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The effects of fructose and phosphate infusions on dry matter intake of lactating cows

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ABSTRACT

The objective of this study was to examine the effects of fructose and phosphate (Pi) infusions on dry matter intake by dairy cows to further understand the mechanisms controlling feed intake related to hepatic energy status. We performed 3 experiments in which we infused fructose and Pi intravenously or abomasally to Holstein cows. The first experiment used 8 cows (4–8 d postpartum) in a duplicated 4 × 4 Latin square experiment with 1 square of multiparous and 1 square of primiparous cows. A 2 × 2 factorial arrangement of treatments was used including jugular infusions of solutions (1 L/h) containing fructose or glucose (0.6 mol/h) and Pi (NaH_2PO_4) or NaCl (0.3 mol/h). Periods were 24 h, including 2 h for infusions and 22 h for recovery. The second experiment used 4 multiparous cows (74–81 d postpartum) in a 4 × 4 Latin square design and infused fructose or glucose and either Pi or no Pi at the same rates as experiment 1. Periods were 24 h, including 1 h for infusions and 23 h for recovery. The third experiment used 4 ruminally cannulated multiparous cows (15–26 d postpartum) in a 4 × 4 Latin square design and infused fructose or glucose and either Pi or NaCl at the same rates as experiment 1 but to the abomasum. Periods were 24 h, including 1 h for infusions and 23 h for recovery. In each experiment, feed intake was recorded by a computerized data acquisition system; blood was analyzed for the concentrations of glucose, nonesterified fatty acids, and Pi; and the liver was analyzed for the concentration of Pi (experiments 2 and 3 only). Overall, fructose infusion increased DMI by fresh cows when infused intravenously and abomasally, but it did not affect DMI by mid-lactation cows. Fructose infusion also reduced hepatic Pi, and Pi infusion increased hepatic Pi when infused abomasally but not intravenously. These results suggest that fructose increases feed intake, likely by sequestering Pi and preventing ATP production. When infused intravenously to multiparous cows, Pi increased DMI and did not affect hepatic Pi content. However, when infused abomasally, Pi reduced DMI and increased hepatic Pi content. These results suggest that although Pi infusion prevents the effect of fructose loading and reduces DMI, it also increases intake through a competing mechanism. Examining long-term effect of Pi infusion on DMI could determine if competing mechanisms complicate the determination of P requirement for dairy cows. These results are consistent with the control of feed intake by hepatic energy status in dairy cows.

Key words: control of feed intake, hepatic oxidation theory, ATP, energy charge

INTRODUCTION

The control of energy intake in dairy cows is complex, including mechanisms that act independently (e.g., distention, osmotic effects) as well as many interacting factors that affect feed intake via their effects on metabolism (Ingvartsen and Andersen, 2000; Allen, 2014).

Moreover, the control of intake changes during the lactation cycle. A growing consensus exists that during the critical first few weeks of lactation, when cows are in negative energy balance because milk energy output greatly exceeds energy intake, the control of feed intake is dominated by fuel-based sensing mechanisms, specifically hepatic oxidation of fuels (Allen et al., 2009; Schäff et al., 2012; Derno et al., 2013; Martineau et al., 2016) and not by gut fill (Allen et al., 2009). Afterward, in the following months, distention by undigested feed residues in the gastrointestinal tract likely dominates the control of feed intake as milk yield and nutrient requirements are high (Allen, 1996).

Research in nonruminants revealed the effect of oxidation of fuels on feed intake by showing that inhibition of fuel oxidation stimulates feed intake and stimulation of oxidation inhibits feed intake; the research also showed that the signal to brain feeding centers is via hepatic vagal afferents (Langhans, 1996). Control of feed intake in nonruminants was demonstrated to be related to hepatic energy status, which is determined by the balance between the rates of production and utiliza-

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tion of ATP (Friedman et al., 1999). Fructose loading results in the accumulation of fructose 1-phosphate in mammalian livers (Kjerulf-Jensen, 1942), temporarily sequestering phosphate (**Pi**). Perfusion of the liver of rats with fructose rapidly (<10 min) decreased hepatic ATP content by 77% with a transient decrease in Pi (Woods et al., 1970). Fructose has a similar effect of reducing available Pi and ATP content in the rat and human liver (Woods et al., 1970; Morris et al., 1978; Abdelmalek et al., 2012), and fructose has elicited feeding in rabbits (Novin et al., 1991). The fructose analog 2,5-anhydro-D-mannitol (**2,5-AM**), which is phosphorylated but not metabolized further, decreased hepatic ATP content and elicited an eating response in rats (Tordoff et al., 1988; Rawson et al., 1994; Koch et al., 1998). The reduction in ATP content was likely from trapping Pi because Pi loading prevented the reduction in hepatic ATP content and stimulation of feeding by 2,5-AM (Rawson and Friedman, 1994). Therefore, fructose loading in the lactating cow might enable us to link hepatic ATP synthesis and feeding behavior, thus elucidating the mechanisms underlying control of feed intake by hepatic oxidation of fuels. We hypothesized that fructose will decrease hepatic ATP content, thus delaying satiety and increasing meal size and DMI, while Pi loading will attenuate its effects. Accordingly, the objective of this study was to examine the effects of fructose and Pi infusions on feeding behavior and metabolic responses of dairy cows.

MATERIALS AND METHODS

Animal Housing and Care

All experimental procedures were approved by the Institutional Animal Care and Use Committee at Michigan State University (East Lansing). For all experiments, cows were housed in tiestalls at the Michigan State University dairy facility, fed a TMR once daily at 1100 h at 120% of expected intake (their intake in the previous day), and milked twice daily in the milking parlor approximately at 500 h and 1600 h. Feed offered and refused was recorded and sampled daily throughout the experiment for determination of nutrient content (Table 1). The amounts of feed offered and refused were weighed, and the feed offered was adjusted daily.

Design and Treatments

Experiment 1. Eight Holstein cows in the early postpartum (**PP**) period (4–8 d PP) were used in a duplicated 4 × 4 Latin square experiment balanced for carryover effects with 1 square of multiparous cows and 1 square of primiparous cows. Cows were offered the prepartum ration beginning 21 d prepartum and the lactation ration beginning at parturition and throughout the experiment (Table 1). All cows were fitted with a single jugular catheter (left or right jugular vein) 2 to 3 d before the beginning of the experiment. Catheter patency was checked daily until removal at the end of the experiment. Cows were randomly assigned to tiestalls and treatment sequences. Periods were 24 h, beginning at the conditioned meal after feeding and including 2 h for infusions and 22 h for recovery. Cows were blocked from feed for 2 h before the beginning of each infusion. A 2 × 2 factorial arrangement of treatments was used, and treatments included jugular infusions (1 L/h) of solutions containing fructose or glucose (0.6 mol/h) and phosphate (NaH_2PO_4) or NaCl (0.3 mol/h). Glucose was used as the control for the fructose treatment because the two sugars have the same molecular mass and energy content and glucose uptake by the liver of mature bovines is negligible (Stangassinger and Giesecke, 1986). NaCl was used as an osmotic control for the Pi treatment. The infusion rate for Pi was estimated based on the work of Rawson et al. (1994) with rats, which used about 2:1 ratio between the fructose analog 2,5-

Table 1. Ingredient and nutrient composition (% of DM unless otherwise noted) of the experimental diets

	Experiment		
Item	1	2	3
Ingredient			
Corn silage	29.9	19.4	29.9
Haylage	15.1	16.6	15.1
Alfalfa hay	13.6	—	13.6
Dry ground corn	19.5	15.2	19.5
Soybean meal	16.4	8.7	16.4
Soybean hulls	4.2	7.0	4.2
Cottonseeds	—	7.6	—
High-moisture corn	—	15.6	—
Wheat straw	—	5.6	—
Vitamin-mineral mix 1[1]	1.4	—	1.4
Vitamin-mineral mix 2[2]	—	4.41	—
Nutrient composition			
DM (%)	56.4	55.7	50.6
Starch	23.9	27.3	20.9
NDF	31.0	28.6	33.0
CP	17.6	16.9	17.6
P	0.39	0.36	0.39

[1]Vitamin-mineral mix 1 contained (DM basis): 11.40–13.60% NaCl, 12.80–15.30% Ca, 0.99% Mg, 0.9% P, 10.90–13.00% Na, 14.0 mg/kg Co, 250 mg/kg Cu, 9.9 mg/kg I, 745 mg/kg Fe, 994 mg/kg Mn, 7.5 mg/kg Se, 1,100 mg/kg Zn, 149,000 IU/kg vitamin A, 23,000 IU/kg vitamin D_3, and 680 IU/kg vitamin E.

[2]Vitamin-mineral mix 2 contained (DM basis): 10.50–12.60% NaCl, 9.30–11.10% Ca, 0.91% Mg, 0.91% P, 8.30–9.90% Na, 14 mg/kg Co, 230 mg/kg Cu, 9.1 mg/kg I, 685 mg/kg Fe, 914 mg/kg Mn, 6.9 mg/kg Se, 1,000 mg/kg Zn, 137,000 IU/kg vitamin A, 23,000 IU/kg vitamin D_3, and 680 IU/kg vitamin E.