TechNote 7

Lipid metabolism

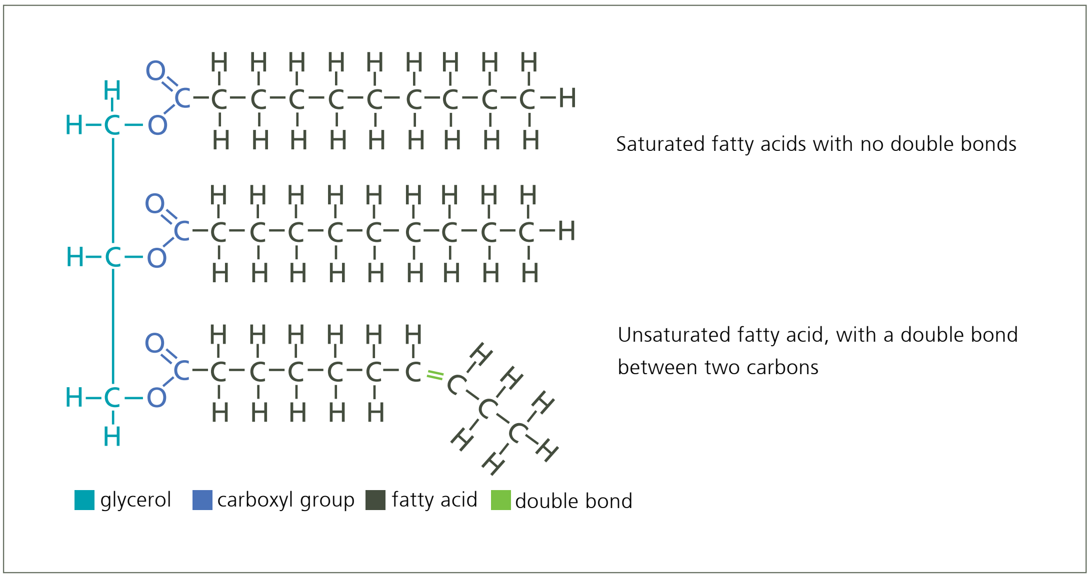
IN THIS TECHNOTE

Lipid (fat) is a substance found in plant and animal products that is not soluble in water. On a weight basis, fat contains more than twice the energy content of carbohydrates. The dietary fat content for dairy cows is typically low, between 2-6% DM for most pasture-based diets. This is because dietary fat contents in excess of 8% can negatively impact rumen function, fibre digestion, dry matter intake (DMI) and milk production.

7.1 Dietary lipid (fat) structure

Dietary fats are generally in the form of a triglyceride. A triglyceride consists of a glycerol backbone joined to 3 fatty acids (Figure 1). These fatty acids can be saturated (no double bonds between the carbons) or unsaturated (one or more double bonds between two carbons).

***Figure 1.** Triglyceride structure containing a glycerol backbone and 3 fatty acids.*



For more details see TechNotes 3: What's in a feed, and 4: Feed composition and characteristics, and online eLearning activity: The role of lipids; dairynz.co.nz/feedright-module-7.

7.2 Fatty acids

The digestion and metabolism of dietary fats is outlined in Figure 2. After ingestion, the majority of dietary fats are quickly hydrolysed in the rumen by enzymes present in plant tissues, or produced by rumen microbes. Hydrolysis of fat breaks apart the fatty acids and the glycerol backbone, producing to soluble sugars, (from the glycerol backbone), and free fatty acids. The sugars can be used by the rumen microbes as an energy source, while the fatty acids are released into the rumen.

The free fatty acids that are released into the rumen are either saturated (no double bonds) or unsaturated (at least one double bond). The number and position of double bonds in a fatty acid can alter the way in which the fatty acid is digested and can also alter its biological activity.

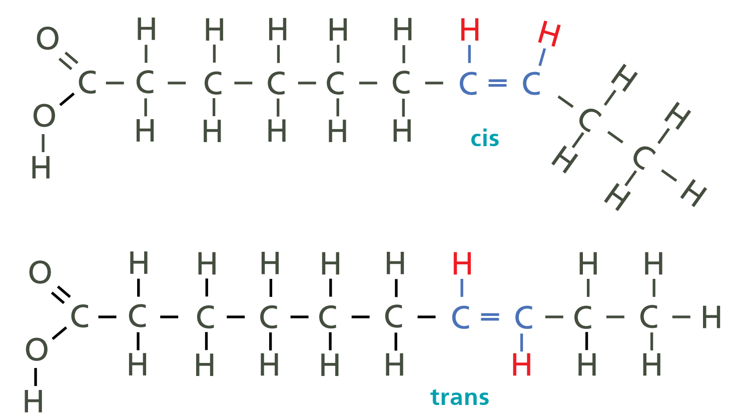
A fatty acid is described by the number of carbons in the chain and how many double bonds are present. For example:

- linoleic acid (C18:2) has 18 carbons in the chain and 2 double bonds, whereas
- vaccenic acid (C18:1) has 18 carbons in the chain and 1 double bond.

The position of these double bonds is also included in the fatty acids description. For example:

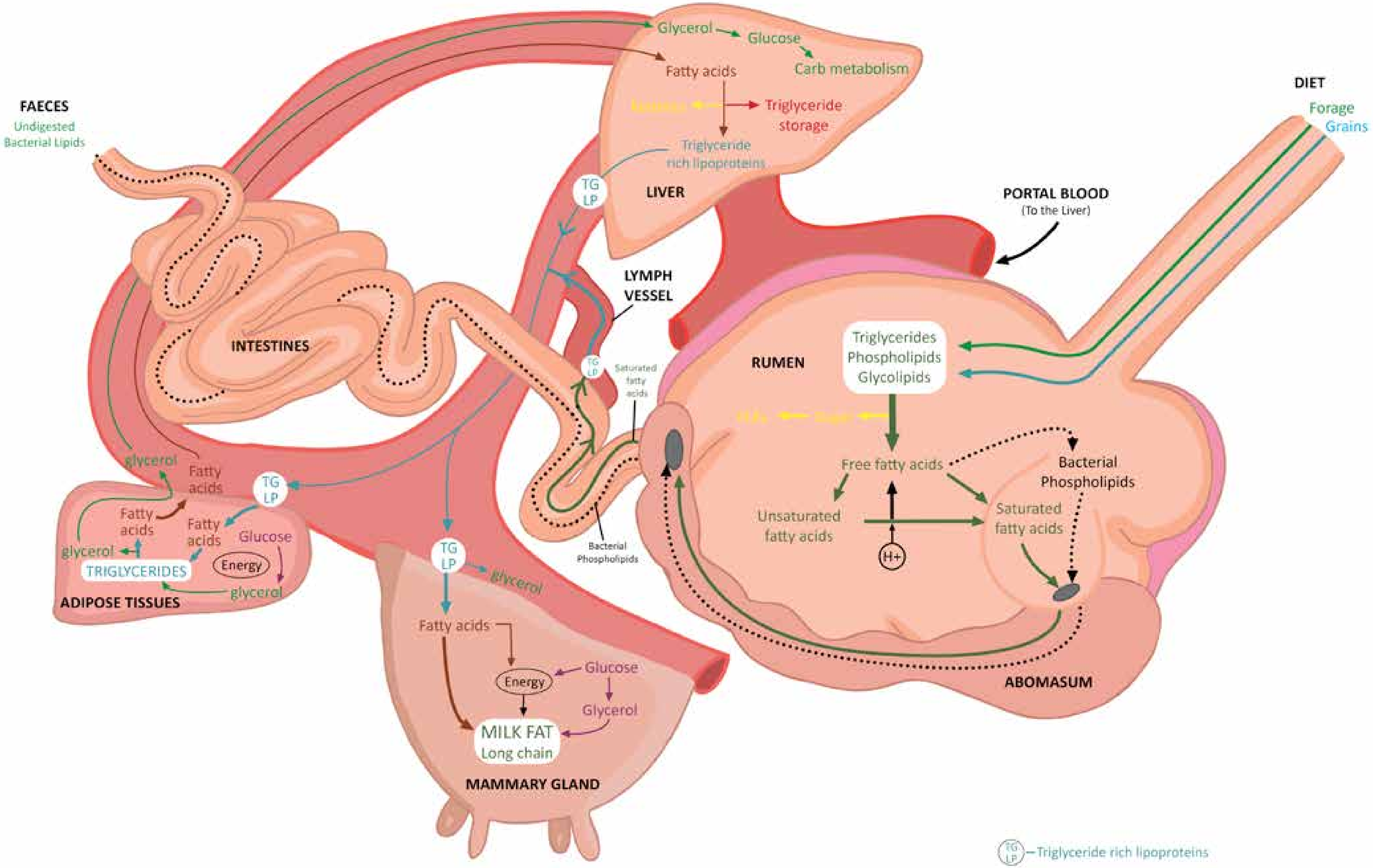
- linoleic acid (*cis*-9, *cis*-12 C18:2) means the 2 double bonds are on the 9th and 12th carbons. The *cis* or *trans* describes the positions of the two hydrogen ions surrounding the double bond (Figure 3).

Figure 3. *cis and trans double bonds in fatty acids.*



The predominant fatty acids found in forages and grains are unsaturated. For example: ryegrass pasture and cereal grains (e.g. barley) contain 2 - 5% fat, of which 75 - 80% is unsaturated.

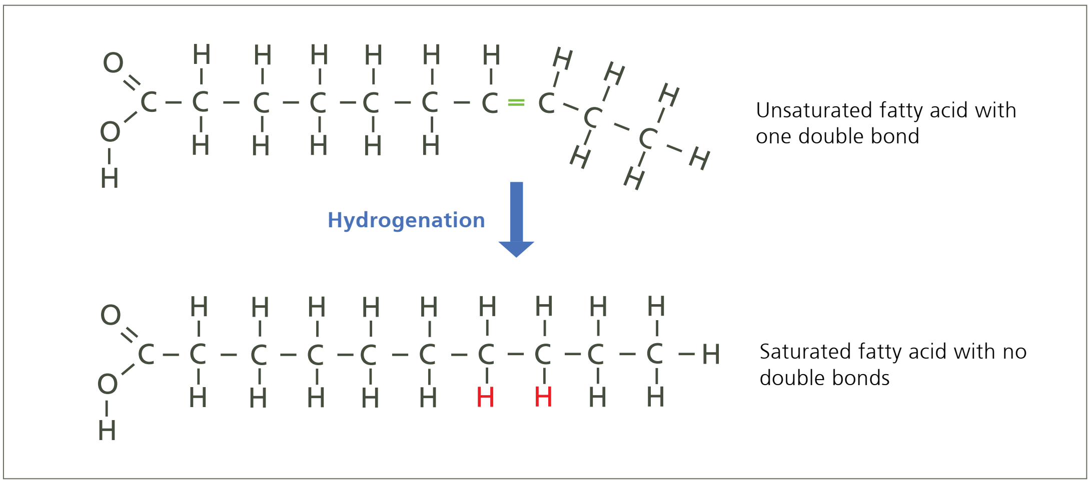
Figure 2. *Lipid metabolism in the dairy cow.*



7.2.1 Unsaturated fatty acids

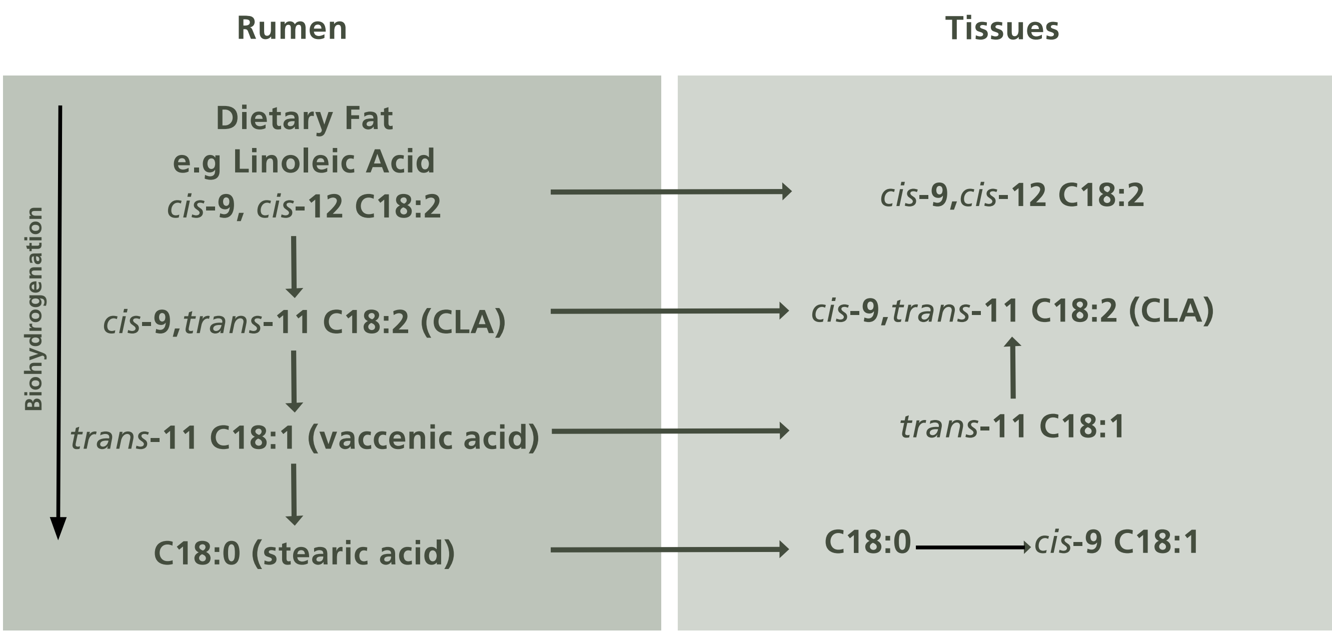
Unsaturated free fatty acids are toxic to many rumen microbes, in particular those that are involved in fibre digestion. In an attempt to detoxify these fatty acids, they undergo biohydrogenation in the rumen. Biohydrogenation is a process in which hydrogen ions are added to the carbons that contain a double bond. The additional hydrogen ions change the double bond to a single bond. When unsaturated free fatty acids are completely biohydrogenated they become saturated fatty acids (Figure 4).

***Figure 4**. Hydrogenation of an unsaturated fatty acid to form a saturated fatty acid.*



While most unsaturated fatty acids are biohydrogenated in the rumen, saturation is not always complete. This results in a variety of free fatty acid intermediates that leave the rumen (Figure 5).

***Figure 5.** An example of different free fatty acid intermediates that can leave the rumen.*



In Figure 5, one of the main unsaturated fatty acids in pasture, linoleic acid (C18:2) which has two double bonds, undergoes biohydrogenation. If completely hydrogenated (i.e. all double bonds removed) a saturated fatty acid (stearic acid; C18:0) is formed. However, if linoleic acid is only partially hydrogenated, intermediate fatty acids, such as CLA conjurgated linoleic acid (CLA) and vaccenic acid (C18:1) which have 2 or 1 double bonds, respectively, can leave the rumen and be taken up into other tissues.

If the lipid content of the diet is less than 6%, the biohydrogenation process can generally keep up with hydrolysis of triglycerides, and detoxify the majority of unsaturated fatty acids; however, if the cow's diet contains too much fat, hydrolysis still occurs and releases free fatty acids, but the biohydrogenation process is overwhelmed. Many of the fatty acids will not be completely saturated and rumen function is reduced. This results in less fibre digestion, lower DMI, and ultimately, poorer cow performance.

7.2.2 Saturated fatty acids

Saturated fatty acids are generally found in animal fats and in some by-product feeds, such as palm kernel expeller. Because these fatty acids are already saturated, when they are hydrolysed and released into the rumen, they are not toxic to the rumen microbes and pass through the rumen unaltered.

7.2.3 Protected fatty acids

Dietary unsaturated fatty acids can be protected from biohydrogenation. This is usually done by industrial treatment of the feed, forming calcium salts of the fatty acids. This makes the free fatty acids insoluble and reduces the interaction with rumen microbes. The protection is not complete, but slows down the rate of hydrolysis and subsequent biohydrogenation of the unsaturated free fatty acids in the rumen.

The use of 'protected' fatty acids allows higher levels of fat to be added to the diet to increase energy content, without the negative impact on rumen digestion and feed intake. It also allows specific unsaturated dietary fatty acids that have positive biological effects to pass through the rumen unaltered and be taken up into tissues.

For more details see TechNotes 3: Feed components, and 5: Carbohydrate metabolism, and online eLearning activity: The role of lipids; dairynz.co.nz/feedright-module-7.

7.3 End products of lipid digestion

In the rumen a small proportion (10-15%) of fatty acids are incorporated into microbial phospholipids; however, the majority of dietary lipid leaves the rumen as free saturated fatty acids (Figure 2). These fatty acids move from the rumen into the small intestine where they are reconnected with a glycerol backbone (formed from blood glucose) to produce a triglyceride (Figure 1). These triglycerides are then packaged into little parcels known as triglyceride rich lipoproteins (TGLP).

The TGLPs enter the lymph vessels and then the general circulation. Unlike carbohydrates and proteins, dietary lipids are absorbed from the digestive system and enter the blood stream directly, with no prior processing in the liver. Once in the blood stream, they are directed to different parts of the body depending on the status of the cow.

7.3.1 Milk fat synthesis

In a lactating cow, TGLPs are directed to the mammary gland, where they are broken down into free fatty acids and a glycerol backbone. The fatty acids are taken up into the mammary gland, repackaged into triglycerides and secreted in the milk.

About 40% of the fat in milk comes from these TGLPs (circulating free fatty acids), while the remaining 60% of milk fat is synthesised within the mammary cells (*de novo* synthesis) from acetate and butyrate (created during carbohydrate metabolism).

Milk fatty acids produced within the mammary gland from acetate and butyrate are shorter chained fatty acids and contain no more than 16 carbons. In contrast, fatty acids taken up from the diet are dependent on the fatty acid composition of the plant/product eaten and the rumen biohydrogenation process. These are generally the longer chained fatty acids (16 carbons or more); however, some dietary products (e.g. palm kernel expeller) contain some shorter chained fatty acids with 12 or 14 carbons.

Composition of the diet can also alter the proportion of milk fatty acids that are synthesised in the mammary gland compared with those taken up from the diet. If cows are fed diets containing high levels of sugar/starch, this can alter the rumen biohydrogenation process and a specific fatty acid intermediate (*trans*-10, *cis*-12 CLA) is produced that reduces milk fat synthesis in the mammary gland. This results in reduced milk fat secretion and in particular, reduced secretion of the shorter chained fatty acids.

7.3.2 Deposition of fat to adipose tissue

If a cow is in a positive energy balance and is gaining body condition, some of the TGLPs (from dietary lipids) are partitioned towards adipose tissue. As in the mammary gland, the TGLPs are broken apart and the resulting glycerol and free fatty acids are transported into the adipose tissue. Once in the adipose tissue, they are reconnected to a glycerol backbone to form a triglyceride and stored as body fat. This process is known as lipogenesis.

For more details see TechNote 5: Carbohydrate metabolism, and online eLearning activity: The role of lipids; dairynz.co.nz/feedright-module-7.

7.4 Mobilisation of fat from adipose tissue

The diet is not the only source of fatty acids used by the cow for milk production or energy. If a cow is in a state of negative energy balance, due to a feed deficit or during early lactation, she cannot obtain enough energy from the diet to meet her demands for maintenance, milk production, activity etc., and therefore mobilises fat from adipose tissue to provide additional energy.

The triglycerides stored in the adipose tissue are broken down to form glycerol and free fatty acids, a process known as lipolysis. The glycerol and free fatty acids are released into the blood stream and then taken up by the liver. The free fatty acids in the blood stream are termed non-esterified fatty acids or NEFAs and blood NEFA content is often used as an indicator of the energy status of the cow. Generally, the higher the blood NEFA content, the more negative the energy status of the cow.

In the liver, the glycerol contributes to glucose production, while the free fatty acids undergo a process known as ß-oxidation to provide energy for the cow. If the cow is in a severe state of negative energy balance these free fatty acids can be converted to ketone bodies, such as ß-hydroxybutyrate, which are used as an alternative energy source by a variety of tissues. Excess production of ketone bodies is indicative of the metabolic disorder ketosis.

If the cow is in a severe negative energy balance and mobilising large amounts of body tissue, many of the fatty acids are transported to the liver. These cannot all be converted to energy via ß-oxidation, or to ketone bodies, and the surplus fatty acids are stored as triglycerides within the liver cells. The dairy cow is not efficient at exporting excess fat out of the liver. The accumulated triglycerides can reduce liver function and glucose production, and predispose the cow to metabolic diseases such as fatty liver and milk fever.

For more details see TechNotes 14: Monitor and mitigate ketosis, and 15: Monitor and mitigate fatty liver.

7.5 Further reading

Bauman, D. E., and C. L. Davis. 1974. Biosynthesis of milk fat. Pages 31 - 75 in Lactation: A comprehensive Treatise, Vol 2. B. L. Larson and V. R. Smith, ed. New York, United States of America: Academic Press.

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The Ruminant Animal: Digestive Physiology and Nutrition. D.C. Church, ed. Illinois, United States of America: Waveland Press, Inc.