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Diets rich in starch improve the efficiency of amino acids use by the mammary gland in lactating Jersey cows

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ABSTRACT

The objective of this study was to test whether the greater milk N yield usually observed when feeding diets based on starch versus fiber was the consequence of a higher efficiency of AA use across the mammary gland and whether this effect depended on dietary crude protein (CP) content. Five midlactation multicatheterized Jersey cows were fed 4 isoenergetic diets to provide 2 different carbohydrate compositions (CHO; rich in starch vs. rich in fiber) crossed by 2 different protein levels (12.0 vs. 16.5% CP) and according to a 4 × 4 Latin square design. Blood samples were collected at the end of each treatment period from the mesenteric artery and mammary vein to determine mammary net nutrient fluxes. The nature of nutrients taken up by the mammary gland differed between starch and fiber diets: mammary net uptake of acetate increased with fiber versus starch diets, whereas mammary net uptake and clearance rate of glucose increased with starch versus fiber diets but only at a normal CP level. In addition, the mammary net uptake of total, essential, and branched-chain AA (BCAA) was significantly enhanced (12, 11, and 26% on average, respectively) when feeding starch versus fiber diets, in line with a greater milk protein yield (7% on average) and regardless of the CP level. The conversion efficiency of plasma essential AA into milk protein was improved with starch diets (33.7% on average) compared with fiber diets (27.5% on average). This higher mammary efficiency use of AA with starch diets was accompanied by a greater fractional extraction and clearance rate of AA belonging to group 2 (BCAA, Lys, Thr) by the mammary gland in absence of effects of CHO on either the mammary blood flow or the mammary AA metabolism. The positive effect of starch diets on mammary clearance rate and uptake of BCAA observed in this study was further improved when increasing dietary CP from 12.0 to 16.5%. Concerning the individual AA, Leu was the only whose mammary uptake accounted for a higher proportion of total essential AA in diets based on starch versus fiber and whose mammary uptake to milk output ratio was modified (together with Pro). Diets rich in starch versus fiber improved the mammary AA utilization; however, some CHO × CP interactions on mammary metabolism support the concept of different metabolic pathways by which starch diets improve milk protein yield at the 2 studied CP levels. Results from this study suggest that mammary Leu and glucose metabolism can be modulated by the supply of glucogenic nutrients to the mammary gland.
Key words: mammary gland, glucogenic, amino acid metabolism, efficiency

INTRODUCTION

Improving milk N efficiency (**MNE**), the proportion of feed N recovered in milk, is an important issue for dairy farms because it may enhance dairy incomes (Godden et al., 2001) and contribute to decrease the N pollution (Castillo et al., 2001). One of the most effective ways in dairy cattle to increase MNE (Huhtanen and Hristov, 2009), and then to reduce the manure N output (Yan et al., 2006), is to reduce the dietary CP content. However, low-protein diets may dramatically affect milk protein yield unless other dietary components, such as dietary energy content (Hanigan et al., 1998a) or AA profile (Haque et al., 2015), are concurrently modified.

Results from large data sets (North European data set in Huhtanen and Hristov, 2009) have shown that at similar energy and N intakes, diets rich in starch promoted higher MNE compared with diets rich in fiber. In this sense, we have recently found that the proportion of feed N absorbed into the portal vein as total amino acids (**TAA**), further released to the peripheral tissues and finally used for milk protein yield, was im-

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proved when the main dietary carbohydrate composition (**CHO**) changed from fiber to starch in iso-NE_L diets (Cantalapiedra-Hijar et al., 2014b). However, no direct AA-sparing effect of starch diets was found in that study (Cantalapiedra-Hijar et al., 2014b), in line with others (Larsen and Kristensen, 2012). One of the hypotheses arising was that starch diets increased milk N yield by improving the mammary anabolic use of AA compared with fiber diets, thus reducing the catabolic use of AA by the portal-drained viscera (Hanigan et al., 1998a, 2004) and liver (Reynolds, 2006) and indirectly improving their posthepatic availability.

Glucose availability for mammary metabolism is often considered limiting for lactose and, hence, milk production (Danfaer, 1994). However, increased glucose availability is not always associated with greater lactose synthesis (Lemosquet et al., 2009), as it is also able to increase milk protein yield at isoenergetic and isonitrogenous levels (Hurtaud et al., 2000; Rulquin et al., 2004). Indeed, although AA availability is the main limiting factor for milk protein synthesis (Bequette et al., 1998), the production of milk protein has also been shown to dramatically increase through endocrine signals only (McGuire et al., 1995; Griinari et al., 1997; Mackle et al., 2000). However, AA supply together with endocrine signals prompted by glucogenic nutrients seem to be highly interconnected in pathways involved in milk protein synthesis (Burgos et al., 2010; Bionaz and Loor, 2011), and some interactions between these stimuli have been previously documented at the molecular level (Vinod and Venkatesh, 2009; Burgos et al., 2010; Rius et al., 2010). Hence, a need to assess the effect of CHO on mammary metabolism at different protein intakes levels exists.

We hypothesized that the profile of nutrients arriving to the mammary gland when changing the main CHO from fiber to starch would increase the AA utilization by the mammary gland and that this effect would be different according to the protein supply. Thus, the aim of our study was to evaluate the effects of the dietary carbohydrate composition (starch vs. fiber diets) on mammary nutrient flux and milk performances in dairy cows fed isoenergetic diets at low (12.0% CP) versus normal (16.5% CP) protein levels.

MATERIALS AND METHODS

Details of this study have been described previously (Cantalapiedra-Hijar et al., 2014b). The experiment was conducted in respect of the national legislation on animal care (Certificate of Authorisation to Experiment on Living Animals, no. 004495, Ministry of Agriculture, Paris, France).

Animals and Experimental Design

Five multiparous Jersey cows in midlactation, averaging 365 ± 33 kg of BW and 78 ± 12 DIM at the onset of the experiment, were used in a 4 × 4 Latin square design, with the fifth cow used as an extra observation in the Latin square. Chronic indwelling catheters were surgically implanted into major splanchnic vessels (including mesenteric artery) before the lactation peak and at least 5 wk before the beginning of the experiment (Cantalapiedra-Hijar et al., 2014b).

Diet composition, chemical composition, and feed values of diets were described in detail in Cantalapiedra-Hijar et al. (2014a). Briefly, 4 iso-NE_L diets were formulated according to a 2 × 2 factorial arrangement of treatments to test 2 different CP contents [12.0 (low CP) and 16.5% (normal CP), meeting 80 and 100% of MP requirements (INRA, 2007), respectively] and 2 different carbohydrate compositions (350 g of starch and 310 g of NDF/kg of DM for the starch diets, and 45 g of starch and 460 g of NDF/kg of DM for the fiber diets), leading to large variations in the profile of absorbed nutrients as outlined in Cantalapiedra-Hijar et al. (2014a).

Each experimental period lasted 28 d. To minimize postprandial variations, feed were offered from automated feeders in equal quantities every 3 h from d 1 through 24 and hourly after that point. Cows were housed in tiestalls lighted 24 h/d and water was freely available to all cows.

Measurements, Sampling, and Laboratory Analysis

Net fluxes of nutrients, blood gases, and hormones across the mammary gland were measured on d 27 of each 4-wk period, whereas milk yield was measured and sampled on d 27 and 28. Milk sampling was conducted twice a day at 0600 and 1700 h for milk composition analysis (n = 4 per treatment and cow), except for milk AA concentration where only the milk sampled at 1700 h on d 27 was analyzed. The AA composition of the milk protein was analyzed using a HPLC (Alliance System, Waters, Guyancourt, France) following protein hydrolysis with 6 *N* HCl (24 h). The sulfur AA (i.e., Met and Cys) were separately liberated by oxidation using performic acid before the protein hydrolysis.

Blood was collected hourly from the mesenteric artery [from 1130 to 1630 h (n = 6); 30 min before and after each meal] and from the mammary vein by venipuncture [right udder at 1130 and 1530 h; left udder at 1230 and 1630 h (n = 4)] into 9-mL tubes containing lithium heparin (5 IU/mL of blood) to determine glucose, lactate, BHBA, individual AA, VFA, O_2, and CO_2 concentrations and EDTA-K (10 μL/mL of blood) to deter-