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Effect of increasing dietary nonfiber carbohydrate with starch, sucrose, or lactose on rumen fermentation and productivity of lactating dairy cows

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ABSTRACT

The objective of this study was to investigate effects of increasing dietary nonfiber carbohydrate (NFC) with starch, sucrose, or lactose on rumen fermentation, volatile fatty acid absorption, and milk production of lactating dairy cows. Twenty-eight multiparous, lactating Holstein cows (141 ± 50 d in milk; 614 ± 53 kg of body weight) including 8 ruminally cannulated cows were used in this study. Cows were assigned to 4 dietary treatments in a 4 × 4 Latin square design with 21-d periods. The treatments were control [27% starch and 4% sugar on a dry matter (DM) basis], a high-NFC diet by increasing dietary starch content (STA; 32% starch and 4% sugar on a DM basis), and 2 more high-NFC diets by increasing dietary sugar content (27% starch and 9% sugar on a DM basis) in which sucrose (SUC) or lactose (LAC) was supplemented. Dry matter intake was greater for cows fed high-NFC diets compared with control diet (27.1 vs. 26.3 kg/d), but rumen pH and milk production did not differ between cows fed control and high-NFC diets. However, cows fed high-disaccharide diets had lower mean rumen pH than those fed STA diet (6.19 vs. 6.32). Although molar proportion of butyrate was greater for high-disaccharide treatments than STA treatment (15.2 vs. 13.7 mol/100 mol), absorption rate of volatile fatty acid in the rumen was not affected by treatment. In addition, cows fed high-disaccharide diets had higher energy-corrected milk yield than cows fed STA diet (39.6 vs. 38.0 kg/d). Dry matter intake did not differ between cows fed 2 high-disaccharide diets. Although cows fed the SUC diet had lower molar proportion of butyrate in the rumen compared with those fed the LAC diet (14.4 vs. 15.9 mol/100 mol), the SUC diet did not decrease rumen pH. In addition, cows fed the SUC diet had lower nutrient digestibility of organic matter than did those fed the LAC diet (59.7 vs. 64.4%), but milk component yields did not differ between the 2 high-disaccharide diet treatments. The results of the present study suggested that partially replacing dietary starch with disaccharides increased DM intake and energy-corrected milk, although rumen pH decreased for high-disaccharide diets, and that the rumen pH responses cannot be attributed to difference in absorption rate of volatile fatty acids in the rumen. In addition, type of sugars affected nutrient digestibility and rumen fermentation, but the effects were not large enough to affect rumen pH and milk production.
Key words: disaccharide, rumen fermentation, volatile fatty acid absorption, nutrient digestibility

INTRODUCTION

Increasing dietary NFC is a common diet-formulation approach to maximize milk production of high-producing dairy cows. Starch is the primary source of NFC in the diets of lactating dairy cows (NRC, 2001), but feeding more starch in dairy diets may also increase the risk of ruminal acidosis, which is associated with decreased feed intake, liver abscesses (Nagaraja and Lechtenberg, 2007), milk fat depression (Kleen et al., 2003), and laminitis (Nocek, 1997). Because the demand and cost of cereal grains has increased in the last decade, partial replacement of grains with high-sugar by-products becomes a diet-formulation approach to decrease feed costs while maintaining high milk yield. Sugars are water-soluble carbohydrates that can be fermented easily and quickly in the rumen (Oba, 2011), consisting of monosaccharides (glucose, fructose, and galactose) and disaccharides (sucrose, maltose, and lactose). Previous research indicated that partial substitution of dietary starch with sugars often increased DMI (Broderick and Radloff, 2004; Broderick et al., 2008; Penner and Oba, 2009) and milk fat yield (Broderick et al., 2008; Penner and Oba, 2009). Therefore, increasing dietary NFC content by feeding more sugars can be a viable option to maximize energy intake and productivity of lactating dairy cows. In addition, a recent review (Oba, 2011) showed that rumen pH did not decrease (McCormick et al., 2001; DeFrain et al., 2004; Broderick et al., 2008), but even increased (Chamberlain et al., 1993; Heldt et al., 1999), when sugar was used to replace a part of dietary starch, even

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though the hydrolysis and fermentation rate of sugar in the rumen is faster than starch (Sniffen et al., 1992). In vitro studies indicated that feeding sugar could result in increased molar proportion of butyrate in the rumen (Vallimont et al., 2004; Ribeiro et al., 2005), and Malhi et al. (2013) reported that ruminal butyrate infusion increased the ruminal epithelia growth and absorption capacity of VFA in the rumen. The increased capacity of ruminal epithelia to uptake acetate and butyrate is positively related to rumen pH (Penner et al., 2009a). As such, we hypothesized that increasing dietary NFC by feeding more disaccharide instead of starch would not decrease rumen pH by increasing the rate of VFA absorption.

Whey and molasses are high-sugar by-products commonly included in diets for dairy cows. Whey is a by-product of cheese manufacturing containing about 70% lactose on a DM basis (Oba, 2011), and molasses is a by-product of refining sugarcane or sugar beets into sugar containing mostly sucrose. In order to use these high-disaccharide by-products efficiently, it is necessary to understand specific effects of feeding sucrose or lactose on rumen fermentation and animal performance. Weisbjerg et al. (1998) reported that the hydrolysis rate of sucrose is faster than that of lactose, and Sutton (1968) showed that glucose and fructose ferment faster than galactose. Therefore, effects of feeding sucrose and lactose on rumen fermentation and animal performance are expected to be different. Previous studies evaluated effects of partial replacement of dietary starch with sucrose (Broderick et al., 2008) or lactose (DeFrain et al., 2004) on rumen fermentation and animal performance. However, because of the different basal dietary ingredients, forage-to-concentrate ratio, and sugar inclusion rate, it is difficult to compare specific effects of feeding sucrose and lactose on rumen fermentation and animal productivity for those previous studies.

The objective of this study was to investigate the effect of increasing dietary NFC content with starch, sucrose, or lactose on rumen fermentation, VFA absorption, and milk production of lactating dairy cows.

MATERIALS AND METHODS

All experimental procedures used in this study were approved by the University of Alberta Animal Care and Use Committee for Livestock and conducted according to the guidelines of the Canadian Council of Animal Care (Ottawa, Ontario, Canada).

Animals, Diets, and Experimental Design

Twenty-eight multiparous, mid-lactating Holstein cows (141 ± 50 DIM; 614 ± 53 kg of BW; mean ± SD) including 8 ruminally cannulated cows were used in this study. Cows were randomly assigned to 1 of 4 dietary treatments in a replicated 4 × 4 Latin square design balanced for carryover effects. Each period consisted of a 17-d diet adaptation period and a 4-d data and sample collection period. The treatments were control (**CON**; 27% starch and 4% sugar on a DM basis; Table 1), a high-NFC diet in which dietary starch content was increased by replacing beet pulp in the CON diet with corn grain (**STA**; 32% starch and 4% sugar on a DM basis), and 2 more high-NFC diets in which dietary sugar content was increased by replacing beet pulp in the CON diet with 5.5% of sucrose (**SUC**; 27% starch and 9% sugar on a DM basis) or lactose (**LAC**; 27% starch and 9% sugar on a DM basis). All experimental diets were formulated according to the NRC (2001) to meet or exceed the nutritional requirements for a 650-kg cow producing 40 kg/d of milk with 3.5% milk fat and 3.2% milk protein, and formulated for similar CP concentrations.

Cows were housed individually in tie-stalls bedded with wood shavings, fed the experimental diets as a TMR once daily at 0800 h, and had free access to water. Feed was offered at 105 to 110% of actual feed intake of the previous day. The amounts of feed offered and refused were recorded daily during sample collection periods. Samples of feed ingredients and orts were collected daily during sample collection periods and composited by period for feed ingredients and by period and cow for orts. The DM concentration of barley silage was determined, by drying samples in a forced-air oven at 55°C for 48 h, twice weekly, and as-fed proportions of feed ingredients were adjusted if necessary. Cows were weighed after the morning milking but before the feeding on 2 consecutive days immediately before the start of the experiment. Cows were milked twice daily at 0400 and 1500 h. Milk was sampled from both a.m. and p.m. milkings on d 18, 19, and 20 of each period of the study.

Rumen pH and Rumen Fermentation

Rumen pH was measured in the ventral sac every 30 s continuously for 72 h (d 18, 19, and 20) in each experimental period using the pH measurement system evaluated by Penner et al. (2006). Minimum, mean, and maximum pH, duration and area below pH 5.8 were determined for each cow daily and averaged over 72-h periods. Similarly, DMI was determined daily for each cow on d 18, 19, and 20 and averaged over 72-h periods. These data were used to determine acidosis index (area under pH 5.8 divided by DMI; Penner et al., 2009c) to assess the severity of SARA normalized for DMI.