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Effect of source and level of sulfur supplementation on mohair characteristics and growth in male goat kids

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Abstract In the present study, twenty-five male goat kids (20±2.5 kg BW) were used during an 84- day experimental period to determine the effect of source and level of sulfur supplementation on mohair characteristics and performance. Experimental diets were diets containing 0.18% (as control), 0.24% and 0.34% DM inorganic or organic sulfur. The data were analyzed as a 2 × 2 factorial design. Methionine and sulfur flower were used as organic and inorganic sources of sulfur, respectively. Diets containing inorganic sulfur increased greasy and clean mohair production and staple length when compared with organic sulfur ($P<0.02$). No significant differences in performance parameters including the dry matter intake (DMI), final body weight (FBW), average daily gain (ADG), feed conversion ratio (FCR) and water intake (WI) were observed between the experimental diets. Diets containing 0.24% DM organic sulfur increased apparent crude protein digestibility when compared with the control diet. The results showed that 0.18% sulfur (DM basis) may be adequate to meet the sulfur requirement of growing male goat kids. Feeding greater levels of sulfur had negligible effect on mohair characteristics and performance.

Keywords: goat kids, sulfur supplementation, mohair characteristics, performance

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Introduction

Mohair is a natural fiber and usually refers to the silk-like fabric or yarn obtained from the hair of Angora goats. The term mohair and also wool is usually limited to describe the fibrous protein derived from the specialized skin cells called follicles. Mohair growth requires all the important nutrients including amino acids, carbohydrates, minerals and vitamins, each playing an important role in mohair growth and the components of fiber growth (length and diameter). Mohair growth requires little energy (Reis, 1992) however the major component of mohair is fiber protein, composed of more than 20 amino acids. These amino acids contribute to protein fiber and therefore, mohair growth is a function of the amount of amino acids reaching the small intestine (Hynd and Allden, 1985). In particular, requirements for the sulfur-containing amino acids (cysteine and methionine) are high and sulfur-containing amino acids are first limiting in terms of wool protein synthesis (Qi and Lupton, 1994).

Qi (1988) reviewed the relationship between fiber production and sulfur nutrition in sheep and found that animal fiber contained 2.7 to 5.4% sulfur and that sulfur amino acids could limit fiber production even if dietary sulfur needs were met. Qi (1988) also, demonstrated that the addition of inorganic sulfur in the sheep diet improved wool growth and wool quality. Qi et al. (1994) suggested that ruminal microbial protein is unable to supply adequate sulfur amino acids for mohair growth. However, inorganic sulfur supplements could be incorporated into methionine in rumen microbial protein, and supplied sulfur amino acid for wool growth (Block et al., 1951).

Reis et al. (1990) using different mixtures of amino acids reported that limiting methionine intake resulted in reduced wool length, growth rate and diameter in sheep. Skin and fiber (wool, mohair) places heavy demands on the utilization of circulating sulfur amino acids. Block et al. (1951) calculated that 80% of the total free sulfur amino acids are used for fiber growth. Supplementary diets of Angora goats with appropriate levels of methionine improved fiber production (Souri et al., 1998). Also, methionine supplementation increased the rate of cell division and proliferation in wool follicles (Hynd, 1988). Information on the sulfur requirements of growing kids for mohair growth and responses in performance of mohair goat kids with sulfur supplementation is limited. Therefore, the present study was conducted with growing mohair kids to determine the influence of 0.24% DM inorganic or organic and 0.34% DM inorganic or organic sulfur on mohair characteristics, growth performance and nutrient digestibility.

Material and methods

Animal management

Markhoz goat is a dual purpose goat in Iran reared for meat and mohair. Twenty-five Markhoz mohair male kids (11–12 months old) with an average weight of 20±2.5 kg were assigned to one of five treatments in a completely randomized design. The goats were confined in individual cages (110 × 100 cm) equipped with water and feed troughs. The goats were identified, vaccinated against enterotoxaemia and treated against internal parasites at the beginning of the experiment. The goats were fed the experimental diet ad *libitum*. During the first 21 days, the animals were allowed to adapt to the experimental diets. The last 84 days were used for data collection. The animals were weighed in the morning prior to feeding at 21-d intervals, and the average daily gain (ADG) and feed conversion ratio (FCR) were calculated.

Experimental diets

The control diet contained 0.18% sulfur (NRC, 2006). Methionine (Evonic- Degussa GmbH, Hanau, Germany) and sulfur (Misagh sulfur powder, cyclic S_8) as organic and inorganic source of sulfur respectively, were added to the control diet to supply 0.24 and 0.34% DM sulfur. Methionine and sulfur contained 21.04 and 26.13% DM sulfur, respectively. The experimental diets were offered as total mixed rations twice daily at 08:00 and 16:00 h in amounts to ensure 10% orts. The amounts of feed offered and refused were recorded daily and feeds offered were dried at 105 °C for 24 h to determine DM intake. Clean drinking water was available at all times and water intake was recorded daily. Prior to formulation of the experimental diets, metabolizable energy (Menke et al., 1979), and chemical composition (AOAC, 2005) of the feedstuffs were determined. The diets (Table 1) were formulated according to the NRC (2006) guidelines for a weight gain of 150 g/animal/day.

Mohair samples collection and analysis

Goat kids were shorn at the beginning and the end of the experiment and the greasy fleece was weighed. A 10 × 10 cm^2 sample was collected from the mid-section half

Table 1. Ingredients and chemical composition of the diets

		Sulfur levels (%DM)			
		0.		0.34	
Ingredients (g/kg DM)	Control	Inorganic	Organic	Inorganic	Organic
Alfalfa	300.0	300.0	300.0	300.0	300.00
Wheat straw	50.0	45.0	45.1	40.0	36.0
Wheat bran	100.0	100.0	100.0	100.0	100.0
Soy bean meal	170.0	170.0	170.0	170.0	170.0
Barley	352.0	354.0	354.0	356.0	359.0
$CaCO_3$	8.3	8.3	8.3	8.3	8.3
Minerals and vitamins[1]	20.0	20.0	20.0	20.0	20.0
Methionine[2]	-	-	2.6	-	7.6
Sulfur flower[3]	-	2.2	-	6.1	-
Chemical composition					
Metabolizable energy (MJ/kg DM)	10.04	10.00	10.04	10.00	10.04
Crude protein (g/kg DM)	124.2	124.2	124.2	124.2	124.2
Calcium (g/kg DM)	4.95	4.95	4.95	4.95	4.95
Phosphorus (g/kg DM)	4.16	4.16	4.16	4.16	4.16
Sulfur (g/kg DM)	1.8	2.4	2.4	3.4	3.4
Neutral detergent fiber (g/kg DM)	287.4	284.0	284.0	280.0	277.0
Acid detergent fiber (g/kg DM)	175.4	172.8	172.9	170.1	167.9
Nitrogen sulfur(N:S) ratio	11.02	8.26	8.26	5.83	5.83

[1]Mineral and vitamin supplement contained: Vitamin A, 6 000 000 IU/kg; Vitamin D3, 1 200 000 IU/kg; Vitamin E, 5 g/kg; Vitamin K3, 1 g/kg; Vitamin B1, 1 g/kg; Vitamin B2, 2 g/kg; Vitamin B12, 8 mg/kg; Vitamin B6, 1 g/kg; pantothenic acid, 3 g/kg; folic acid, 250 mg/kg; niacin amide, 5 g/kg; biotin, 3 mg/kg; choline chloride, 15 g/kg; methionine, 15 g/kg; manganese oxide, 10 g/kg; ferrous sulfate, 4 g/kg; potassium iodide, 60 mg/kg; cobalt sulfate, 20 mg/kg; copper sulfate, 3 g/kg; zinc sulfate, 2 g/kg; and sodium selenite, 5 g/kg. [2]Methionine had 21.04% DM sulfur. [3]Sulfur flower had 26.13% DM sulfur.

way between the back and belly, weighed, extracted using xylene, dried at 60°C for 1 h, and weighted again (Grégoire et al., 1996). Fiber diameter was measured using a projection microscope (Sherlock et al., 2001). Fiber staple and fiber length were measured by a ruler on 50 kemps and 200 normal fibers. Medullated fibers were counted when measuring fiber diameter and the percentage was calculated by dividing the number of medullated fibers by the total number of fibers measured (Grégoire et al., 1996).

Digestibility trial

In the last week of the experiment, feces were collected daily for 5 days from each goat. Each fecal sample was mixed and a 10% subsample from each collection bulked over the 5-day period. The total amount of feed offered and refused by the animals were recorded and subsamples bulked for subsequent analysis. Samples of feed ingredients, feed refusals and feces were dried in a forced-air oven (60 °C), ground to pass a 2-mm screen and analyzed for DM, organic matter (OM) and crude protein (CP) according to AOAC (2005).

Statistical analysis

The experimental design was a 2 × 2 factorial design with a control diet outside the factorial. The data were analyzed as a 2 × 2 factorial design without the control diet by ANOVA using the GLM procedure of SAS (2001) and the means were compared using the Duncan's multiple range test. The Dunnett's test was used to check for significant differences among the means of the control diet and factorial.

Results

Mohair characteristics

Mohair characteristics were not affected by the level of dietary sulfur (Table 2). Source of sulfur significantly affected (P<0.05) mohair characteristics with the exception of fiber diameter and kemp fiber. Inorganic sulfur resulted in higher greasy and clean mohair production, staple length and non-medullated fiber compared with organic sulfur (P<0.05). Inclusion of 0.24 and 0.34% DM sulfur in the diet had no significant effect on mohair characteristics (P>0.05). No significant effect of sulfur level by source was observed.

Mohair characteristics of goat kids fed control, 0.24 and 0.34% DM inorganic or organic sulfur are shown in Table 2. The clean mohair production, staple length, fiber length, fiber diameter and kemp fiber of goat kids fed 0.24% and 0.34% DM inorganic or organic were similar to that of control diet. Also, non-medulated and medulated fibers were similar (P>0.05) between goat kids fed 0.24% and 0.34% DM inorganic or organic and that of control goat kids.

Sources of sulfur significantly affected (P<0.05) mohair characteristics with the exception of fiber diameter and kemp fiber. Inclusion of inorganic sulfur in goat kid diets resulted in higher greasy and clean mohair production, staple length and non-medulated fiber when compared with diet inclusion of organic sulfur (P<0.05). Inclusion of 0.24 and 0.34% DM sulfur in the diet had no significant effect on mohair characteristics (P>0.05). No significant effect of different sulfur levels × sources was observed (P>0.05).

Performance and nutrient digestibility

Performance parameters and nutrient digestibility were not affected by the inclusion of 0.24% and 0.34% DM inorganic or organic sulfur (Table 3). Inclusion of 0.24% DM inorganic or organic and 0.34% DM inorganic sulfur in the diet decreased organic matter digestibility compared with the control diet (P<0.05). Diet containing 0.24% DM inorganic sulfur significantly decreased CP digestibility compared with the control diet. Inclusion of 0.24 and 0.34% DM sulfur in the diet did not affect the performance. The sources of sulfur did not affect the performance and nutrient digestibility with the exception of organic matter digestibility. Organic matter digestibility in the goat kids fed organic sulfur were higher than those fed inorganic sulfur (P<0.05). Crude protein digestibility and organic matter digestibility in the goat kids fed 0.34% DM sulfur were higher than that of kids fed 0.24% DM sulfur. No significant interaction was found between sulfur level and source.

Discussion

Mohair characteristics

Clean mohair production was not influenced by level of organic or inorganic sulfur. In contrast to our findings, Bassett et al. (1982) showed that mohair growth increased when 0.1 and 0.2% of encapsulated methionine was included in the diet. These discrepancies may be attributed to different form of methionine. In the current study, we added rumen-unprotected methionine. It has been proven that simply adding sulfur amino acids to the diet is not effective, because rumen microorganisms degrade these amino acids and introduction of methionine into the rumen increased total methionine degradation (Mbanzamihigo et al., 1997). Therefore, it can be

Table 2. Effects of source and dietary level of sulfur on mohair characteristics in Markhoz goat male kids

Sulfur level (%DM)	Sources of sulfur[1]	Greasy mohair (g/d)	Clean mohair (g/d)	Staple length (cm)	Fiber length (cm)	Fiber diameter (µm)	Non-Medullated fiber (%)	Medullated fiber (%)	Kemp fiber (%)
0.24	Inorganic	4.60^{ab}	4.05^{ab}	8.66	11.62^{a}	27.83	95.06	4.43	0.49
0.24	Organic	3.81^{ab}	3.37^{ab}	7.46	9.69^{b}	26.24	91.24	7.28	1.47
0.34	Inorganic	5.42^{a}	4.82^{a}	9.46	11.69^{a}	27.93	90.73	7.49	1.77
0.34	Organic	3.54^{b}	2.99^{b}	8.27	10.64^{ab}	28.48	90.47	7.77	1.75
0.18 (control)		4.6	4.06	7.74	9.37	28.82	94.3	4.31	1.38
Pooled SEM		0.26	0.24	0.3	0.33	0.38	0.87	0.81	0.2
0.24	-	4.2	3.71	8.06	10.66	27.03	90.65	8.35	0.98
0.34	-	4.48	3.9	8.88	11.16	28.2	90.64	7.63	1.76
-	Inorganic	5.05^{a}	4.43^{a}	9.03^{a}	11.65^{a}	27.88	92.90^{a}	5.96^{b}	1.13
-	Organic	3.67^{b}	3.18^{b}	7.82^{b}	10.11^{b}	27.36	88.35^{b}	10.35^{a}	1.61
Source of variation					*P* values				
Control vs factorial		0.17	0.13	0.25	0.52	0.24	0.31	0.49	0.29
Sulfur level		0.62	0.7	0.19	0.45	0.21	0.97	0.35	0.11
Source of sulfur		0.02	0.02	0.04	0.04	0.57	0.28	0.41	0.31
Sulfur level × source interaction		0.33	0.26	0.98	0.52	0.25	0.35	0.49	0.3

[1]Inorganic sulfur= sulfur flower, Organic sulfur= methionine. [a–c] Means with common letter (s) within the same column do not differ significantly by Duncan's multiple-range test ($P< 0.05$).

*$P < 0.05$; different from control (Dunnett's test).

Table 3. Performance and nutrient digestibility of male goat kids fed with diets containing different source and level of sulfur supplementation

		Performance					Digestibility (%)		
Sulfur level (%DM)	Sources of sulfur[1]	Dry matter intake (g/d)	Final body Weight (kg)	Daily gain (g/d)	Feed conversion ratio	Water intake (l/d)	Dry matter digestibility	Organic matter digestibility	Crude protein digestibility
0.24	Inorganic	1410	38	123.6	11.68	2.56	47.04	63.24[*b]	47.83[*b]
0.24	Organic	1482	36.1	112.2	13.37	2.59	44.89	63.22[*b]	51.61[b]
0.34	Inorganic	1450	37.8	124.2	12.21	3.17	54.85	64.29[*b]	58.11[a]
0.34	Organic	1473	38.4	122.8	12.05	2.77	51.42	69.02[a]	61.14[a]
0.18 (control)		1450	38.8	133.2	11.2	3.25	47.39	69.29*	58.83*
Pooled SEM		27.62	0.64	4.41	0.42	0.15	1.58	0.79	1.51
0.24	-	1461.7	37.05	117.9	12.53	2.57	45.96	63.23[b]	49.72[b]
0.34	-	1446	38.1	123.5	12.13	3.01	53.48	66.74[a]	59.63[a]
-	Inorganic	1430	37.9	123.9	11.94	2.86	50.94	63.76[b]	52.97
-	Organic	1477	37.25	117.5	12.71	2.66	47.5	66.21[a]	56.37
Source of variation						*P* values			
Control vs factorial		0.87	0.73	0.8	0.64	0.59	0.2	0.006	0.001
Sulfur level		0.81	0.5	0.58	0.68	0.31	0.06	0.007	0.003
Source of sulfur		0.48	0.67	0.53	0.44	0.62	0.42	0.006	0.07
Sulfur level × Source of sulfur		0.72	0.42	0.62	0.35	0.56	0.85	0.006	0.82

[1]Inorganic sulfur: sulfur flower, Organic sulfur= methionine.. [a–c]Means with common letter (s) within the same column do not differ significantly by Duncan's multiple-range test ($P < 0.05$).
*$P < 0.05$; different from control (Dunnett's test).

inferred that similar greasy and clean mohair of goats fed 0.34% DM methionine and 0.24% DM inorganic sulfur in our study could be due to the extensive degradation of methionine by the rumen microorganisms.

Our results showed that greasy and clean mohair of goat kids fed methionine numerically were lower than that of the control ($P > 0.05$). Masters et al. (1993) indicated that lack of sulfur containing amino acids is unlikely to be limiting to wool growth although arginine, lysine or threonine deficiencies may be limiting for wool growth. It has also been shown that the histone protein is rich in lysine and is important for active cell division (Sahlu and Fernandez, 1992). In the current study, the lysine level of the experimental diets was constant; therefore, it can be concluded that an increase in the dietary methionine level might cause to increase lysine requirement. Also, an amino acid imbalance for mohair production (Sahlu and Fernandez, 1992) and synthesis of the inner root sheath protein of the fiber resulted in lower production of greasy and clean mohair when methionine was added to the experimental diets (Reis and Colebrook, 1972). However, there is a lack of knowledge on the effect of amino acid imbalance on mohair production in goats fed on 'normal' diets.

Goat kids fed inorganic sulfur produced 9.78 and 9.11% more greasy and clean mohair, respectively, compared with the goat kids not receiving sulfur supplement. These values agreed with the data obtained by Qi et al. (1994) who found that adding sulfate to the basal diet increased mohair production. Similarly, Qi (1998) found that sheep supplemented with inorganic sulfur produced 17% more wool than the unsupplemented sheep. Carneiro et al. (2000) studied the effect of dietary inorganic sulfur on the amino acid concentrations in ruminal bacteria of goats and reported that as dietary sulfur level increased, cysteine concentrations in bacterial DM changed quadratically, and cysteine as a percentage of total amino acids increased linearly. Inorganic sulfur supplement incorporated into cystine and methionine of rumen microorganism protein resulted in higher greasy and clean mohair production in goat kids (Reis et al., 1990). Also, Hale and Garrigus (1953) reported that labeled cystine appeared in wool proteins following the feeding of labeled elemental sulfur and labeled sodium sulfate. The mode of action of sulfur amino acids and inorganic sulfur in promoting fiber production was reviewed by Qi and Lupton (1994) who concluded that cyst(e)ine may be limiting for keratin synthesis, because inorganic sulfur can be used as a substrate for keratin synthesis. The mechanism might include the specific effect of sulfur containing amino acid as a stimulator of mitotic activity in the follicular bulb (Reis, 1967). Other possible mechanisms include increased production of co-factors important in protein and energy metabolism and stimulation of sulfhydryl group. Also, methionine may be directed away from the fiber follicle and be used in the synthesis of the inner root sheath protein of the fiber (Sahlu and Fernandez, 1992).

The staple length, fiber length and fiber diameter were not affected by the level and source of sulfur when compared to that of the control group (Table 2). In agreement with these findings, it was reported that neither organic (Reis et al., 1990) nor inorganic (Nezamidoust et al., 2012) sulfur affected the fiber length. Similarly, Qi *et al*. (1993) determined mohair response to diets containing 0.16% , 0.23%, 0.29%, or 0.34% sulfur (DM basis) and found that mohair diameter, medullated fiber and kemp fiber were unaffected by sulfur supplementation. However, in contrast to our finding, Reis (1992) found when wool growth is increased by a nutritional manipulation, fiber diameter automatically increases; an increase in fiber diameter reduces the quality and thereby the value of a given weight of wool. This study showed that it is possible to increase mohair production while holding mohair diameter constant through inorganic sulfur supplementation.

Performance and digestibility of nutrients

Dry matter intake, FBW, ADG and WI were not influenced by organic or inorganic sulfur supplementation. Also, results of the current study showed that 0.18% sulfur may be adequate to meet the sulfur requirement of growing male goat kids. These findings are in agreement with those of Qi et al. (1994) who demonstrated that dietary DM should contain a minimum of 0.18% sulfur for growing goats, and that a N:S ratio of 10.4: 1.0 was recommended. Results of the present study are in agreement with Qi et al. (1993) who found that adding sulfate to the basal diet of goats did not affect the feed intake and body weight gain. Our result showed that the recommendation of NRC (2006) for sulfur (a N:S ratio of 10.4:1.0) was adequate to maximize growth performance by Angora goats. In contrast to these finding, Qi et al. (1993) in Angora kids showed that supplementation of diet with 0.20% DM sulfur increased ADG, DMI and gain to feed ratio in comparison to lower level (0.11% DM sulfur).

In the present experiment dietary supplementation of sulfur did not alter dry matter digestibility. This result supported the data of Qi et al. (1993) who reported that digestibility of dry matter was not altered by sulfur content of the diet. In contrast to our finding, inclusion of methionine in the goat kid diets, compared to inorganic sulfur, increased the *in vitro* but not the *in vivo* DM digestibility (Spears et al., 1976).

Inclusion of organic sulfur in the diets increased organic matter digestibility compared to inorganic sulfur. In agreement with these findings, Gil et al. (1973) observed that sulfur amino acids increased the *in vitro* organic matter digestibility, while inorganic sulfur had no effect. They suggested that the conversion of inorganic sulfur to sulfur-containing amino acids was a slow process that limited the potential of microbial protein synthesis while sulfur amino acids stimulated bacterial growth by providing a precursor for rapid microbial proliferation. It is also probable that inorganic sulfur might be absorbed from the rumen and become unavailable to the rumen microorganisms. In contrast to our findings, addition of inorganic sulfur to the diet improved organic matter digestibility in sheep (Morrison et al., 1990). This may be explained by differences in the basal diet composition and animal species. The crude protein digestibility of goats fed 0.34% DM sulfur was higher than that of 0.24% DM sulfur diet. According to the present data, providing sulfur as methionine might stimulate protein digestion more efficiently compared with the inorganic sulfur.

Conclusions

The National Research Council recommendation for sulfur (0.18% DM) seems to be adequate in meeting the sulfur requirements of growing Markhoz goat kids for mohair production, performance and nutrient digestibility. However, inorganic sulfur somewhat was more effective than organic sulfur in improving performance. Further research is needed to verify the effect of sulfur level and source on growing goat kids.

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چکیده در تحقیق حاضر، ۲۴ راس بزغاله نر (میانگین وزن بدن ۲/۵ ± ۲۰) در طول یک دوره آزمایشی ۸۴ روزه، به منظور تعیین تاثیر منبع و سطح مکمل گوگرد بر مشخصات موهر و عملکرد استفاده شد. جیره‌های آزمایشی حاوی ۰/۱۸٪ (به عنوان جیره شاهد)، ۰/۲۴٪ و ۰/۳۴٪ ماده خشک گوگرد آلی و معدنی بودند. داده در قالب یک طرح فاکتوریل ۲×۲ تجزیه تحلیل شدند. متیونین و گوگرد به ترتیب به عنوان منابع آلی و معدنی استفاده شدند. در جیره‌های حاوی گوگرد معدنی، تولید موهر شسته و موهر نشسته و طول دسته الیاف در مقایسه با گل گوگرد آلی افزایش یافت (P<۰/۰۵). اختلاف معنی داری در پارامترهای عملکرد شامل ماده خشک مصرفی، وزن بدن نهایی، میانگین افزایش وزن روزانه، ضریب تبدیل خوراک و آب مصرفی میان جیره‌های آزمایشی مشاهده نشد. در جیره‌های حاوی ۰/۲۴٪ ماده خشک گوگرد آلی قابلیت هضم ظاهری پروتئین خام در مقایسه با جیره شاهد افزایش یافت (P<۰/۰۵). نتایج حاصل از این مطالعه نشان داد که ۰/۱۸٪ ماده خشک گوگرد، سطح مناسب جهت تامین احتیاجات گوگرد در بزغاله‌های در حال رشد می‌باشد.تغذیه سطوح بالاتر گوگرد تاثیر جزیی بر مشخصات موهر و عملکرد داشت.