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Small Ruminant Research 15 (1994) 19–29

Small Ruminant Research

Effects of sulfate supplementation on performance, acid–base balance, and nutrient metabolism in Angora kids

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Accepted 5 December 1993

Abstract

Twelve Angora goat kids (BW: mean ± SE = 18.1 + 0.6 kg; castrated males) were individually fed isonitrogenous and isocaloric diets containing 0.11 (basal), 0.20, 0.28 or 0.38% S of dietary DM (added as $CaSO_4$). During the 8-wk growth phase, sulfate supplementation up to 0.20% S in the diet increased average daily gain (ADG) by 44%, dry matter intake (DMI) by 17%, and feed conversion efficiency (FE, ADG/DMI) by 23% compared with average Angora kids fed the other diets. Clean mohair production was numerically highest for kids fed the 0.28% S diet, but mohair fiber diameter was not affected ($P > 0.20$) by added S. Mohair staple length tended to increase quadratically ($P < 0.20$) with sulfate supplementation. Average daily gain ($P < 0.05$) and DMI ($P < 0.0001$) were lower for Angora than for Alpine kids (70 vs. 95 g and 762 vs. 1125 g/d, respectively), but FE was higher ($P > 0.20$) for Angora than Alpine kids. Plasma free cysteine was quadratically increased by S supplementation in Angora kids. Blood pH did not differ between breeds. Blood HCO_3^-, total CO_2 content, pCO_2, base excess in extra-cellular fluids, and standard bicarbonate were lower ($P < 0.05$) in Angora than in Alpine kids, but blood partial pressure of O_2 and oxygen saturation were higher ($P < 0.05$) in Angora than in Alpine kids, perhaps due to increased heat dissipation via respiration by Angora kids. Plasma glucose, urinary outputs of creatinine and uric acid were lower ($P < 0.05$), and plasma free cysteine concentration higher ($P < 0.01$) for Angora than for Alpine kids. Ruminal L-lactate concentration ($P < 0.001$) and purine N content in isolated bacteria ($P < 0.01$) were lower, but ruminal NH_3-N content ($P < 0.10$) was higher, and ruminal sulfide-S content ($P < 0.20$) tended to be higher for Angora than for Alpine kids. Angora kids were faunated, whereas Alpine kids were fauna-free. The N/S ratio in isolated rumen bacteria was lower ($P < 0.10$) for Angora than for Alpine kids. Calculated by regression, ADG was maximum with 0.22% S (N/S = 10.4:1) for Angora kids vs. 0.21% S for Alpine kids.

Keywords: Goat; Sulfur; Growth; Angora; Nutrient metabolism

1. Introduction

Sulfur metabolism and requirements of adult Angora goats and lactating Alpine goats were evaluated previously (Qi et al., 1992a,b,c). Differences between Angora and Alpine goats were detected in S metabolism and requirements, and in plasma and ruminal responses to added S. However, because effects of experimental diets were confounded with management, results could not be compared directly. Therefore, we conducted an additional trial using 12 Angora kids to:

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SSDI 0921-4488(93)E0140-N

(1) determine S requirement for growth; (2) evaluate effects of dietary S levels on acid–base balance, blood and ruminal metabolites; (3) quantify effects of S supplementation on DMI and digestibilities of DM, OM and ADF, and N utilization; (4) monitor and compare ruminal microbial populations and effects on ruminal and blood metabolites; and (5) evaluate mohair yield and quality. The methods for determination of S requirement and evaluation of plasma and ruminal metabolites were presented previously (Qi et al., 1993). This paper will focus on the effects of sulfate supplementation in Angora kids and compare responses between Angora and Alpine kids to sulfate supplementation.

2. Materials and methods

2.1. Animals and diets

Goat kids were castrated 3 weeks after birth and weaned at age 75 d and 17 kg BW. One month after weaning, 12 Angora kids (18.1 ± 0.6 kg) were selected. Kids were blocked according to age, and randomly assigned to one of four diets in a randomized complete block design (Cochran and Cox, 1957). The trial was conducted simultaneously with another trial with Alpine kids (Qi et al., 1993) to allow direct comparisons.

Compositions of experimental diets, management procedures, and method for collection and analysis of feed, blood, fecal, urinary, and ruminal samples were presented previously (Qi et al., 1993). For fixing, staining and counting protozoa, 2 ml fresh ruminal fluid from samples of each goat kid were transferred to bottles (1 ml per bottle) containing 24 ml of methylgreen-formalin saline solution (Ogimoto and Imai, 1981). Protozoa were counted using an Olympus microscope (BHA model, Olympus, Lake Success, NY) and a Petroff-Hausser bacteria counter (Hausser Scientific, Blue Bell, PA).

Angora kids were completely shorn of their mohair with an animal clipper (Model EW610, Sunbeam, Milwaukee, WI) before and after the growth phase (8 wks). Mohair was weighed and evaluated for grease fleece weight, laboratory scoured yield (ASTM, 1990a), clean fleece weight, and staple length (ASTM, 1990b). Average mohair diameter was measured as described previously (Qi et al., 1992a).

2.2. Statistic analysis

Data were analysed for effects of block and diet using the GLM procedure of SAS (1985). The residual mean square was used as the error term. Weaning weight served as a covariate for ADG and DMI analyses. Polynomial regressions were used to detect linear, quadratic and cubic effects of S concentration in the diet. Breed effects were compared in the overall model that included effects of block, breed, diet, breed by diet interaction. Difference was declared when $P < 0.10$, whereas $0.10 < P < 0.20$ was interpreted as a trend.

3. Results and discussion

3.1. Growth trial

During the 8-wk growth phase, ADG, DMI, and FE (gain/feed, g/kg) (Table 1) were highest for Angora kids fed the 0.20% S diet. According to the fitted quadratic regression equation, ADG was maximum at a dietary S level of 0.22% (N/S = 10.4 : 1); DMI was maximum at 0.16% S (N/S = 14.3 : 1); FE was maximum at 0.24% S (N/S = 9.5 : 1). When averaged, these values equal 0.22% S of dietary DM or a N/S ratio of 10.4 : 1. This estimate of S requirement for Angora kids was similar to that for Alpine kids (Qi et al., 1993) and to NRC estimates (NRC, 1981) . Clean mohair production was higher for Angora kids fed 0.28% S diet, which agreed with our earlier results with adult Angora goats that S requirements for mohair growth of adult Angora goats were estimated at 0.27% of dietary DM (Qi et al., 1992a).

Mohair staple length tended to increase quadratically ($P < 0.20$) (Table 1) with sulfate supplementation, but mohair diameter was not affected ($P > 0.20$) by S supplementation. Average body weight of Angora kids used in this trial was less than half that of adult Angora goats (Qi et al., 1992a). However, mohair production by Angora kids was 80% of adult Angora goats. Intake of S for maximum mohair growth was 3.1 g/d in adult Angora goats vs. 2.1 g/d in Angora kids. Intake of S for maximum BW gain of Angora kids was 1.7 g/d.

Sulfate supplementation did not affect ($P > 0.20$)

Table 1
Least-squares means of average daily gain (ADG), dry matter intake (DMI), and feed efficiency (FE) in Angora kids

Item	Dietary S (%)				SE[e]
	0.11	0.20	0.28	0.38	
ADG[a] (g/d)	67	89	59	60	15 NS
DMI[b] (g/d)	758	850	734	689	57 NS
FE[c] (g ADG/kg DMI)	88.0	105.3	83.3	86.4	18.9 NS
Grease mohair production (g/d)	16.8	17.1	17.0	15.3	4.2 NS
Mohair yield[d] (%)	55.7	55.4	56.8	56.3	<0.1 NS
Clean mohair production (g/d)	9.3	9.5	9.7	8.5	1.1 NS
Mohair staple length (mm/d)	0.879	0.986	1.001	0.860	0.006 $^{+}$Q
Mohair diameter (μm)	26.50	27.30	27.82	26.58	0.78 NS

[a]ADG = 39.13 + 363.57 X − 821.62 X^2, where X is the dietary S level (% of dietary DM).
[b]DMI = 723.96 + 643.94 X − 1991.57 X^2, where X is the dietary S level (% of dietary DM).
[c]FE = 53.64 + 419.33 X − 876.30 X^2, where X is the dietary S level (% of dietary DM).
[d]Moisture regain = 13.87%.
[e]NS (not significant), $P > 0.20$; $^{+}P < 0.20$; $^{++}P < 0.10$; $*P < 0.05$; $**P < 0.01$; $***P < 0.001$; L, linear; Q, quadratic; C, cubic.

Table 2
Least-squares means of blood pH, acid–base balance and plasma metabolites in Angora goats

Item[a]	Dietary S (%)				SE[b]
	0.11	0.20	0.28	0.38	
pH	7.38	7.39	7.39	7.39	0.01 NS
HCO_3^- (mM)	22.50	20.25	24.05	22.43	1.00 $^{+}$C
CO_2ct (mM)	23.68	21.25	25.27	23.53	1.04 $^{++}$C
pCO_2 (mmHg)	37.78	33.20	39.51	36.55	1.43 *C
pO_2 (mmHg)	47.00	45.50	40.50	43.50	3.46 NS
BEb (mM)	−1.65	−3.20	0.17	−1.43	0.92 $^{+}$C
BEecf (mM)	−2.80	−4.95	−1.12	−2.70	1.09 $^{+}$C
SBC (mM)	23.15	21.90	24.12	23.20	0.69 $^{+}$C
sO_2c (%)	80.85	81.30	75.52	77.30	3.63 NS
Glucose (mg/dl)	45.68	49.65	63.44	58.40	6.90 $^{+}$L
L-Lactate (mg/dl)	24.83	38.65	26.95	19.55	3.91 $^{+}$L*Q^{+}C
Sulfate-S (mg/l)	145.48	130.30	123.08	124.08	8.23 $^{++}$L
Total cysteine (μM)	13.00	16.09	17.08	15.03	1.56 $^{+}$Q
Free cysteine (μM)	4.27	4.57	5.10	4.81	0.38 NS
Cystine[c] (μM)	8.73	11.53	11.98	10.49	1.52 $^{+}$Q
Urea N (mg/dl)	29.18	19.14	29.44	27.52	2.08 $^{++}$Q**C

[a]CO_2ct = total CO_2 content; pCO_2 = partial pressure of carbon dioxide; pO_2 = partial pressure of oxygen; BEb = base excess; BEecf = base excess in extra-cellular fluid; SBC = standard bicarbonate; and sO_2c = oxygen saturation at p50.
[b]See footnote in Table 1.
[c]Expressed as cysteine equivalent.

blood pH (Table 2). However, S supplementation tended to increase (cubic, $P < 0.20$) blood HCO_3^-, and increased (cubic, $P < 0.10$) total CO_2 content and partial pressure of CO_2. These cubic trends also were found in blood base excess, base excess in extra-cellular fluids, standard bicarbonate, and oxygen saturation. In all cases, values were lowest for Angora kids fed 0.20% S diet.

Sulfate supplementation tended to increase (linear, $P<0.20$) plasma glucose concentration (Table 2). Sulfate supplementation increased plasma sulfate-S (linear, $P<0.10$), and L-lactate (linear, $P<0.10$) concentrations. Sulfate supplementation tended to increase (quadratic, $P<0.20$) plasma total cysteine and cystine concentrations, but did not affect ($P>0.20$) free cysteine concentration of blood plasma. Plasma urea N responded cubically ($P<0.10$) to sulfate supplementation.

Sulfate supplementation did not affect ruminal pH, but ruminal pH was higher ($P<0.05$) before feeding than 4 h postprandial (Table 3). Before feeding, ruminal concentration of protozoa was numerically lower for goats fed 0.20% S diet; however, 4-h postprandial, ruminal concentration of protozoa was numerically higher for goats fed 0.20% S diet. Patton et al. (1970) found that sheep wethers on a concentrate diet had more ruminal protozoa when they received methionine hydroxy analog (MHA, another S source) supplemented at 11 g/kg of dietary DM.

Sulfate supplementation did not affect ($P>0.20$) ruminal fluid L-lactate concentration (Table 3), but tended to increase (linear, $P<0.20$) sulfide-S concentration in the ruminal fluid. Sulfate supplementation increased (linear, $P<0.01$) ruminal sulfide-S and free, non-ionized (H_2S) sulfide-S concentration. The linear increase in sulfide-S may have inhibited the growth response in kids received high S diet.

Ruminal fluid ammonia N tended to decrease quadratically ($P<0.20$) with sulfate supplementation (Table 3). Because both total ammonia N and pH tended to be lower, the free, non-ionized ammonia N (NH_3-N) in the rumen was numerically lowest for goat kids fed 0.20% S diet.

Sulfate supplementation did not affect ($P>0.20$) ruminal total purine N, purine N content of isolated bacteria or bound purine N content (Table 3). Sulfate supplementation did not affect ($P>0.20$) S content of isolated bacteria, but linearly decreased ($P<0.05$) their N content. As a result, the bacterial N/S ratio tended to decrease linearly ($P<0.20$) with sulfate supplementation.

Table 3
Least-squares means of ruminal pH, protozoa density, and metabolites in Angora kids

Item	Dietary S (%)				SE[a]
	0.11	0.20	0.28	0.38	
Ruminal pH					
0 h postprandial	7.14	7.08	7.89	7.19	0.30 NS
4 h postprandial	6.07	5.90	6.20	6.00	0.23 NS
Ruminal protozoa (No./ml) $\times 10^3$					
0 h postprandial	55.110	33.782	52.729	78.163	0.042 NS
4 h postprandial	83.094	102.500	38.917	47.980	0.038 NS
L-Lactate (mg/dl)	14.20	16.10	13.28	21.91	4.05 NS
Sulfate-S (mg/l)	110.75	122.85	172.57	138.21	18.79 $^{+}$L
Sulfide-S (mg/l)					
Total	2.23	3.38	4.46	4.38	0.45 **L
H_2S-S	1.75	2.92	3.48	3.55	0.41 **L^{+}
Ammonia N					
Total (mg/dl)	39.25	30.83	31.45	43.13	4.89 $^{+}$Q
NH_3-N (μg/dl)	60.96	22.40	60.69	64.62	34.00 NS
Total purine N (%)	0.89	0.85	0.77	0.66	0.14 NS
Free bacterial purine N (%)	0.85	0.73	0.61	0.66	0.20 NS
Bound purine N (%)	0.04	0.12	0.16	0.01	0.07 NS
Bacterial S (%)	0.46	0.45	0.44	0.51	0.04 NS
Bacterial N (%)	8.08	8.16	7.91	7.19	0.28 *L
Bacterial N/S ratio	18.44	18.11	18.79	14.29	1.99 $^{+}$L

[a]See Table 1.

3.2. Metabolism trial

During the metabolism trial (wk 11 to 12 following the growth trial), sulfate supplementation did not affect ($P > 0.20$) intakes of DM, OM, digestible OM, GE, DE, ME and ME per metabolic BW (Table 4), although values tended to be highest for Angora kids fed 0.20% S diet.

Apparent digestibilities of DM, OM, GE, and ash tended to decrease quadratically ($P < 0.20$) with sulfate supplementation (Table 4). Presumably, these decreases were due to higher DMI of goats fed diets supplemented with an optimal amount of S. Sulfate supplementation did not affect ($P > 0.20$) ADF digestibility, but it was low for all diets, probably due to low ruminal pH (Table 3).

Sulfate supplementation increased S intake (linear, $P < 0.01$) and fecal S output (linear, $P < 0.05$) (Table 5). This response in fecal S output differed from results with adult Angora goats (Qi et al., 1992a), in which fecal S output was not affected by added S. This may be related to the different response to S supplementation in feed intake between kids and adult goats.

Sulfate supplementation linearly increased ($P < 0.01$) apparent digestibility of dietary S (Table 5). Partitioned by linear regression into S from the basal diet versus added S, digestibility of S was 45% for the basal dietary S vs. 71% for S added as calcium sulfate. This value for added S was slightly lower than that of adult Angora goats (78.1%; Qi et al., 1992a). Sulfate supplementation linearly increased urinary S output ($P < 0.0001$), S retention ($P < 0.01$), and decreased absorbed S retained ($P < 0.001$) (Table 5). Mohair S yield was not affected by sulfate supplementation.

Absorbed S (Y, g/d) was regressed on ingested S of each goat (X, g/d) as suggested by Biddle et al. (1975). The regression equation was: $Y = -0.2250 + 0.8231 \cdot X$ ($R^2 = 0.98$, $P < 0.05$); which can be interpreted as truly absorbed S was 82.3% of ingested S and metabolic fecal S loss was 0.23 g/d or 24.5 mg/(kg$^{0.75}$·d). Similarly, total urinary S output (Y, g/d) was regressed on truly absorbed S of each goat (X, g/d) (Biddle et al., 1975). The regression equation was: $Y = -0.1635 + 0.6842 \cdot X$ ($R^2 = 0.99$, $P < 0.05$). This value which can be interpreted as biological value of supplemented S was 68.4% and endogenous urinary S totalled 0.16 g/d or 17.8 mg/(kg$^{0.75}$·d).

For maintenance, S is required to replace metabolic fecal S and endogenous urinary S. The amount of absorbed S needed for maintenance of growing Angora kids was calculated to be 0.38 g/d or 42.3 mg/(kg$^{0.75}$·d). This absorbed S need for maintenance in Angora kids was quite similar to that of Alpine kids (42.3 vs. 41.5 mg/(kg$^{0.75}$·d)). This maintenance need

Table 4
Least-squares means of nutrient intakes in Angora kids during the metabolism trial

Item	Dietary S (%)				SE[a]
	0.11	0.20	0.28	0.38	
Intake					
DM (g/d)	544	781	655	705	107 NS
OM (g/d)	505	724	608	651	99 NS
Digestible OM intake (g/d)	270	348	278	323	60 NS
GE (Mcal/d)	2.48	3.54	2.98	3.18	0.48 NS
DE (Mcal/d)	1.34	1.73	1.39	1.59	0.30 NS
ME (Mcal/d)	1.01	1.42	1.14	1.31	0.24 NS
ME (Mcal/(kg BW kg$^{0.75}$·d))	0.12	0.15	0.12	0.14	0.024 NS
Digestibility (%)					
DM	54.38	46.55	46.01	49.18	2.50 $^{+}$L^{+}Q
OM	53.33	46.70	45.78	49.43	2.62 $^{+}$L^{+}Q
GE	54.08	47.72	46.61	49.74	2.51 $^{+}$L^{+}Q
Ash	53.99	44.81	46.81	46.08	3.25 $^{+}$Q
ADF	11.84	9.22	10.24	10.23	3.29 NS

[a]See Table 1.

Table 5
Least-square means of sulfur and nitrogen metabolism in Angora kids during the metabolism trial

Item	Dietary S (%)				SE[a]
	0.11	0.20	0.28	0.38	
S metabolism					
Intake (g/d)	0.58	1.52	1.83	2.68	0.34 **L
Fecal output (g/d)	0.32	0.59	0.73	0.93	0.17 *L
Digestibility (%)	44.9	61.6	60.5	66.7	3.9 **L^{+}C
Urinary output (g/d)	0.08	0.45	0.62	1.04	0.09 ***L
Retention (g/d)	0.18	0.48	0.48	0.71	0.08 **L
Absorbed S retained (%)	68.7	52.5	41.3	40.7	4.3 **L^{+}Q
N metabolism					
Intake (g/d)	12.49	17.90	15.03	16.16	2.44 NS
Fecal output (g/d)	3.78	5.86	5.15	5.47	0.85 $^{+}$L
Digestibility (%)	69.4	66.8	66.7	66.3	2.0 NS
Urinary output (g/d)	4.89	6.40	4.75	5.10	0.74 $^{+}$C
Retention (g/d)	3.82	5.64	5.13	5.59	1.14 NS
On % of intake basis					
Fecal output	30.57	33.17	33.34	33.69	1.95 NS
Urinary output	38.93	36.27	32.82	32.44	3.80 NS
Retention	30.49	30.56	33.84	33.87	3.64 NS
Absorbed N retained (%)	43.9	45.5	51.1	51.2	5.3 NS

[a]See Table 1.

Table 6
Least-squares means of urinary creatinine and uric acid outputs in Angora kids during the metabolism trial

Item	Dietary S (%)				SE[a]
	0.11	0.20	0.28	0.38	
Creatinine concentration (mg/dl)	3.91	11.49	8.38	3.20	2.74 $^{+}$Q
Creatinine output (mg/d)	12.12	29.16	17.59	12.56	4.16 $^{+}$Q^{+}C
Creatinine output (mg/BW kg)	0.61	1.47	0.90	0.59	0.36 $^{+}$Q^{+}C
Creatinine output (mg/BW kg$^{0.75}$)	1.29	3.10	1.89	1.27	0.46 $^{+}$Q^{+}C
Uric acid concentration (mg/dl)	10.33	25.95	13.86	10.38	2.69 *Q^{+}C
Uric acid output (mg/d)	31.13	97.43	28.09	45.12	21.12 *Q^{+}C
Uric acid output (mg/BW kg)	1.57	4.59	1.45	2.12	0.91 $^{+}$Q^{+}C
Uric acid output (mg/BW kg$^{0.75}$)	3.31	9.85	3.04	4.56	1.99 $^{+}$Q^{+}C

[a]See Table 1.

for S, assuming true digestibility of 82.3%, was 0.47 g/d (51.4 mg/(kg$^{0.75}$·d)) and was 6% higher than a previous estimate (48.3 mg/(kg$^{0.75}$·d)) proposed by Joyce and Rattray (1970) for growing sheep of 20 to 30 kg BW.

Nitrogen intake was numerically highest for Angora kids fed 0.20% S diet (Table 5) because feed intake tended to be highest with this diet. Fecal N output tended to increase linearly ($P<0.20$) with sulfate supplementation. Nitrogen digestibility, N retention and mohair N yield were not affected ($P>0.20$) by sulfate supplementation. Expressed as a percentage of N intake, N metabolism was not affected ($P>0.20$) by sulfate supplementation.

Urinary creatinine concentration and output, expressed as absolute units or per unit BW or metabolic size tended to increase (quadratic, $P<0.20$) with S supplementation (Table 6). The quadratic trend in cre-

atinine output might be interpreted to indicate that lean tissue mass was greater in Angora kids fed optimal amount of S (Schroeder et al., 1990), and the higher average daily gain was not due to increased water content of organs or gut fill (Mertz and Roginski, 1969).

Sulfate supplementation increased (quadratic, $P<0.05$) urinary uric acid concentration, and tended to increase (quadratic, $P<0.20$) uric acid output expressed either as amount per kg of BW or per kg of metabolic BW (Table 6).

3.3. Comparisons of Angora with Alpine kids

No diet by breed interactions were detected ($P>0.10$). Thus, means of the two breeds were compared. Average daily gain and DMI were lower ($P<0.01$) in Angora than Alpine kids (Table 7). Growth curves of Alpine and Angora kids from birth to 25 wk of age are in Fig. 1. Birth weights of the two breeds were close ($P>0.20$), although Angora were slightly lighter than Alpine kids. Weaning weights of the two breeds were similar. However, after weaning Alpine kids grew much faster ($P<0.01$) than Angora kids. Feed efficiency (FE, ADG/DMI) was similar ($P<0.20$) between breeds. Because Angora kids produced 8.97 ± 1.05 g/d of clean mohair, total efficiency of energy utilization would tend to be higher for Angora than Alpine kids.

Blood pH did not differ ($P>0.20$) between breeds (Table 7). However, other criteria for blood acid–base balance were different ($P<0.05$) between breeds. Blood HCO_3^-, total CO_2 content, partial pressure of CO_2, base excess, base excess in extra-cellular fluids, and standard bicarbonate were lower ($P<0.05$) in Angora than in Alpine kids, but blood partial pressure of O_2 and oxygen saturation were higher ($P<0.01$) in

Table 7
Comparisons of performance, acid–base balance, and plasma metabolites between Alpine kids and Angora kids

Item	Alpine	Angora	SE	Significance[b]
Performance				
ADG (g/d)	95	70	7	**
DMI (g/d)	1125	762	22	***
FE (g ADG/kg DMI)	84.0	92.3	6.1	NS
Clean mohair (g/d)	–	8.97	1.05	–
Blood acid–base balance[a]				
Blood pH	7.38	7.39	0.01	NS
HCO_3^- (mM)	25.32	22.36	0.48	***
TCO_2 (mM)	26.62	23.48	0.49	***
pCO_2 (mmHg)	42.08	36.69	0.80	***
pO_2 (mmHg)	38.35	44.39	1.42	**
BEb (mM)	0.69	−1.53	0.49	**
BEect (mM)	0.07	−2.81	0.55	**
SBC (mM)	24.68	23.17	0.39	*
SO_2C (%)	70.88	79.01	1.95	**
Plasma metabolites				
Glucose (mg/dl)	67.52	54.45	2.20	***
Lactate (mg/dl)	30.06	27.68	2.62	NS
Sulfate (mg/dl)	138.0	131.3	3.69	NS
Total cysteine (μM)	15.45	15.40	0.75	NS
Free cysteine (μM)	3.86	4.62	0.17	**
Cysteine[c] (μM)	11.59	10.78	0.73	NS
Urea (mg/dl)	26.81	26.36	0.79	NS

[a]See Table 2.
[b]See Table 1.
[c]Expressed as cysteine equivalent.

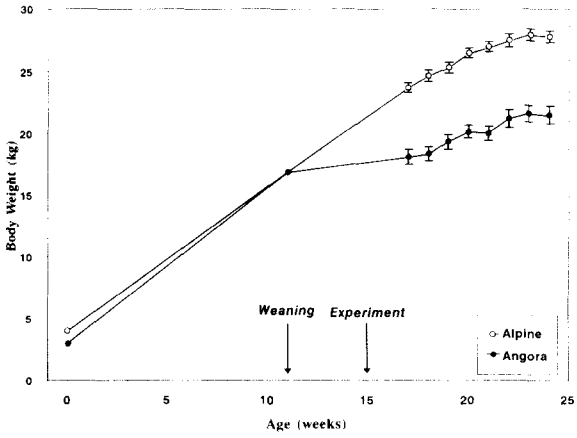

Fig. 1. Growth comparison of Alpine and Angora kids from birth to 25 weeks of age. Vertical bars represent mean ± SE, $n = 12$.

Angora than in Alpine kids. Perhaps the greater hair cover in Angora goats reduced surface heat loss so that Angora goats must have developed a respiration system to dissipate metabolic heat and result in lower base excess in blood.

Blood plasma glucose concentration was lower ($P < 0.001$) in Angora than in Alpine kids (Table 7), possibly reflecting lower DMI. Blood plasma cysteine was higher ($P < 0.01$) in Angora than in Alpine kids. Plasma L-lactate, sulfate-S, cysteine plus cystine, cystine, and urea N were not different ($P > 0.20$) between breeds.

Ruminal pH values at both sampling times were higher ($P < 0.05$) in Angora than in Alpine kids (Table 8), but ruminal fluid L-lactate concentration was lower ($P < 0.0001$) in Angora than in Alpine kids (Table 8). These differences can be ascribed to lower feed intake by the Angora kids or differences in ruminal protozoa numbers. Angora kids were faunated, whereas Alpine kids were fauna-free in this experiment, possibly due to isolation of the Alpine kids from adult goats. By engulfing starch particles to reduce starch fermentation rate, protozoa can stabilize pH and decrease ruminal L-lactate concentration (Veira, 1986). The concentrations of ruminal ammonia N ($P < 0.10$) and sulfide-S ($P < 0.20$) tended to be higher in Angora than in Alpine kids. These increases presumably were due to presence of protozoa in the rumen of Angora kids. Ivan (1988) reported that when ruminal protozoa were present, ruminal ammonia N and sulfide-S concentrations were increased, presumably due to greater proteolytic activity of the ruminal microflora.

Ruminal total purine N content and purine N content of isolated bacteria were not different ($P > 0.20$) between breeds (Table 8). However, residual purine N content in the rumen was lower ($P < 0.001$) in Angora than in Alpine kids. Again, this difference in ruminal residual purine N content can be ascribed to presence of protozoa in the rumen of Angora kids. Protozoa attach to particles in the rumen and would be removed from ruminal fluid by centrifugation during isolation of bacteria. On this basis, 8% ruminal purine could have been present as protozoa and only 9% as firmly attached bacteria. Bacterial N content in the rumen was not different ($P > 0.20$) between breeds, but ruminal S content of isolated bacteria was higher in Angora than in Alpine kids. As a result, the N/S ratio of isolated bacteria tended to be lower ($P < 0.20$) in Angora than in Alpine kids, implying Angora kids may be more efficient in microbial synthesis in sulfur-containing amino acids.

During the metabolism trial, intakes of DM, OM, GE, DE, ME and ME per metabolic BW were lower ($P < 0.10$) in Angora than in Alpine kids (Table 9). However, digestibilities of GE, DM, OM, and ADF were not different ($P > 0.20$) between breeds. Ash digestibility tended to be lower ($P < 0.20$) in Angora than in Alpine kids.

Sulfur intake and urinary S output were lower ($P < 0.0001$) in Angora than in Alpine kids (Table 10) because DMI was less in Angora kids. Apparent S digestibility was lower ($P < 0.0001$) in Angora than in Alpine kids because the proportion of metabolic fecal S in total fecal S was higher in Angora than in Alpine kids (data not shown). However, S retention was identical for the two breeds. Efficiency of S retention was higher ($P < 0.05$) in Angora than in Alpine kids. Because each of the Angora kids grew a mean 8.97 g/d clean mohair, and mohair contained about 3.12% S, approx. 50% of retained S was deposited in mohair by Angora kids.

Because DMI was lower, nitrogen intake and urinary N output were lower ($P < 0.0001$) in Angora than in Alpine kids (Table 10). However, unlike S digestibility, N digestibility was not affected ($P > 0.20$) by breed. Lower urinary N output by Angora kids resulted in higher ($P < 0.10$) N retention, largely ascribable to retention of N in mohair. As a percentage of N intake,

Table 8
Comparisons of ruminal metabolites between Angora kids and Alpine kids

Item	Alpine	Angora	SE	Significance[a]
Ruminal pH				
0 h postprandial	6.55	7.07	0.10	**
4 h postprandial	5.60	6.00	0.09	**
Ruminal L-lactate (mg/dl)	46.38	16.29	2.96	***
Ruminal sulfate-S (mg/dl)	149.0	134.0	11.6	NS
Ruminal ammonia N				
Total (mg/dl)	27.92	35.37	3.20	+
NH_3-N (μg/dl)	20.08	46.99	9.04	+
Sulfide-S (mg/dl)				
Total	2.89	3.54	0.23	+
H_2S-S	2.62	2.91	0.19	NS
Total purine N (%)	0.85	0.80	0.07	NS
Free bacterial purine N (%)	0.72	0.72	0.09	NS
Bound purine N (%)	0.13	0.07	0.04	**
Bacterial N (%)	8.06	7.86	0.34	NS
Bacterial S (%)	0.41	0.46	0.02	++
Bacterial N/S ratio	19.94	17.80	1.12	+

[a]See Table 1.

Table 9
Comparisons of urinary creatinine and uric acid outputs between Angora kids and Alpine kids

Item	Alpine	Angora	SE	Significance[a]
Creatinine (mg/dl)	3.61	6.18	1.61	NS
Creatinine output (mg/d)	35.02	15.76	11.46	NS
Creatinine output (mg/BW kg)	1.30	0.80	0.44	NS
Creatinine output (mg/BW $kg^{0.75}$)	2.97	1.69	0.99	NS
Uric acid (mg/dl)	7.70	14.83	1.36	**
Uric acid output (mg/d)	91.91	50.48	7.92	***
Uric acid output (mg/BW kg)	3.43	2.44	0.33	*
Uric acid output (mg/BW $kg^{0.75}$)	7.81	5.20	0.72	*

[a]See Table 1.

fecal N output was similar, but urinary N output was lower in Angora than in Alpine kids. The percentage of absorbed N retained was twice as greater ($P<0.0001$) in Angora than in Alpine kids.

Urinary creatinine concentration was numerically higher in Angora than in Alpine kids, but urinary creatinine output was numerically lower in Angora than in Alpine kids (Table 11). Urinary uric acid concentration and output were lower ($P<0.05$) in Angora than in Alpine kids.

Alpine kids were fauna-free perhaps due to their isolation. Angora kids were allowed to nurse from birth to weaning at 75 d of age, whereas Alpine kids were moved to their cages (steam-cleaned, stainless steel cage) 3 days after birth and fed pasteurized milk to 75 d of age. One week postweaning (at 82 d of age), they were moved to a fenced pasture for 3 wk until they were returned to steam-cleaned, stainless steel cages for this experiment. These Alpine kids did not mix with adult goats and remained fauna-free until the end of the growth-monitoring phase except for two, presumably due to accidental contact with adult goats.

Metabolic differences between Angora and Alpine kids were surprisingly large. However, differences (blood HCO_3^-, plasma glucose and free cysteine, ruminal pH and L-lactate, and urinary uric acid) cannot be fully ascribed to physiological dissimilarities because Alpine kids were largely fauna-free. Presence of pro-

Table 10
Comparisons of nutrient intakes and digestibilities between Angora kids and Alpine kids

Item	Alpine	Angora	SE	Significance[a]
Intakes				
DM (g/d)	941	677	42	***
OM (g/d)	872	627	39	***
Digestible OM (g/d)	441	308	24	***
GE (Mcal/d)	4.27	3.07	0.19	***
DE (Mcal/d)	2.18	1.53	0.12	***
ME (Mcal/d)	1.79	1.26	0.10	++
ME (Mcal/BW $kg^{0.75}$)	0.15	0.13	0.01	***
Digestibility (%)				
GE	50.81	49.70	1.04	NS
DM	50.48	48.95	1.07	NS
OM	50.32	49.00	1.11	NS
ADF	11.27	10.44	1.93	NS
Ash	52.57	48.31	1.41	+

[a]See Table 1.

Table 11
Comparisons of sulfur and nitrogen metabolism between Angora kids and Alpine kids

Item	Alpine	Angora	SE	Significance[a]
S metabolism				
Intake (g/d)	2.22	1.67	0.11	***
Digestibility (%)	70.52	58.27	1.32	***
Urinary output (g/d)	1.17	0.55	0.04	***
Retention (g/d)	0.47	0.47	0.07	NS
Intake S retained (%)	20.61	29.30	2.38	*
N metabolism				
Intake (g/d)	21.58	15.52	0.96	***
Digestibility (%)	66.61	67.23	0.75	NS
Urinary output (g/d)	11.24	5.34	0.64	***
Retention (g/d)	3.13	5.07	0.63	+
Fecal output (% of intake)	33.39	32.77	0.75	NS
Urinary output (% of intake)	53.11	34.92	2.54	***
Retention (% of intake)	13.50	32.32	2.58	***
Absorbed N retained (%)	20.18	48.14	3.80	***

[a]See Table 1.

tozoa in the rumen of Angora kids can explain higher ruminal ammonia N and sulfide S concentration (Table 11).

4. Conclusion

Optimal dietary sulfur level for maximum daily gain of Angora kids was approx. 0.22% of dietary DM for a N/S ratio of 10.4:1, similar to that of Alpine kids (0.22% S). The performance of Angora kids tended to increase quadratically with sulfate supplementation due to enhanced bacterial protein synthesis (at 0.20% S) in the rumen. The growth performance and nutrient metabolism of Angora and Alpine kids differed substantially. This was partially because of inherent physiological dissimilarities and partially due to environmental effects (fauna-free vs. faunated). Some

of the specific breed differences may be due to presence or absence of specific types of ruminal microbes.

Acknowledgements

The authors thank P.L. Claypool for consultation in statistical analyses, and the farm crew for animal care.

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