

## Fat Metabolism

### (Breakdown of Fat/ Oxidation of Fat)

Fat degradation in plants is a crucial metabolic process, mainly occurring during seed germination to fuel growth, where stored **triacylglycerols** (TAGs) are broken down by lipases into fatty acids and glycerol. These components are converted into sucrose via  **$\beta$ -oxidation** and the **glyoxylate cycle** in glyoxysomes, providing energy before photosynthesis begins.

The process occurs in specialized peroxisomes known as **glyoxysomes** within germinating seeds. Lipases hydrolyze stored fats, releasing fatty acids and glycerol to power early seedling development. Fatty acids are broken down in a cycle that removes two-carbon units (acetyl-CoA), which are then used in the glyoxylate cycle to produce carbohydrates (gluconeogenesis).

Beyond germination, lipid degradation is crucial for membrane turnover and in response to environmental stresses, such as wounding or low temperatures, which trigger lipid metabolism. Lipid droplets (LDs) in pollen are mobilized during pollination and tube growth.

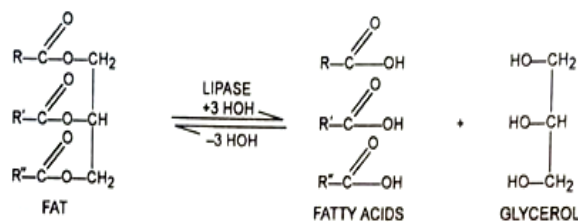
**Glycerol Pathway:** Converted into PGAL (phosphoglyceraldehyde) or DHAP, which then enters the **glycolysis** pathway.

In plants, glycerol metabolism centers on glycerol-3-phosphate (G3P), which is crucial for lipid synthesis, stress responses, and energy production. G3P is synthesized from dihydroxyacetone phosphate (DHAP) via G3P dehydrogenase or formed from free glycerol by glycerol kinase (GK). This pathway is critical for developing oilseed crops and inducing systemic acquired resistance

Glycerol reacts with ATP and forms  $\alpha$ -Glycerophosphate

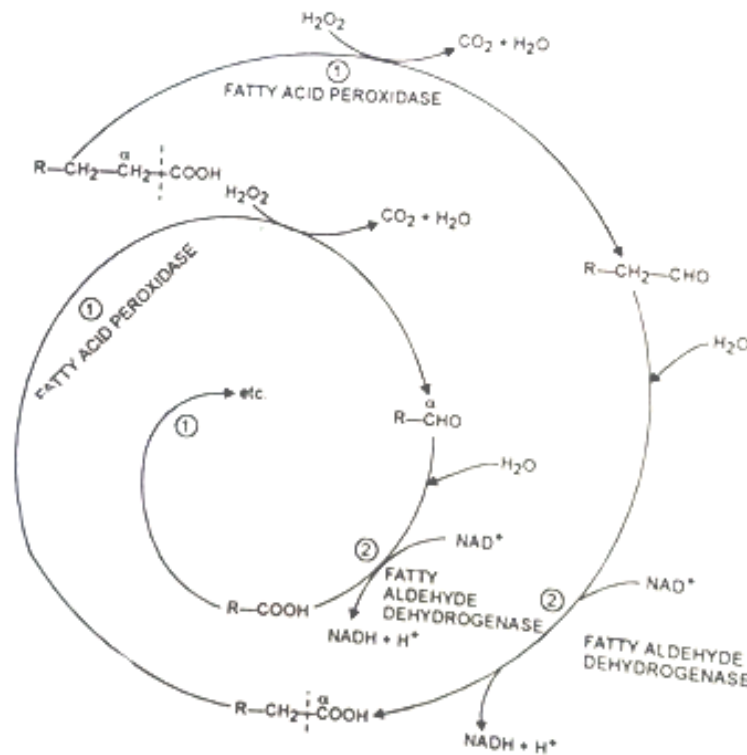


The  $\alpha$ -glycerophosphate is oxidized by  $\text{NAD}^+$  in presence of enzyme *dehydrogenase* to form dihydroxy acetone phosphate, which enters into glycolysis.



## Breakdown of Fatty Acids

**Fatty Acid Pathway:** Fatty acids undergo oxidation and are degraded into Acetyl-CoA, which directly enters the **Krebs cycle** (Citric Acid Cycle). The fatty acids liberated from the degradation of fats can be subjected to either  $\beta$  oxidation or  $\alpha$  oxidation. The name of these two oxidations signify that either  $\beta$ -carbon or  $\alpha$ -carbon atom is attached and oxidized first.



### $\alpha$ -OXIDATION

The  $\alpha$ -oxidation of fatty acids exists in some higher plants but does not occur in animals. The substrates for this are long chain fatty acids with 13 – 18 C atoms. Shorter fatty acids with less than 13 C atoms are not degraded by this process. It can convert fatty acids with even number of C-atoms into those with odd number. The fatty acids with odd number of C-atom could be degraded by  $\beta$ -oxidation. The  $\alpha$ -oxidation involves the following steps, which are summarised in Fig.

(1) The fatty acids are oxidatively decarboxylated by an enzyme *fatty acid peroxidase*. The oxidizing agent is  $H_2O_2$  and the fatty acid is converted to an aldehyde having one less carbon

(2) The aldehyde is then directly oxidized with  $NAD^+$  by an enzyme *fatty aldehyde dehydrogenase*. The coenzyme  $NAD^+$  is reduced to  $NADH + H^+$  and a fatty acid with one less carbon atom is produced, which can enter the cycle again (Fig.)

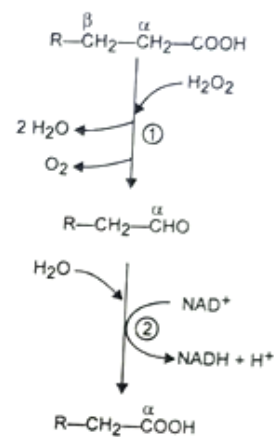


Fig. Two reactions of  $\alpha$ -oxidation of fatty acid.

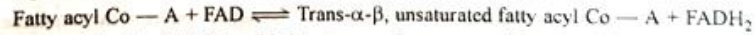
## β-OXIDATION

The β-oxidation was first studied by F. Knoop (1904). It is important process of fatty acid degradation in plants. Knoop (1904) suggested that 2 carbons were removed at a time, following the oxidation by the β-oxidation in fatty acids. The process involves successive release of 2-C fragments in the form of acetyl Co-A. The β-oxidation pathway for a saturated fatty acid is outlined in Fig. 20.7. The various steps are given below :

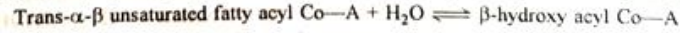
(1) The fatty acids are activated, reacting with coenzyme A and ATP to form its Co-A derivative. The reaction is catalysed by enzyme *thiokinase* in outer mitochondrial membrane.



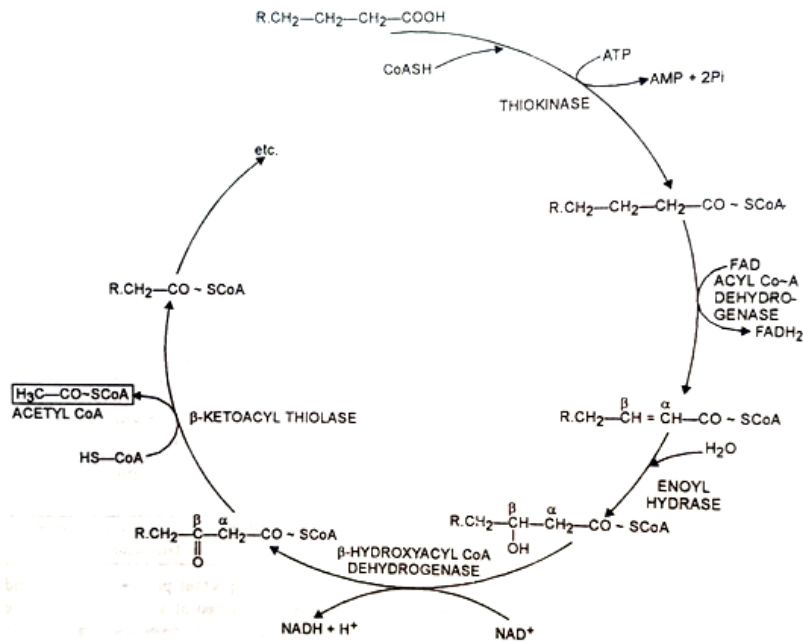
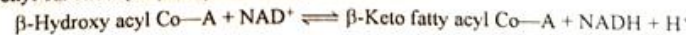
(2) The second step involves removal of 2 H atoms between α and β carbon atoms. Fatty acyl Co - A is converted to trans-α-β, unsaturated fatty acyl Co - A in presence of enzyme *acyl-Co-A dehydrogenase*.



(3) A molecule of H<sub>2</sub>O is added to trans-α-β-unsaturated fatty acyl Co - A across the double bond to form β-hydroxyacyl Co - A in presence of enzyme *enoyl - CoA hydrolase*



(4) The β-hydroxy acyl Co - A is dehydrogenated to form β-keto fatty acyl Co - A. NAD<sup>+</sup> is reduced in this step. The reaction is catalysed by enzyme *dehydrogenase*. The β-C atom now bears a carbonyl function (*i.e.*, the β-oxidation).

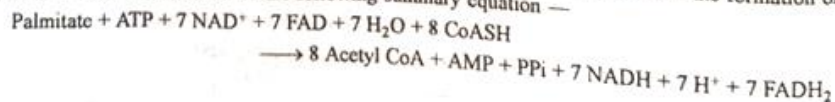


(5) The β-keto fatty acyl Co - A finally undergoes "thiolastic" cleavage in presence of enzyme *β-keto acyl thiolase* to release a molecule of acetyl Co - A (2 C-unit) and a molecule of fatty acyl-Co - A.



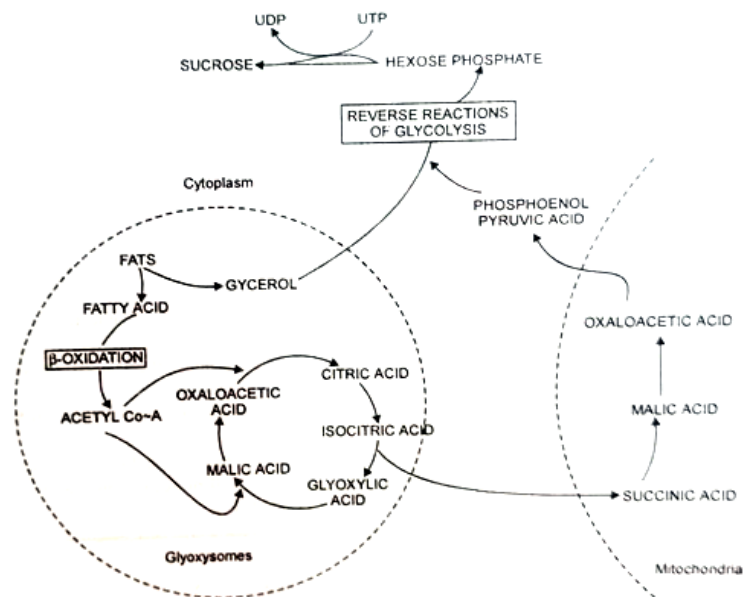
The fatty acyl Co - A, produced in the reaction, is shorter by 2 C atoms. It reenters the β-oxidation spiral until 2 more carbon atoms are split out as acetyl Co - A. In this way, the long chain fatty acid released step by step 2C units and finally degraded to acetyl Co - A molecules.

For example, the complete β-oxidation of one molecule of palmitate results in the formation of 8 acetyl CoA molecules as shown in the following summary equation -



## Conversion of Fats to Sucrose (Glyoxylate Cycle)

The conversion of fats into carbohydrates is primarily called **gluconeogenesis**. Gluconeogenesis is the metabolic pathway that produces glucose (a carbohydrate) from non-carbohydrate precursors, such as glycerol (derived from fats), amino acids, and lactate. This process occurs mainly in the liver and, to a lesser extent, in the kidneys. Even-chain fatty acids cannot be directly converted into glucose in humans. However, the glycerol component of triglycerides can, and in some contexts, ketone bodies derived from fats can contribute. It is highly active during periods of fasting, starvation, intense exercise, or when dietary carbohydrate intake is very low. In plants and some microorganisms, this conversion is specifically achieved through the **glyoxylate cycle**.



The glyoxylate cycle is basically a modified Krebs cycle as shown in the figure. The reactions are as follows

- (1) Fats are degraded to fatty acids and glycerol. The molecules of glycerol enter into glycolysis whereas fatty acids are converted to acetyl Co-A molecules through beta oxidation.
- (2) Acetyl Co-A combines with oxaloacetic acid to form citric acid.
- (3) Citric acid is converted to cis-aconitic acid, which is then converted to isocitric acid.
- (4) Isocitric acid is converted into succinic acid and glyoxylic acid in presence of enzyme iso-citrase.

(5) The succinic acid is converted into fumaric acid, the fumaric acid to malic acid and the malic acid to oxaloacetic acid as in the Krebs cycle.

(6) The glyoxylic acid combines with another molecule of acetyl Co—A to form malic acid in presence of enzyme *malate synthetase*.

(7) The malic acid is oxidized to form oxaloacetic acid in presence of enzyme *malic dehydrogenase* and  $\text{NAD}^+$ .

(8) Oxaloacetic acid is decarboxylated in presence of ATP to form phosphoenol pyruvic acid.

(9) Phosphoenol pyruvic acid is converted to glucose and fructose phosphates by a reversal of the reaction of glycolysis.

(10) Glucose and fructose phosphates combine to produce sucrose.

**Site of glyoxylate cycle.** The  $\beta$ -oxidation of fatty acids and the glyoxylate cycle occurs in single membrane bound, approximately spherical organelles of about  $0.8 \mu$  diameter known as **glyoxysomes**. The conversion of succinic acid to oxaloacetic acid and oxaloacetic acid to phosphoenol pyruvic acid occurs in side the mitochondria. The remaining reactions leading to sucrose biosynthesis occur in the cytoplasm.