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Optimal Forage Choices for Lactating Murciano-Granadina Dairy Goats: Feed Intake, Behavior Time Budget, Milk Production, and Blood Metabolites

Research Article

M.H. Khabbazan[1,2], H. Amanlou[2], D. Zahmatkesh[2], E. Mahjoubi[2] and A. Nikkhah[1,3*]

[1] Ferdows Pars Agriculture and Livestock Holding Co., Tehran, Iran
[2] Department of Animal Science, University of Zanjan, Zanjan, Iran
[3] Department of Animal Science, Faculty of Veterinary Medicine, University of Tehran, Tehran, Iran

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*Correspondence E-mail: anikkha@yahoo.com

ABSTRACT

It is important to optimize forage choices for improved milk production and goat health under intensive raising systems. Our hypothesis was that alfalfa hay (AH), corn silage (CS), and wheat straw (WS) can be utilized by lactating Murciano-Granadina goats towards efficient milk production and that feed intake and efficiency and milk quantity and quality responses as well as metabolic parameters would differ among the forage sources. The objective was to determine effects of feeding different major forages on feed intake, behavior time budget, milk production and composition, and circulating blood metabolites in lactating Murciano-Granadina goats. Thirty lactating goats were used in a completely randomized design study with three treatments including diets containing 1) WS, 2) AH, or 3) CS at 40.3% of diet dry matter. Treatment diets were formulated to be isoenergetic (ME) and isonitrogenous (CP). Ten goats were assigned to each treatment. Forage source affected ($P<0.01$) dry matter intake (DMI), such that the highest intake was for CS (1904 g/d) and the lowest intake was for WS (1406 g/d) with AH being intermediate (1674 g/d). The yields of raw and fat-corrected milk, milk protein, lactose, and solids-nonfat were greater ($P<0.01$) for CS than for other two forages. Milk contents of fat, total solids, urea nitrogen, unsaturated fatty acids, polyunsaturated fatty acids, and blood concentrations of total proteins were greater ($P<0.05$) for AH than for other forages. Milk somatic cell counts tended to be lower ($P<0.10$) for CS than for AH and WS. Treatments did not affect ($P>0.10$) times spent standing, lying and ruminating, and blood concentrations of glucose, albumin, and non-esterified fatty acids. Total protein concentrations in serum were, however, greater ($P<0.05$) for AH than for CS and WS. In conclusion, different forage choices can be fed to lactating Murciano-Granadina goats with different aims; CS for increased milk yield, AH for improved milk fat content, and WS for lower feed cost. Changes in forage cost and availability, production systems and strategies, and consumers' demand will determine how to optimize forage choices for lactating goats.

KEY WORDS feeding behavior, forage, metabolite, milk, Murciano-Granadina goat.

INTRODUCTION

The world commercial goat population and milk production have been increasing (Miller and Christopher, 2019). This change is mainly because of goat adaptability to different climates and the increasing demand for goat meat and milk products (Clark and Garcia, 2017). Goat milk contains functional compounds that enhance human immune system and overall health (Silvani *et al.* 2019). Goat milk is enriched with functional peptides, conjugated linoleic acid, and healthy oligosaccharides that can immensely benefit human immunity and health (Park *et al.* 2007; Assis *et al.*

2016). Murciano-Granadina goats are dairy ruminants with many unanswered questions in their responses to dietary and forage treatments.

The fluctuating trends in feed and forage availability and costs have led ruminant farmers to contemplate optimization of forage choices (FAO, 2011). Goats are usually capable in utilizing lower quality forages (Askar *et al.* 2016). In few recent studies (Romero-Huelva *et al.* 2017; Marcos *et al.* 2020), alfalfa hay was compared with different by-products and local feeds with no significant effects found on rumen fermentation and milk production or composition. Murciano-Granadina goats were capable to utilize low quality fiber sources towards milk production (Fernandez *et al.* 2019). However, to our knowledge, no definitive comparisons have been documented among major commercial forage sources including CS, AH, and WS in diets for Murciano-Granadina goats. Wheat straw is a relatively cheap and highly available forage choice in many countries (El-Meccawi *et al.* 2009). Corn silage is a high-energy forage that needs to be studied if it can be successfully fed to lactating goats at significant amounts (Desnatie *et al.* 2020). It is of economic importance to study if CS and WS can replace AH as a protein-rich forage in diets well balanced for energy and protein. Our main hypothesis was that alfalfa hay, corn silage, and wheat straw can be utilized by lactating Murciano-Granadina goats towards efficient milk production and that feed intake and efficiency and milk yield and quality responses as well as metabolic parameters would differ among the forage sources. For instance, CS would increase milk yield and AH would improve milk fat. Therefore, the objective of this study was to determine comparative effects of feeding diets based on different forage choices (i.e., CS, AH, and WS) on feed intake and behavior, milk production and composition, and blood concentrations of selected metabolites.

MATERIALS AND METHODS

Animals and treatments

This experiment was conducted in Magsal Commercial Dairy Goat Farm (Qazvin, Iran) from September through December 2019. Thirty second-parity Murciano-Granadina goats (190±3 days in milk; 2±0.03 kg/d milk yield) were used in a completely randomized design study with three treatments. The treatments were diets containing 1) WS, 2) AH or 3) CS at 40.3% of diet dry matter. Each treatment was fed to 10 goats. The experimental period was 10 weeks long including 2 weeks of adaptation and 8 weeks of sampling and data collection. Goats were housed in individual pens (1.5×2 m) indoor with controlled temperature and humidity. All animals were cared for according to the guidelines of the Iranian Council on Animal Care (1995).

Diets were formulated based on NRC (2007) requirements and using the Small Ruminant Nutrition System software program (SRNS, 2012). Diets were formulated for mid and late lactation goats producing 2 kg of milk daily. To enable rigorous comparisons among forage sources, treatment diets were balanced to be isoenergetic and isonitrogenous (Table 1). As a result, treatment diets had similar crude protein (CP, %) and metabolizable energy (ME, Mcal/kg) contents. Treatment diets had also similar forage to concentrate ratios (40.3:59.7). The concentrate portion of the rations was similarly ground (1 mm mean particle size) for all treatments. Diets were fed as total mixed rations and delivered 6 times daily. Diets were fed *ad libitum* for 5-10% daily orts. Goats had free access to fresh water all the time. Goats were milked twice daily at 07:00 and 19:00 h in a milking parlor (Westfalia Dema Tron 70).

Feed and milk sampling and analysis

Feed and milk (from a.m. and p.m. milkings) samples were collected weekly for later analytical measurements. Feed was analyzed for neutral detergent fiber (NDF) (Van Soest *et al.* 1991), crude protein, ether extract, and ash (AOAC, 2002). Goats were weighed weekly just before the morning feed delivery. The amounts of total mixed ration(s) (TMRs) delivered and orts remained were recorded daily to calculate daily dry matter intake (DMI) by subtracting the DM content (dried at 100 degrees Celsius for 24 h) of orts from that of TMRs. Milk samples were analyzed for fat, protein, lactose, total solids, solids-nonfat, somatic cell count, urea nitrogen, total fatty acids, unsaturated fatty acids, monounsaturated fatty acids, and polyunsaturated fatty acids using an analytical machine (CombiScope FTIR 600, Delta Instruments, Drachten, The Netherlands). The fat-corrected milk yield (3.5% fat) was also calculated: fat-corrected milk (FCM)= milk yield × (0.634+0.1046×fat) (Curro *et al.* 2019).

Behavior time budget, and blood sampling and analysis

To determine goat behavior time budgets; eating, ruminating, and resting times were observed and recorded by technical individuals on days 30 and 50 of the experiment in two 24-h period. The above-mentioned activities were observed and recorded every 5 min with the assumption that each activity would persist for 5 min (Yang *et al.* 2000; Kowsar *et al.* 2008). Blood samples were taken at 08:00 h on d 1, 30, and 56 using vacuum tubes to obtain serum. Blood tubes were then centrifuged at 3000 rpm for 15 min at room temperature. Serum was transferred to 1.5 mL tubes and stored at -20 ˚C for later analysis of circulating metabolites. Serum was analyzed for non-esterified fatty acids (NEFA) (Rendox, UK), glucose, albumin, and total proteins (Pars Azmoon, Iran) by using commercial kits.

Table 1 Dietary ingredients and calculated chemical composition (% of DM)

Ingredient	Alfalfa hay	Corn silage	Wheat straw
Corn silage-immature (no ears) medium	0.00	40.27	0.00
Alfalfa hay-early bloom	40.27	0.00	0.00
Wheat straw-fine chop	0.00	0.00	40.25
Barley grain-finely Ground	7.19	6.28	9.99
Corn grain-finely ground	16.18	18.56	23.07
Beet pulp-dehy. pellet	4.00	2.86	0.00
Soybean meal-44 finely ground	3.95	12.61	11.42
Soybean-whole roasted medium	1.81	1.81	1.81
Canola meal-fine	2.43	2.43	1.43
Corn gluten meal 60% CP fine	0.00	0.00	0.00
Wheat bran-finely ground	20.94	10.76	0.00
Calcium carbonate	0.48	1.67	1.14
Magnesium oxide	0.19	0.19	0.19
Salt	0.33	0.33	0.29
Mineral supplement[1]	0.76	0.76	0.76
Sodium bicarbonate	0.67	0.67	0.67
Bentonite	0.67	0.67	0.67
Toxin binder	0.14	0.14	0.14
Megalac	0.00	0.00	5.71
Calcium phosphate (mono)	0.00	0.00	1.05
Urea	0.00	0.00	1.43
Chemical composition (DM basis)			
Neutral detergent fiber (NDF)	33.53	37.13	38.96
Crude protein (CP)	15.11	15.08	15.10
Metabolizable energy, Mcal/kg	2.35	2.33	2.30
Fat	3.3	3.31	8.25
Ash	9.64	11.5	9.87
Calcium	1.03	1.06	0.91
Phosphorus	0.58	0.54	0.5
Dietary forage, % of diet DM	40.3	40.3	40.2

[1] Provided (per kg of diet): vitamin A: 750000 IU; vitamin D: 204000 IU; vitamin E: 5400 IU; monencin: 2000 mg; Ca: 250 g; Mg: 35700 mg; Co: 17 mg; Cu: 1650 mg; I: 52 mg; Mn: 3200 mg; Se: 45 mg and Zn: 9350 mg.

Statistical analysis

The data were analyzed with Mixed Models Procedures of SAS (2004) program. Treatment effect was considered fixed while animal and residuals were considered random. Model for repeated measures of blood metabolites consisted of treatment, week, and their interaction (treatment×week) as fixed effects and animal within treatment plus residuals as random effects. Initial measurements for feed intake, milk production and blood metabolites were modeled as covariate. Least square means were estimated using Maximum Likelihood method. For repeated measures analysis, the covariance structure with the best fit criteria was utilized (i.e., autoregressive). Significant treatment effects were declared at $P < 0.05$. Trends for significance were declared at $P < 0.10$.

RESULTS AND DISCUSSION

Feed intake, behavior time budget, and body weight

This study provides new information on comparative effects of three major commercial forage sources (CS, AH, and WS) on feed intake, behavior time budget, productivity, and circulating blood metabolites of lactating Murciano-Granadina goats. Data for body weight (BW), feed intake, and feeding behavior are presented in Table 2. Body weight and its changes were similar among treatments, implying that nutrient partitioning towards tissue accretion or depletion was not different among treatments during the study, since goats were in late lactation. However, DMI was 228 g greater for CS than for AH ($P<0.05$). Dry matter intake for WS was the least (1406 g/d) and lower than that for other forage choices ($P<0.05$).

The lower consumption of the WS containing diet was likely because of its greater indigestible cell wall and fat content. Comparing avocado pulp and alfalfa, Evan *et al.* (2020) found a decrease in DMI of Murciano-Granadina goats fed avocado pulp. This may highlight differences in the physical effectiveness of fiber from various forage sources. These researchers used palm fat and barley straw to balance their rations. In another experiment, feeding alfalfa instead of by-products increased DMI of goats (Romero-Huelva *et al.* 2017).

Table 2 Body weight, dry matter intake (DMI), and behavior time budget (standing, resting and ruminating times) in dairy goats fed the experimental diets

Item	Treatment[1]			SEM	P-value
	Wheat Straw	Alfalfa hay	Corn silage		
Body weight (kg)	35.58	36.25	35.34	0.748	0.235
Body weight changes, kg/wk	-0.200	-0.276	0.122	0.252	0.323
DMI (g/day)	1406.0^c	1674.0^b	1904.0^a	29.63	< 0.001
Standing time (min/d)	516.1	575.6	600.0	37.84	0.314
Resting time (min/d)	459.4	434.4	414.0	25.35	0.441
Ruminating time (min/d)	384.4	350.6	346.0	22.82	0.432

[1] Treatment diets contained 40.3% (DM basis) either of forages.

The means within the same row with at least one common letter, do not have significant difference (P>0.05).

SEM: standard error of the means.

However, CS was not used in their study. Decreased DMI for diets with WS and AH compared with CS could at least partially be related to the increased dietary fat and indigestible cell wall in the former diets. Corn silage is higher in energy than is WS. As a result, dietary fat was included in the WS diet. The negative impact of fats on concentrate intake has also been shown (Sanz Sampelayo *et al.* 2002). Nonetheless, the possible confounding effects of different ingredients used to formulate the three treatment diets should be considered in data interpretation. The results of the current study may suggest that CS is more palatable and likely more digestible than AH and WS. With similar NDF content, a diet with more digestible NDF has increased DMI (Marcos *et al.* 2020). Because of lower DMI and yet competitive milk yield, feed efficiency (FCM/DMI) was significantly higher for WS than for AH and CS (Table 3). These findings may indicate that WS could be an optimal forage source from a feed efficiency (i.e., feed cost) perspective. The current study is unique because the treatment diets were formulated to be isoenergetic and isonitrogenous. However, it should be noted that different digestibility due to nutrient interactions might affect the amount of energy and protein utilized by the animals. In addition, comparisons were made among three major and commercially available forage sources.

Ruminating, standing, and resting times were not different among treatments (Table 2, P>0.10). These data suggest that despite the differences in forage nutritional characteristics, digestibility, and intake, ruminating time was similar among treatments. Goats are different than sheep and cattle in terms of feed preference and selection (Lu, 1988; Reid *et al.* 1990). The ruminating times observed in the current experiment (Table 2) are in line with the literature reports (Lu *et al.* 2005; Beatriz *et al.* 2019). Thus, the behavior data would indicate that goats consumed the CS diet at greater amounts while they still had adequate, similar, and reasonable ruminating activity when compared to WS and AH. However, these data should be interpreted cautiously given that goats are different than cattle and sheep in preference for forage type, particle size, palatability, moisture, digestibility, and passage rate (Allen, 2001; Beauchemin *et al.* 1994).

Milk production and composition

As presented in Table 3, raw and fat-corrected milk yields were greater for CS than for AH and WS (P<0.01). This was most likely a result of increased DMI. However, milk yield was not different for AH *vs.* WS (P>0.10). Similar to milk volume, daily yields of milk protein, lactose, and total solids were also greater for CS than for other treatments (Table 3).

This could be a result of increased milk volume and unchanged milk contents of protein and lactose for CS. Milk fat content was greater (P<0.01) for AH but milk fat yield tended (P<0.10) to be greater for CS than for other treatments. These data suggest that certain combinations of AH and CS may be optimal for simultaneous improvements in milk fat content and yield, which will need future experiments to be accurately determined. In light of the isoenergetic nature of the experimental diets, increased yields of milk and milk solids by feeding CS instead of AH and WS suggests that nutrient and energy availability for milk production was higher for goats on CS than for goats on other treatments. As such, total dry matter intake (i.e., energy and protein intake) was considerably greater for CS than for other treatments (Table 2). The increased milk fat content for AH compared to orange leaves has been previously reported (Fernandez *et al.* 2019).

These authors reported increased percentage of acetic acid in rumen when AH was fed. This change may have happened in the current experiment as well. Milk urea nitrogen was greater (P<0.05) for AH than for CS and WS (Table 3), suggesting that dietary protein was more degradable in AH than in other dietary treatments. This data indicates that feeding lactating goats solely AH may not be most desirable and that feeding CS alongside may favor rumen and reproductive health. Future studies are required to address this issue. The increased milk fat content in the AH group could at least partly be because of the milk concentration effect.

Table 3 Milk production and composition for dairy goats fed the experimental diets

Item	**Treatment[1]**			**SEM**	**P-value**
	Wheat straw	Alfalfa hay	Corn silage		
Raw milk, g/day	852.7^{b}	801.3^{b}	1050.7^{a}	63.05	0.004
3.5% FCM[2], g/day	1287.1^{b}	1292.8^{b}	1540.6^{a}	89.80	< 0.001
3.5% FCM/DMI	0.978^{a}	0.858^{b}	0.827^{b}	0.044	0.004
Fat, g/day	71.16	74.62	80.75	40.87	0.056
Protein, g/day	38.0^{b}	35.0^{b}	43.0^{a}	2.45	0.002
Lactose, g/day	37.97^{b}	35.26^{b}	46.52^{a}	2.89	< 0.001
Total solids, g/day	144.27^{b}	138.91^{b}	168.26^{a}	9.15	0.003
Solids-nonfat, g/day	84.5	78.62	134.96	34.67	0.115
Fat (%)	8.20^{b}	9.39^{a}	7.82^{b}	0.42	0.002
Protein (%)	4.52	4.49	4.18	0.12	0.117
Lactose (%)	4.43	4.41	4.45	0.04	0.742
Total solids (%)	16.76^{b}	17.48^{a}	16.16^{b}	0.31	0.018
SNF (%)	9.77	9.65	9.47	0.12	0.211
Somatic cell count (×1000)	1156	1625	866	227	0.075
Urea N, mg/dL	16.28^{b}	19.85^{a}	15.82^{b}	0.69	< 0.001
De novo FA (%)	2.36	2.47	2.38	0.09	0.623
Free FA (%)	3.19^{b}	3.63^{a}	3.12^{b}	0.14	0.026
Unsaturated fatty acids (%)	6.35^{b}	6.60^{a}	6.05^{b}	0.15	0.002
Monounsaturated fatty acids (%)	4.52	4.49	4.18	0.12	0.117
Polyunsaturated fatty acids (%)	1.82^{b}	2.11^{a}	1.87^{b}	0.06	0.004

[1] Treatment diets contained 40.3% (DM basis) either of forages.

[2] Fat corrected milk (FCM)= milk yield × (0.634+0.1046×fat) (Curro *et al.* 2019).

The means within the same row with at least one common letter, do not have significant difference (P>0.05).

SEM: standard error of the means.

Table 4 Blood serum metabolites concentrations for dairy goats fed the experimental diets

Item	**Treatment[1]**			**SEM**	**P-value**
	Wheat Straw	Alfalfa hay	Corn silage		
Glucose (mg/dL)	57.0	58.0	59.0	1.42	0.42
Non-esterified fatty acids (NEFA) (mmol/L)	0.197	0.272	0.174	0.05	0.14
Total protein (g/dL)	7.66^{b}	8.01^{a}	7.58^{b}	0.19	0.03
Albumin (g/dL)	4.10	4.14	4.10	0.08	0.87

[1] Treatment diets contained 40.3% (DM basis) either of forages.

The means within the same row with at least one common letter, do not have significant difference (P>0.05).

SEM: standard error of the means.

This would mean that with reduced milk yield, milk fat content would increase, as was happened for AH in the current study. Milk fat content ranges of the present study were greater than those reported by others (Sanz Sampelayo *et al.* 2007; Romero-Huelva *et al.* 2017; Evan *et al.* 2020).

This difference in milk fat content could be due to a multitude of factors including differences in climate (between Iran and Europe), forage nature and nutritional characteristics, milk production level, and stage of lactation. The inter-treatment differences found in the type of milk fatty acids could be because of dissimilarities in fatty acid profiles among the three forage sources as well as the likely different rumen conditions. The latter might have altered rumen biohydrogenation of fatty acids (Leiber *et al.* 2005; Vasta *et al.* 2008).

Goats on AH had greater (P<0.01) milk unsaturated and polyunsaturated fatty acids concentrations than did goats on other forage treatments (Table 3). This could have human health implications and is in line with increased milk fat content in AH-fed goats. This improvement in milk fatty acids profile may be due to the active plant compounds in alfalfa including phenolic compounds and saponins and their effects on rumen biohydrogenation. Milk somatic cell counts tended to be lower (P<0.10) for CS than for AH and WS, reiterating that feeding solely AH and WS may not be optimal from a mammary gland health perspective, as well. This data provides foundation for upcoming experiments to investigate different combinations of these major forages towards optimizing rumen and host metabolism, milk production and composition, and goat health indices.

As presented in Table 4, treatments did not affect circulating concentrations of glucose, albumin and non-esterified fatty acids (NEFA) in blood (P>0.10). Glucose and NEFA values are usually interpreted as indices for energy status of experimental animals. Similar glucose and NEFE concentrations in blood for the three forage treatments could be evaluated in light of the fact that goats were in mid and late lactation and thus were not in negative energy balance. As a result, they may have not been metabolically sensitive enough to respond to treatments at this stage of lactation. Blood concentrations of total proteins were greater for AH than for other treatments (P<0.05; Table 4). Blood total proteins were increased when goats selected younger and more digestible parts of plants (Casamassima *et al.* 2007). Nonetheless, the increased blood total proteins concentrations for AH in the current study might also be related to unknown active and functional compound in AH. Such an effect could also be mediated via increased ruminal undegradable proteins. Blood total proteins may not be affected by dietary protein and goat breed (Sahlu *et al.* 1993; Whitney *et al.* 2017). Future experiments are required to enable more inclusive interpretation of blood data in lactating Murciano-Granadina goats.

CONCLUSION

Murciano-Granadina goats possess high adaptability to a variety of climates. Findings of this study suggest that lactating Murciano-Granadina goats are capable to utilize different forage sources including AH, CS and WS. However, CS leads to greater raw and fat-corrected milk yields, whereas AH increases milk fat content. For greater feed efficiency and lower feed cost and where more available, WS may be used in Murciano-Granadina goat diets. To improve milk yield and fat content and yield simultaneously, certain combinations of AH and CS may be required. Determining this will require future experimentation. Future experiments could also investigate forage choice effects on milk fatty acids profile and other functional compounds.

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