J. Dairy Sci. 98:1–21
http://dx.doi.org/10.3168/jds.2015-9649

Comparison of the nutritional regulation of milk fat secretion and composition in cows and goats

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ABSTRACT

A study with 2 ruminant species (goats and cows) with inherent differences in lipid metabolism was performed to test the hypothesis that milk fat depression (MFD) due to marine lipid supplements or diets containing high amounts of starch and plant oil is caused by different mechanisms and that each ruminant species responds differently. Cows and goats were allocated to 1 of 3 groups (4 cows and 5 goats per group) and fed diets containing no additional oil (control) or supplemented with fish oil (FO) or sunflower oil and wheat starch (SOS) according to a 3 × 3 Latin square design with 26-d experimental periods. In cows, milk fat content was lowered by FO and SOS (−31%), whereas only FO decreased milk fat content in goats (−21%) compared with the control. Furthermore, FO and SOS decreased milk fat yield in cows, but not in goats. In both species, FO and SOS decreased the secretion of <C16 and C16 fatty acids (FA), and FO lowered >C16 FA output. However, SOS increased milk secretion of >C16 FA in goats. Compared with the control, SOS resulted in similar increases in milk *trans*-10,*cis*-12 conjugated linoleic acid (CLA) in both species, but caused a 2-fold larger increase in *trans*-10 18:1 concentration in cows than for goats. Relative to the control, responses to FO in both species were characterized by a marked decrease in milk concentration of 18:0 (−74%) and *cis*-9 18:1 (−62%), together with a ∼5-fold increase in total *trans* 18:1, but the proportionate changes in *trans*-10 18:1 were lower for goats. Direct comparison of animal performance and milk FA responses to FO and SOS treatments demonstrated interspecies differences in mammary lipogenesis, suggesting a lower sensitivity to the inhibitory effects of *trans*-10,*cis*-12 CLA in goats and that ruminal biohydrogenation pathways are more stable and less prone to diet-induced shifts toward the formation of *trans*-10-containing intermediates in goats compared with cows. Even though a direct cause and effect could not be established, results suggest that regulation of milk fat synthesis during FO-induced MFD may be related to a shortage of 18:0 for endogenous mammary *cis*-9 18:1 synthesis, increase in the incorporation of *trans* FA in milk triacylglycerols, and limitations in the synthesis of FA de novo to maintain milk fat melting point. However, the possible contribution of biohydrogenation intermediates with putative antilipogenic effects in the mammary gland, including *trans*-9,*cis*-11 CLA, *trans*-10 18:1, or *cis*-11 18:1 to FO-induced MFD cannot be excluded.

Key words: cow, goat, milk fatty acid, milk fat depression

INTRODUCTION

Milk fat synthesis represents a major energy cost for milk production and plays a central role in determining dairy product quality and the partitioning of energy into milk. Transfer of dietary FA into milk fat is energetically favorable compared with FA synthesis de novo (Moe, 1981). Depending on payment scheme, economic advantages may exist for producing milk with a specific fat content, whereas legal limits on the minimum amount of fat in whole milk are imposed in numerous countries. For these reasons, there has been considerable interest for more than 3 decades in understanding the influence of diet on the regulation of milk fat secretion and FA composition and identifying the causes of diet-induced milk fat depression (**MFD**; Palmquist and Jenkins, 1980; Bauman and Griinari, 2003; Shingfield et al., 2010).

Several theories have been proposed to explain the causes of MFD, with most found to be inadequate or incomplete (Bauman and Griinari, 2003; Shingfield and Griinari, 2007). The biohydrogenation (**BH**) theory appears to be the most universal, and it attributes diet-induced MFD to an inhibition of mammary lipogenesis by specific FA intermediates formed in the rumen on

Received March 30, 2015.
Accepted June 9, 2015.
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certain diets as a consequence of alterations in ruminal BH pathways (Bauman and Griinari, 2003). *Trans*-10,*cis*-12 CLA is the only BH intermediate shown unequivocally to inhibit milk fat synthesis, but additional BH intermediates including *cis*-10,*trans*-12 CLA, *trans*-9,*cis*-11 CLA, and possibly *trans*-10 18:1, as well as other mechanisms, may also be involved (Harvatine et al., 2009; Shingfield et al., 2010). Although the BH theory provides a basis for explaining most cases of MFD on starch-rich diets or plant oil in cows, direct inhibition by the BH intermediates with confirmed or putative antilipogenic effects (*trans*-10,*cis*-12 CLA, *cis*-10,*trans*-12 CLA, and *trans*-9,*cis*-11 CLA) does not, in isolation, explain MFD in cows or sheep fed diets containing marine oils (Loor et al., 2005a; Gama et al., 2008; Toral et al., 2010). To accommodate these findings, Shingfield and Griinari (2007) proposed an extension of the BH theory to include the role of changes in the availability of preformed long-chain FA to the mammary gland. Several reports have suggested that a shortage of 18:0 for endogenous *cis*-9 18:1 synthesis in the mammary gland, together with an increase in the supply of *trans* FA formed in the rumen, would increase milk fat melting point, exceeding the capacity to maintain milk fat fluidity and thereby lower the rate of fat removal in mammary epithelial cells (Loor et al., 2005a; Gama et al., 2008). This phenomenon may offer an explanation for MFD in ewes offered supplements of fish oil or marine algae, whereas high-starch diets, plant oil, and oilseed supplements do not alter milk fat content in this species (Shingfield et al., 2010; Toral et al., 2010). However, milk production in goats is characterized by an absence of diet-induced MFD, even on diets containing high amounts of starch and plant oil (Chilliard et al., 2003; Martínez Marín et al., 2012; Bernard et al., 2009) or in response to dietary fish oil supplements (Toral et al., 2014).

The reasons for the differential lipogenic responses between ruminant species are not well understood, but based on indirect comparisons of milk FA composition, have been suggested to reflect differences in ruminal BH and mammary lipid metabolism (Chilliard et al., 2007, 2014; Shingfield et al., 2010). However, no direct interspecies comparisons of diet-induced MFD have been reported in the literature.

A comparative study with lactating cows and goats presenting differences in their susceptibility to diet-induced MFD was undertaken to test the hypotheses that MFD due to marine lipid supplements or a diet containing high amounts of starch and plant oils is caused by distinct mechanisms and that mammary lipogenic responses differ between ruminant species. To meet these objectives, cows and goats were fed a basal diet containing no additional lipid (control), a similar diet supplemented with fish oil (**FO**), or a diet containing additional starch and sunflower oil (**SOS**). Changes in milk production, fat yield, and milk FA were measured and used to infer possible mechanisms responsible for differences in the regulation of mammary lipogenesis due to diet and ruminant species.

MATERIALS AND METHODS

Animals, Experimental Design, Diets, and Management

All experimental procedures were approved by the Animal Care Committee of INRA in accordance with the guidelines established by the European Union Directive 2010/63/EU. Twelve Holstein cows and 15 Alpine goats, all multiparous, nonpregnant, and at similar lactation stage (67 ± 6.5 and 73 ± 1.4 DIM for cows and goats, respectively) were used. Cows and goats were housed in individual stalls in separate dedicated facilities at the same research site. Animals were then allocated to 1 of 3 groups (4 cows and 5 goats per group) that were balanced according to DIM, milk production, milk fat content, parity, and the genotype score at the αS1-CN locus for goats, and used in a replicated 3 × 3 Latin square to test the effects of 3 treatments during three 26-d experimental periods (Kaps and Lamberson, 2009) from April to June 2012. Unfortunately, 1 goat had to be withdrawn from the experiment due to diarrhea.

All animals were offered grass hay ad libitum supplemented with concentrates containing no additional lipid (control), fish oil (**FO**; anchovy oil, SA Daudruy Van Cauwenberghe et Fils, Dunkerque, France) or sunflower oil (Auvergne Trituration, Lezoux, France) and wheat starch (**SOS**; Table 1). Both fish oil and sunflower oil (stored in the dark at room temperature) were mixed manually with other ingredients immediately before feeding out and fed in amounts to supply 420 and 1,000 g of oil/d in cows and 50 and 120 g of oil/d for goats, respectively. Diets were offered as 2 equal meals at 0830 and 1600 h. Hay and concentrate refusals were weighed daily and used to adjust the amounts of feed offered the following day to maintain the targeted dietary forage-to-concentrate ratio (40:60 on a DM basis). Before starting the experiment, all animals received the control diet during a 28-d adaptation period. Animals had access to a constant supply of fresh water and were milked at 0800 and 1530 h.

Measurements and Sampling Procedures

Individual feed intake was recorded daily, but only measurements collected during the last 3 d of each