PHOTOSYNTHESIS IN HIGHER PLANTS
THE C4 PATHWAY

ALTERNATIVE CYCLES OF CARBON FIXATION:

It includes following cycles.

(A) Hatch and Slack cycle or C_4-cycle

(B) Crassulacean acid metabolism or CAM cycle.

C_4 PLANTS:

- **Kortschak, Hartt & Burr (1965)** on providing CO_2 to leaf of sugarcane found that the first stable product was not a 3-C compound but it was a **4-C compound oxaloacetic acid (OAA).**
- **Hatch & Slack (1967)** discovered this alternative pathway of CO_2 fixation called as Hatch and Slack cycle. It is also called C_4-cycle because **first stable compound is 4C compound oxaloacetic acid (OAA)** in this cycle. It is usually found in various monocotyledons **e.g.: Maize, Sugarcane, Panicum, Atriplex and some dicotyledons e.g. Amaranthus, Chenopodium, Salsola etc.**
- In the C_4 plants the bundle sheath cells of leaf show **Kranz Anatomy** in which vascular tissues are
  surrounded by concentric rings of bundle sheath cells followed by mesophyll cells.

Features of Kranz Anatomy :

(i) Mesophyll is not differentiated into palisade and spongy tissue.
(ii) Cells of bundle sheath arranged in concentric rings around vascular bundle. (Wreath manner)
(iii) Cells of mesophyll and bundle sheath are interconnected by plasmodesmata.
(iv) Bundle sheath cells may form several layers around the vascular bundle ;
they are characterised by :
(a) Having a large number of chloroplast
(b) Thick walls impervious to gaseous exchange

(c) No intercellular spaces.

- C_4 plants are also characterised by Dimorphic chloroplast.

(a) Chloroplasts of mesophyll cells are small in size and granal (with grana)

(b) Chloroplasts of bundle sheath cells are large in size and agranal (without grana)

(A) HATCH AND SLACK CYCLE OR C_4-CYCLE:

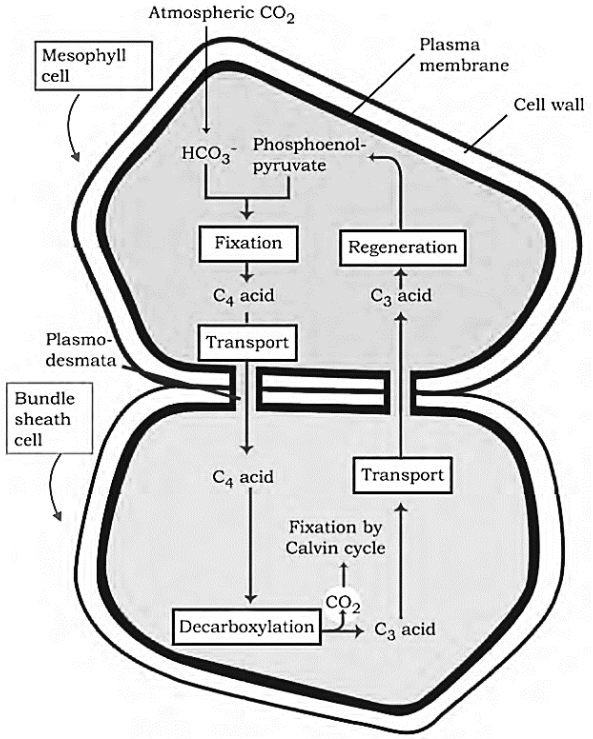

Fig. : Hatch Slack Pathway (C_4 cycle)

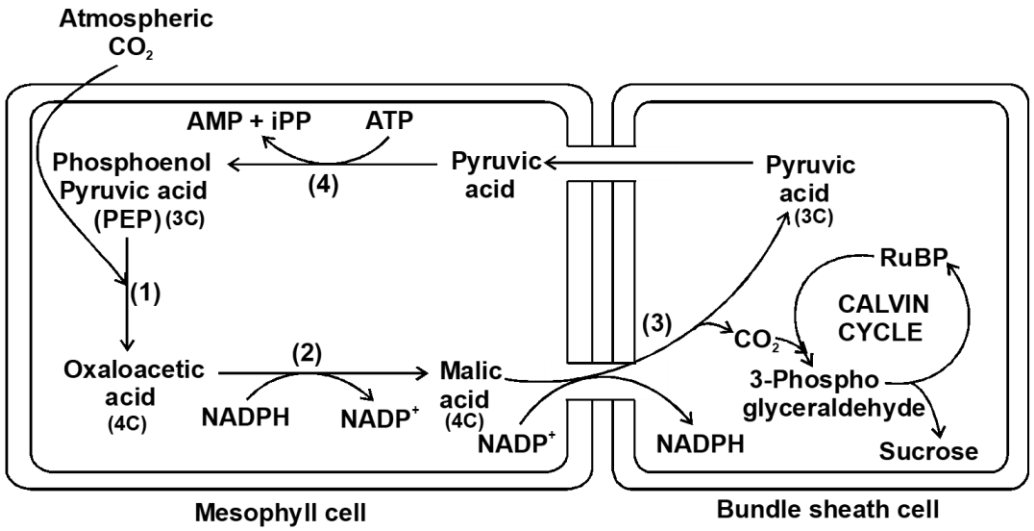

Fig:- Hatch Slack Pathway (C_4 Cycle)

(1) Phosphoenol Pyruvic acid carboxylase,
(2) Malate dehydrogenase,
(3) Malic enzyme,
(4) Phosphopyruvate dikinase

PEP carboxylase enzyme is found in mesophyll cells and RUBP carboxylase is found in bundle sheath.

C_4-cycle includes following steps.

1. **In mesophyll cells:**

- In C_4 plants CO_2 is firstly accepted in the mesophyll cells by **phosphoenol pyruvate (PEP)** and forms a 4C compound oxaloacetic acid (First stable compound).

$$PEP + CO_2 + H_2O \xrightarrow{\text{PEP carboxylase}} \text{Oxaloacetic acid}$$

(3C) (OAA) (4C)

OAA converts into 4C compound malic acid. Hydrogen is provided by $NADPH + H^+$

$$OAA + NADPH + H^+ \xrightarrow{\text{dehydrogenase}} \text{Malic acid} + NADP^+$$

(4C) (4C)

2. **In Bundle sheath:**

- The malic acid now moves to the bundle sheath cells where it is decarboxylated into pyruvic acid & CO_2. CO_2 is accepted by RUBP and refixed into hexose sugars through Calvin cycle.

$$\text{Malic acid} + NADP^{+} \xrightarrow{\text{Malic enzyme}} \text{Pyruvic acid} + NADPH + H^{+} + CO_2$$

(4C) (3C)

3. Pyruvic acid moves to mesophyll cell and is converted into phosphoenol pyruvate (PEP) with the help of ATP.

   $$\text{Pyruvic acid} + ATP + iP \xrightarrow{\text{Phosphopyruvate dikinase}} PEP + AMP + iPP$$

- In some plants Aspartic acid is transferred from leaf mesophyll to bundle sheath. It is converted into malic acid to liberate CO_2 **Ex : Panicum maximum.**

Significance of C_4 plants:

1. Hatch-Slack pathway begins with carboxylation of phosphoenol pyruvate and not of ribulose bi phosphate because PEP carboxylase has great affinities with CO_2 than RUBP carboxylase.
2. Bundle sheath in C_4 plants being close to xylem harmful effects of water scarcity are less.
3. Due to high photosynthetic efficiency in C_4 plants and their adaptability to survive in adverse conditions these plants develop as strong weeds. **e.g.: Chenopodium, Amaranthus, Salsola.**
4. C_4 plants are mostly found in hot deserts where high temperature and high light intensity are found. These conditions stimulate photorespiration in plants but photorespiration is absent in C_4 plants
5. C_4 path provides more CO_2 for RUDP, RUDP carboxylase enzyme is less sensitive to CO_2.

Crassulacean Acid Metabolism or CAM cycle:

- The process was first observed in the plants belonging to family **Crassulaceae** by **O-leary, Rouhani** and **Black**. So it is called CAM.
- CAM plants are mainly **succulent xerophytes**. **Ex: Opuntia, Bryophyllum, Pineapple, Kalanchoe, Sedum, Agave, Aloe, Crassula, Euphorbia sp.**
- Stomata open at night in these plants, these stomata are called **scotoactive stomata.**
- Meosphyll cells of leaves of CAM plants contain enzymes of C_3 and C_4 cycles but Kranz anatomy is absent. In these plants C_3-cycle occur in day while C_4 in night.

This metabolic pathway involves:

1. **Acidification:**

   In dark, stored carbohydrates are converted in to phosphoenol pyruvic acid (PEP) by the process of glycolysis due to opening of stomata. So CO_2 enters into leaf and PEP react with CO_2 in the presence of enzyme PEP carboxylase to form oxaloacetic acid (OAA). OAA is then reduced to malic acid in presence of enzyme malic dehydrogenase with the help of $NADH+H^+$. This malic acid is stored in vacuole.

2. **Deacidification:**

   In light the malic acid is decarboxylated to produce pyruvic acid and evolve CO_2, this process is called deacidification. The CO_2 produced by above process is then consumed in normal photosynthetic process to produce carbohydrates.

- Thus in CAM plants fixation of CO_2 occurs two times in day and night.