Utilization of DL-1,2-propanediol by young and adult goats

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DL-1,2-propanediol (propylene glycol) has been recognized as an interesting substance for ruminant nutrition, since as shown by JOHNSON¹⁾, it is a glucogenic substance effective to the treatment of bovine ketosis. Concerning the utilization of 1,2-propanediol by other experimental animals, considerable amounts of data²⁻⁴⁾ have been reported since 1901. Apparent adaptive metabolism of 1,2-propanediol in growing rats was initially reported by HANZLIK *et al.*⁴⁾ and recently confirmed by ITOH *et al.*⁵⁾ EMERY *et al.*⁶⁾ also suggested an adaptive metabolism in the ruminant. However, YOSHIDA *et al.*⁷⁾ found no active adaptation in the chick. BAYLEY *et al.*⁸⁾ found that up to 8 % of propanediol could replace an equivalent amount of corn starch in the chick. In Japan 1,2-propanediol from petroleum oil has drawn attention as a future energy source for poultry and other farm animals. In this paper feeding and digestion trials of the rations containing 1,2-propanediol by the ruminant and the fate of 1,2-propanediol administered into the rumens of preadapted and non-adapted goats were described.

Materials and Methods

Japanese meat-type goats of various ages were used in these trials.

Trial 1. Four kids having been fed only liquid milk replacers in cages with metal floor for 36 days from birth were begun to be fed a complete diet containing DL-1,2-propanediol (Table

Table 1. Composition of experimental diets

Trial Diet	1		3	
	Prapanediol diet	Control diet	Propanediol diet**	Starch diet**
	%			
Ground yellow corn	36.76	31.32	52.32	52.32
Soybean oil meal	30.64	34.64	23.98	23.98
Wheat bran	—	—	13.63	13.63
Tricalcium phosphate	0.34	0.33	—	—
Calcium carbonate	—	—	0.45	0.45
Salt	0.34	0.33	0.45	0.45
Vitamin A,D supplement*	0.15	0.07	0.07	0.07
Rice straw meal	22.69	33.31	—	—
DL-1,2-propanediol	9.08	—	9.10	—
Corn starch	—	—	—	9.10

* The supplement contains 10,000 IU of vitamin A and 2,000 IU of vitamin D per g.

** In these diets Cr₂O₃ was included at 0.1% level as an indicator substance.

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1). They were weaned at 44 days old and continuously fed ad libitum only the diet for subsequent 4 weeks. A control diet containing no propanediol (Table 1) was fed to 6 kids in the same manner shown above in a different experimental period. Weekly body weights and feed consumption were recorded, and ruminal tissue and papillae developments were examined by killing at 72 days old.

Trial 2. A digestion experiment consisting of 16-days preliminary and 7-days collection periods was carried out by total collection method using 4 goats of 6 months old averaging 8 kg. The same diet containing propanediol used in trial 1 and another diet of the same composition as the former diet except containing no propanediol were fed at daily rate of 10% of metabolic body size ($\text{kg}^{0.75}$).

Trial 3. Twelve goats of 8 to 11 months old weighing 9 to 16 kg were divided into 4 groups and allocated to two diets containing either DL-1,2-propanediol or corn starch (Table 1). Each diet was fed daily at the level of 1,050 or 1,200 g per group for 3 weeks and ad libitum consumption of Italian ryegrass hay was also allowed. Weekly body weights were recorded.

Trial 4. Using two mature, ruminally fistulated goats weighing about 30 kg, a digestion experiment consisting of 14-days preliminary and 5-days collection periods was carried out by the index method using Cr_2O_3 . Each goat received 400 g of either propanediol-containing or starch-containing diet used in trial 3 with 400 g of Italian ryegrass hay-daily in two feedings. A switchback design involving two test periods was adopted. Ruminal inješta samples were taken 3 hours after morning feeding twice in each collection period. Dry matter content, pH and concentration and molar proportions of volatile fatty acids (VFA) were determined in each ruminal inješta samples.

Trial 5. Two mature, ruminally fistulated and castrated goats weighing about 38 kg were used. They were allocated to each of the two diets used in trial 3 containing either propanediol or starch. Five hundred grams of the diets with 500 g of chopped Italian ryegrass hay were fed daily in one morning feeding for the adaptation period of 2 weeks. After the adaptation period both goats were administered 150 ml of aqueous solution containing 50 g of DL-1,2-propanediol via rumen fistula instead of morning feeding. Ruminal fluid and jugular blood samples were taken just before the administration (zero-hour) and 1, 2 and 3 hours after the administration. No feed or water was allowed during the sampling period. Almost the same procedure was repeated a second time at weekly interval without changing the feeding program. In this case 250 ml of aqueous solution containing 50 g of DL-1,2-propanediol were administered, and samplings were done at zero, 2 and 6 hours after the administration. Urine was also collected during zero to 8 hours after the administration.

For the calculation of dry matter digestibility of total rations containing propanediol, propanediol itself was considered entirely digestible as shown by EMERY *et al.*⁶⁾, and propanediol intake was not included in the digestibility calculation. DL-1,2-propanediol used was a reagent grade chemical (Koso Chemical Co., Ltd. Tokyo, Japan). Moisture and crude fiber were determined by the AOAC method⁹⁾. The amount of Cr_2O_3 was determined according to the procedure described by KAMEOKA *et al.*¹⁰⁾ Concentration and molar proportions of VFA were determined by the routine method described by HAMADA *et al.*¹¹⁾ The determination of pH of ruminal fluid was done with a glass-electrode apparatus. Propanediol concentration of blood and ruminal fluid samples were determined by the calorimetric method using KOMAROVSKY reaction¹²⁾. Blood glucose was analyzed according to the 0-toluidine method described by MORRILL and FARMER¹³⁾.

Results

Trial 1. Average daily gains and feed conversions during 4-weeks experimental period are shown in Table 2. Although no difference of daily gains was observed, the feed conversion of the propanediol-fed group was much lower than that of the group fed control diet. As the experimental periods of the two groups and compositions of the two rations (Table 1) were not the same, no definite conclusions could be derived from these results. However, there is a possibility that inclusion of propanediol into the complete ration containing a large amount of rice straw meal may improve the feed conversion rate. Dustiness and preservation quality of the ration were improved by the inclusion of propanediol. Ruminal tissue and papillae development seemed to remain apparently normal by the inclusion.

Table 2. Comparison of average daily gains and feed conversions (kg feed/kg gain) of the kids fed either propanediol diet or control diet during 4-weeks experimental period of trial 1

Ration	Propanediol diet	Control diet
Number of kids used	4	6
Average initial weight (kg)	3.21	2.93
Daily gain (g)	76*±17**	76±16
Feed conversion	2.52±0.30	3.57±0.43

* Mean

** Standard deviation

Trial 2. Dry matter and crude fiber contents of the ration containing propanediol were 87.7 and 8.0 %, respectively, while those of the ration containing no propanediol were 87.7 and 8.8 %, respectively. The dry matter content of the former ration was assumed as the same with that of the latter ration, since a part of propanediol was volatile in the air oven at 135°C. On average of two goats, apparent digestion coefficients of dry matter and crude fiber of the ration containing propanediol were 69 and 22 %, respectively, while those of the ration containing no propanediol were 68 and 27 %, respectively.

Trial 3. Average daily gains of young goats fed the two diets containing either propanediol or starch were 77 and 60 g, respectively. There was found a significant difference between them ($P<0.05$). Some reasons for this difference might be attributed to higher gross energy (5,650 versus 4,000 kcal/kg) and better utilization of propanediol compared with starch.

Trial 4. On average of two goats, apparent digestion coefficients of dry matter and crude fiber of the ration (PR-ration) including the propanediol-diet and hay were 69 and 58 %, respectively, while those of the ration (ST-ration) including the starch-diet and hay were 67 and 51 %, respectively. Average concentration and molar proportions of acetic acid, propionic acid, n-butyric acid and n-valeric acid of the ruminal fluid samples taken from the goats fed PR-ration were 98 mM and 56, 31, 10 and 2 %, respectively, while those taken from the goats fed ST-ration were 95 mM and 60, 26, 13 and 1 %, respectively. Average dry matter content and pH of the ruminal fluid samples of the goats fed PR-ration were 8.5 % and 6.1, respectively, while those of the goats fed ST-ration were 11.5 % and 6.1, respectively.

Trial 5. Preadapted and non-adapted goats to propanediol for 2 weeks were administered the same amount of propanediol via the rumen fistula. The changes of concentration and molar proportions of ruminal VFA are shown in Table 3. Ruminal fluid samples at zero-hour corres-

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Table 3. The changes of concentration and molar proportions of volatile fatty acids (VFA) in the rumens of preadapted and non-adapted goats administered DL-1,2-propanediol intraruminally

Sampling hour	Preadapted goat			Non-adapted goat		
	Total VFA concentration	Molar proportion of C_3	Molar ratio $(C_3/C_2) \times 100^*$	Total VFA concentration	Molar proportion of C_3	Molar ratio $(C_3/C_2) \times 100$
	mM	%		mM	%	
(1st sampling)						
zero	42	57	44	64	53	45
1	28	45	82	30	51	59
2	29	39	108	37	46	80
3	24	35	142	25	44	90
(2nd sampling)						
zero	55	56	39	36	54	46
2	47	37	122	30	45	84
6	45	27	214	28	39	117

* C_3/C_2 means molar ratios of propionic acid to acetic acid.

ponded to more than half a day after previous rations had been consumed. The concentrations of total VFA dropped to considerably lower levels at 1 hour, after which they kept fairly constant levels. The conversion of propanediol into propionic acid was found in both goats as shown by the increase of molar ratios of propionic acid to acetic acid with advancing time. However, this conversion rate was much higher in the preadapted goat than in the non-adapted goat.

The changes of propanediol concentrations of ruminal fluid and whole blood samples are shown in Fig. 1 and 2, respectively. Relatively lower concentrations of ruminal propanediol were obtained in the preadapted goat than in the non-adapted goat. Although slightly faster clearance of blood propanediol was observed in the preadapted goat, the maximum concentrations of blood propanediol were attained in 2 to 3 hours after the administration of propanediol in both goats. Gradual increases of jugular blood glucose above the concentrations at zero-hour were 2 to 7 mg % during 6 hours after the administration in both goats. Urinary loss of propanediol corresponded to about 4 to 5 % of the total amounts administered in the rumen during the sampling period of 8 hours after the administration in both goats.

Fig. 1. The changes of ruminal propanediol concentration after the administration of propanediol intraruminally

Fig. 2. The changes of blood propanediol concentration after the administration of propanediol intraruminally

Discussion

The results of the growth experiments of trials 1 and 3 suggest that propanediol can be successfully included in the ration as an energy source for the young ruminant. The complete ration used in trial 1 for young kids contains a large amount of rice straw meal whose feeding value is extremely low. By the inclusion of propanediol into this ration at a ratio of 1:10, the feeding value and physical quality of the ration can be improved. In this case, a mixture of propanediol and cane molasses (about 1:1 by weight) was also found to be easily included in the ration, since the viscosity of molasses was decreased by the inclusion of propanediol. EMERY *et al.*⁶⁾ reported that when propanediol exceeded about 5 % of the ration, some reduction in feed intake occurred with dry cows, but that the lactating cow did not reduce feed intake even when propanediol constituted 16.7 % of the dry matter intake (0.4 % of body weight). It was observed that the peculiar odor of propanediol caused only temporary rejection to eat in some animals.

The results of the digestion experiments of trials 2 and 4 suggest that although some discrepancy has been obtained in the crude fiber digestibilities between trials 2 and 4, which may reflect some chemical heterogeneity of the crude fiber fractions of rice straw and Italian ryegrass hay, no adverse effect on dry matter digestibility will be caused by the inclusion of propanediol into the total ration at about 10 % level. EMERY *et al.*⁶⁾ reported some tendency for reduction in dry matter digestibility as the propanediol dose increased from 0.03 to 0.40 % of body weight.

Although EMERY *et al.*⁶⁾ showed a depression of total VFA production by the inclusion of propanediol at the level of 25 % of the ration (0.40 % of body weight), the present results of trial 4 showed no such depression by the inclusion at the level of about 5 % of the total ration. Higher molar proportion of propionic acid of the propanediol-fed goats in trial 4 suggests a partial conversion of propanediol into propionic acid, as initially reported by WALDO and SCHULTZ¹⁴⁾.

Higher conversion rates of propanediol into propionic acid in the preadapted goat than in the non-adapted goat in trial 5 suggest that the ability of ruminal flora to metabolize propanediol into propionic acid can increase by the adaptation of ruminal flora to propanediol. According to GASTON and STANDTMAN¹⁵⁾, a GRAM-positive, spore-forming rod isolated from mud, *Clostridium glycolicum*, has such ability to convert propanediol into propionic acid and n-propyl alcohol by a balanced oxidation-reduction process.

The disappearing rate of ruminal propanediol and the appearing rate of blood propanediol shown in Fig. 1 and 2 were very similar to the data presented by EMERY *et al.*⁶⁾, in which the half life of ruminal propanediol was reported as 1.7 hours, when they administered propanediol equal to 0.15 % of body weight intraruminally to dry cows. In these data maximum concentrations of blood propanediol attained in 2 to 3 hours after the administration. However, in a lactating cow a maximum concentration of blood propanediol was reported to attain in 0.5 hours after the administration by EMERY *et al.*¹⁶⁾, when they administered propanediol equal to 0.06 % of body weight intraruminally to lactating cow.

In our data of trial 5 the gradual increase of blood glucose values was observed in 6-hours sampling period. WALDO and SCHULTZ¹⁴⁾ also reported 6 mg % increase above the levels at zero-hour in 8 hours after the administrations of propanediol equal to 0.06 to 0.2 % of body weights. In the data of a lactating cow reported by EMERY *et al.*¹⁶⁾, blood glucose derived from pro-

panediol attained a maximum at 3 hours after the administration. These facts suggest that the turnover rate of blood propanediol may be higher in a lactating animal than in a maintenance animal.

The present results support the view of EMERY *et al.*¹⁶⁾ that propanediol is primarily absorbed as such from the rumen and that propanediol is partially converted to propionic acid in the rumen. Although no active adaptation was found in the metabolic conversion rate of propanediol into glucose, ruminal conversion rate of propanediol into propionic acid can be increased by the adaptation of ruminal flora.

Summary

Using Japanese meat-type goats of various ages, the following conclusions were obtained concerning the utilizations of DL-1,2-propanediol by the ruminant.

1. As an energy source for the young ruminant, propanediol could be successfully included in the ration at the levels of 5 to 10 %.
2. By the inclusion of propanediol at these levels, dry matter digestibility of total ration scarcely changed.
3. The conversion rate of propanediol into propionic acid in the rumen was increased by the adaptation of ruminal flora to propanediol for 2 weeks.
4. No remarkable differences were found in the disappearing rate of ruminal propanediol, the appearing rate of blood propanediol and the increase of blood glucose after the administration of propanediol intraruminally between preadapted and non-adapted goats to propanediol.

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References

- 1) JOHNSON, R.B. (1954) Cornell Vet., 54: 6.
- 2) NEUBAUER, O. (1901) Arch. f. experim. Pathol. u. Pharmakol., 46: 133.
- 3) MIURA, S. (1911) Biochem. Z., 36: 25.
- 4) HANZLIK, P.J., H.W. NEWMAN, W. VAN WINKLE, JR., A.J. LEHMAN and N.K. KENNEDY (1939) J. Pharma. Exp. Therapie., 67: 101.
- 5) ITOH, H., E. FUKUBE and K. ASHIDA (1965) Abstracts of Papers, 36th National Meeting of Agricultural Chemical Society of Japan, Tokyo. 123.
- 6) EMERY, R.S., N. BURG, L.D. BROWN and G. N. BLANK (1964) J. Dairy Sci., 47:1074.
- 7) YOSHIDA, M., H. HOSHII and H. MORIMOTO (1968) Japan. Poultry Sci., (In Press.)
- 8) BAYLEY, H.S., S. J. SLINGER and J.D. SUMMERS (1967) Poultry Sci., 46: 19.
- 9) Assoc. of Official Agr. Chemists (1960) Official Methods of Analysis, 9th Ed. 283.
- 10) KAMEOKA, K., M. YOSHIDA, D. KUBOTA and S. TAKAHASHI (1957) Bull. Nat. Inst. Agric. Sci. (Japan), G 13: 67.
- 11) Hamada, T., S. OMORI, K. KAMEOKA, S. HORII and H. MORIMOTO (1968) J. Dairy Sci., 51: 228.
- 12) NOGARE, S.D. and J. MITCHELL, JR. (1953) Anal. Chem., 25: 1376.
- 13) MORRILL, J.L. and E.L. FARMER (1965) J. Dairy Sci. (Abstr.) 48: 818.
- 14) WALDO, D.R. and L.H. SCHULTZ (1960) J. Dairy Sci., 43: 496.
- 15) GASTON, L.W. and E.R. STANDTMAN (1963) J. Bact., 85: 356.
- 16) EMERY, R.S., R.E. BROWN and A.L. BLACK (1967) J. Nutr., 92: 348.

子山羊と成山羊における DL-1,2-プロパンジオールの利用について

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いろいろの年令の在来種肉用山羊を用いて、反芻家畜に対する DL-1,2-プロパンジオールの利用について検討し、つぎのような結論を得た。

1) 子山羊のエネルギー源として、全飼料中に 5~10% のプロパンジオールを混入しても何ら支障はおきず、よく利用された。

2. この程度のプロパンジオールの混入によっては、全飼料の乾物消化率はほとんど変らなかった。

3) 反芻胃内におけるプロパンジオールのプロピオン酸への経時的転換率は、反芻胃内微生物をプロパンジオールに 2 週間適応させることによって増加した。

4) プロパンジオールに対して適応した山羊と適応しない山羊との間で、反芻胃内に投与したプロパンジオールの消失速度、プロパンジオールの血中への出現速度、および血糖値の増加量において、著しい差異を見出せなかった。