LIPIDS

ALİ ÇALIK, PHD

LIPIDS

- Lipids are defined as hydrocarbon compounds that are soluble in organic solvents (e.g., chloroform and ethanol) and, except for some small molecules, are generally insoluble in water
- Found in plant and animal tissues.
- Complete oxidation of these compounds provides an average of **9.45 Kcal/g,** or **2.25** times more energy than the average provided by carbohydrates and proteins.

LIPIDS

In nature, examples of lipids are fatty acids, triacylglycerols (TAGs), glycerolipids, glycerophospholipids, sphingolipids, cholesterol, cortisol, testosterone, progesterone, and vitamin A (Mead et al. 1986).

Lipids account for 1%–50% of the body weights of animals, depending on their species, age, nutritional state, and disease

In proximate feedstuff analysis, lipids are determined together as the ***ether extract*** and are called ***crude fats***

LIPIDS

Lipids found in forage plants are mainly represented by **galactolipids** and **phospholipids**, whereas fat found in animals and cereal grains are basically **triglycerides**

Most FA from forage plants and vegetables are unsaturated (generally more than 70 %) and mainly represented by **linoleic** (cis-9, cis-12, 18:2) and **linolenic** (cis-9, cis-12, cis-15, 18:3) acids.

LIPIDS

- Lipids have **structural, storage, regulatory, protective, secretory, and transport** functions in animals.
  - For example, excess energy is stored as fats in all animals
  - Insulation of the body
  - Digestion and absorption of lipid-soluble vitamins
  - Regulate nutrient metabolism
  - Deficiencies of nutritionally essential fatty acids result in skin lesions, growth restriction, and diseases

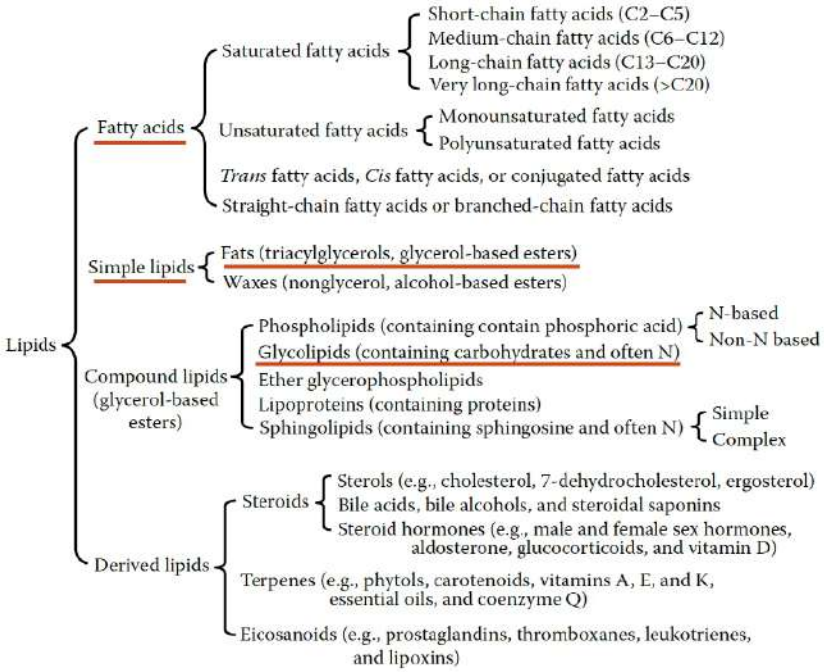
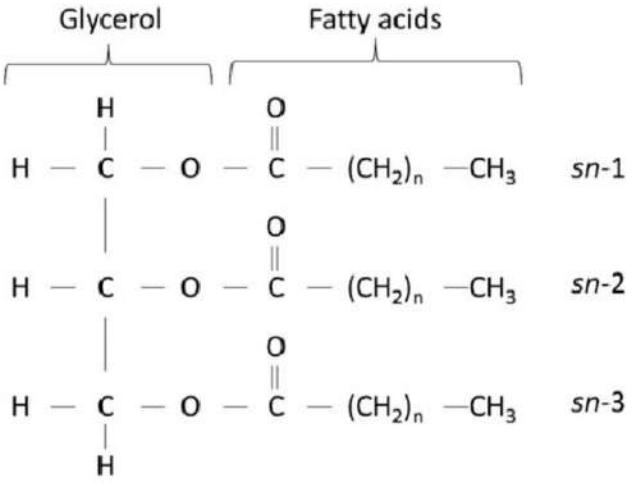


FIGURE 3.1 Classification of lipids in animal nutrition. Lipids are composed of fatty acids (precursor lipids), as well as simple, compound, and derived lipids. Serine, choline, and ethanolamine are often components of phospholipids and sphingolipids. N, nitrogen.

Triacylglycerol (TAG)/Fat structure



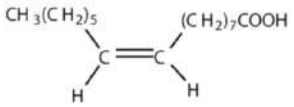
Fats are make up the largest fraction (**~98%**) of lipids in most concentrate feedstuffs (e.g. corn, soybean) for animals

FATTY ACIDS

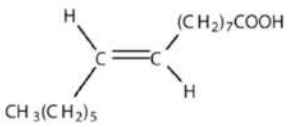
Protein	Amino acids
Carbohydrates	Simple Sugars
Lipids	Fatty Acids

Definition of Fatty Acids

Fatty acids are hydrocarbon chains with 2 or more carbon atoms and a carboxyl group



cis fatty acid



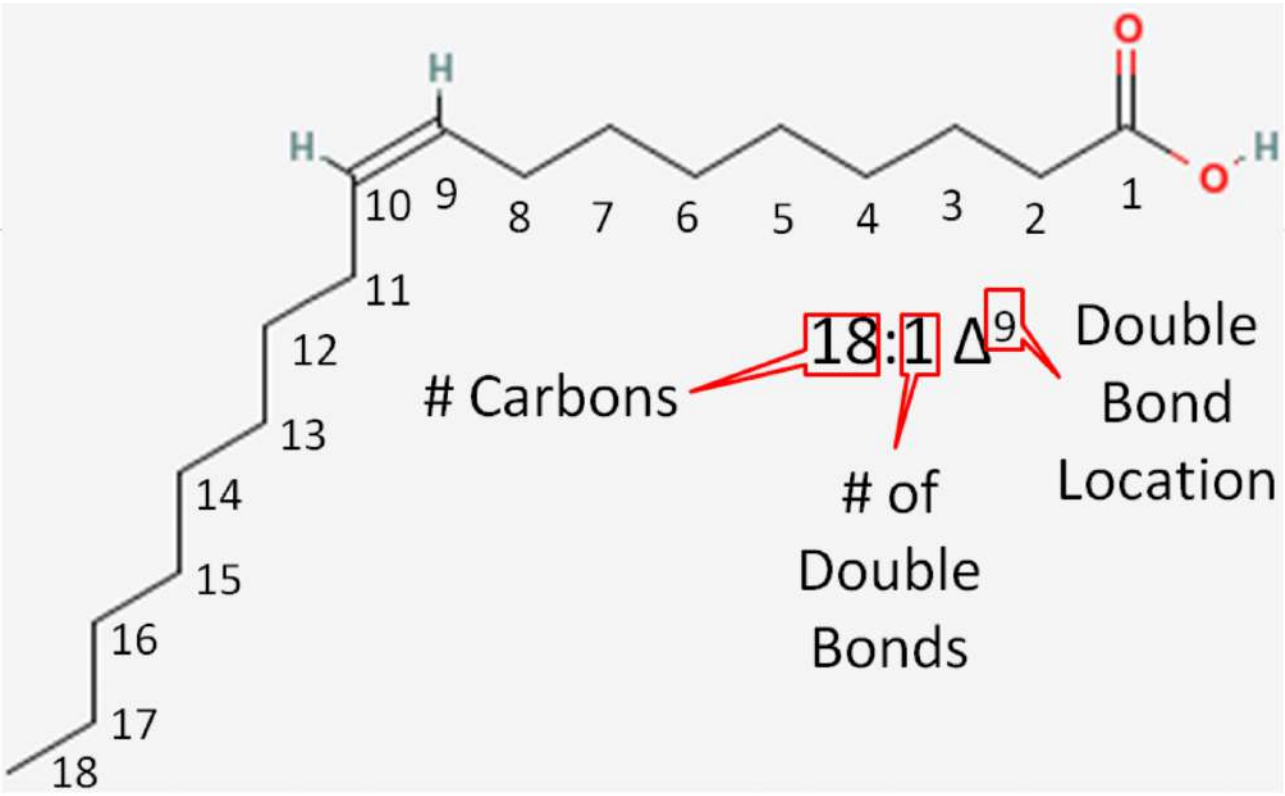
trans fatty acid

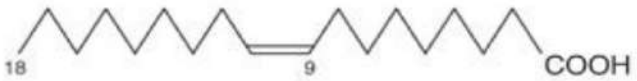
FATTY ACIDS

- **According to the length of the carbon chain, fatty acids are categorized as;**

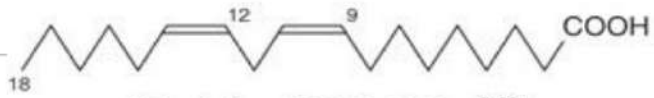
  - Short-chain fatty acids (C2–C5)
  - Medium-chain fatty acids (C6–C12)
  - Long-chain fatty acids (C13–C20)
  - Very long-chain fatty acids (>C20)

- **On the basis of the number of double bonds in the carbon chain, fatty acids are classified as:**
  - (1) saturated fatty acids without a double bond;
  - (2) monounsaturated fatty acids with one double bond;
  - (3) PUFAs with two or more double bonds

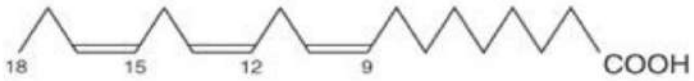

H
H
O
O
H
10
9
8
7
6
5
4
3
2
1
11
12
13
14
15
16
17
18
18:1 Δ9
Carbons
of Double Bonds
Double Bond Location



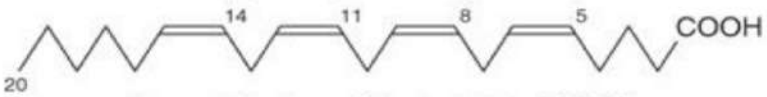
Oleic acid (ω9, 18:1, Δ^{9})



***Linoleic acid (ω6, 18:2, $\Delta^{9,12}$)**



***α-Linolenic acid (ω3, 18:3, $\Delta^{9,12,15}$)**



***Arachidonic acid (ω6, 20:4, $\Delta^{5,8,11,14}$)**

Eicosapentaenoic acid (ω3, 20:5, $\Delta^{5,8,11,14,17}$)

Examples of saturated fatty acids

Common name	Chemical structure	*C*:*D*[9]
Caprylic acid	$CH_3(CH_2)_6COOH$	8:0
Capric acid	$CH_3(CH_2)_8COOH$	10:0
Lauric acid	$CH_3(CH_2)_{10}COOH$	12:0
Myristic acid	$CH_3(CH_2)_{12}COOH$	14:0
Palmitic acid	$CH_3(CH_2)_{14}COOH$	16:0
Stearic acid	$CH_3(CH_2)_{16}COOH$	18:0
Arachidic acid	$CH_3(CH_2)_{18}COOH$	20:0
Behenic acid	$CH_3(CH_2)_{20}COOH$	22:0
Lignoceric acid	$CH_3(CH_2)_{22}COOH$	24:0
Cerotic acid	$CH_3(CH_2)_{24}COOH$	26:0

Common monounsaturated fatty acids

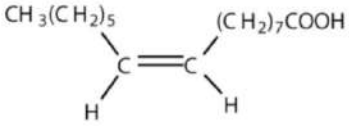
Common name	Chemical structure	*C:D*[9]
Myristoleic acid	$CH_3(CH_2)_3\mathbf{CH{=}CH}(CH_2)_7COOH$	14:1
Palmitoleic acid	$CH_3(CH_2)_5\mathbf{CH{=}CH}(CH_2)_7COOH$	16:1
Oleic acid	$CH_3(CH_2)_7\mathbf{CH{=}CH}(CH_2)_7COOH$	18:1
Erucic acid	$CH_3(CH_2)_7\mathbf{CH{=}CH}(CH_2)_{11}COOH$	22:1

Common polyunsaturated fatty acids

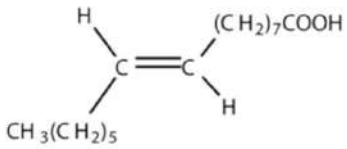
Linoleic acid	$CH_3(CH_2)_4\mathbf{CH=CH}CH_2\mathbf{CH=CH}(CH_2)_7COOH$	18:2
α-Linolenic acid	$CH_3CH_2\mathbf{CH=CH}CH_2\mathbf{CH=CH}CH_2\mathbf{CH=CH}(CH_2)_7COOH$	18:3
Arachidonic acid	$CH_3(CH_2)_4\mathbf{CH=CH}CH_2\mathbf{CH=CH}CH_2\mathbf{CH=CH}CH_2\mathbf{CH=CH}(CH_2)_3COOH$ NIST	20:4
Eicosapentaenoic acid	$CH_3CH_2\mathbf{CH=CH}CH_2\mathbf{CH=CH}CH_2\mathbf{CH=CH}CH_2\mathbf{CH=CH}CH_2\mathbf{CH=CH}(CH_2)_3C$ OOH	20:5
Docosahexaenoic acid	$CH_3CH_2\mathbf{CH=CH}CH_2\mathbf{CH=CH}CH_2\mathbf{CH=CH}CH_2\mathbf{CH=CH}CH_2\mathbf{CH=CH}CH_2\mathbf{CH=CH}(CH_2)_2COOH$	22:6

Most fatty acids contain *cis* double bonds, because fatty acid desaturases in plants and animals cannot produce *trans* double bonds

The solubility and acidity (ionization of the carboxyl group) of fatty acids in water decrease markedly with the length of the carbon chain



cis fatty acid



trans fatty acid

Short-Chain Fatty Acids (C2-C5)

- SCFAs are volatile organic substances, including **acetic, propionic, butyric, isobutyric, valeric, and isovaleric acids**.
- They are highly soluble in water and are present in the rumen and blood of ruminants as **products of carbohydrate and amino acid** fermentation.
- In ruminants, SCFAs produced in the rumen meet **50–70%** of the energy requirement for the animal

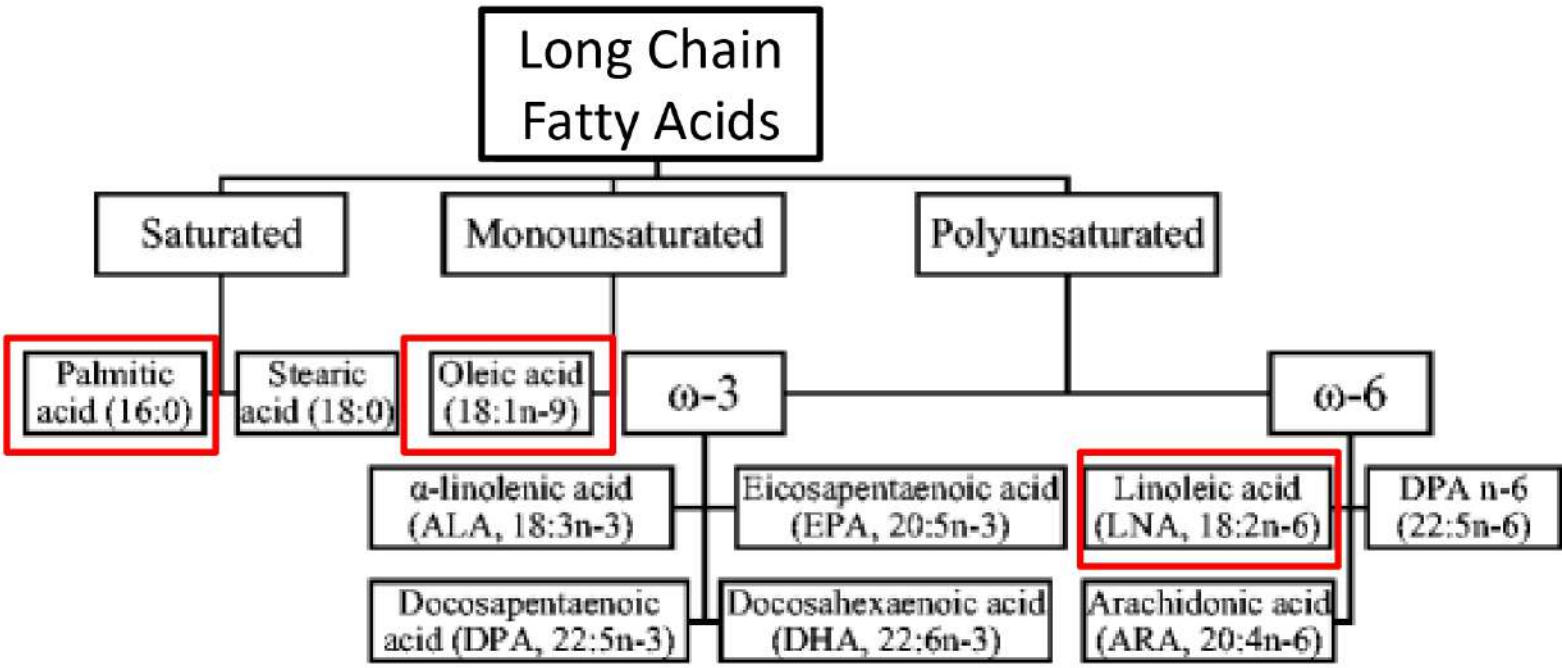
MCFA and LCFA

Medium-Chain Fatty Acids

- Contains 6–12 carbons.
- Coconut oil (58.7%) and palm kernel oil (56.4%)

Long-Chain Fatty Acids

- Contains 13-20 carbons
- LCFAs are generally insoluble in water. They include saturated fatty acids (e.g., palmitic, stearic, and arachidic acids) and unsaturated fatty acids (e.g., palmitoleic, oleic, linoleic, α-linolenic, γ-linolenic, and arachidonic acids).

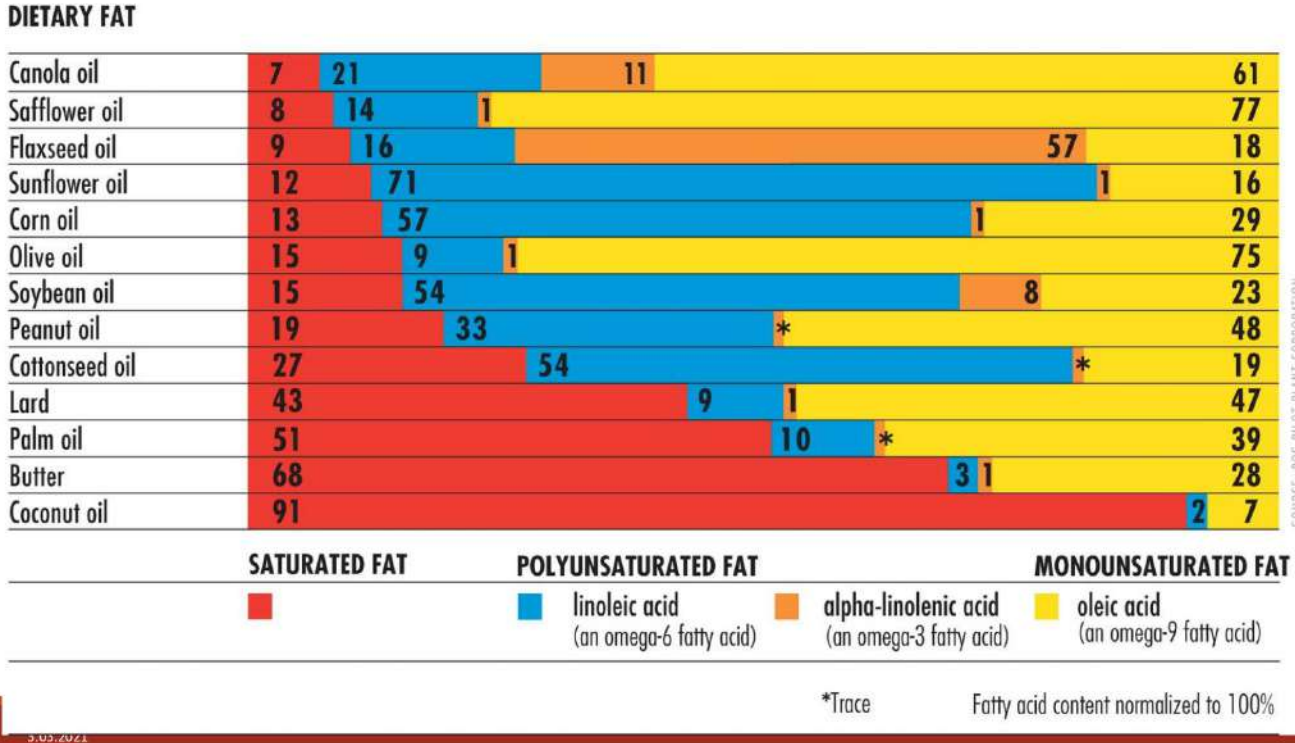


In plants and animals, the most common saturated LCFA is palmitic acid, the most common monounsaturated LCFA is oleic acid, and the most common polyunsaturated LCFA is linoleic acid

Linoleic acid (C18:2, ω6) and α-linolenic acid (C18:3, ω3) cannot be synthesized by animals and are nutritionally essential for them.

High amounts of both ω6 and ω3 PUFAs are available from certain plant products, such as canola oil and soybean oil

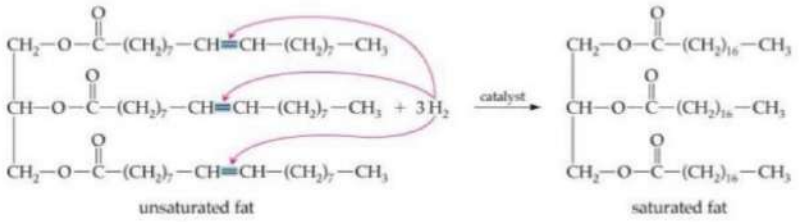
Comparison of Dietary Fats



Hydrogenation of Unsaturated Fatty Acids

An unsaturated fatty acid, which is liquid at 37°C, can be converted into a saturated fatty acid by the hydrogenation of its double bonds

This process is used to convert oil into solid margarine.



Hydrogenation of Unsaturated Fatty Acids

Rumen microorganisms enzymatically hydrogenate unsaturated fatty acids, which is called ***biohydrogenation***. This explains why the percentage of saturated fatty acids among total lipids in white adipose tissue and skeletal muscle is higher in ruminants than in nonruminants and why the body fat is "harder" in ruminants than in nonruminants.

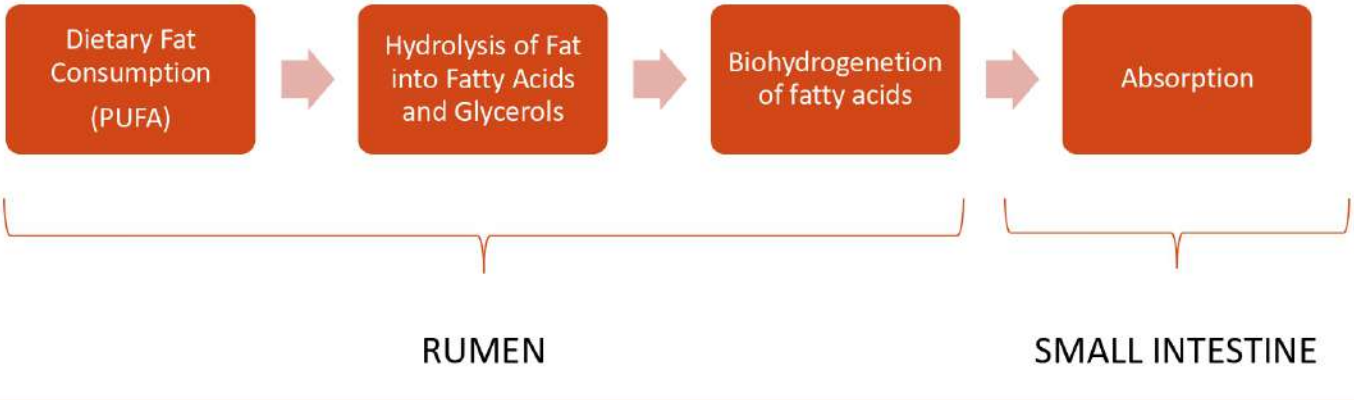
DIGESTION AND ABSORPTION OF LIPIDS IN RUMINANTS

- There are marked differences in lipid digestion and absorption between ruminant and nonruminant animals
- Ruminant diets normally have low lipid content due to the small lipid amount (2–5 %) of the plant sources used to formulate these diets (e.g. roughages)
- Excess fat has toxic effect on ruminal microorganism, mainly on GRAM positive bacteria that digest cellulose.

DIGESTION AND ABSORPTION OF LIPIDS IN RUMINANTS

- Specifically, ruminants exhibit
- (1) significant **hydrolysis** of fats in the rumen;
- (2) a relatively low ability of ruminal microbes to degrade dietary lipids in comparison with carbohydrates;
- (3) a high capacity for the ruminal **biohydrogenation** of unsaturated fatty acids;
- (4) a relatively low pancreatic lipase activity in the small intestine

DIGESTION AND ABSORPTION OF LIPIDS IN RUMINANTS



BIOHYDROGENATION

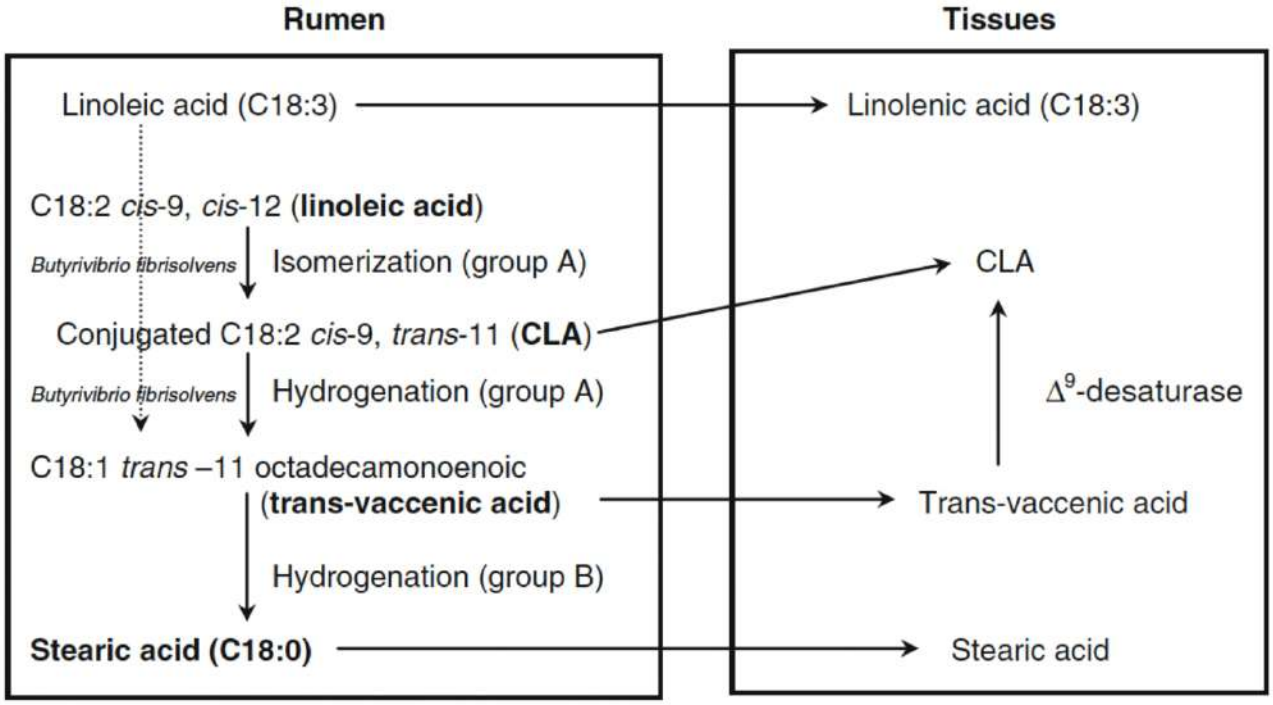
- Most of the cattle diets predominantly contains **PUFA** as part of plant triglycerides and glycolipids.
- Bacteria in the rumen split off the fatty acids (and sugars) from the glycerol backbone called as **lipolysis or Hydrolysis.**
- Then the released fatty acids undergo hydrogenation called as **Biohydrogenation.**

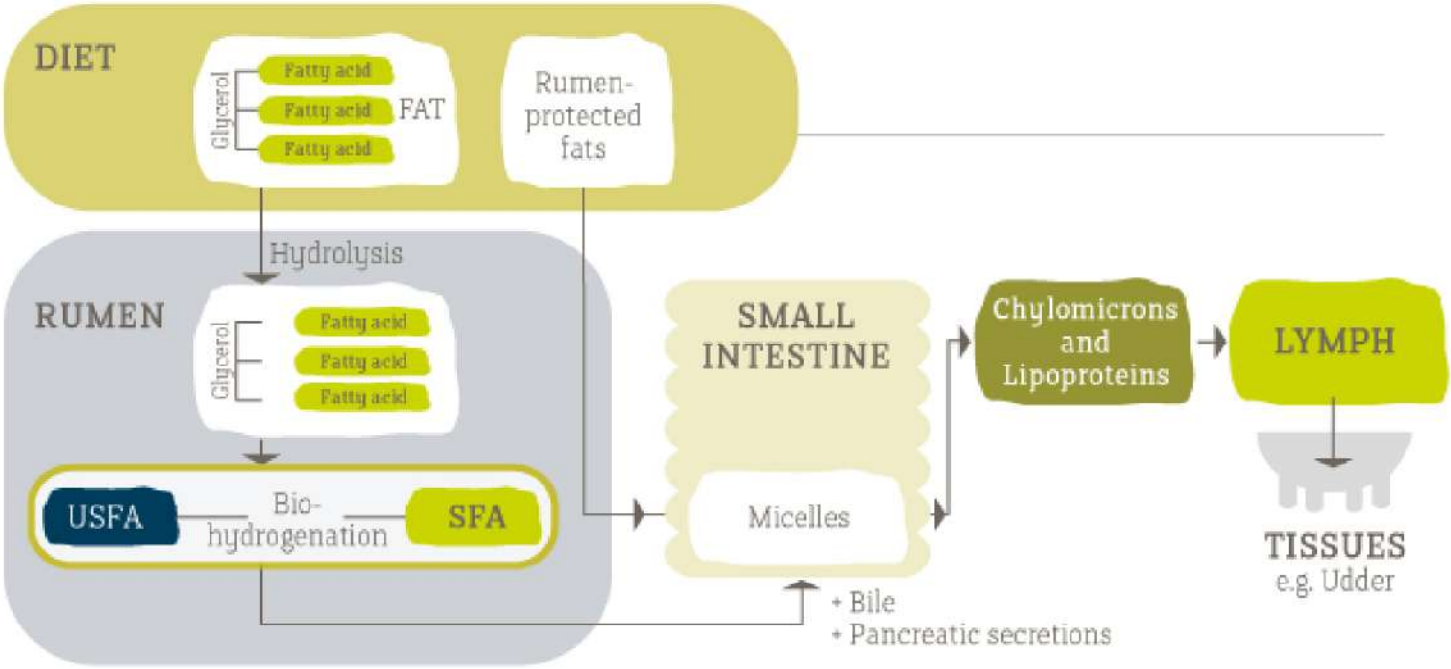
BIOHYDROGENATION

- The fatty acids released in the rumen are not absorbed from the rumen, but rather will pass to the **abomasum** and then **the small intestine, which is the primary site for absorption of the fatty acids.**
- However, the profile of fatty acids that reaches the intestine will be very different from what the animal has consumed.
- This is because of the extensive **Biohydrogenation** that occurs in the **rumen** as a result of bacterial activity.

BIOHYDROGENATION

- The initial step in biohydrogenation is an **Isomerization reaction** that converts the *cis*-12 double bond in unsaturated fatty acids to a *trans*-11 isomer.
- During the biohydrogenation process due to isomerization , intermediate compounds with **trans-double bonds** are produced e.g. *conjugated linoleic acid* (CLA).
- Some of these trans-intermediates escape from the rumen and are incorporated into body fat and milk fat of ruminants.


Rumen
Tissues
Linoleic acid (C18:3)
Linolenic acid (C18:3)
C18:2 cis-9, cis-12 (linoleic acid)
Butyrivibrio fibrisolvens
Isomerization (group A)
CLA
Conjugated C18:2 cis-9, trans-11 (CLA)
Butyrivibrio fibrisolvens
Hydrogenation (group A)
Δ9-desaturase
C18:1 trans –11 octadecamonoenoic
(trans-vaccenic acid)
Trans-vaccenic acid
Hydrogenation (group B)
Stearic acid (C18:0)
Stearic acid


DIET
Glycerol
Fatty acid
Fatty acid
Fatty acid
FAT
Rumen-protected fats
Hydrolysis
RUMEN
Glycerol
Fatty acid
Fatty acid
Fatty acid
USFA
Bio-hydrogenation
SFA
SMALL INTESTINE
Micelles
Chylomicrons and Lipoproteins
LYMPH
TISSUES
e.g. Udder
+ Bile
+ Pancreatic secretions

DIGESTION AND ABSORPTION OF LIPIDS IN NONRUMINANTS

- Nonruminants require certain degree of fats in their diet.
- Swine diets usually contain **5%** lipids, but pigs can digest at least **20%** lipids in diets
- Lipid content in chicken diets is usually between **5-8%** (age related)
- Equine diets usually contain **4%–5%** lipids, but horses can digest up to **20%** lipids
- Fish diets usually contain **5%–15%** lipids, but some fish (e.g., salmon) can digest **30%** lipids

DIGESTION AND ABSORPTION OF LIPIDS IN NONRUMINANTS

- The digestibility of fats in grain cereals or added lipids is high in postweaning nonruminant mammals (e.g., often 90%–95%)
- Chickens (e.g., 82% at Day 2, 89% at Day 21, and 90%–95% after 3 weeks of age)
- The rates of digestion and absorption of dietary lipids are enhanced by the presence of unsaturated fatty acids in diets.
  - Soy oil or Sunflower oil > Tallow or Lard
- For example, the digestibility of saturated fats is poor in young chicks (e.g., 40% and 79% for tallow at Days 1 and 7 of age), due to the limited production of bile salts
- The absorption of lipids **occurs primarily in the jejunum**, and to a lesser extent, in the duodenum and ileum

DIGESTION AND ABSORPTION OF LIPIDS IN NONRUMINANTS

Events of lipid digestion and absorption in all nonruminants include:

(1) Emulsification of lipid by bile salts

(2) Hydrolysis of lipids by lipases (from the pancreas and enterocytes);

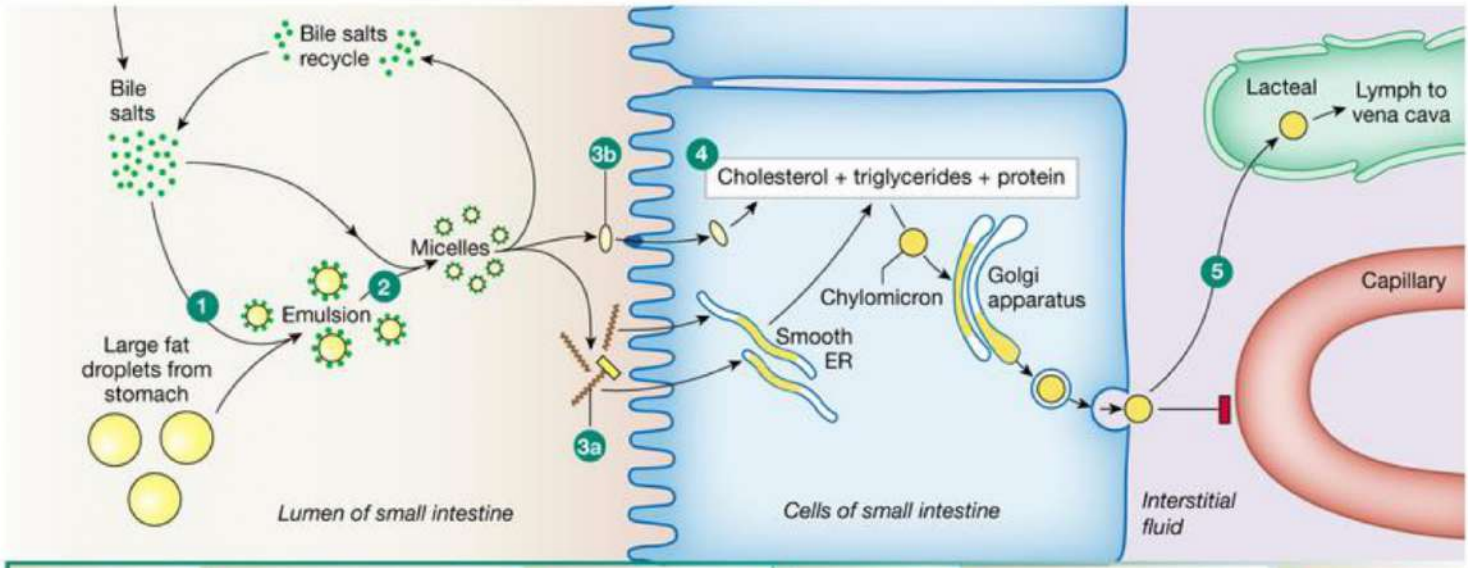
(3) The micellar solubilization of lipid digestion products in the small intestine;

(4) The uptake of the solubilized products by enterocytes through the apical membrane;

(5) The resynthesis of TAGs, as well as the assembling of chylomicrons in enterocytes;

(6) The secretion of the lipoproteins into the lymphatic circulation (most of nonruminants) or the portal vein (poultry).

(d) Fat digestion and absorption



1 Bile salts from liver coat fat droplets.

2 Pancreatic lipase and colipase break down fats into monoglycerides and fatty acids stored in micelles.

3a Monoglycerides and fatty acids move out of micelles and enter cells by diffusion.

3b Cholesterol is transported into cells.

4 Absorbed fats combine with cholesterol and proteins in the intestinal cells to form chylomicrons.

5 Chylomicrons are removed by the lymphatic system.

- Bile salts, which are the conjugates of bile acids with taurine and/or glycine, are synthesized from cholesterol in the liver and secreted into the duodenum.
- *Taurine is an essential amino acid for cats*
- *Cats can only conjugate bile acids with taurine to make bile salts.*
- *Taurine continues be lost in the gastrointestinal tract through this conjugation with bile*

THANK YOU