J. Dairy Sci. 91:2771–2785
doi:10.3168/jds.2007-0383

Long-Chain Fatty Acid Metabolism in Dairy Cows: A Meta-Analysis of Milk Fatty Acid Yield in Relation to Duodenal Flows and De Novo Synthesis

F. Glasser,*[1] A. Ferlay,* M. Doreau,* P. Schmidely,† D. Sauvant,† and Y. Chilliard*
*INRA, UR1213 Herbivores, Site de Theix, F-63122 Saint-Genès-Champanelle, France
†INRA, UMR791 Physiologie de la Nutrition et Alimentation, INAPG, 16 rue Claude Bernard, F-75231 Paris, France

ABSTRACT

This study is a meta-analysis of the response of milk long-chain fatty acid (FA) yield and composition to lipid supply, based on published experiments reporting duodenal FA flows or duodenal lipid infusions and milk FA composition (i.e., 39 experiments reporting 139 experimental treatments). Analysis of these data underlined the interdependence between milk yields of C18 and short- and medium-chain (C4 to C16) FA. Lipid supplementation (producing an increase in duodenal C18 flow) decreased linearly milk C4 to C16 yield (–0.26 g of C4 to C16 produced per gram of duodenal C18 flow increase) and increased quadratically milk C18 yield. When these 2 effects increased the percentage of C18 in milk FA up to a threshold value (around 52% of total FA), then milk C18 yield was limited by C4 to C16 yield, decreasing the C18 transfer efficiency from duodenum to milk with high-lipid diets. Moreover, for a given duodenal C18 flow, a decrease in milk C4 to C16 yield induced a decrease in milk C18 yield. Despite high variations in C18 transfer efficiency between duodenum and milk, for a given experimental condition, the percentages of C18 FA in milk total C18 could be predicted from their percentages in duodenal C18, and the percentages at the duodenum and in milk were very similar when mammary desaturation was taken into account (i.e., considering the sums of substrates and products of mammary desaturase). The estimated amounts of 18:0, *trans*-11–, and *trans*-13–18:1 desaturated by the mammary gland were a linear function of their mammary uptake, and mammary desaturation was responsible for 80, 95, and 81%, respectively, of the yield of their products (i.e., *cis*-9–18:1; *cis*-9, *trans*-11–, and *cis*-9, *trans*-13–18:2). Thus, mammary FA desaturation capacity did not seem to be a limiting factor in the experimental conditions published so far.

Key words: dairy cow, duodenal flow, milk fatty acid, desaturation

INTRODUCTION

Public health concerns are driving research into modifying fatty acid (**FA**) profiles of cow milk, particularly toward less saturated medium-chain FA and more long-chain polyunsaturated FA. The simplest way of altering milk fat composition is to supplement cow diets with unsaturated lipids (Chilliard et al., 2007). Over the last 40 yr, there have been hundreds of published studies on the response of milk fat yield and composition to dietary lipid supplements or duodenal infusion of lipids. These studies have highlighted a wide range of milk fat yield and composition responses to lipid supplementation; whereas the yield of short- and medium-chain FA is almost always decreased, the response of C18 FA yield is much more variable. Some experiments report almost no increase in C18 yield (Chilliard et al., 1991b; Chelikani et al., 2004), whereas others report increases in C18 yield (Avila et al., 2000), and others suggest that the response depends on basal diet (Loor et al., 2005b).

Due to the extensive biohydrogenation of unsaturated FA in the rumen (Doreau and Ferlay, 1994; Glasser et al., 2008), FA intakes are not a representative indicator of the FA actually available for the animal. For this reason, we only used publications reporting FA flows at the duodenum and postruminal infusions of FA, which are more representative of FA availability for milk fat synthesis. The aim of the present study is to quantitatively determine, from the published data, the response of milk FA yield and C18 composition to duodenal C18 flow.

MATERIALS AND METHODS

Overview of the Logical Development of the Paper and Chosen Approaches

Most experiments reporting duodenal FA flows (or duodenal FA infusions) and milk FA yields are experi-

Received May 24, 2007.
Accepted March 13, 2008.
[1]Corresponding author: fglasser@clermont.inra.fr

ments of lipid supplementation, generally comparing a low-lipid diet with one or several lipid-supplemented diets. The approach chosen was 3-fold:

1. We studied the determinants of milk C18 yield. Within experiment and on a data set including dietary experiments and duodenal lipid infusions, we studied the response of milk C18 yield to the increase in duodenal C18. We observed that in several experiments milk C18 yield did not depend on duodenal C18 flow. In these cases, there was a positive relationship between milk C18 yield and milk C4 to C16 yield, contrary to the most frequent cases of negative relationships. Then, on a subset of data with variations in milk C4 to C16 yield without significant variation in duodenal C18 flow (including *trans*-10, *cis*-12–18:2 infusions, a known inhibitor of de novo FA synthesis), we studied whether variations in milk C18 yield could be linked to variations in de novo synthesis (evaluated by milk C4 to C16 yield). These studies demonstrated that milk C18 yield could be mainly driven by either C18 availability or de novo FA synthesis, according to the nutritional and physiological conditions.
2. Because milk total C18 yield could not be directly predicted from duodenal C18 flow, the prediction of the milk yield of individual C18 FA from their duodenal flow was not possible either. We thus studied the relationships between C18 FA at duodenum and in milk with a composition approach, all C18 being expressed as a percentage of total C18.
3. The last component of the study concerns mammary desaturation: the preceding results on milk C18 composition enabled us to assume that all C18 FA were taken up in similar proportions by the mammary gland and thus to produce estimates of the amounts of FA desaturated by the mammary gland according to their uptake.

Inclusion of Publications

We compiled all available experiments on dairy cows (published until 2006) reporting duodenal FA flows, milk fat yield and milk FA profiles, or any set of data that could be used to calculate these criteria. From this data set, we excluded 1 experimental treatment with saturated tallow and very low intestinal digestibility (Pantoja et al., 1996), 1 experiment containing discrepancies between FA intake and duodenal flows (Loor et al., 2002), and 1 experiment comparing different forages with almost no difference between treatments in duodenal C18 flow (Dewhurst et al., 2003), thus not relevant for our meta-analysis. The final data set of dietary experiments included 16 experiments reported in 21 publications (Klusmeyer and Clark, 1991; Tice et al., 1994; Wonsil et al., 1994; Pantoja et al., 1996; Enjalbert et al., 1997; Kalscheur et al., 1997a,b; Christensen et al., 1998; Avila et al., 2000; Piperova et al., 2002; Shingfield et al., 2003; Ueda et al., 2003; Chelikani et al., 2004; Gonthier et al., 2004; Loor et al., 2004, 2005b,c,d; Lundy et al., 2004; Qiu et al., 2004; Gonthier et al., 2005). To this data set, we added all available experiments on duodenal infusion of unsaturated fats reporting milk fat yield and FA composition (i.e., 13 experiments reported in 12 publications; Chilliard et al., 1991a,b; Christensen et al., 1994; Gaynor et al., 1994; Ottou et al., 1995; Bandara, 1997; Enjalbert et al., 1998; Wagner et al., 1998; Enjalbert et al., 2000; Romo et al., 2000; DePeters et al., 2001; Bell and Kennelly, 2003). Finally, to test the possible impact of de novo synthesis on C18 FA yield, independently to duodenal C18 flow, we also included experiments on postruminal infusions of *trans*-10, *cis*-12–18:2, which is a potent inhibitor of de novo synthesis (Baumgard et al., 2000). Infusions with a significant difference ($P < 0.05$) in DMI among experimental treatments were excluded to ensure that duodenal C18 flows could be considered equal between control and infused treatments. Eleven studies on *trans*-10, *cis*-12–18:2 infusions were thus included (Chouinard et al., 1999a,b; Baumgard et al., 2000, 2001, 2002; Bell and Kennelly, 2003; Loor and Herbein, 2003; Mackle et al., 2003; de Veth et al., 2004; Perfield et al., 2004; Saebo et al., 2005). In total, our final database included 39 experiments and 139 experimental treatments. All but 2 experiments were conducted on Holstein or Friesian cows. The mean forage percentage was 52% (on a DM basis, range 35 to 100%), the main forage being alfalfa silage or haylage in 11 experiments, corn silage in 10 experiments, alfalfa hay in 9 experiments, grass silage in 6 experiments, grass hay in 2 experiments, and fresh grass in 1 experiment. Three of the experiments were conducted on early lactation cows (<30 DIM), 24 on midlactation cows (30 to 150 DIM), and 12 on late-lactation cows (>150 DIM).

Several equations were derived from this database. For each equation, a subset of experiments was selected based on their relevance for the studied relationship. The selection criteria, number of experiments, and experimental treatments used for adjustment of each equation are described under their corresponding paragraph headings.

Calculation of Flows and Mammary Desaturation

Total milk FA yields were computed from the milk fat yields reported in the publications, assuming that total FA represent 93.3% of milk fat (Glasser et al.,