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Effects of dietary cation-anion difference on ruminal metabolism and blood acid-base regulation in dairy cows receiving 2 contrasting levels of concentrate in diets

E. Apper-Bossard,*†[1,2] P. Faverdin,*† F. Meschy,‡§ and J. L. Peyraud*†
*INRA, UMR1080 Dairy Production, F-35000 Rennes, France
†Agrocampus Ouest, UMR1080 Dairy Production, F-35000 Rennes, France
‡INRA, UMR Physiology of Nutrition and Feeding, F-75231 Paris Cedex 05, France
§Agro Paris Tech, UMR Physiology of Nutrition and Feeding, F-75231 Paris Cedex 05, France

ABSTRACT

Dietary cation-anion difference [DCAD = Na + K − Cl in mEq/kg of dry matter (DM)] increases DM intake (DMI) in cows fed diets containing rapidly degraded starch. Increased DMI of diets containing rapidly degraded starch could potentially exacerbate subacute acidosis. The objective of this study was to determine metabolic effects of increasing DCAD in low and high starch diets. Six cannulated Holstein cows were blocked into 2 groups of 3 cows and assigned to two 3 × 3 Latin squares in a split-plot design. Each group received a level of concentrate at either 20 or 40% on a DM basis. The diet containing 20% concentrate supplied 4% rapidly degraded starch, whereas the diet containing 40% concentrate supplied 22% rapidly degraded starch. Diets in each square were formulated to provide a DCAD of 0, 150, or 300 mEq/kg of DM. The 3 values were obtained by manipulating Na and Cl contents. Increasing the proportion of rapidly degraded starch decreased rumen pH and the acetate to propionate ratio but did not affect digestibility, blood acid-base status, pH of urine, and strong ion excretion. Increasing DCAD increased DMI, the effect being higher when the cows were fed the 40% concentrate diet. Increasing DCAD did not affect mean ruminal pH, molar proportion of VFA, and fiber digestibility; reduced the range of rumen pH decrease during the meal in cows fed the 40% concentrate diet; and strongly increased blood pH and blood HCO_3 concentration. Increasing DCAD increased urine pH and modified the urinary excretion of minerals. With low DCAD, 70% of Cl and only 16% of Na were excreted in urine whereas with high DCAD, 33% of Cl and 53% of Na were excreted. These results suggest that DMI of cows fed diets rich in rapidly degraded starch and low DCAD was limited to maintain the blood pH in a physiological range. Increasing DCAD allowed the cows to increase DMI because of the ability of positive DCAD to maintain blood acid-base status. A localized rumen buffering effect could not be excluded and could be linked with a higher amount of HCO_3 recycled into the rumen. Main mechanisms involved in regulating blood pH might be renal excretion of protons and strong ions and renal HCO_3 reabsorption.
Key words: dietary cation-anion difference, rumen, blood acid-base status, dairy cow

INTRODUCTION

High producing dairy cows are commonly fed diets containing a high proportion of rapidly degraded starch. This feeding practice often causes SARA and a decrease in DMI, milk yield, and milk fat content, which imply economic losses. Subacute ruminal acidosis is characterized by a decrease in ruminal pH and an increase in VFA production, an increase in propionate production (Plaizier et al., 2008), and an alteration in ruminal biohydrogenation of dietary polyunsaturated fatty acids (Bauman and Griinari, 2003). Besides these well-known effects, some results suggest that SARA could generate some changes in blood acid-base status. Goad et al. (1998) and Brown et al. (2000) have reported a decrease in blood pH, blood HCO_3 concentration, and blood standard base excess (**SBE**) in grain-challenged beef steers, thus showing that an acid load in the rumen can deplete HCO_3 from the blood. Faverdin et al. (1999) have shown that blood HCO_3 was negatively correlated with the VFA concentration in ruminal fluid.

Sodium and K are absorbed from the gastrointestinal tract in exchange for the secretion of a proton, whereas Cl and S are often absorbed in exchange for the secretion of a bicarbonate ion. Because of these properties, a large positive DCAD (defined as mEq of Na + K − Cl − S/kg of DM) should assist in preventing metabolic

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[1]Corresponding author: e.bossard@groupe-esa.com
[2]Present address: ESA, Ecole Supérieure d'Agriculture, 22 rue Rabelais, F-49100 Angers, France.

acidosis. An increased DCAD from negative or null to highly positive values increases DMI and milk yield (Hu and Murphy, 2004; Apper-Bossard et al., 2009). Recently, Apper-Bossard et al. (2006) showed that high DCAD increases DMI in cows fed diets rich in rapidly degraded starch but not in cows fed diets with low amount of rapidly degraded starch. Nevertheless, the mechanisms involved are not yet well understood. In addition to an increase of performance, increasing DCAD increases blood pH, blood HCO_3 concentration, and urinary pH (Hu and Murphy, 2004; Peyraud and Apper-Bossard, 2006), suggesting an effect on blood acid-base homeostasis. A positive DCAD could also alter ruminal fermentation and increase ruminal pH, as suggested by Roche et al. (2005). Several results reported in the study of Apper-Bossard et al. (2006) also suggest a ruminal buffering effect of positive DCAD. The involved mechanisms are confounded by the fact that in most of published studies, increased DCAD was obtained by manipulating sodium bicarbonate content in the diet although sodium bicarbonate is a well-described ruminal buffer (Erdman, 1988). This study aimed to examine the effects of increasing DCAD from 0 to 300 mEq/kg of DM, manipulating salts other than sodium bicarbonate, on blood, ruminal, and urinary acid-base regulation in high producing dairy cows fed diets with different roughage to concentrate ratios.

MATERIALS AND METHODS

Experimental Design and Cows

The trial was conducted as a split-plot design with 6 Holstein cows. Cows were assigned to 2 groups of 3 each according to parity (1 primiparous and 2 multiparous), stage of lactation (74 ± 21 DIM), milk production (38.7 ± 7.6 kg/d), milk protein (2.88 ± 0.39%) and fat content (3.59 ± 0.47%), and BW (683 ± 38 kg). Each group of cows received one of 2 levels of concentrate during the experiment. Within each group, cows were assigned to 3 planned levels of DCAD according to a 3 × 3 Latin square design. The trial included a 3-wk adaptation period to the basal diet. Each experimental period lasted 3 wk.

Each cow was fitted with a large rumen cannula (123 mm i.d.). They were housed in tie stalls inside an artificially ventilated barn and were allowed free access to water. The cows were milked twice daily at 0700 and 1730 h and were weighed at the end of each period. To control mineral supply, no straw or mineral blocks were provided.

Treatments and Feeding

Six diets differing in concentrate and DCAD levels were formulated. The diets were very similar to those used by Apper-Bossard et al. (2006). The low concentrate (**LC**) diets consisted of 21% concentrate and minerals and 79% corn silage on a DM basis. The high concentrate (**HC**) diets consisted of 41% concentrate and minerals and 59% corn silage. The 3 planned DCAD levels were low (0 mEq/kg of DM), medium (150 mEq/kg of DM), and high (300 mEq/kg of DM). The 6 experimental diets were low concentrate with low DCAD, low concentrate with medium DCAD, low concentrate with high DCAD, high concentrate with low DCAD (**HCLD**), high concentrate with medium DCAD, and high concentrate with high DCAD.

Two energy concentrates were formulated to maximize the difference in rapidly degraded starch between the 2 groups of diets. The composition of the 2 concentrates was described by Apper-Bossard et al. (2006). On DM basis, the concentrate of LC diets contained 21.5% barley, 44.2% formaldehyde-treated soybean meal, 32.3% soybean meal, and 2.0% distillery residues. The concentrate of HC diets contained 39.2% wheat, 20.2% barley, 13.5% formaldehyde-treated soybean, 13.5% soybean meal, 8.1% dehydrated alfalfa, and 5.5% molasses. Dehydrated alfalfa and molasses were added to ensure similar DCAD for the 2 diets before adding the experimental mineral mixtures.

Differences in DCAD values were achieved by manipulation of dietary Na and Cl. Two mineral mixtures were used to set the medium and high DCAD levels. The ingredients of the mineral mixtures are shown in Table 1. Sodium bicarbonate was not used. High DCAD mineral mixture was achieved by replacing $CaCO_3$ with Na_2CO_3 and Na_2HPO_4. Low DCAD diets were achieved by adding 0.8% of NH_4Cl to the medium DCAD diets.

The chemical composition of the 6 diets is given in Table 1. For LC and HC diets, the proportions of highly fermentable cereals were 3.7 and 22.0% DM, respectively, and the proportions of NDF were 35.1 and 31.3%, respectively. With increasing DCAD, Na content increased from 0.20 to 0.50% DM whereas Cl content decreased from 1.05 to 0.43% DM and concentrations of other minerals were kept constant to ensure that the observed effects could be attributed to the manipulation of DCAD. The K, S, Ca, P, and Mg contents averaged 1.13, 0.12, 0.78, 0.33, and 0.20% DM respectively. The S content was low because of the corn silage, which contained only 0.61 g of S/kg of DM but was the same among the 6 diets.