Effect of Sodium Bicarbonate and of Roughage on Milk Yield and Milk Composition of Goats and on Rumen Fermentation of Sheep

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ABSTRACT
Forty Damascus dairy goats and 12 Chios wether sheep were used to assess effects of sodium bicarbonate and roughage on milk yield and milk composition of Damascus goats and rumen fermentation and apparent digestion coefficients of Chios wether sheep.

Addition of sodium bicarbonate increased apparent digestibility coefficients of dry matter, organic matter, gross energy, and of crude fiber on low roughage diet only. Wethers on diets supplemented with sodium bicarbonate gave higher urinary sodium output. Water intake was correlated .62 with volume of urine, .58 with urinary sodium output, and .61 with dry matter intake. Roughage was more efficient than bicarbonate in elevating rumen pH, isovalerate, and acetate molar proportions. Sodium bicarbonate increased acetate and reduced propionate molar proportion. There were no significant differences among diets in rumen ammonia nitrogen concentration.

High roughage decreased live-weight gain. Neither bicarbonate nor roughage had a significant effect on conversion efficiencies of dry matter to milk and fat-corrected milk. The sodium bicarbonate diet proved acceptable to the animals. Absolute and fat-corrected milk yields were not affected, but the bicarbonate diet caused an increase in fat content and total solids content of milk.

INTRODUCTION
Economic and climatic circumstances usually dictate feed components in ruminant diets. Diets of only roughage will provide insufficient energy to support average energy requirements of modern breeds of dairy animals. Furthermore, scarcity of good quality roughages in countries with low rainfall creates pricing pressures which result in grains being a more economic source of energy than roughage. High-concentrate, restricted-roughage diets result in marked depression of milk fat yield and content (7). Increases in ruminal propionate and decreases in ruminal acetate and pH (3) have been associated with decreased milk fat concentration.

Effects of feeding certain additives such as sodium and potassium bicarbonate (11) on rumen fermentation pattern and on milk fat content in mid-lactation have been examined extensively although their effects in early lactation have been neglected (10). Recent experimental data (2, 15) showed an increase in milk fat content as a result of feeding an artificial saliva mixture (16) to Jersey cows in early lactation. Contrary to these, no change in cow milk fat content as a result of sodium bicarbonate (NaHCO₃) supplementation was reported by others (9, 13).

Data on effects of buffers in diets of dairy goats and sheep are lacking. As intensively fed small ruminants have a genetic potential for high milk yields, animals are fed diets high in concentrate, especially in early lactation, and their milk is used for cheese making; this investigation was undertaken to study effects of roughage and of NaHCO₃ on (a) milk yield and milk composition of Damascus goats in early lactation and (b) apparent digestion coefficients and rumen fermentation pattern of Chios wether sheep.

MATERIALS AND METHODS

Trial 1
Forty multiparous Damascus goats approximately 63 kg live weight were in a randomized complete block design with 2 x 2 factorial arrangement of treatments. Two contents of NaHCO₃, 0% (B₁) and 4% (B₂) of
concentrate, comprised one factor, and two
percentages of barley hay, 15% (R1) and 30%
(R2) of the finished feed, comprised the other
factor. The basic concentrate mixture was
(g/kg) 549 barley grain, 236 sorghum grain, 70
wheat bran, 120 soyabean meal, 20 limestone,
and 5 sodium chloride. A trace element-vitamin
mixture was added to the concentrate mixture
supplying per kg diet 5000 IU vitamin A, 500
IU vitamin D3, 200 mg MgO, 50 mg Fe, .5 mg
Co, .75 mg I, 20 mg Mn, 25 mg Zn, 110 mg Ca,
and 30 mg S. Animals were assigned to five
groups of eight goats each on daily milk yield
and date of kidding. Initial daily milk yield
was based on milk recordings around the 10th
to 14th day of lactation. Animals of each group
were assigned randomly into one of the four
experimental diets 16 days postpartum. After
1-wk gradual change to experimental diets,
animals were allowed 3-wk adaptation followed
by 10-wk experimental period. Goats were
housed in individual pens bedded with wood
shavings, and they were weaned from their kids
48 h postpartum. Concentrates (5 mm cubes)
and hay were in separate feed containers. Feed
residues were collected and weighed daily.
Animals were fed to maintenance plus the
appropriate milk production (Economides,
unpublished). Energy allowance was adjusted
once a week based on metabolic live weight (kg
•75) and fat-corrected milk yield. Samples of
barley hay and of concentrates were taken once
weekly, dried in a fan ventilated oven at 105°C
for 48 h for dry matter determination. Proxi-
mate constituents were measured on bulk,
ground (1 mm) feed samples. Animals were
milked twice daily. Milk yields were recorded 5
days/wk. Representative milk samples from
morning and afternoon milkings were taken
once a week. The two samples were bulked and
analyzed for protein, fat, ash, and total solids
(21). Goats had free access to water. Water
consumption was measured for 2 consecutive
days for four goats per treatment. Goats were
weighed at 0800 h for 2 consecutive days at
commencement and end of the trial and once
weekly during the course of the trial. Data were
analyzed as described by Cochran and Cox (5).
Two goats, one on treatment B1R1 and one on
B2R1, suffered a severe decline in milk yield
during wk 6 and wk 7 of lactation and were
excluded from the trial. However, it was
accepted that this problem was not from any
effect of diet, and missing data were estimated
(5).

Trial 2

Twelve Chios wether sheep approximately
66 kg live weight and 32 mo of age were used
to determine rumen fermentation characteris-

TABLE 1. Means by diet for digestion coefficients, water intake, and feces and urine characteristics.1

<table>
<thead>
<tr>
<th>Diet</th>
<th>No NaHCO3</th>
<th></th>
<th>NaHCO3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15% hay</td>
<td>30% hay</td>
<td>15% hay</td>
<td>30% hay</td>
</tr>
<tr>
<td>B1</td>
<td>B1R1</td>
<td>B1R2</td>
<td>B2R1</td>
<td>B2R2</td>
</tr>
<tr>
<td>SE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Digestibility (%)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter</td>
<td>79b</td>
<td>76c</td>
<td>82a</td>
<td>77ca</td>
</tr>
<tr>
<td>Organic matter</td>
<td>81b</td>
<td>79c</td>
<td>84a</td>
<td>79c</td>
</tr>
<tr>
<td>Gross energy</td>
<td>78b</td>
<td>77c</td>
<td>82a</td>
<td>78c</td>
</tr>
<tr>
<td>Crude fiber</td>
<td>46b</td>
<td>50ab</td>
<td>56a</td>
<td>53a</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>77</td>
<td>78</td>
<td>83</td>
<td>82</td>
</tr>
<tr>
<td>Water intake (kg/day)</td>
<td>2.29c</td>
<td>3.54ab</td>
<td>3.21ab</td>
<td>4.28a</td>
</tr>
<tr>
<td>Urine output (kg/day)</td>
<td>.89b</td>
<td>1.84ab</td>
<td>1.60a</td>
<td>2.67a</td>
</tr>
<tr>
<td>Urinary-Na output (g/day)</td>
<td>2.85c</td>
<td>4.60b</td>
<td>11.60a</td>
<td>12.75a</td>
</tr>
<tr>
<td>Fecal-Na output (g/day)</td>
<td>.20b</td>
<td>.30b</td>
<td>.36ab</td>
<td>.63a</td>
</tr>
<tr>
<td>Urine pH</td>
<td>8.50b</td>
<td>8.80a</td>
<td>8.90a</td>
<td>8.87a</td>
</tr>
</tbody>
</table>

1 Means on the same line with unlike superscripts differ (P<.05); means on the same line with unlike sub-
scripts differ (P<.01).

SODIUM BICARBONATE AND ROUGHAGE

and apparent digestibility coefficients of the four experimental diets. Animals were fed 1.1 \times \text{maintenance energy requirements}. Wethers on \text{NaHCO}_3\text{-supplemented diets were given 890 whereas those on the unsupplemented 860 g dry matter/head daily. Feed was offered twice daily in approximately two equal portions. Six animals were randomly assigned to each diet. Following 4-wk adaptation, total fecal and urine collections were made for 7 days. One-tenth of the daily output of feces and of urine was stored (-20° C) for providing a bulk sample of each at the end of the trial. Urine samples were subjected to pH measurements for 2 consecutive days over the adaptation period. Rumen contents were sampled by stomach tube at the end of the trial and analyzed for volatile fatty acids (VFA), \text{NH}_3-N, and pH. Rumen liquor samples were taken 3 h after morning feeding and strained immediately after collection through two layers of fine muslin before their pH was determined. For \text{NH}_3-N estimation an equal volume of .2 N HCl was added to the strained rumen liquor; to that for VFA determination, 1 ml of 5 N H_2SO_4 was added to 5 ml of rumen liquor. Concentration of \text{NH}_3-N was measured by steam distillation of rumen liquor and titration of the distillate. Molar proportion of VFA in strained rumen liquor was measured by Varian Gas Liquid Chromatography, fitted with flame ionization detector. The stainless-steel column was packed with 10% carbowax 20M-TPA on 60/80 mesh cromsorb W-Acid washed. Proximate constituents of feeds and feces were analyzed by methods detailed in MAFF (21). Data were analyzed by one-way analysis of variance (5).

RESULTS

Digestion coefficients of proximate constituents, gross energy (GE), daily water intake, urinary output, and urinary and fecal-Na output for sheep in Trial 2 are in Table 1. On the low roughage diet (B_2R_1), \text{NaHCO}_3 increased apparent digestibility coefficients of dry matter (DM), organic matter (OM), GE (P<.01), and of crude fiber (P<.05). Overall DM, OM, and GE digestibility coefficients were significantly higher on low compared with high roughage diets. Although there was a trend towards higher nitrogen digestibility on \text{NaHCO}_3-supplemented diets, differences were not significant. Wethers on diet B_2R_2 had a greater urine output compared with diet B_1R_1 (Table 1). Incorporation of \text{NaHCO}_3 altered fecal (P<.05) and urinary-Na output (P<.001). Dietary \text{NaHCO}_3 raised significantly urine pH in the low roughage diet only (Table 1).

TABLE 2. Means by diet for rumen characteristics. ¹

<table>
<thead>
<tr>
<th></th>
<th>No \text{NaHCO}_3</th>
<th>Diet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15% hay</td>
<td>30% hay</td>
</tr>
<tr>
<td>VFA concentration (mm/liter)</td>
<td>B_1R_1</td>
<td>B_1R_2</td>
</tr>
<tr>
<td>Acetate</td>
<td>63.5\textsuperscript{b}</td>
<td>71.3\textsuperscript{a}</td>
</tr>
<tr>
<td>Propionate</td>
<td>21.7\textsuperscript{a}</td>
<td>14.4\textsuperscript{b}</td>
</tr>
<tr>
<td>Butyrate</td>
<td>13.7</td>
<td>11.2</td>
</tr>
<tr>
<td>Isovalerate</td>
<td>1.1</td>
<td>3.1</td>
</tr>
<tr>
<td>\text{NH}_3-N (mg/liter)</td>
<td>149</td>
<td>162</td>
</tr>
<tr>
<td>Rumen pH</td>
<td>6.1\textsuperscript{b}</td>
<td>6.9\textsuperscript{a}</td>
</tr>
</tbody>
</table>

¹ Means on the same line with unlike superscripts differ (P<.05), means on the same line with unlike subscripts differ (P<.01).
² The method for VFA analyses possibly did not separate isovaleric from 2-methyl butyric.
Table 2 shows means for rumen metabolites. Diets B1R2 and B2R2 (high roughage) reduced \((P<.01)\) total VFA (volatile fatty acid) concentration, and increased molar proportions of acetate and isovalerate. Roughage was more effective than NaHCO3 in elevating ruminal pH and acetate molar proportion. The increase in acetate molar proportion was consistently at the expense of the molar proportion of propionate. There were no significant differences among diets in rumen NH3-N concentration.

Means for intake and live-weight changes by the lactating goats are in Table 3. As expected, goats on diets B1R2 and B2R2 consumed higher \((P<.01)\) amounts of barley hay. Ratios of roughage to concentrate were lower than those intended for all four diets; more hay residues were collected than concentrate residues. The proportion of roughage affected \((P<.05)\) average live-weight changes. Neither buffer nor roughage had a significant effect on conversion efficiencies of DM to milk and fat-corrected milk. There was no significant change in water consumption between low and high roughage diets, but bicarbonate increased water consumption by 1.46 liters per head daily.

Milk yields and milk composition relating to the four diets are in Table 3. There were no significant differences in absolute milk yield among diets. When yields were fat corrected, increase was slight in buffered diets, but differences were not significant. Incorporation of NaHCO3 in the concentrate mixture resulted in significant increase in fat \((P<.01)\) and total solids \((P<.05)\) content of milk. Figure 1 shows the significant effect of NaHCO3 on milk fat content. Goats receiving the bicarbonate diets started producing milk of higher milk fat content 2 to 3 wk after they were offered the buffered diets. The addition of NaHCO3 did not show any significant effect on crude protein and ash content of milk (Table 3).

**DISCUSSION**

Supplementation of the low roughage diet with NaHCO3 resulted in a significant increase of apparent digestion coefficients for DM, OM, GE, and crude fiber in agreement with (17). Apparent nitrogen digestibility tended to increase on the bicarbonate containing diets, though differences failed to reach significance, at variance with (17). Part of the reason at least for the increase in DM digestibility is that 4% of...
the concentrate mixture was in the form of NaHCO₃, and excess of cations was excreted in the urine from animals offered bicarbonate containing diets. The higher OM, GE, and crude fiber digestibilities on the high concentrate diet probably reflected more favorable conditions in the rumen from the buffer. Such an effect may be the result of a change in microbial flora (18, 24). Increased cellulose digestion following NaHCO₃ administration was reported in (22). Furthermore, Mertens (19) postulated that, in general, buffers would be expected to improve fiber digestion with fermentable carbohydrate in the diet, and Davis (6) reported that incorporation of CaCO₃ in diets of lactating cows improved digestibility of starch in the lower gut.

Higher water consumption on diets B1R2 and B₂R₂ compared with diets B₁R₁ and B₂R₁ was possibly from differences in the nature of the food (1). Overall water consumption by Chios wethers tended to increase (.83 liter) on diets supplemented with NaHCO₃. Diven (8) reviewing limited data concluded that water consumption is not affected adversely and may be increased when NaHCO₃ is incorporated into feed reasonably. Higher water intakes by wethers on diets supplemented with NaHCO₃ reflect the higher Na content in these diets. Supplemental Na mainly was excreted in urine. Water intake was correlated with volume of urine .62 and urinary-Na output .58 in agreement with (25). During production studies water intake mainly was correlated with dry matter intake .61 whereas milk production was unrelated .03. High correlations between water intake and dry matter intake also have been reported (4).

Supplementation of diets with NaHCO₃ resulted in significant ($P<.05$) changes in VFA pattern in agreement with the data of (12, 15, 16, 24). The increase in acetate molar proportion was associated with reduction in propionate molar proportion. In contrast with the data of (16, 17) butyrate molar proportion did not alter significantly from buffer supplementation. The higher isovalerate molar proportion finds support from the data of (20). Numerous investigators have studied effects of feeding on rumen fermentation pattern. In my study roughage was more efficient than NaHCO₃ in elevating the molar proportion of acetate and also ruminal pH. In agreement with (12, 15, 16, 24) addition of buffers did not alter ruminal pH significantly.

Addition of NaHCO₃ to the concentrate mixture had no adverse effects of milk yield. This agrees with (12, 15). In accordance with (12, 15, 20) bicarbonate supplementation increased milk fat content significantly. In my work the increase in milk fat content from dietary inclusion of bicarbonate was related to an increase in normal milk fat content for the breed, and 15% long barley hay in the finished diet was sufficient to maintain the characteristic milk fat content for the breed. However, the constant milk yields and the higher milk fat content is at variance with the data of (9, 13) in which NaHCO₃ supplementation improved actual milk yield but did not affect milk fat content. Sodium bicarbonate did not reduce intake of the animals in agreement with (14, 23). Weight losses on high roughage diets were mainly from higher refusals by goats on these diets (B₁R₂ and B₂R₂).
In conclusion, it seems reasonable that addition of NaHCO₃ to diets predisposing the low milk fat syndrome is likely to prove of increasing importance in dairy goats in the early stage of lactation. Furthermore, in countries where roughage is scarce because of extended drought, bicarbonates may play a major role in maintaining feed inputs in milk producing animals fed low roughage diets and in maintaining high quality in the milk produced.

ACKNOWLEDGMENTS

The author is grateful to D. G. Armstrong for reviewing the manuscript, A. P. Mavrogenis for statistical advice, D. Hadjidemetriou for VFA determination, and G. Kyprianou, G. Hadjiavriel, M. Theodoridou, M. Karavia, and N. Parouti for skilled technical assistance.

REFERENCES