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First-pass uptake and oxidation of glucose by the splanchnic tissue in young goats fed soy protein-based milk diets with or without amino acid supplementation

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ABSTRACT

The study was designed to examine whether feeding soy protein isolate as partial replacement of casein (CN) affects glucose metabolism in young goats and whether effects may be ameliorated by supplementation of those AA known to be lower concentrated in soy than in CN. Goat kids (d 20 of age) were fed comparable milk protein diets, in which 50% of the crude protein was either CN (control, CON), soy protein isolate (SPI), or soy protein isolate supplemented with AA (SPIA) for 43 d (n = 8 per group). On d 62 of age, a single bolus dose of D-[$^{13}C_6$]glucose (10 mg/kg of BW) was given with the morning diet, and simultaneously, a single bolus dose of D-[6,6-$^{2}H_2$]glucose (5 mg/kg of BW) was injected into a jugular vein. Blood samples were collected between −30 and +420 min relative to the tracer administration to measure the ^{13}C and ^{2}H enrichments of plasma glucose and the ^{13}C enrichment of blood CO_2. Glucose first-pass uptake by the splanchnic tissues was calculated from the rate of appearance of differentially labeled glucose tracer in plasma. Glucose oxidation was calculated from ^{13}C enrichment in blood CO_2. In addition, plasma concentrations of triglycerides, nonesterified fatty acids, glucose, insulin, and glucagon were measured. On d 63 of age, kids were killed and jejunal mucosa and liver samples were collected to measure lactase mRNA levels and lactase and maltase activities in the jejunum and activities of pyruvate carboxylase and phosphoenolpyruvate carboxykinase (PEPCK) in the liver. Basal plasma glucose concentration tended to be higher in the CON than the SPIA group, whereas basal insulin was higher in the CON group than the SPI and SPIA groups, and glucagon was higher in the CON than the SPIA group. Plasma glucose and insulin concentrations increased during the first hour after feeding, whereas plasma glucagon increased immediately after feeding and after 1 h of feeding. First-pass uptake and glucose oxidation were not affected by diet. Maltase activities in proximal and mid jejunum and lactase activities in mid jejunum were lower in the CON than in the SPIA group. Activities of PEPCK were higher in the SPIA than in the SPI group. In conclusion, feeding milk diets with soy protein isolate seems to affect glucose status in kids, but has no effect on first-pass uptake and oxidation of glucose. The highest activities of lactase and maltase were observed after supplementation with AA. Higher PEPCK activities in the liver may point at elevated gluconeogenic activities after AA supplementation in soy-fed kids.
Key words: goat kid, soy protein, glucose first-pass uptake, stable isotope

INTRODUCTION

In preruminants, feeding soy protein instead of milk protein leads to alterations in the intestinal morphology, with consequences on the absorptive function (Seegraber and Morrill, 1986; Montagne et al., 1999). Studies by Lalles et al. (1995) in veal calves indicated that soy protein reduces the absorptive permeability of the small intestine to xylose. Boudry et al. (2003) demonstrated that soy protein impairs the sodium-dependent glucose absorption in the small intestine of piglet. However, supplementation of indispensable AA to soy protein partly avoided mucosal growth retardation (Schönhusen et al., 2010b) and increased the capacity of glucose uptake across the jejunal brush border membrane in the mid jejunum of goat kids (Giere, 2009). Recently, we found that Thr, Val, Ile, Leu, His, Lys, and Met supplemented to soy protein change jejunal proteins involved in processes related to cytoskeleton formation and energy metabolism in goat kids (Kuhla et al., 2007; Schönhusen et al., 2010b). Moreover, studies in lambs have shown that the glucose uptake along the small intestine is influenced by dietary AA and peptides via sodium-dependent glucose transporter1 activity; however, the regulatory action of dietary protein and its

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interaction with membrane transporters are not fully understood (Mabjeesh et al., 2003). It is conceivable that AA and peptides may provide some extra- or intracellular signals to activate the sodium-dependent glucose transporter1 protein. On the other hand, AA have been reported to increase the endogenous glucose production and utilization in growing lambs (Abdul-Razzaq and Bickerstaffe, 1989). Both dietary AA and glucose are oxidative substrates and are used by the intestinal mucosa for energy generation (Windmueller and Spaeth, 1980). Dietary glucose oxidation by the intestine seems to become more important for providing energy in adaptation processes during which the intestinal digestive and absorptive function is stimulated (van der Schoor et al., 2001).

Due to alterations in the small intestinal morphology after soy protein feeding, we hypothesized that soy protein feeding may impair glucose metabolism, especially glucose first-pass uptake (**FPU**) and oxidation by the splanchnic tissues and endogenous glucose production, especially gluconeogenesis, in the liver. Amino acid supplementation to soy protein isolate may ameliorate these effects on systemic and hepatic glucose metabolism. The extent to which orally administered glucose is taken up by the intestine and metabolized within the splanchnic tissue (intestine and liver) or transported to the systemic circulation was determined by a dual-stable-isotope-tracer technique (van der Schoor et al., 2004; Steinhoff-Wagner et al., 2011a).

MATERIALS AND METHODS

Animals and Diets

The experimental protocol was approved by the relevant authorities (Landesamt für Landwirtschaft, Lebensmittelsicherheit und Fischerei Mecklenburg-Vorpommern, Germany; LALL M-V/TSD/7221.3–2.1–017/05). Details on animals, housing, feeding, and the experimental protocol were as described by Schönhusen et al. (2010a). In brief, 24 male kids (German White dairy goat) were randomly assigned by age and BW to 3 treatment groups (n = 8 each). Dietary treatments started on d 20 of life for a period of 43 d (Montagne et al., 1999). All diets were based on skim milk powder (28% CP and 27% crude fat in DM; Table 1). In the control group (**CON**) 50% of the milk protein was replaced by CN (1.3% crude ash, 97.6% CP, and 1.1% crude fat in DM). In the soy group (**SPI**), 50% of the milk protein was replaced by soy protein isolate (4.7% crude ash, 90.0% CP, and 2.5% crude fat in DM), whereas in the soy group with AA supplementation (**SPIA**) 50% of the milk protein was replaced by soy protein isolate, supplemented with those AA known to be at lower concentrations in soy protein isolate than in CN (Table 1). Diets were formulated to be isonitrogenous and isoenergetic. Lactose was added to provide a constant proportion of protein to N-free extracts in all 3 diets. A DMI of 33 g/(kg of $BW^{0.75}$ × d) was provided, and energy and protein were supplied at 0.6 MJ/(kg of $BW^{0.75}$ × d) and 11 g/(kg of $BW^{0.75}$ × d), respectively. Diets were fed twice daily in equal parts by bottle. Kids were weighed weekly before the morning feeding, and DMI was adjusted for BW. Daily intake of DM, CP, and ME were not different among the groups. Kids of the CON, SPI, and SPIA groups did not differ with regard to initial and final BW. Details on feed intake, growth performance (mean ADG was 148 ± 8 g/d), and feed efficiency (mean feed efficiency was 786 ± 31 g of ADG/kg of DMI) were recently presented (Schönhusen et al., 2010a).

Analytical Procedures

Feed. Dry matter, crude ash, ether extract, and crude fat of the dried dietary components and experimental diets were determined according to the Weende standard procedure (Naumann and Bassler, 1993). Nitrogen was determined by combustion analysis (CNS-2000, Leco Corp., St. Joseph, MI) and CP was then calculated by multiplying the N content with 6.25. The ME content of feed was calculated using digestible nutrients (Bezabih and Pfeffer, 2003). Digestible nutrients were calculated from the measured nutrient contents multiplied by the digestibility of nutrients using feedstuff tables (German Society of Nutrition Physiology, 2003). Lactose concentration was measured by the β-galactosidase method using a commercial kit (no. 10 176 303 035; R-Biopharm AG, Darmstadt, Germany). Lactose is hydrolyzed to D-glucose and D-galactose in the presence of β-galactosidase. D-Galactose is oxidized by NAD to D-galactonic acid in the presence of β-galactose dehydrogenase. The amount of NADH formed in reaction is stoichiometric to the amount of lactose. The increase in NADH is measured by light absorbance at 340 or 365 nm. Dietary AA concentrations were measured by liquid ion-exchange chromatography (Hennig et al., 2004). Soy protein isolate was analyzed for the content of daidzein and genistein by HPLC after acid hydrolysis and extraction (Degen et al., 2002).

Blood. Blood samples were collected via a jugular vein catheter (Vasofix Certo; B. Braun Melsungen AG, Melsungen, Germany) in K_3-EDTA containing Monovettes (Sarstedt AG & Co., Nümbrecht, Germany; 1.8 g/L of blood) on d 62 of life at 30 and 5 min before and at 5, 10, 15, 20, 30, 40, 60, 90, 120, 180, 260, 300, 360, and 420 min after the morning feeding to measure plasma concentrations of glucose, NEFA,