fatty acids (%)	7.37	7.22	0.26	0.68
C16:0 (%)	24.10	25.63	1.00	0.30
C18:0 (%)	11.05	11.30	0.44	0.69
C18:1C9 (%)	8.52	10.41	1.08	0.24
Non esterified fatty acids (µeq/L)	480.58	530.91	33.42	0.31
Beta hydroxy butyrate (mmol/L)	0.12	0.13	0.01	0.44
Acetone (mmol/L)	0.22	0.21	0.01	0.38

The dietary inclusion of corn silage, instead of dry forages, did not affect plasma glucose, triglyceride, cholesterol, total protein, and albumin concentrations, as well as the albumin to globulin ratio in lactating goats (Table 4).

Table 4

the effects of replacing dry forage with corn silage on some biochemical blood plasma parameters in Mahabadi lactating goats

Item	Treatments		SEM	P-value level
	Control	Corn silage		
Glucose (mg/dl)	46.75	46.99	1.02	0.87
Triglyceride (mg/dl)	27.39	26.02	1.59	0.60
Cholesterol (mg/dl)	54.03	54.64	4.38	0.92
Total protein (g/dl)	5.13	5.21	0.60	0.93
Albumin (g/dl)	2.43	2.36	0.16	0.75
Albumin to globulin ratio	2.55	1.53	0.90	0.48
Urea nitrogen (mg/dl)	16.15 ^a	14.20 ^b	0.31	0.01
^{a-b} Means with no common superscript within each column are significantly ($P<0.05$) different.				

The plasma urea nitrogen content was markedly ($P<0.01$) decreased in goats fed with corn silage compared to those fed with the control diet (Table 4).

As shown in Table 5, the dietary inclusion of corn silage caused no significant effects on creatinine, total purine derivatives, the excreted purine derivatives, the absorbed purine derivatives, microbial nitrogen, nitrogen intake, feces nitrogen, urine nitrogen, milk nitrogen, and nitrogen retention contents in lactating goats when compared to those who were fed with the control diet.

Table 5
the effects of replacing dry forage with corn silage on urine purine derivatives, microbial nitrogen, and nitrogen balance in Mahabadi lactating goats

Item	Treatments		SEM	P-value level
	Control	Corn silage		
Creatinine (mmol/L)	0.88	0.98	0.10	0.10
Total purine derivatives (mmol/L)	13.8	14.1	3.30	0.20
The excreted purine derivatives (mmol/L)	2.08	2.11	0.20	0.12
The absorbed purine derivatives (mmol/L)	1.86	1.98	0.23	0.14
Microbial nitrogen (g/d)	8.45	9.71	0.77	0.11
Nitrogen intake (g/d)	29.0	30.9	0.76	0.39
Feces nitrogen (g/d)	14.1	12.0	0.54	0.38
Urine nitrogen (g/d)	6.90	7.80	0.19	0.11
Milk nitrogen (g/d)	5.00	6.60	0.45	0.45
Nitrogen retention (g/d)	3.00	4.50	0.39	0.15

Feeding diet contains corn silage, dissimilar to the diet containing dry forages, had no significant effects on ruminal volatile fatty acids, acetic acid, propionic acids, butyric acid, iso valeric acid, valeric acid, and isobutiric acid percentages, as well as acetic acid to propionic acid ratio at both before and three hours after the feeding times (Table 6). Additionally, feeding corn silage in diet significantly ($P<0.05$) lowered pH level in rumen within three hours before the feeding time and also tended to decrease ($P=0.07$) the ruminal ammonia nitrogen concentration in lactating goats by passing three hours from the feeding time (Table 6).

Table 6
the effects of replacing dry forage with corn silage on ruminal fermentation parameters in
Mahabadi lactating goats

Item	Treatments		SEM	P-value level
	Control	Corn silage		
Before feeding				
pH	7.05 ^a	6.72 ^b	0.09	0.02
Ammonia nitrogen (mg/dl)	17.96	18.96	0.97	0.11
Total volatile fatty acids (mmol/L)	58.24	73.80	6.44	0.13
Acetic acid (%)	60.99	62.00	1.27	0.58
Propionic acid (%)	18.83	15.96	1.44	0.21
Butyric acid (%)	11.75	12.97	0.90	0.37
Isovaleric acid (%)	2.90	3.20	0.28	0.46
Valeric acid (%)	2.54	2.42	0.21	0.69
Isobutyric acid (%)	2.99	3.45	0.31	0.79
Acetic acid to propionic acid ratio	3.56	4.05	0.33	0.31
Three hours after feeding				
pH	6.34	6.21	0.09	0.32
Ammonia nitrogen (mg/dl)	21.26	17.01	1.51	0.07
Total volatile fatty acids (mmol/L)	95.60	102.45	6.85	0.51
Acetic acid (%)	56.39	54.69	1.38	0.42
Propionic acid (%)	26.01	26.83	2.08	0.79
Butyric acid (%)	12.06	13.33	0.91	0.33
Isovaleric acid (%)	1.51	1.46	0.16	0.83
Valeric acid (%)	2.63	2.34	0.20	0.33
Isobutyric acid (%)	1.40	1.35	0.15	0.80
Acetic acid to propionic acid ratio	2.39	2.13	0.24	0.48
^{a-b} Means with no common superscript within each column are significantly (P<0.05) different.				

The effects of feeding corn silage on antioxidant capacity in lactating goats are shown in Table 7. In this study, the dietary addition of corn silage significantly enhanced the antioxidant capacity in rumen liquor ($P<0.05$), plasma ($P<0.01$), and milk ($P<0.01$) in Mahabadi lactating goats compared to the control diet.

Table 7
the effects of replacing dry forage with corn silage on antioxidant capacity in rumen liquor, plasma, and milk in Mahabadi lactating goats

Antioxidant capacity (mmol Fe+2/L)	Treatments		SEM	P-value level
	Control	Corn silage		
Rumen liquor	1.76 ^b	1.96 ^a	0.06	0.03
Plasma	0.28 ^b	0.32 ^a	0.08	0.01
Milk	1.38 ^b	1.72 ^a	0.05	0.01
^{a-b} Means with no common superscript within each column are significantly ($P<0.05$) different.				

4. Discussions

Milk yield and compositions including fat, protein, lactose, solids, solids non-fat, total cell numbers, de novo relative fats, the mixed relative fats, performed relative fats percentages, and free fatty acids were unaffected by dietary inclusion of corn silage in Mahabadi goats. In line with our observations, Colombini et al. (2012) in their study have reported that milk fat, protein, and lactose percentages were not affected by feeding corn silage in lactating Holstein cows.

The replacement of corn silage instead of dry alfalfa/straw in diet led to a decline in the milk urea nitrogen concentration in goats. Correspondingly, this might be related to the simultaneous availability of both energy (diet contains corn silage as the energy source; Khaing et al. 2015) and protein in the rumen, which led to the synthesis of microbial protein by bacteria. It is noteworthy that Milk urea nitrogen concentration is used as a nutritional indicator (Giovanetti et al. 2019). Several studies have previously found that milk urea nitrogen content in ruminants is correlated with dietary crude protein, rumen degradable protein, rumen undegradable protein, and the simultaneous availability of both substrate and N components in the rumen (Munyaneza et al. 2017). Moreover, it has been demonstrated that dietary crude protein in the rumen is degraded to ammonia by microbes, then absorbed into the portal blood, and finally converted to urea in the liver; in turn, urea readily diffuses from the blood into the milk (McCormick et al. 1999). Bacteria need the energy source, especially fermentable carbohydrate, in order to capture the ammonia in the rumen, which leads to microbial protein synthesis (Broderick et al. 2003).

Dietary addition of corn silage caused a decrease in milk fat percentage by passing four weeks from the time of lactation. In ruminants, both the concentration and composition of milk fat were affected by the diet (Palmquist 2006). Accordingly, this might be ascribable to the lower NDF content in diets containing corn silage (Table 1). Additionally, by including readily-fermentable carbohydrates (rich in starch) in diet, a

decrease in milk fat concentration was observed (Yang et al. 2019). Our findings are in line with those of the study by Brito and Broderick (2006), which showed that a decline in alfalfa silage to corn silage ratio in diet resulted in a significant decrease in milk fat percentage in dairy cows.

While feeding corn silage in diet didn't affect milk C_{16:0}, and C_{18:0} percentages, it led to a decrease in saturated fatty acids, and PUFA percentages and a rise in monounsaturated fatty acids, C_{18:1}C₉, and non-esterified fatty acids contents in milk within six weeks after lactation. Dewhurst et al. (2006) and Kliem et al. (2008) in their studies have reported that ensiled forages, known as the PUFA sources, can also modulate milk fatty acids composition. It is reported that feeding forage or concentrate rich in starch is related to the increased unsaturated fatty acids with 18 carbons and the decreased milk fatty acid with 6 to 16 carbons (Tripathi 2014). In another study, Glasser et al. (2013) have found that corn silage contains a low level of linolenic acid along with high levels of both α -linoleic acid and oleic acid. The reasonable explanation for the difference between milk fatty acids profiles may possibly be that the mobilization of body fat reserves resulted from the high energy demands for the high milk production (Yang et al. 2019). In addition, Oleic acid is known as a marker of fat mobilization (Nogalski et al. 2012).

In this regard, several researchers have previously reported that the dietary inclusion of corn silages in dairy cows can increase *Trans* fatty acid contents as well as decreasing n-3 level, leading to high n-6 to n-3 ratio of milk fat (Kliem et al. 2008; Shingfield et al. 2005). Of note, an increase in non-esterified fatty acids concentration might be related to the mobilization of body fat reserves resulted from higher milk production compared to feed intake (Tarverdi Sarabi et al. 2021), leading to a negative energy balance (Fiore et al., 2017).

Dietary inclusion of corn silage, instead of dry alfalfa/straw, had no effects on plasma glucose, triglyceride, total protein, and albumin concentrations in Mahabadi goats. Our findings are in agreement with those reported in the study by Wang et al. (2016), which showed that the dietary inclusion of corn silage has no effect plasma glucose, total protein contents, and blood urea nitrogen contents, but it enhanced plasma triglyceride concentration in Saanen goats.

Feeding corn silage in diet instead of dry alfalfa/straw decreased plasma urea nitrogen content in lactating goats. Accordingly, this may probably be due to the simultaneous availability of both energy (corn silage as the energy source; Khaing et al. 2015) and protein in the rumen, which resulted in the decreased ruminal N content. As well, it was considered that the dietary N to energy ratio, forage intake level, protein degradability, and dietary carbohydrate level can affect blood urea nitrogen content in ruminants (Hammond et al. 1994). In addition, blood urea nitrogen, which is correlated with the solubility of fed nitrogen ingredients, is known as a good marker of rumen ammonia concentrations (Polat et al. 2009). Our observations are in contrary to those reported in the research by Polat et al. (2009), as they observed that replacement of corn silage had no significant effect on blood urea nitrogen content in lactating dairy cows.

Inclusion of corn silage in diet didn't affect creatinine, total purine derivatives, the excreted purine derivatives, urine nitrogen, milk nitrogen, and nitrogen retention concentrations in goats. In another study, Gregorini et al. (2010) have noticed that corn silage is used to dilute N intake, decrease N intake, and decrease urinary N excretion. Purine derivative excretion is also considered as a marker for microbial protein outflow from the rumen (Tas and Susenbeth 2007). In contrary to our findings, Al-Marashdeh et al. (2015) in their study have observed that feeding corn silage at 3 kg of DM lowered urinary N excretion compared to those fed with herbage only.

The ruminal volatile fatty acids, acetic acid, propionic acids, butyric acid, iso valeric acid, valeric acid, and isobutyric acid percentages, as well as acetic acid to propionic acid ratio at both before and three hours after the feeding times were unaffected in goats fed on corn silage instead of dry alfalfa/straw. In line with our findings, van Gastelen et al. (2015) have also observed that feeding corn silage did not affect volatile fatty acid concentration, and acetate, propionate, butyrate, valerate, and iso valerate proportions in dairy cows when compared to those fed with silage grass. Our observations are in contrast with those of the Lopes et al.'s study (2015), reporting that dietary inclusion of corn silage resulted in the decreased pH value and acetate to propionate ratio, along with the increased propionate proportion in rumen of dairy cows when compared to those fed with alfalfa silage. In another research, Peyrat et al. (2016) have reported that the dietary inclusion of corn silage at maturity time led to the increased ruminal acetate proportion as well as the decreased ruminal propionate, butyrate, and valerate proportions in dairy cows. Arndt et al. (2015) in their study have shown that feeding the high ratio alfalfa silage to corn silage led to the increased acetate proportion and acetate to propionate ratio, as well as the declined propionate proportion in rumen in dairy cows.

Dietary addition of corn silage instead of dry alfalfa/straw lowered the ruminal ammonia nitrogen content in goats by passing three hours from the feeding time. This might be due to the better simultaneous availability of N components and energy substrates, which consequently resulted in higher microbial protein production (Broderick 2003).

Antioxidant capacity in rumen liquor, plasma, and milk in Mahabadi lactating goats was fortified by feeding corn silage instead of dry alfalfa/straw. Anthocyanin, which is a polyphenol, existed in corn silage and it possesses an antioxidant activity (Hosoda et al. 2009; Sawai 2012). In agreement with our findings, Hosoda et al. (2012) have reported that the dietary inclusion of corn silage led to a rise in plasma antioxidant function in sheep. Similarly, in another study, Matsuba et al. (2019) have reported that feeding corn silage significantly enhanced blood superoxide dismutase concentration in dairy cows.

5. Conclusion

This study showed that replacing dry forage with corn silage resulted in the enhanced the antioxidant capacity in rumen liquor, plasma, and milk in Mahabadi lactating goats. Therefore, it is recommended corn silage be included in the diet of lactating goats to improve milk quality.

Declarations

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Conflict of interest

The authors declare that they have no conflict of interest.

Ethics approval

All the protocols for animal handling and experimental procedures were conducted according to the guidelines approved by the Agricultural Research, Education and Extension Organization, Animal Science Research Institute of Iran, and Karaj Care and Use Committee.

Consent to participate

Not applicable.

Consent for publication

All authors agree to submit the paper for publication in the Tropical Animal Health and Production.

Data availability and material

All data will be made available on reasonable request.

Code availability

Not applicable.

Authors' contribution

Tarverdi Sarabi Sh conducted the study. Fattah A, Papi N, and Ebrahimi Mahmoudabad SR planned the study and did statistical analysis and editing. All the authors read and approved the manuscript.

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