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Invited review: Palmitic and stearic acid metabolism in lactating dairy cows

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ABSTRACT

Energy is the most limiting nutritional component in diets for high-producing dairy cows. Palmitic (C16:0) and stearic (C18:0) acids have unique and specific functions in lactating dairy cows beyond a ubiquitous energy source. This review delineates their metabolism and usage in lactating dairy cows from diet to milk production. Palmitic acid is the fatty acid (FA) found in the greatest quantity in milk fat. Dietary sources of C16:0 generally increase milk fat yield and are used as an energy source for milk production and replenishing body weight loss during periods of negative energy balance. Stearic acid is the most abundant FA available to the dairy cow and is used to a greater extent for milk production and energy balance than C16:0. However, C18:0 is also intimately involved in milk fat production. Quantifying the transfer of each FA from diet into milk fat is complicated by de novo synthesis of C16:0 and desaturation of C18:0 to oleic acid in the mammary gland. In addition, incorporation of both FA into milk fat appears to be limited by the cow's requirement to maintain fluidity of milk, which requires a balance between saturated and unsaturated FA. Oleic acid is the second most abundant FA in milk fat and likely the main unsaturated FA involved in regulating fluidity of milk. Because the mammary gland can desaturate C18:0 to oleic acid, C18:0 appears to have a more prominent role in milk production than C16:0. To understand metabolism and utilization of these FA in lactating dairy cows, we reviewed production and milk fat synthesis studies. Additional and longer lactation studies on feeding both FA to lactating dairy cows are required to better delineate their roles in optimizing milk production and milk FA composition and yield.
Key words: stearic acid, palmitic acid, milk fat, milk production, body condition

INTRODUCTION

Energy is and will continue to be the major nutritional challenge to the ever-increasing lactation productivity of dairy cows. Because of this, dairy producers and nutritionists have increased the use of high-energy feed ingredients, such as fat, in lactating dairy cow diets. Dry, ruminally inert fat supplements have become common feed ingredients in diets because of their energy content and versatility on farms, where they can be added to grain mixes, mineral mixes, TMR, or top dressed. Dry, rumen-inert fats usually contain high concentrations of long-chain FA (**LCFA**), with the most common being palmitic (C16:0), stearic (C18:0), oleic (C18:1), and linoleic (C18:2). Research over the last several years has shown FA are not just a ubiquitous source of energy, but have metabolically different functions in the cow and contribute to the productive function of cows in different ways. This paper discusses the roles of C16:0 and C18:0, the 2 most common SFA found in rumen-inert fats, in the metabolism and productivity of lactating dairy cows.

CHEMICAL PROPERTIES OF PALMITIC AND STEARIC ACID

Palmitic acid is a 16-carbon SFA denoted as *n*-hexadecanoic acid with a chemical formula of $CH_3(CH_2)_{14}CO_2H$. It has a melting point of 62.8°C and an acid dissociation constant ($\mathbf{p}\boldsymbol{K}_\mathbf{a}$) of 4.78 (Budavari, 1989). French scientist Michel Eugene Chevreul discovered palmitic acid in the early 1800s (Lemay and Oesper, 1948) and it was first used by the French chemist Edmond Frémy in the middle 1800s for the making of candles. Palmitic acid is the most common SFA found in plants, animals, and many microorganisms. Major sources of C16:0 are palm oil, palm kernel oil, coconut oil, and milk fat.

Stearic acid is an 18-carbon SFA denoted as *n*-octadecanoic acid with a chemical formula of $CH_3(CH_2)_{16}CO_2H$. Michel Eugene Chevreul first described C18:0 in the early 1800s (Lemay and Oesper, 1948). Stearic acid is a prevalent FA in nature, found in many animal and

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vegetable fats, but is usually higher in animal fat than vegetable fat. It has a melting point of 69.4°C and a pK_a of 4.50 (Sukhija and Palmquist, 1990).

DIGESTION AND ABSORPTION

Most naturally occurring fats consumed by the dairy cow are in the form of triacylglycerols (**TAG**), phospholipids, and glycolipids. Bacteria and protozoa in the rumen hydrolyze these complex lipids into LCFA, glycerol, sugars, choline, serine, phosphates, and other organic compounds (Buccioni et al., 2012). The number of rumen microorganisms capable of hydrolyzing esterified lipids is low, but their activity is highly specific and efficient, as 85 to 95% of the dietary lipids reaching the duodenum are FFA (Doreau and Ferlay, 1994; Buccioni et al., 2012). Only unsaturated FFA released during hydrolysis can be biohydrogenated to saturated FFA, primarily C18:0 and secondarily C16:0. However, the biohydrogenation process is not entirely complete and some intermediate unsaturated FA exit the rumen, including isomers that may cause milk fat depression (Jenkins et al., 2008; Bauman et al., 2011; Buccioni et al., 2012).

FA Flow into the Duodenum

The flow of C18:0 from the rumen is several times greater than the amount consumed because of biohydrogenation of PUFA in the forages and grains fed to dairy cows. Wu et al. (1991) was one of the first studies to show that C18:0 was the only FA to increase in amount flowing from the rumen above the amount fed with or without fat supplemented in the diet. Outflow of C18:0 from the rumen was 46, 24, and 44% of the total FA intake (Table 1) when no supplemental fat, rumen-inert fat, or animal-vegetable (**AV**) blend fat was fed in a diet of 40% concentrate and 60% forage (alfalfa hay, haylage, and corn silage). Intake and rumen outflow of C16:0 remained similar, at 71 and 83 g, respectively, when no fat was supplemented in the diet, but with rumen-inert or AV supplementation, outflow of C16:0 was less than intake. Wu et al. (1991) also fed a rumen-inert fat high in C16:0 and *cis*-18:1 that changed amount and profile of FA intake and flow from the rumen; but, as a result of biohydrogenation, 6 times more C18:0 was flowing into the duodenum than the amount fed. Stearic acid was the only FA where the amount flowing from the rumen was greater than amount fed (Table 1).

Loor et al. (2004) also showed C18:0 was only 2.1 to 2.4% of the total FA fed in a high- (65%) or low-concentrate (35%) diet, but the amount flowing into the duodenum was 25 times higher than the amount fed and accounted for 46 to 39% of the total FA flow leaving the rumen in the low- and high-concentrate diets, respectively. Supplementing 3.0% linseed oil in these diets increased C18:0 to about 3.3% of the total FA fed and changed the C18:0 in the FA flowing into the duodenum to 54 and 30% for low- and high-concentrate diets, respectively. In all diets, the amount of C18:0 flowing into the duodenum was higher than for any other FA. Changes in C16:0 from intake to duodenal flow were much less than for C18:0 with C16:0 intakes between 10 to 21% of the total FA fed and 10 to 17% of the total duodenal FA flow (Loor et al., 2004).

The effects of feeding multiple ingredients and supplemental fats on microbial metabolism of FA in the rumen and FA flow into the duodenum are reported in the meta-analysis of Glasser et al. (2008b) on digestion of FA in ruminants. Stearic acid was the predominant FA flowing from the rumen, at 69.5% of the total FA flow into the duodenum when fish meal was not included in the diet; but including fish meal decreased C18:0 to 34% and increased *trans*-C18:1 to 45% of the FA flow to the duodenum. Amounts of C18:0 flowing from the rumen in general were 3 times greater than flow of C16:0.

On exiting the rumen, most FA are present as salts of sodium, potassium, or calcium combined in an insoluble particulate phase of feed particles and microbial cells. These salts are dissociated and protonated to a great extent in the abomasum due to low pH, and thus enter the duodenum mostly as nonionized FFA. If these FFA are not absorbed, they may reform as salts as pH

Table 1. Fatty acid intake and rumen outflow in cows fed a 40% concentrate diet without fat (control) or with rumen-inert fat or animal-vegetable blend (AV)[1]

	Fat supplementation		
FA,[2] g/d	Control	Rumen-inert[3]	AV blend[4]
C16:0			
Intake	71	400	165
Outflow	83	313	152
C18:0			
Intake	12	39	104
Outflow	186	254	410
C18:1, total			
Intake	79	308	297
Outflow	60	158	126
Total FA			
Intake	431	1,052	934
Outflow	402	837	810

[1]Adapted from Wu et al. (1991).

[2]Rumen-inert and AV blend intake and outflow values are means of feeding supplements at 3 and 6% of the diet DM.

[3]The FA composition of the rumen inert fat was 50.8% C16:0, 4.2% C18:0, and 35.5% *cis* C18:1.

[4]The FA composition of the AV blend was 17.0% C16:0, 17.2% C18:0, and 34.5% *cis* C18:1.