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Morphological adaptation of rumen papillae during the dry period and early lactation as affected by rate of increase of concentrate allowance

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ABSTRACT

Knowledge of the morphological adaptation of rumen papilla, which plays an important role in volatile fatty acid absorption, in dry and early lactation dairy cattle is limited. Therefore, macro- and microscopic changes in papilla morphology during the dry period and lactation and the effect of rate of increase of concentrate allowance were studied. Samples were collected from 12 rumen-cannulated Holstein Friesian dairy cows during a pretreatment period, 50, 30, and 10 d antepartum (the dry period) and 3 d postpartum (pp), and a treatment period, 9, 16, 30, 44, 60, and 80 d pp. Cows had free access to either a dry period ration [27% grass silage, 27% corn silage, 35% wheat straw, and 11% soybean meal on a dry matter (DM) basis] or a basal lactation ration (42% grass silage, 41% corn silage, and 17% soybean meal on a DM basis, and 0.9 kg of DM/d concentrate). Treatment consisted of either a rapid (1.0 kg of DM/d; RAP; n = 6) or gradual (0.25 kg of DM/d; GRAD; n = 6) increase of concentrate allowance (up to 10.9 kg of DM/d), starting at d 4 pp, aimed at creating a contrast in rumen-fermentable organic matter (FOM) intake. Papillae were collected from the ventral, ventral blind, and dorsal blind rumen sacs and measured digitally. Intake of DM (11.9 kg/d) and FOM (5.7 kg/d) did not change during the pretreatment period, but increased during the treatment period to 24.5 and 15.0 kg/d at 80 d pp, respectively. Concentrate treatment and sampling day interacted for FOM intake, which was 22% greater in RAP at 16 d pp compared with GRAD. Papilla surface area decreased during the pretreatment period by 19% to 28.0 mm^2 at 3 d pp, thereafter increasing to 63.0 mm^2 at 80 d pp. Concentrate treatment and sampling day interacted for surface area, which was greater in RAP compared with GRAD at 16 (46.0 vs. 33.2 mm^2), 30 (55.4 vs. 41.2 mm^2), and 44 (60.5 vs. 49.7 mm^2) days pp, showing that papillae can respond to a rapid rate of increase of FOM intake by increasing growth rate. Microscopic morphology was affected by sampling day, but neither by concentrate treatment nor by their interaction, with a decrease in papilla and epithelium thickness during the lactation. In conclusion, the rumen papillae respond to changes in FOM intake and the magnitude of this response depends on the rate of increase of FOM intake. This response in surface area of the rumen papillae potentially facilitates the absorption of the volatile fatty acids.
Key words: transition dairy cow, rumen papillae, rumen epithelium, rumen adaptation

INTRODUCTION

In ruminants, the reticulorumen is the major site for microbial fermentation of feed and, hence, production of VFA, which provide approximately 75% of total ME (Bergman, 1990). The luminal surface of the rumen wall is covered with papillae which increase the surface area for absorption of VFA. However, factors such as rumen VFA concentration and pH (Dijkstra et al., 1993), epithelial blood flow (Storm et al., 2012), and changes at the cellular level (Penner et al., 2011) may affect VFA absorption capacity as well. The absorption of VFA is seen as the primary process for maintaining rumen VFA concentration and pH within physiological limits, thereby supporting microbial fermentation of feed (Penner et al., 2009; Aschenbach et al., 2011; Dijkstra et al., 2012).

The proliferation of rumen papillae in young ruminants is triggered by the consumption of solid feed (Tamate et al., 1962; Sutton et al., 1963; Suárez et al., 2006), and thus associated with the intake of rumen fermentable organic matter (**FOM**) and its associated production of VFA. Furthermore, Dirksen et al. (1984) and Liebich et al. (1987) reported a positive relationship between the plane of nutrition and papilla surface area in the rumen. Therefore, it can be suggested that

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differences in surface area of rumen papilla are associated with differences in intake of FOM.

Currently, knowledge of macroscopic morphological changes of the rumen papillae (papilla surface area, length, and width) in dairy cows in the dry period until early lactation is limited (Shen et al., 2005; Malhi et al., 2013; Steele et al., 2015), or experiments have yielded inconclusive results (Reynolds et al., 2004). Likewise, knowledge about changes on the microscopic scale in rumen papilla (thickness of the papilla and epithelial layer) in the aforementioned period is limited as well. Diet- and time-related changes in thickness and organization of rumen epithelium have been reported by Dirksen et al. (1984), Liebich et al. (1987), Steele et al. (2011), and Bannink et al. (2012), but a comprehensive description of those changes during the dry period and early lactation is currently lacking (Martens et al., 2012). Therefore, the aim of the present experiment was to study macro- and microscopic morphological changes of rumen papillae from 50 d before expected calving date until 80 d postpartum in dairy cattle. After calving, 2 rates of increase of concentrate allowance were applied to create a contrast in FOM intake and evaluate its effect on morphological changes of the papillae. It was hypothesized that a rapid versus a gradual rate of increase of concentrate allowance creates a temporarily larger daily intake of FOM, inducing a greater rate of increase of surface area, length, and width of rumen papilla and a decrease in thickness of the papilla and its epithelial layer.

MATERIALS AND METHODS

The experimental procedures were approved by the Animal Care and Ethics Committee of Wageningen UR and conducted under the Dutch Law on Animal Experiments.

Animals, Experimental Design and Management

Three months before the start of the experiment 12 first-parity Holstein Friesian dairy cows were fitted with a rumen cannula (10 cm i.d., Bar Diamond Inc., Parma, ID). Eight weeks before the expected date of calving, cows were dried off and entered the experiment. The experiment had a randomized block design with repeated measurements. Cows were blocked by expected date of calving, and within each block cows were randomly assigned to either a rapid rate of increase of concentrate allowance or a gradual rate of increase of concentrate allowance. Samples were collected during the pretreatment period at 50, 30, and 10 d antepartum (**ap**) and 3 d postpartum (**pp**), as well as during the treatment period at 9, 16, 30, 44, 60, and 80 d pp. Cows were milked at 0530 and 1530 h, and milk yield was recorded daily. Each week milk samples from 4 consecutive milkings (same days every week) were analyzed for fat and protein content (ISO, 1999c; Qlip NV, Zutphen, the Netherlands). During the experiment, dry and lactating animals were housed in separate groups in a freestall barn with concrete slatted floor. Stalls were fitted with rubber mattresses covered with sawdust. On sampling days, cows were moved to a tiestall after the morning milking for the experimental procedures.

Rations and Experimental Treatments

Cows had free access to either a dry period ration or a basal lactation ration (Table 1) and free access to water throughout the experiment. Both rations had similar relative proportions of grass silage, corn silage and soybean meal (DM basis). In the dry period ration, however, chopped wheat straw was included to lower the energy density of the ration. The rations were mixed and fed once a day at ~1000 h. Concentrates were fed from calving onwards, with a daily allowance of 0.9 kg of DM/d, up to 3 d pp, irrespective of treatment. Thereafter, the concentrate treatment started and concentrate allowance was increased at either a rapid rate of 1.0 kg of DM/d (**RAP**) or a gradual rate of 0.25 kg of DM/d (**GRAD**). Maximum concentrate allowance was set at 10.9 kg of DM/d, irrespective of rate of increase, and was achieved at 13 and 43 d pp for RAP and GRAD, respectively.

Daily intake of the dry period ration or the basal lactation ration (kg/d) was measured individually using feed bins (Insentec, Marknesse, the Netherlands), with a maximum stocking density of 2 cows/bin. Cows had access to all feed bins. Concentrate was fed using a concentrate dispenser (Manus VC5, DeLaval, Steenwijk, the Netherlands) and made the individual daily allowance available in equal portions over six 4-h periods and recorded the quantity actually dispensed (kg/d). Concentrate and ration ingredient samples were taken once a week. One sample of concentrate and one of each ration ingredient was immediately used for DM determination by forced-air oven drying (105°C, 24 h); the remaining samples were stored at −20°C pending analyses. If necessary, basal ration formulation (on product basis) was adjusted for changes in ration ingredient DM content; DM content of concentrate was constant throughout the experiment.

After forced-air oven drying (60°C, 24 h) and determination of DM (ISO, 1999b), feed samples were ground (1-mm screen) and pooled (each pool containing samples of 4 consecutive weeks) before determination crude ash (ISO, 2002), crude fat (ISO, 1999a), starch (ISO, 2004),