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EFFICIENCY OF ENERGY UTILIZATION OF VOLATILE FATTY ACIDS BY MATURE CATTLE GIVEN A HAY OR HIGH-CONCENTRATE DIET

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Summary

Three experiments were conducted with dry and lactating Holstein cows to determine the efficiency of energy utilization of volatile fatty acids (VFA). The cows were fed a hay or high concentrate (HC) diet as a basal diet (BD). Three VFA mixtures containing acetic, propionic and butyric acid in the following molar proportions (%) 2, 7 and 1; 4.5. 4.5 and 1; 7, 2 and 1 were infused into the rumen to supply 50% of metabolizable energy required for maintenance (MEm) or for maintenance plus milk production. VFA infusion had only a small effect on the digestive function of the rumen. There was a clear nitrogen sparing effect of propionate when the energy supplied was above MEm. Total energy balance (TEB) from VFA energy increased with an increase in the proportion of acetic acid infused when the hay diet was given as BD, while it increased with an increase in the proportion of propionic acid infused when the HC diet was given as BD. The efficiency of energy utilization of the VFA mixtures in dry cows was 0.572 (TEB<0) and 0.529 (TEB>0) when BD was HC diet, while the values were 0.525 (TEB<0) and 0.444 (TEB>0) when BD was hay. MEm and an efficiency of milk production were calculated to be 485 kJ/kg$^{0.75}$ and 0.664, respectively.
Keywords: dairy cow, diet, volatile fatty acids, infusion, energy utilization

Introduction

Many attempts have been made to clarify the efficiency of energy utilization of volatile fatty acids (VFA). In most experiments, the efficiency was measured when only 10 to 20 % of metabolizable energy (ME) was added as VFA to a basal diet (Holter et al., 1972; Tyrrell et al., 1979) or when VFA was infused into an empty rumen without feed (Ørskov et al., 1979, 1991). However, it is considered that the proportion of total energy supplied as infused VFA was relatively small in the former experiment and the contribution of rumen function to ruminant nutrition is ignored in the latter. Moreover, the efficiency of energy utilization of infused acetate has been shown to be dependent on the type of diet fed (Tyrrell et al., 1979). Therefore, in our experiments, mature cows given different types of basal diet and infused relatively large amount of VFA mixtures into the rumen were used to determine the efficiency of energy utilization of VFA.

Materials and Methods

Experiment 1. Two dry rumen fistulated Holstein cows with an average body weight (BW) of 686 kg were used in 2 trials. They were fed italian ryegrass hay (IRG) in trial 1 and a high concentrate (HC) diet (IRG :concentrate ratio=3:7) in trial 2 as the basal diet (BD). BD was fed twice daily. Three different VFA mixtures were used containing acetic, propionic and butyric acid in the following proportions (molar basis) 2, 7 and 1 (A2P7); 4.5, 4.5 and 1 (A45); 7, 2 and 1 (A7P2) respectively. The VFA mixture, prepared by partially neutralizing with 300g $NaHCO_3$, was diluted to 20 liters with tap water and infused into the rumen at a constant rate over 23 hr of each day to supply 50%

of ME required for maintenance (MEm; AFFRC, 1994). The treatments for both trials were (1)BD50: BD equivalent to 50% of MEm, (2)A2P7: BD50+A2P7 solution, (3)A45: BD50+A45 solution, (4)A7P2: BD50+A7P2 solution, (5)BD100; BD equivalent to 100% of MEm. The period of one treatment was 14 days. Studies of digestion were done during the last 4 days. Rumen and blood samples were taken at 0, 1 and 3 hr after morning feeding and the disappearance rate of dry matter (DM) in the rumen was measured by the nylon bag technique for 48 hr and heat production (HP) was measured by using open-circuit respiration chambers during the last 2 days.

Experiment 2. Four dry Holstein cows with rumen fistulas (668kg BW) were used in 2 trials. They were fed IRG in trial 1 and fed the same HC diet used in Expt 1 as BD. Three VFA mixtures, the same as in Expt 1, were infused into the rumen. The amount and procedure of VFA infusion were the same as in Expt 1. The treatments for both trials were (1)BD100: BD equivalent to 100% of MEm, (2)A2P7: BD100+A2P7 solution, (3)A45: BD100+A45 solution, (4)A7P2: BD100+A7P2 solution, (5)BD150; BD equivalent to 150% of MEm. The experimental design and procedure were the same as Expt 1.

Experiment 3. Three lactating Holstein cows with rumen fistulas (675kg BW) were used in a 3x3 latin square design with 14 days for each period. They were fed IRG and concentrate (IRG : concentrate ratio=4:6) as the BD. Soybean meal (3kg/d) was added to the BD to satisfy crude protein (CP) requirements. The VFA mixture, prepared by partially neutralizing with 400g $NaHCO_3$, was diluted (60 liters daily) with tap water and infused into the rumen to supply 50% of MEm plus milk production (AFFRC, 1994). The treatments were (1) BD300: BD equivalent to 100% of MEm and milk production (3xMEm)+60 liters of water (2)A2P7: 50% of BD300+A2P7 solution, (3)A45: 50% of BD300+A45 solution. In addition to 3 treatments, A7P2 treatment (50% of BD300+ A7P2 solution) was also done. The procedure of measurements and sampling were the same as Expt 1.

Results and Discussion

Data obtained from Expt 1 and 2 were combined and analyzed by the GLM procedure (SAS Institute, 1988) for 2-way classification. Data from Expt 3 were also analyzed as 2-way classification data to analyze for 4 treatments including A7P2 treatment as well as analysis by 3x3 latin square design. There were no significant differences in DM digestibility (DMd), DM disappearance rate of hay in the rumen (rumen DMd) and total bacterial counts among treatments in both dry and lactating cows. Therefore, it is considered that VFA infusion had only a small effect on the digestive function of the rumen. Total protozoal counts were not different among VFA treatments but VFA infusion significantly reduced protozoal counts compared with BD treatments in both dry and lactating cows. Urinary allantoin excretion (UAE) was not affected by both BD and VFA treatment in dry cows. However, feeding HC diet tended to increase UAE compared with feeding hay. This could be attributed to higher synthesis of rumen microbial protein because of the higher CP and digestible organic matter content in the HC diet. Nitrogen (N) balance did not show any significant differences between BD and among VFA treatments in both dry and lactating cows. However, in lactating cows, N balance increased with an increase in the proportion of propionic acid infused. It is suggested that there was a clear N sparing effect of propionate when energy supplied was above MEm, as reported previously for sheep (Ørskov et al., 1979).

There were no significant differences in the yield and composition of milk among treatments. Milk yield was the highest at BD300. Fat content of milk tended to be lower during the A2P7 treatment which is a similar trend to that observed by other workers (Armstrong and Blaxter, 1965; Holter et al., 1972) while the protein content of milk tended to be higher in A2P7 and A45 treatments. However, the milk fat content remained at a high level even though the ruminal acetate to propionate ratio was very low (0.7). Sutton et al. (1988) reported that constant absorption of VFA and reduced fluctuation in the concentration of plasma insulin by frequent feeding reduced the severity of milk-fat depression. In the present experiments, there were no significant differences in the concentrations of plasma glucose and insulin between VFA treatments in dry cows. In lactating cows, plasma insulin during the A45 and A2P7 treatments was relatively higher than those of A7P2 and BD300. However, no severe depression of milk fat content in A2P7 could be attributed to the similarity in physiological status of frequent feeding and constant infusion of VFA.

Table 1.Least square means for DM digestibility, ruminal parameters and N and energy utilization

Item	Dry Cows (Expt 1 and 2)						Lactating Cows (Expt)			
	Basal Diet[3]		Treatment				Treatment			
	HC	Hay	A2P7	A45	A7P2	BD100	BD300	A2P7	A45	A7P2
DMd, %	68.9^{**}	59.0	63.4	62.5	63.9	65.8	72.9	75.3	72.3	72.7
Rumen[1]										
DMd,hay, %	64.3	63.6	60.2	61.1	59.0	65.2	48.4	34.8	30.3	25.1
A:P	3.2^{**}	2.8	1.0^{a}	1.7^{b}	3.7^{c}	3.7^{c}	$3.3^{a,A}$	$0.6^{b,B}$	$1.3^{b,B}$	3.2^{a}
Bacteria[2]	9.3^{**}	8.7	9.0	9.0	9.1	8.9	9.3	9.2	9.3	9.3
Protozoa[2]	4.9^{**}	4.4	4.3^{a}	4.2^{a}	4.1^{a}	5.2^{b}	4.7^{a}	3.6^{b}	3.4^{b}	3.4^{b}
UAE, g/d	8.8	6.1	5.1	3.3	3.0	9.3	75.0^{A}	45.9^{B}	54.8^{B}	38.5
N balance, %[2]	5.0	6.2	12.4	-1.4	11.6	9.4	7.1	8.3	4.1	-10.8
Plasma[1,2]										
Glucose	70.9	70.6	71.8	73.6	71.0	70.6	$76.4^{a,A}$	$70.3^{b,B}$	$70.5^{b,B}$	72.4^{b}
Insulin	47.7^{**}	60.4	59.5	53.6	62.3	53.5	$18.3^{a,A}$	$29.0^{b,c,B}$	$29.8^{c,B}$	$2.4^{a,b}$
Energy balance										
VFA GE[2]	118	121	243^{a}	239^{a}	234^{a}	0^{b}	$0^{A,a}$	$604^{B,b}$	$601^{B,b}$	668^{b}
GE[2]	904^{**}	1043	1019	977	1009	1009	2477^{a}	$1949^{a,b}$	$1887^{a,b}$	1776^{b}
ME[2]	579	564	648	612	640	555	1576	1486	1409	1395
HP/GE, %	59.5^{**}	51.5	54.5	56.4	54.2	50.0	36.6^{a}	47.3^{b}	$46.3^{a,b}$	48.3^{b}
TEB/GE, %	4.6	3.6	10.3	7.8	10.3	5.4	27.2	28.9	28.4	30.3
Milk/GE, %							15.9	17.1	18.8	17.6
VFA HI, %	38.4	36.5	39.6	37.6	35.1			70.8	67.1	67.6
VFA TEB, %	58.7	57.8	54.0	55.9	64.8			33.6	30.9	36.4
Milk										
Yield, kg/d							18.85	16.29	16.11	14.79
Fat, %							3.66	3.55	3.97	3.78
Protein, %							3.41	3.50	3.53	3.31

a,b,c: Means in the same row within dry cows or lactating cows with different superscripts differ ($P<0.05$) by 2-way classification variance analysis.

A,B : Means in the same row within lactating cows with different superscripts differ ($P<0.05$) by latin square analysis.

1) Ruminal A:P, bacteria, protozoa and plasma glucose and insulin were the average value for daily 3 measurements on 2 days (6 measurements).

2) Units: Total counts of bacteria and protozoa, log No./ml rumen fluid; N balance, % N intake; Glucose, mg/dl; Insulin, μU/ml; GE and ME intake, $kJ/kg^{0.75}$.

3) Least square means of all treatments in each BD (effect of BD; $^{**}P<0.01$).

In the dry cows, no significant differences among VFA treatments were noted in energy partition. Although HP in the HC diet was significantly higher compared with the hay diet, total energy balance (TEB; ME intake minus HP) in the HC diet was higher. To clarify the energetics of the VFA mixtures, the increment of HP and TEB from infused

VFA (VFA HI and VFA TEB) were calculated by subtracting the estimated HP or TEB due to BD intake from observed HP or TEB. HP and TEB from BD were estimated from the values of HP and TEB as well as GE at BD50, BD100 and BD150. There were no significant differences in VFA HI and TEB between BD and among VFA treatments. The values of VFA HI were slightly higher than the value of acetate determined for cattle fed a high concentrate diet (Tyrrell et al., 1979). VFA TEB in A7P2 was higher than in A2P7 and A45. The mean value of both BD was 58% which is similar to the 55% observed in steers (Ørskov et al., 1991). However, a different tendency for VFA TEB between the BD was observed. VFA TEB increased with an increase in the proportion of acetic acid infused when the hay diet was given as BD, while it increased with an increase in the proportion of propionic acid infused when the HC diet was given as BD. The efficiency of energy utilization of the VFA mixtures was tested for dry cows and for lactating cows by regressing TEB on ME intake. The regression equations were as follows:

	TEB<0	TEB>0
Dry cows		
BD: HC diet	TEB = 0.572 ME intake - 264.1	TEB = 0.529 ME intake - 228.4
BD: Hay diet	TEB = 0.525 ME intake - 286.5	TEB = 0.444 ME intake - 190.8
All data	TEB = 0.619 ME intake - 299.2	
Lactating cows	TEB>0	
BD: HC diet	TEB = 0.720 ME intake - 428.2	

All data including dry and lactating cows: TEB = 0.639 ME intake - 309.9

The efficiency of utilization of VFA in the dry cows was 0.572 (TEB<0) and 0.529 (TEB>0) when BD was HC diet, whilst it was 0.525 (TEB<0) and 0.444 (TEB>0) when BD was the hay diet. From the above results, it is concluded that the efficiency of energy utilization of VFA depends upon the type of diet given.

In lactating cows, the efficiency of conversion of ME to TEB was 0.72 which was higher than that of dry cows. MEm calculated from the regression equation fitted to the values of lactating cows was 595kJ/kg$^{0.75}$. This value is higher than 556kJ/kg$^{0.75}$ which is the suggested value of NRC (1989). A single estimate from all values was 485kJ/kg$^{0.75}$ which is similar to 487kJ/kg$^{0.75}$ (AFFRC, 1994). The efficiency of milk production at zero body energy retention, which was calculated according to Armstrong and Blaxter (1965), was 0.626 and 0.696 using 485kJ/kg$^{0.75}$ and 595kJ/kg$^{0.75}$ respectively as MEm obtained from the present experiments. The value of 0.696 is almost identical to the average value (0.691) observed in goats (Armstrong and Blaxter, 1965). However, the true efficiency might be slightly lower than 0.696 because the value of MEm (595kJ/kg$^{0.75}$) used in this analysis seems to be high. An efficiency of 0.664 was obtained using the MEm value of NRC (1989), which seems to be probable.

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