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Effects of dietary starch content and rate of fermentation on methane production in lactating dairy cows

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ABSTRACT

The objective of this study was to investigate the effects of starch varying in rate of fermentation and level of inclusion in the diet in exchange for fiber on methane (CH_4) production of dairy cows. Forty Holstein-Friesian lactating dairy cows of which 16 were rumen cannulated were grouped in 10 blocks of 4 cows each. Cows received diets consisting of 60% grass silage and 40% concentrate (dry matter basis). Cows within block were randomly assigned to 1 of 4 different diets composed of concentrates that varied in rate of starch fermentation [slowly (S) vs. rapidly (R) rumen fermentable; native vs. gelatinized corn grain] and level of starch (low vs. high; 270 vs. 530 g/kg of concentrate dry matter). Results of rumen in situ incubations confirmed that the fractional rate of degradation of starch was higher for R than S starch. Effective rumen degradability of organic matter was higher for high than low starch and also higher for R than S starch. Increased level of starch, but not starch fermentability, decreased dry matter intake and daily CH_4 production. Milk yield (mean 24.0 ± 1.02 kg/d), milk fat content (mean 5.05 ± 0.16%), and milk protein content (mean 3.64 ± 0.05%) did not differ between diets. Methane expressed per kilogram of fat- and protein-corrected milk, per kilogram of dry matter intake, or as a fraction of gross energy intake did not differ between diets. Methane expressed per kilogram of estimated rumen-fermentable organic matter (eRFOM) was higher for S than R starch–based diets (47.4 vs. 42.6 g/kg of eRFOM) and for low than high starch–based diets (46.9 vs. 43.1 g/kg of eRFOM). Apparent total-tract digestibility of neutral detergent fiber and crude protein were not affected by diets, but starch digestibility was higher for diets based on R starch (97.2%) compared with S starch (95.5%). Both total volatile fatty acid concentration (109.2 vs. 97.5 m*M*) and propionate proportion (16.5 vs. 15.8 mol/100 mol) were higher for R starch– compared with S starch–based diets but unaffected by the level of starch. Total N excretion in feces plus urine and N retained were unaffected by dietary treatments, and similarly energy intake and output of energy in milk expressed per unit of metabolic body weight were not affected by treatments. In conclusion, an increased rate of starch fermentation and increased level of starch in the diet of dairy cattle reduced CH_4 produced per unit of eRFOM but did not affect CH_4 production per unit of feed dry matter intake or per unit of milk produced.
Key words: methane, starch fermentability, starch level, dairy cow

INTRODUCTION

Starch is a major source of glucogenic energy for high-yielding dairy cows and a source of fermentable energy for rumen microorganisms (Koenig et al., 2003). In addition to carbon dioxide, microbial matter, and VFA production, fermentation of feeds in the rumen results in release of hydrogen, which is used by methanogenic archaea to reduce carbon dioxide and produce methane, a potent greenhouse gas that has 25 times more global-warming potential than carbon dioxide (IPCC, 2007). The production of methane (CH_4) is influenced by dietary factors, such as type and amount of feed, and various dietary strategies have been suggested to reduce enteric CH_4 production (Hristov et al., 2013; Knapp et al., 2014). Compared with dietary fiber, starch fermentation in the rumen may result in reduced enteric CH_4 production because fermentation of starch favors production of propionate (Bannink et al., 2006), creating an alternative hydrogen sink to methanogenesis. Moreover, unlike fiber and sugar, a substantial fraction of potentially fermentable starch may escape from rumen fermentation to be digested enzymatically in the small intestine, adding to the energy supply of the animal without associated losses of energy with CH_4 production (Dijkstra et al., 2011).

The use of starch versus fiber as well as increasing dietary starch content in the concentrate are potential

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options to reduce ruminal CH_4 production, relative to total energy supply to the animal (Hristov et al., 2013). Using a modeling approach, Benchaar et al. (2001) estimated that the use of less ruminally fermentable starch and replacing fibrous concentrate with starchy concentrate reduces CH_4 emissions by 17 and 22% in ruminants, respectively. Compared with rapidly fermentable starch sources such as barley or wheat, the use of a slowly fermentable starch such as corn may result in a reduction of CH_4 production (Mills et al., 1999, 2001), mainly attributed to a shift in starch digestion from the rumen to the small intestine. Similarly, the substitution of sugar in the concentrate with a rapidly fermentable starch source such as barley or wheat was estimated to reduce CH_4 production in ruminants (Mills et al., 2001), due to lower ratio of acetate and butyrate to propionate production from starch fermentation (Benchaar et al., 2001; Mills et al., 2001) and the subsequent increase in ME supply to the dairy cow (Mills et al., 2001). However, increasing the amount of rapidly fermentable starch in the diet at the expense of forage fiber can increase the production of VFA beyond the buffering and absorptive capacity of the rumen, leading to a decreased ruminal pH that has negative consequences on fiber degradation and production of dairy cows (Dijkstra et al., 2012). Moreover, the level of abatement of enteric CH_4 production achievable in dairy cattle with grass silage–based diets in which sources and levels of starch in the concentrate vary is largely lacking.

The objective of this study was to evaluate the effects of starch varying in rate of fermentation and in level of inclusion in concentrate that accounted for 40% of the TMR DM on CH_4 production of dairy cows. We hypothesized that increasing the inclusion of ruminally fermentable starch in the diet at the expense of fiber enhances propionate production, and that decreasing rate of fermentation of the starch in the rumen shifts starch digestion from the rumen to the small intestine, both expected to decrease CH_4 production expressed per unit of feed or milk.

MATERIALS AND METHODS

This experiment was conducted as a complete randomized block design at the animal research facility of Wageningen University (Wageningen, the Netherlands). All experimental procedures were approved by the Institutional Animal Care and Use Committee of Wageningen University and carried out under the Dutch Law on Animal Experimentation.

Cows, Experimental Design, and Diets

Forty multiparous lactating Holstein-Friesian dairy cows were selected and grouped in 10 blocks based on parity (2.9 ± 1.1; mean ± SD), DIM (215 ± 89 d), fat- and protein-corrected milk (**FPCM**; 35.9 ± 9.5 kg/d) at the start of the experiment, and presence or absence of rumen cannula. Sixteen cows were rumen cannulated and used to evaluate the effects of dietary treatments on rumen fermentation characteristics (pH and VFA concentration). Cows within a block were randomly assigned to 1 of 4 dietary treatments. Treatments were 1) 270 g of slowly fermentable starch per kilogram of concentrate DM, 2) 530 g of slowly fermentable starch per kilogram of concentrate DM, 3) 270 g of rapidly fermentable starch per kilogram of concentrate DM, and 4) 530 g of rapidly fermentable starch per kilogram of concentrate DM. Cows were fed a total mixed diet composed of grass silage and concentrate mixed at a 60:40 ratio (DM basis). Diets were offered individually and in equal portions during a.m. and p.m. (0600 and 1600 h) feedings. The concentrates were in meal form and mixed with the forage portion manually when fed.

The primary starch sources in the concentrate were native corn grain, which is slowly fermentable (**S**), and gelatinized corn grain, which is rapidly fermentable (**R**), and each source was included at 2 levels: a low (**L**, 270 g of starch/kg of concentrate DM) and a high (**H**, 530 g of starch/kg of concentrate DM) level. Increasing the level of starch in concentrate was achieved by exchanging either ground native corn grain or ground gelatinized corn grain with beet pulp and palm kernel expeller on DM basis. The ingredient composition of the concentrates is shown in Table 1. Both native and gelatinized corn grain were obtained from a single batch of corn. These 2 starch sources were chosen to create a large difference in rate of starch fermentation.

The experiment was conducted in 10 successive periods of 17 d each. In each period cows were individually housed in tie-stalls for 12 d as an adaptation period and to determine individual daily feed intake. Diets were supplied ad libitum for the first 8 d in the tie-stalls (approximately at 110% of expected voluntary intake). From d 9 to 17, feed intake was restricted per block to 95% of the ad libitum feed intake of the animal consuming the lowest amount of feed during d 3 to 8 within a block to avoid the potential confounding effect of feed intake level on CH_4 measurements. After the end of the adaptation period, cows were housed for 5 d in 1 of the 2 identical climate-controlled respiration chambers for the measurement of CH_4 production. In addition, digestibility measurements and a complete N and energy balance were performed. Because 2 chambers were available, measurements were obtained in 10 periods, staggered in time in an incomplete randomized block design, as described previously by Van Zijderveld et al. (2011a). Within each period, 2 cows receiving the same treatment were housed in one chamber, and 2 cows re-