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A Review on Biosynthetic Pathways in Plants

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A B S T R A C T

Cellular metabolism is a complex network of biochemical reactions crucial for the sustenance and growth of organisms. Anabolic metabolism produces essential macromolecular building blocks such as amino acids and nucleotides, while catabolic metabolism generates primary metabolites vital for energy production and substrate utilization. Industrially significant primary metabolites include amino acids, nucleotides, vitamins, solvents, and organic acids. Key biosynthetic pathways encompass photosynthesis, glycolysis, and the pentose phosphate pathway (PPP).

Photosynthesis, paramount in ecosystems, harnesses sunlight to convert carbon dioxide and water into oxygen and energy-rich sugars. Glycolysis, a ten-step enzymatic process occurring in all cells, transforms glucose into pyruvate, yielding ATP. The pentose phosphate pathway branches off glycolysis to synthesize sugars crucial for DNA and RNA. Secondary metabolites, non-essential for organism survival but pivotal for ecological functions, derive from primary metabolism pathways like the shikimic acid, acetate malonate, and acetate mevalonate pathways. These pathways produce aromatic amino acids, fatty acids, polyketides, and isoprenoids, among other compounds, enriching biological diversity and ecological interactions. Understanding these metabolic pathways enhances insight into cellular processes and facilitates biotechnological applications in diverse fields.

Keywords: Biosynthetic Pathways, primary metabolite, Secondary metabolite, biosynthetic pathways

1. Introduction

Biosynthesis is a process of forming larger organic compounds from small subunits within a living organism. As an example, photosynthesis occurs inside the chloroplast. The light energy is converted into chemical energy during photosynthesis. The larger molecule glucose is biosynthesized from water and carbon dioxide by photosynthetic organisms.(ATP, Enzyme, Cofactors) The various primary and secondary metabolites are bio synthesized during these processes. The biosynthetic processes for primary metabolites involve photosynthesis, Calvin cycle and pentose phosphate pathway while the secondary metabolites are synthesized by Shikimic acid pathway, acetate pathways(malonate and mevalonate) and amino acid pathways.

1.1 Plant Biosynthesis

Plants synthesize an amazing diversity of volatile organic compounds (VOCs) that facilitate interactions with their environment, from attracting pollinators and seed dispersers to protecting themselves from pathogens, parasites and herbivores. Living plants are solar-powered biochemical and biosynthetic laboratory which manufactures both primary and secondary metabolites from air, water, minerals and sunlight. The primary metabolites like sugars, amino acids & fatty acids that are needed for general growth & physiological development of plant which distributed in nature & also utilized as food by man. The secondary metabolites such as alkaloids, glycosides, Flavonoids, volatile oils etc. are biosynthetically derived from primary metabolites. The living plant may be considered as a biosynthetic laboratory not only for primary metabolites like sugars, Amino acids and fatty acids and for a multitude of secondary products of pharmaceutical significance such as glycosides, alkaloids, flavonoids, volatile oils etc. Living cell require energy for biosynthesis, transport of nutrient, motility and maintenance. Energy is obtained from the catabolism of carbon compounds (carbohydrate) Carbohydrates are synthesized from CO2 and H2O in the present of light by photosynthesis

1.2 Metabolites

Metabolites are intermediates and products of metabolism and a typically characterised by small molecules with various functions. They can be categorised into

1) Primary metabolites

2) Secondary metabolites

1.2.1 Primary metabolites

Primary metabolites are involved in growth, development, and reproduction of the organism. The primary metabolite is typically a key component in maintaining normal physiological processes; thus, it is often referred to as a central metabolite. Primary metabolites are typically formed during the growth phase as a result of energy metabolism, and are deemed essential for proper growth. They are involved in maintaining normal physiological processes that are essential for proper growth ,development and reproduction.

Examples- amino acids, vitamins, carbohydrates, lipids etc

1.2.2 Secondary metabolites

Secondary metabolites are typically organic compounds produced through the modification of primary metabolite synthases. Secondary metabolites do not play a role in growth, development, and reproduction like primary metabolites do, and are typically formed during the end or near the stationary phase of growth. Many of the identified secondary metabolites have a role in ecological function, including defence mechanism(s), by serving as antibiotics and by producing pigments. They are small molecules which are products of metabolism that are not absolutely required for the survival of plants but has an important ecological function.

Examples-alkaloids, essential oils, glycosides, terpenes, steroids etc

1.3 Biosynthesis of primary metabolites

Primary metabolites are products made during the exponential phase of growth whose synthesis is an integral part of the normal growth process. They include intermediates and end- products of anabolic metabolism, which are used by the cell as building blocks for essential macromolecules (e.g. amino acids, nucleotides) or are converted to coenzymes (e.g. vitamins). Other primary metabolites result from catabolic metabolism; they are not used for building cellular constituents but their production, which is related to energy production and substrate utilization, is essential for growth. Industrially, the most important primary metabolites are amino acids, nucleotides, vitamins, solvents and organic acids. Major biosynthetic pathways include-

- Photosynthesis
- Glycolysis
- The pentose phosphate pathway (PPP)

1.3.1 Photosynthesis

Photosynthesis is the process by which plants use sunlight, water, and carbon dioxide to create oxygen and energy in the form of sugar. Photosynthesis may be the most important process in ecosystems, both brings in energy needed within the ecosystem, and produce oxygen (O2) needed for cellular respiration, and the production of more ATP.

Photosynthesis has three basic steps:

1. Energy is captured from the sunlight.
2. Light energy is converted into chemical energy in the form of ATP and NADPH.
3. Chemical energy is used to power the synthesis of organic molecules (e.g. carbohydrates) from carbon dioxide (CO2).

Photosynthesis reaction

$\mathbf{H_20+LIGHT+ADP+P \rightarrow O_2+ATP+e^-}$

After the above steps occur in photosystem II, the electron is finally sent to photosystem I, where the following happens.

$\mathbf{e^-+NADP+H \rightarrow NADPH}$

Now there are two high energy molecules, fully charged and ready to be used. Plants make more energy that it needs immediately, so the NADPH and ATP are used to make glucose as follows:

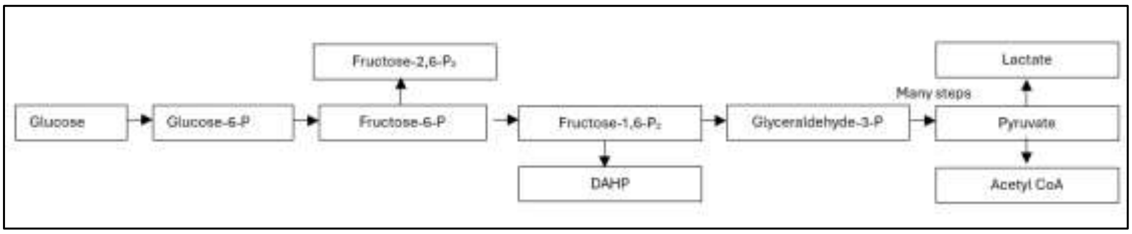
$\mathbf{CO_2+ATP=NADPH \rightarrow C_6H_{12}O_6}$

1.3.2 Glycolysis

Glycolysis is the sequence of 10 enzyme-catalyzed reactions that converts glucose into pyruvate with simultaneous production on of ATP. In this oxidative process, 1mol of glucose is partially oxidized to 2 moles of pyruvate. This major pathway of glucose metabolism occurs in the cytosol of all cells. This unique pathway occurs aerobically as well as anaerobically & doesn’t involve molecular oxygen. It also includes formation of Lactate from Pyruvate.

The glycolytic sequence of reactions differs from species to species only in the mechanism of its regulation & in the subsequent metabolic fate of the pyruvate formed. In aerobic organisms, glycolysis is the prelude to Citric acid cycle ETC. Glycolysis is the central pathway for Glucose catabolism.

Fig:1 Glycolysis pathway simplified



1.3.3 Pentose phosphate pathway

While the products of glycolysis are sent through the rest of cellular respiration to produce energy , there is also an alternative branch off glycolysis to produce the sugars that make up DNA and RNA. This pathway, called the Pentose Phosphate Pathway, Pentose phosphate pathway is also called Hexose monophosphate pathway/ HMP shunt/ Phosphogluconate pathway.

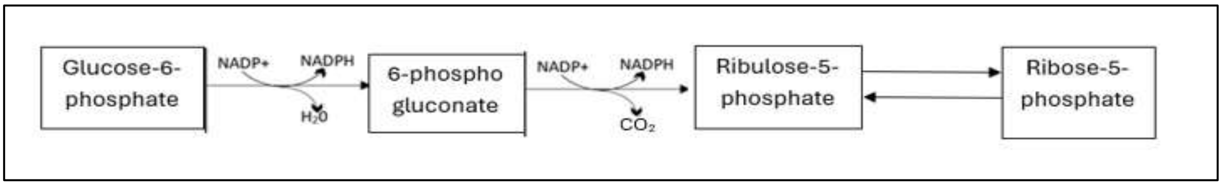


Fig:2

Pentose Phosphate Pathway

1.4 Biosynthesis of secondary metabolite

Secondary metabolites is a term for pathways for small molecule and products of metabolism that are not absolutely required for the survival of the organism. A secondary metabolite has an important ecological function.

Primary metabolism is interconnected to the secondary metabolism by way of the production of secondary metabolite compounds, through the biosynthetic pathway. Types of biosynthetic pathway in plant secondary metabolism are –

- Shikimic acid (shikimate) pathway,
- Malonic acid (acetate malonate) pathway,
- Mevalonic acid (acetate mevalonate) pathway.
- Amino acid pathway.

1.4.1 Shikimic acid pathway

The shikimate pathway is a seven step metabolic route used by bacteria, fungi, algae, parasites, and plants for the biosynthesis of aromatic amino acids (phenylalanine, tyrosine, and tryptophan). This pathway is not found in animals; therefore, phenylalanine and tryptophan represent essential amino acids that must be obtained from the animal's diet.

Animals can synthesize tyrosine from phenylalanine, and therefore is not an essential amino acid.

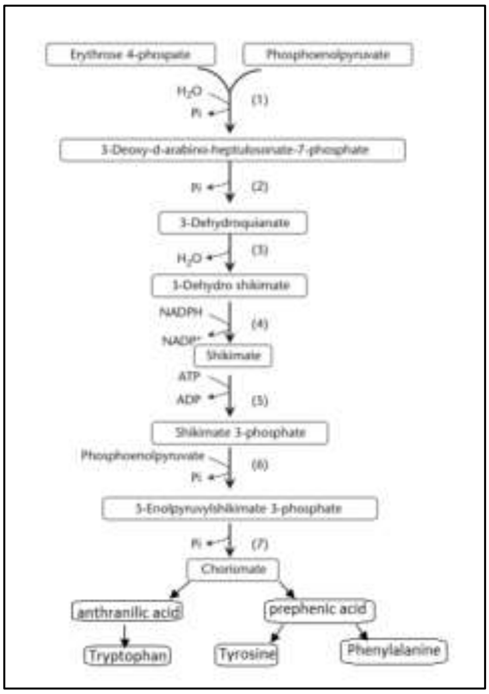


Fig3: Shikimic acid pathway

1.4.2 Acetate malonate pathway

Acetate-Malonate pathway includes synthesis of fatty acids and aromatic compounds with the help of secondary metabolites.Main precursors of Acetate-Malonate Pathway are Acetyl-CoA and Malonyl-CoA.

Product of this pathway can be saturated or unsaturated fatty acids or polyketides. Polyketides are secondary metabolites which further synthesize aromatic compounds by Polyketide Pathway

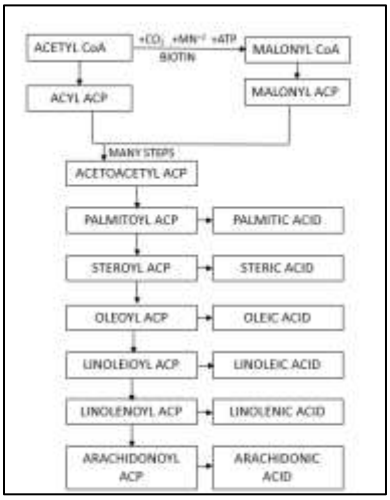


Fig4: Acetate malonate pathway

1.4.3Acetate mevalonate pathway

Acetate mevalonate pathway is the basic metabolism pathway which is useful for the biosynthesis of various secondary metabolites like hemiterpenes, sesquiterpenes, carotenoids, squalene, steroids, etc. The mevalonate pathway begins with acetyl-CoA and ends with the production of Isopentenyl pyrophosphate (IPP)and Dimethylallyl pyrophosphate (DMAPP) which are used to make isoprenoids, a diverse class of over 30,000 biomolecules such as cholesterols , Vitamin K, and all steroid hormones

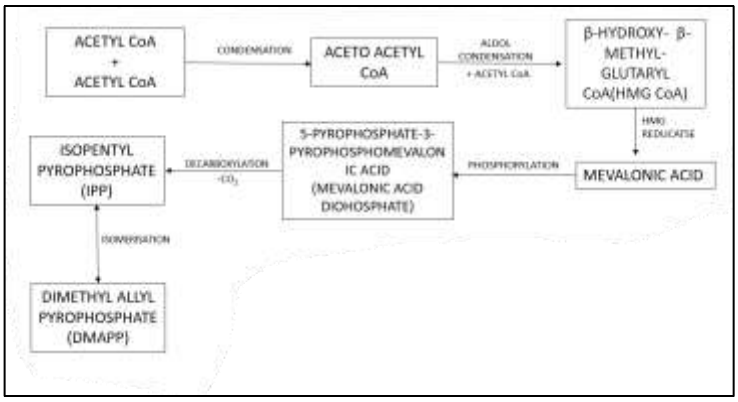


Fig5: Acetate mevalonate pathway

1.4.4 Amino acid pathway

Precursors in this are intermediates in glycolysis, the citric acid cycle, or the pentose phosphate pathway. They are used to make nucleotides.

Histidine comes from Ribose 5-phosphate that is product of pentose phosphate pathway. Serine comes from 3-phosphoglycerate and from serine we can make more amino acids like glycine and cysteine.

Tryptophan and tyrosine comes from phosphoenolpyruvate. Pyruvate used to make alanine, valine, leucine and isoleucine.Aspartate is produced from oxaloacetate and aspartate is used in production of other amino acids like asparagine, methionine, threonine and lysine. Glutamate is synthesized from alpha ketoglutarate. From glutamate we can make more amino acids like glutamine, proline and arginine .

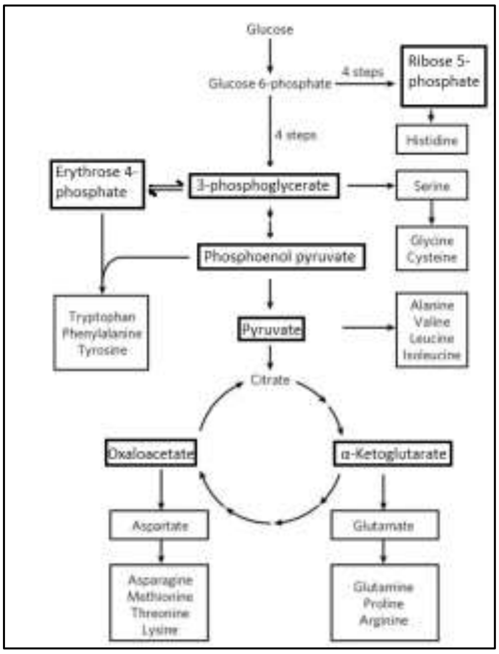


Fig:6 Amino Acid pathway

2. Conclusion

Natural ingredient produced by plants are widely used for therapeutic treatment, because they are believed to have fewer side effects and are cheaper than synthetic drugs. Plants used as treatment media contain natural secondary metabolites compounds derived from primary and secondary metabolism.

Primary metabolism is the basic stage in the formation of complex molecules in plant medicinal products, while secondary metabolism form more advanced products in synthesize the phytochemicals. Plant secondary metabolites involved three chemically basic group of compounds: terpenoids, phenolics, and alkaloids. Biosynthetic pathways of secondary metabolites are conducted through the Shikimic-acid, Malonic-acid, Mevalonic-acid, and pentose-phosphate pathway. Glucose is the main molecule for the metabolism of these secondary metabolites.

A radioactive tracer, radiotracer, or radioactive tag is a chemical compound in which one or more atoms have been replaced by a radionuclide so that, due to its radioactive decay, it can be used to investigate the mechanism of chemical reactions by following the path that the radioisotope takes from the reactants to the products. Radio labelling or radio monitoring is therefore the radioactive component of an isotope tag.

The tracer technique mainly deals with the secondary metabolites and its applications in synthesis of in pharmacognosy. This technique involves the stable (1H2,6C13,7N15,8O18) and unstable (1H1,6C14) radioactive isotopes. This technique which utilizes a labelled compound to find out or to trace the different intermediates and various steps in biosynthetic pathways in plants, at a given rate & time and also deeply focused on the methods in tracer technique. Now a days this method is more useful to identify the secondary metabolites

Hydrogen, carbon, phosphorus, sulphur and iodine radioisotopes have been used extensively to map the course of biochemical reactions. A radioactive tracer may also be used to track the distribution of a material within a natural system, such as a cell or tissue.

References

- Stincone A, Prigione A, Cramer T, Wamelink MM, Campbell K, Cheung E, Olin-Sandoval V, Grüning NM, Krüger A, Tauqeer Alam M, Keller MA, Breitenbach M, Brindle KM, Rabinowitz JD, Ralser M. The return of metabolism: biochemistry and physiology of the pentose phosphate pathway. Biol Rev Camb Philos Soc. 2015 Aug;90(3):927-63. doi: 10.1111/brv.12140. Epub 2014 Sep 22. PMID: 25243985; PMCID: PMC4470864.
- Vickery, M.L., Vickery, B. (1981). The Acetate-Mevalonate Pathway. In: Secondary Plant Metabolism. Palgrave, London. https://doi.org/10.1007/978-1-349-86109-5_5
- Sanchez S, Demain AL. Metabolic regulation and overproduction of primary metabolites. Microb Biotechnol. 2008 Jul;1(4):283-319. doi: 10.1111/j.1751-7915.2007.00015.x. PMID: 21261849; PMCID: PMC3815394.
- Anoman AD, Flores-Tornero M, Rosa-Telléz S, Muñoz-Bertomeu J, Segura J, Ros R. The specific role of plastidial glycolysis in photosynthetic and heterotrophic cells under scrutiny through the study of glyceraldehyde-3-phosphate dehydrogenase. Plant Signal Behav. 2016;11(3):e1128614. doi: 10.1080/15592324.2015.1128614. Erratum in: doi: 10.1104/pp.15.00696. PMID: 26953506; PMCID: PMC4883961.
- Ge T, Yang J, Zhou S, Wang Y, Li Y and Tong X (2020) The Role of the Pentose Phosphate Pathway in Diabetes and Cancer. *Front. Endocrinol.* 11:365. doi: 10.3389/fendo.2020.00365