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Fuels derived from starch digestion have different effects on energy intake and metabolic responses of cows in the postpartum period

Laura B. Gualdrón-Duarte and Michael S. Allen[1]
Department of Animal Science, Michigan State University, East Lansing 48824-1225

ABSTRACT

Absorbed fuels from the digestion of starch include propionic acid (PA) produced by ruminal fermentation and glucose (GLU) from intestinal digestion, which may be partially metabolized to lactic acid (LA) by intestinal tissues. Our objective was to evaluate the effects of these fuels on dry matter intake (DMI) and feeding behavior of cows in the postpartum period. We hypothesized that these fuels affect feed intake differently and that their effects are related to differences in their hepatic metabolism. Glucose was expected to have little effect on feed intake because little or no GLU is extracted from the blood by the liver. Whereas both LA and PA are anaplerotic and can stimulate oxidation of acetyl CoA in hepatocytes, hepatic extraction of PA is greater than LA, which depends on cytosolic redox state. Continuous isoenergetic infusions (150 kcal of ME/h) of PA, LA, or GLU or no infusion were administered abomasally to 8 ruminally cannulated multiparous Holstein cows (12.4 ± 6.2 d postpartum) in a duplicate 4 × 4 Latin square design experiment, with four 1-d infusion periods, balanced for carry-over effects. Treatment sequences were assigned to cows randomly, and treatments included control (CON, no infusion), PA (0.41 mol/h), LA (0.46 mol/h), and GLU (0.22 mol/h). Solutions containing treatments were infused at 500 mL/h for 22 h/d and provided ~3.3 Mcal/d. Feeding behavior was recorded by a computerized data acquisition system. Gross energy digestibility of the diet was determined for each cow and used to calculate metabolizable energy intake (MEI) from the diet. Total MEI was calculated as the sum of MEI from the diet plus energy from infusions. Data were analyzed statistically with a mixed model including the fixed effect of treatment and random effects of block and cow within block. Each treatment was compared with CON by contrasts. Compared with CON, PA decreased DMI by 24% (14.3 vs. 18.9 kg/d) and total MEI by 13% (34.8 vs. 40.2 Mcal/d) with a tendency to decrease meal frequency. Lactic acid decreased DMI by 14% (16.3 vs. 18.9 kg/d) compared with CON by decreasing meal size 20% but did not affect MEI. Glucose infusion did not affect DMI or MEI. Treatment effects on DMI and MEI were consistent with their expected effects on hepatic oxidation. Depression of feed intake in diets containing highly fermentable starch is likely because of differences in hepatic metabolism.
Key words: appetite, hepatic oxidation theory, metabolic fuels

INTRODUCTION

Cereal grains high in starch are included in rations to meet dietary energy requirements of high-producing dairy cows. However, highly fermentable starch sources can depress feed intake compared with less fermentable starch sources (Allen, 2000). High-moisture corn decreased DMI 8% for mid-lactation cows (Oba and Allen, 2003a) and 11% for cows in the postpartum (**PP**) period (Albornoz and Allen, 2016), compared with the less fermentable dry ground corn. Ruminal fermentability of starch varies greatly from ~30% to ~90% (Allen, 2000) depending upon genetics, maturity, processing, and storage method of the starch source (Kotarski et al., 1992; Larson and Hoffman, 2008). This wide variation affects the type and supply of fuels available for absorption including propionic acid from ruminal fermentation, glucose from enzymatic hydrolysis of starch that passed from the rumen to the small intestine, and lactic acid from the partial metabolism of glucose by enterocytes. Once absorbed, metabolism of these fuels varies with different efficiencies of extraction from the blood by the liver and potential of stimulating hepatic oxidation. According to the hepatic oxidation theory (**HOT**) of the control of feed intake, anaplerotic fuels extracted by the liver may promote oxidation of acetyl CoA (**AcCoA**) contributing to satiety (Allen et al., 2009). Of the primary fuels absorbed from starch digestion in ruminants, propionate and lactate are anaplerotic, whereas little glucose is extracted from the blood by the liver. However, hepatic extraction of propionate

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[1]Corresponding author: allenm@msu.edu

from the blood is greater than lactate (Reynolds et al., 2003), which is dependent upon cytosolic redox state in the hepatocyte (Allen et al., 2009). The objective of this experiment was to evaluate the short-term effects of fuels derived from fermentation and digestion of starch on DMI and feeding behavior of cows in the PP period. We hypothesized that these fuels differ in their effects on DMI and ME intake (**MEI**) and that their effects are consistent with their ability to stimulate hepatic oxidation.

MATERIALS AND METHODS

Animals, Housing, and Care

All experimental procedures were approved by the Institutional Animal Care and Use Committee at Michigan State University, East Lansing. Cows were ruminally cannulated at least 45 d before expected calving date. Each cow was housed in the same individual tiestall for the duration of the experiment. Cows were fed once daily (1200 h) at 125% of expected intake and milked in their stalls twice daily at 0530 and 1730 h.

Experimental Design, Diets, and Treatments

Eight multiparous Holstein cows (12.4 ± 4.2 d PP) at the Michigan State University Dairy Teaching and Research Center were used in a duplicated 4 × 4 Latin square design with 2 squares of cows with 4 cows each. Cows within each square were randomly assigned to treatment sequence. The squares were conducted at different times because of cow availability and are therefore referred to as blocks. Cows were blocked by date of parturition; the first block was conducted during March 2015 and the second during October 2015. Each block was conducted over an 8-d period with 4 infusion days separated by a washout day. Abomasal infusion devices were placed in each cow at least 2 d before start the infusion treatments and remained in place for the duration of the experiment. Placement was verified at the beginning and end of each infusion day. All cows received a common experimental diet from parturition through the end of the experiment. The experimental diets (Table 1) were formulated to meet or exceed estimated requirements for cows according to NRC (2001) and fed as a TMR.

Treatments were propionic acid (**PA**; food grade, 99.5%, Kemin Industries Inc., Des Moines, IA), L-lactic acid (**LA**; food grade 88.0%, Sena International Inc., Polo, IL), and glucose (**GLU**; ≥99.5%, Sigma Aldrich, Chemical Co., St. Louis, MO) infused continuously into the abomasum, and control (**CON**; no infusion). Isoenergetic amounts of PA (0.41 mol/h), LA (0.46 mol/h), and GLU (0.22 mol/h) dissolved in distilled water were infused at a rate of 508 mL/h for 22 h/d, providing 3.26 Mcal of ME/d (148 kcal/h), which is approximately 10% of daily MEI by cows in the PP period. Rate of infusion was selected based on previous studies in which PA decreased DMI of cows in the PP period compared with acetic acid (Oba and Allen, 2003b; Stocks and Allen, 2012). Metabolizable energy content of treatments were assumed to equal their gross energy of 365.0 kcal/mol for PA (Labedeva, 1964), 321.2 kcal/mol for LA (Saville and Gundry, 1959), and 673.4 kcal/mol (Emery and Benedict, 1911) for GLU. Solutions were infused into the abomasum using Baxter Flo-Gard 6201 infusion pumps (Baxter Medical Products, Deerfield, IL) through vinyl tubing (0.95 cm o.d., 0.71 cm i.d.) connected to a Nalgene bottle (3.8 cm diameter, 8.5 cm long) held in place with a rubber disk as described in Gualdrón-Duarte and Allen (2017).

Data and Sample Collection

Cows were withheld from feed from 1000 to 1200 h daily, and the amount of feed offered and orts were weighed for each cow daily. Samples (0.5 kg) of all dietary ingredients and the TMR were collected daily throughout the experiment, and orts for each cow were collected at the end of each infusion day and stored in plastic bags at −20°C until processed. Feeding behavior data (feed disappearance and water intake) were recorded continuously for 22 h daily for each cow during infusions via computer every 5 s, and size, length, and frequency of meals, intermeal interval, total eating

Table 1. Ingredients and nutrient composition of diets fed for blocks 1 and 2

Item	Block 1	Block 2
Ingredient, % of DM		
Corn silage	39.6	33.8
Soybean meal	16.1	15.9
Alfalfa silage	14.1	5.54
Ground corn	10.4	17.8
Alfalfa hay	9.9	9.7
Soybean hulls	5.7	5.5
Grass silage	—	7.6
Vitamin and mineral mix[1]	4.2	4.1
Nutrient composition		
DM, %	51.0	55.0
Starch, % of DM	19.8	22.0
NDF, % of DM	35.1	34.2
Forage NDF, % of DM	29.5	27.5
CP, % of DM	16.6	16.0

[1]Vitamin and mineral mix contained 25.6% NaCl, 10.0% Ca, 2.0 Mg, 2.0% P, 30 mg/kg of Co, 506 mg/kg of Cu, 20 mg/kg of I, 2,220 mg/kg of Fe, 2,080 mg/kg of Mn, 15 mg/kg of Se, 2,030 mg/kg of Zn, 300 kUI/kg of vitamin A, 50 kIU/kg of vitamin D, 1,500 kIU/kg of vitamin E.