Plant Electron Transport Chain (ETC)

Electron Transport Chain In Plant Respiration

In plants, for carbon and energy metabolism, photosynthesis and respiration are the primary pathways. In respiration they use the end product of photosynthesis, i.e., carbohydrate and utilise this carbohydrate for growth and maintenance. Glycolysis, Oxidative pentose pathway and TCA cycle play essential roles in the central respiratory pathway; all these pathways work to supply carbon intermediate to various other biosynthetic processes; achieved by Co_2 coupling along with reduction of NADP to NADPH.

Cellular respiration in plants is a dynamic system. It differs from classical system in having certain additional proteins (*flavoproteins*) and some alternate oxidoreductase mitochondrial dehydrogenase network activity *(AOX)* that supplies electron to the respiratory chain.

Location:

In the process of cellular respiration, oxidation of organic compounds occurs and chemical energy in the form of ATP is generated. For the Electron transport chain (ETC), plant mitochondria is the main reaction centre. All enzymes for ETC can be found in the inner mitochondrial membrane.

How the plant ETC functions:

- In this process, four oxidoreductase complexes take part, namely,
  1. NADH dehydrogenase (Complex I)
  2. Succinate dehydrogenase (Complex II)
  3. Cytochrome C reductase (Complex III)
  4. Cytochrome C oxidase (Complex IV)

- Moreover, two mobile electron transporters also participate; lipid ubiquinone and cytochrome c. Over all, in this reaction transfer of electrons occurs from coenzymes to the formation of molecular oxygen which is ultimately reduced to water.

- Out of the four, three oxidoreductase complexes (complex I, III and IV), couple with inner mitochondrial membrane for their electron transport and proton translocation reactions. Results of these reaction include a proton gradient formation which is made used by complex V for ADP phosphorylation.

- In classical description of ETC, cellular respiration is based on linear manner from NADH to complex I, III and IV and finally to molecular oxygen. Contrastingly, in plant ETC System, which is also highly branched, electron(s) can either enter or leave at various alternative points and supra molecular structures. In here, all electrons enter through NADPH (which is generated by several dehydrogenase in matrix of mitochondria or intermembrane spaces/cytoplasm.) or through flavin nucleotides like FADH2 and FMNH2, known as flavoproteins.

- Sequence of the electron pathway can be defined as:
  A) The NADPH matrix pathway
  B) The FADH2 matrix pathway
  C) The inter mediate space NADPH pathway
  D) The intermediate space FADH2/FMDH2 pathway
    - In NADPH matrix pathway; oxidation of various carbon compounds happens by dehydrogenases in mitochondrial matrix, electrons are transferred in the form of NADH, in ETC. Complex I re-oxidises NADH.
    - In matrix Fadh2 pathway: carbon compounds are oxidised by FAD containing enzymes in mitochondrial matrix directly or indirectly and transfer the electron to the ubiquinone pool. (in direct proDH and indirect ETF/ ETFQ system includes).
    - In IMS-NAD pathway; NADPH which is formed in cytoplasm is deoxidised by external alternative dehydrogenases.
    - In IMS FADH2 pathway: oxidation of carbon containing compounds occur by FAD/FMN containing enzymes, in intermembrane space.

<u>Summary:</u>

i. Complex I, NADH dehydrogenase and other plant specific alternate dehydrogenases couple with NADPH and reduction of ubiquinone pool occurs.

ii. Further, complex II supply electron for ubiquinone pool.

iii. Then, ubiquinol electron is passed to complex III and Cytochrome C and finally electron goes to cytochrome oxidase or Complex IV.

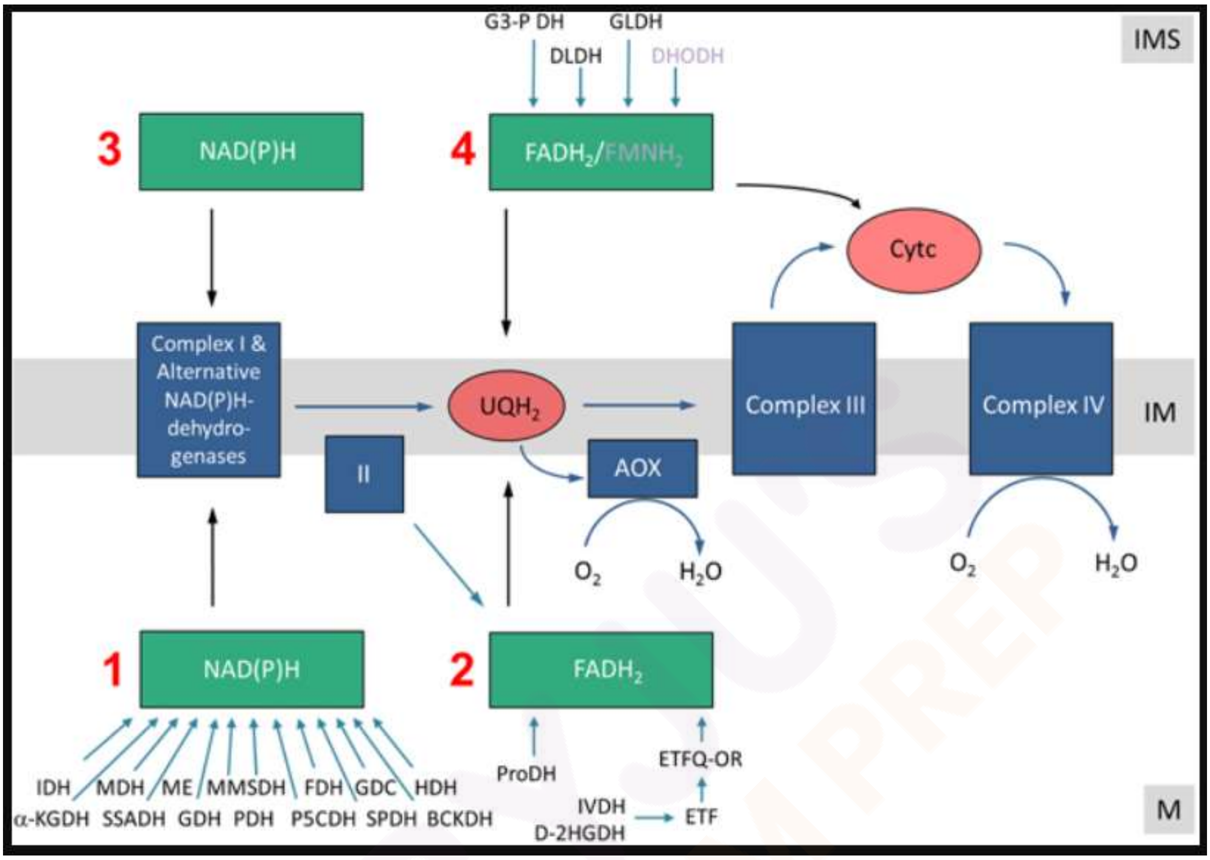
iv. After that catalysis of electron occurs and reduction of oxygen occur to H_2O.

v. Transportation of electron at complexes I, III and IV are coupled with translocation of proton from the matrix of mitochondria to inner membranous space, results in a proton motive force generation that is used by complex V (ATP synthase) for the generation of ATP from ADP and inorganic phosphate.

Alternative Oxidase: *presence & importance*

An important feature of plant ETC is the presence of two terminal oxidases, One being the *Alternate oxidase, AOX* which directly couples ubiquinol oxidation with reduction of oxygen to water.

- Alternate oxidase also play an important role, it is non energy consuming enzyme. In plants AOX provides relaxation in coupling reaction of respiratory carbon oxidation pathways, electron transport and ATP transport and maintain metabolic homeostasis.
- AOX activity also controls the mitochondrial signalling potential by regulating signalling molecules like nitric oxide and superoxide and other redox couples,
- Thus, AOX provides signalling homeostasis particularly, when the plant faces several types of stress, both abiotic and biotic alike; infection, environmental stress and chemical stress.
- It is integral in developing cyanide resistant respiration and imparts other type of stress tolerance to plants.
- AOX direct a branch in ETC; in ubiquinol electron are partitioned between Cytochrome pathway and AOX. AOX reduces the net ATP (energy yield) of respiration as because of AOX bypass, no proton pumping occurs between Complex III and IV; electron flow occurs because of proton pumping of complex I.



Source: frontiersin.org

ETC In Plant System

Abbreviations—alphabetically ordered. I, complex I; II, complex II; III, complex III; IV, complex IV; α-KGDH, α-ketoglutarte dehydrogenase; AOX, alternative oxidase; BCKDH, branched-chain α-ketoacid dehydrogenase complex; Cytc, cytochrome c; D-2HGDH, D-2-hydroxyglutarate dehydrogenase; DHODH, dihydroorotate dehydrogenase; DLDH, D-lactate dehydrogenase; ETF, electron transfer flavoprotein; ETFQOR, electron transfer flavoprotein ubiquinone oxidoreductase; FDH, formate dehydrogenase; GDC, glycine dehydrogenase; GDH, glutamate dehydrogenase; GLDH, L-galactono-1,4-lactone dehydrogenase; G3-PDH, glyceraldehyde 3-phosphate dehydrogenase; HDH, histidinol dehydrogenase; IDH, isocitrate dehydrogenase; IVDH, isovaleryl-coenzyme A dehydrogenase; MDH, malate dehydrogenase; ME, malic enzyme; MMSDH, methylmalonate-semialdehyde dehydrogenase; P5CDH, pyrroline-5-carboxylate dehydrogenase; PDH, pyruvate dehydrogenase; ProDH, proline dehydrogenase; SPDH, saccharopine dehydrogenase; SSADH, succinic semialdehyde dehydrogenase; UQH2, ubiquinol.

ATP Yield

Upon considering the total ATP gain in plant respiration, the net gain of ATP from glycolysis is 2; 2 GTP equivalent to ATP come from TCA Cycle; 4 ATP come from oxidative phosphorylation; each NADH gives 2.5 no. of ATP from NADH, which depends on through which shuttle it enters chain, malate dehydrogenase of glycerol aspartate shuttle number will change as 2.5 or 3,ATP. Hence, from NADH (2 from glycolysis and 6 from Kreb/TCA cycle) we get 16 ATP and from FADH2 total 3 ATP. Summing up, the net ATP gain will be 32, as shown in table below.

SN	Process	Form of ATP	Total ATP	
1	Glycolysis	ATP	2	
		NADH (2)	5	
2	Pyruvate oxidation	NADH (2)	5	
3	TCA	ATP	2	
		NADH (6)	15	
		FADH2	3	
			32	NET ATP Gain is 32