J. Dairy Sci. 98:1–14
http://dx.doi.org/10.3168/jds.2014-8827

Effects of partial replacement of dietary starch from barley or corn with lactose on ruminal function, short-chain fatty acid absorption, nitrogen utilization, and production performance of dairy cows

G. E. Chibisa,*[1] P. Gorka,*[2] G. B. Penner,* R. Berthiaume,†[3] and T. Mutsvangwa*[4]
*Department of Animal and Poultry Science, University of Saskatchewan, Saskatoon, SK, S7N 5A8 Canada
†Dairy and Swine Research and Development Centre, Agriculture and Agri-Food Canada, Sherbrooke, QC, J1M 0C8 Canada

ABSTRACT

In cows fed diets based on corn-alfalfa silage, replacing starch with sugar improves milk production. Although the rate of ruminal fermentation of sugar is more rapid than that of starch, evidence has been found that feeding sugar as a partial replacement for starch does not negatively affect ruminal pH despite increasing diet fermentability. The mechanism(s) for this desirable response are unknown. Our objective was to determine the effects of replacing barley or corn starch with lactose (as dried whey permeate; DWP) on ruminal function, short-chain fatty acid (SCFA) absorption, and nitrogen (N) utilization in dairy cows. Eight lactating cows were used in a replicated 4 × 4 Latin square design with 28-d periods and source of starch (barley vs. corn) and level of DWP (0 vs. 6%, DM basis) as treatment factors. Four cows in 1 Latin square were ruminally cannulated for the measurement of ruminal function, SCFA absorption, and N utilization. Dry matter intake and milk and milk component yields did not differ with diet. The dietary addition of DWP tended to increase ruminal butyrate concentration (13.6 vs. 12.2 mmol/L), and increased the Cl^--competitive absorption rates for acetate and propionate. There was no sugar effect on minimum ruminal pH, and the duration and area when ruminal pH was below 5.8. Minimum ruminal pH tended to be lower in cows fed barley compared with those fed corn (5.47 vs. 5.61). The duration when ruminal pH was below pH 5.8 tended to be shorter (186 vs. 235 min/d), whereas the area (pH × min/d) that pH was below 5.8 was smaller (47 vs. 111) on the corn than barley diets. Cows fed the high- compared with the low-sugar diet had lower ruminal NH_3-N concentration. Feeding the high-sugar diet tended to increase apparent total-tract digestibility of dry matter and organic matters and increased apparent total-tract digestibility of fat. Apparent total-tract digestibility of N tended to be greater in cows fed barley compared with those fed corn, whereas apparent total-tract digestibility of acid-digestible fiber was greater in cows fed corn compared with those fed barley. In conclusion, partially replacing dietary corn or barley starch with sugar upregulated ruminal acetate and propionate absorption, suggesting that the mechanisms for the attenuation of ruminal acidosis when sugar is fed is partly mediated via increased SCFA absorption.

Key words: starch, lactose, short-chain fatty acid absorption, lactation performance

INTRODUCTION

There is potential to use by-products with high sugar content as energy sources in diets for lactating dairy cows (Broderick et al., 2008). The replacement of corn starch with sugar has been reported to induce desirable production responses, including increased DMI (Broderick and Radloff, 2004; Broderick et al., 2008; Penner and Oba, 2009), milk production (Broderick and Radloff, 2004), and milk fat yield (Broderick et al., 2008; Penner and Oba, 2009). Although sugars are rapidly fermented (>500%/h; Weisbjerg et al., 1998), recent studies have demonstrated that increasing dietary sugar content up to 13% of dietary DM by replacing a portion of dietary corn starch with either sucrose (Broderick et al., 2008) or lactose (DeFrain et al., 2004) did not cause a decrease in ruminal pH in lactating cows. In fact, ruminal pH tended to increase (Penner and Oba, 2009) or increased (Martel et al., 2011) when feeding up to 9% sugar as a partial replacement for corn starch. Although several theories have been suggested to explain why feeding more rapidly fermented sugars in place of starch does not depress ruminal pH (Penner et al., 2009a; Oba, 2011), butyrate-induced changes in

Received September 6, 2014.
Accepted January 3, 2015.
[1]Current address: Agriculture and Agri-Food Canada, Lethbridge Research Centre, Lethbridge, AB, T1J 4B1, Canada.
[2]Current address: Department of Animal Nutrition and Feed Management, University of Agriculture in Krakow, al. Mickiewicza 24/28, 30-059 Krakow, Poland.
[3]Current address: Valacta, 555 boul. des Anciens-Combattants, Sainte-Anne-de-Bellevue, QC, Canada.
[4]Corresponding author: tim.mutsvan@usask.ca

the permeability of ruminal epithelia to short-chain fatty acids (**SCFA**) has received little attention. Feeding lactose increases ruminal butyrate concentrations (Doreau et al., 1987; DeFrain et al., 2004, 2006); during its absorption into blood, up to 90% of ruminal butyrate is metabolized, mainly to BHBA (Bergman, 1990), and several studies (Doreau et al., 1987; DeFrain et al., 2004) have reported elevated plasma BHBA concentrations in dairy cows fed supplemental lactose. Butyrate metabolism during absorption is known to stimulate growth and proliferation of ruminal papillae by increasing cellular mitogenic rate while decreasing apoptosis rate (Mentschel et al., 2001). Morphological surface enlargement resulting from an increase in papillae number and size as diet fermentability and ruminal butyrate concentration increase is well documented (Sakata and Tamate, 1978; Dirksen et al., 1985; Liebich et al., 1987; Baldwin et al., 2004; Naeem et al., 2012). This enhancement of epithelial absorptive area could potentially explain why dietary addition of sugar does not cause an accumulation of SCFA and, subsequently, a decrease in ruminal pH (Ordway et al., 2002; Penner et al., 2009b). However, increasing evidence suggests that functional adaptation in ruminal epithelial cells is characterized by changes in ion transport mechanisms, as diet fermentability increases also play a key role in pH regulation. Sehested et al. (2000) measured short-term adaptation in ruminal absorption of SCFA in cows by feeding additional carbohydrate once daily and measuring epithelial butyrate absorption. In spite of the absence of proliferative changes, butyrate absorption increased as ruminal SCFA concentration increased, possibly implying upregulation of cellular protein-mediated transport (Sehested et al., 2000). Moreover, Penner et al. (2009b) also observed that sheep that were less susceptible to SARA exhibited greater in vitro apical uptake of acetate and butyrate that was mediated via an upregulation in epithelial cell transporter activity. To our knowledge, no study has determined whether dietary inclusion of sugar in dairy cow diets causes changes in SCFA absorption in vivo. It is also not clear if any changes in absorptive function alter the relative proportions of SCFA absorbed via passive diffusion or protein-mediated transport.

Replacing dietary starch with sugar can also alter N utilization via changes in ruminal fermentation. It is well established that carbohydrates digested in the rumen provide energy that drives microbial protein (**MCP**) synthesis (NRC, 2001). Across Canada and the United States, dairy cow diets usually contain barley or corn as the main carbohydrate source. Because sugar is more rapidly fermented in the rumen than starch, substitution of starch with sugar may increase energy availability, thus allowing for more efficient MCP synthesis; however, perusal of the literature indicates that the effects on MCP production of replacing dietary starch with sugar have been equivocal. Intraruminal infusions of sucrose in dairy cattle fed grass silage-based diets (Kim et al., 1999, 2000) or substitution of starch with sugar in continuous culture (Stokes et al., 1991) enhanced MCP production. Conversely, the substitution of starch with sucrose yielded less MCP in dairy cows (Sannes et al., 2002) and in vitro incubations (Hall and Herejk, 2001). These discrepant responses could be attributed to several factors, including differences in the type of sugar (Chamberlain et al., 1993), the forage source (Oelker et al., 2009), and the source of dietary starch that is being replaced with sugar. Corn contains more starch than barley (72 vs. 58%; Huntington, 1997). Also, the rates and extents of ruminal starch degradation differ, with 55 to 70% of corn starch and 80 to 90% of barley starch being degraded in the rumen (Huntington, 1997). Because barley and corn differ in their starch content and ruminal starch digestion, replacing starch with sugar might elicit different responses in ruminal N utilization in lactating cows fed corn or barley as the primary fermentable energy source.

Our objective in the current study was to investigate the effects of partial replacement of barley or corn starch with lactose on ruminal SCFA absorption and ruminal acidosis. The second objective was to delineate the effects of partial replacement of starch from barley or corn with lactose on ruminal fermentation, N utilization, and production performance. We hypothesized that partial replacement of dietary starch with lactose would attenuate ruminal acidosis and improve N utilization and production performance in dairy cows and that the effects would be dependent on the source of starch being partially replaced (i.e., barley or corn).

MATERIALS AND METHODS

Animals and Experimental Design

Eight lactating, multiparous Holstein dairy cows (711 ± 37 kg BW; 109 ± 36 DIM) were used in a replicated 4 × 4 Latin square design with 28-d periods (18 d of dietary adaptation and 10 d of measurements) and a 2 × 2 factorial arrangement of dietary treatments. Four cows in 1 Latin square were ruminally cannulated for the measurement of ruminal fermentation characteristics, SCFA absorption, and N utilization. All cows were housed in individual tiestalls at the Greenbrae Dairy Research Facility (University of Saskatchewan). The University of Saskatchewan Animal Care Committee approved the use of cows for this experiment (UCACS Protocol No. 20040048).