SECONDARY METABOLITES

[ALKALOIDS; TANNINS; VOLATILE OILS; GLYCOSIDES; SAPONINS; PHENOLICS]

Various metabolic activities occur inside living cell of plants constantly like photosynthesis, respiration, biosynthesis of amino acids, protein synthesis, etc. Final products as well as some intermediate products of these processes continue to form further products and by-products. Various such biochemical forms are produced and stored in the plant cells. Vacuoles are the main store-houses for such products. Involvement of enzymes is a pre-requisite for such processes. Every step of all pathways involves some or the other enzymes. This gives rise to two types of metabolites – primary and secondary.

Primary metabolites are the ones which are produced in every plant cell and is necessary for the metabolic activity of every plant cell. "Secondary metabolites are compounds formed in certain plant cells / parts that do not participate in basic metabolic activities, formed in minute quantities and may have more specific function in the plant body."

Primary metabolites	Secondary metabolites
Involved in all the essential metabolic activities of the cells. Eg. Protein synthesis	Not involved in the essential metabolic activities; rather some intermediate compounds formed due to altered route of pathways
Easily produced regularly in the cells	Primary metabolites are further metabolized to biosynthetically derive the secondary metabolites
Produced in large quantities	Produced in comparatively less quantities
Due to its significance, found in all the plants; widely distributed	Specifically produced in certain taxonomic groups only
Products used as a food source by humans	Products mainly used for their medicinal values by humans
Eg. Carbohydrates obtained from wheat; proteins from mushrooms; etc.	Eg. Alkaloids from periwinkle (*Catharanthus roseus*); oil from castor (*Ricinus communis*); resins from pine wood (*Pinus* spp.) etc.

Ability of secondary metabolite production has followed evolutionary significance. It arose according to the need of the plants.

Examples:

- fragrance of the flower petals to attract insect and bird pollinators

- toxic chemicals to ward off herbivores and pathogens
- inhibiting the growth of other neighbouring plants
- chemicals in fruits and seeds to prevent spoilage
- incentives in fruits and seeds to help in their dispersal
- resistance to environmental stresses

ALKALOIDS

Sources:

- The term ‘alkaloids’ means alkali – like substances containing nitrogen.
- The term ‘alkaloid’ was introduced in 1819 by a German chemist Carl F. W. Meissner.
- They are natural substances which occur in about 50% of all vascular terrestrial plants.
- They occur in monocots (Liliaceae, Amaryllidaceae) and dicots (Papaveraceae, Rubiaceae, Solanaceae, Apocynaceae, Asteraceae)
- Within a plant, alkaloids may be present in different parts. For example, entire plant of *Vinca* (periwinkle); bark of *Holarrhena antidysenterica* (Kuda, kurchi) and *Cinchona officinalis* (for quinine drug to cure malaria); roots of *Withania somnifera* (Ashwagandha) and *Rouwolfia serpentina* (Sarpgandha); leaves of tobacco (*Nicotiana tabacum*), Adulsa (*Adhatoda vasica*), Datura (*Datura stramonium*) etc.; fruits of black pepper (*Piper*), coffee (*Coffea arabica*), cocoa (*Theobroma cocao*); seeds of poppy (*Papaver somniferum*), nux-vomica (*Strychnos nux-vomica*), areca nuts (*Areca catechu*), Datura, etc.
- The names of alkaloids are formed by adding the suffix ‘-ine’ to the species or generic alkaloids. For example, morphine, nicotine, quinine, vasicine, vincristine, caffeine, etc. if several alkaloids are extracted from one plant then their names often contain suffixes like ‘-idine’, ‘-anine’, ‘-aline’, ‘-inine’, etc.
- Alkaloids are reserve substances and help in defense mechanism also detoxification in plants.
- They also serve as protective agents, plant regulators and reservoirs of protein synthesis.

Properties:

- Alkaloids are naturally produced by bacteria, fungi, plants as well as animals.
- They have a complex molecular structure.

- Alkaloids have a sharp melting point.
- They are secondary, tertiary and quaternary amines, hence they have basic properties.
- They show specific physiological action on human body when used in small quantities.
- Alkaloids are colourless, crystalline, non-volatile and bitter solids. Some alkaloids are amorphous gums.
- They are insoluble in water and completely soluble in organic solvents such as alcohol, ether, chloroform, etc.
- When they form salt with an inorganic acid, they prevent decomposition in many cases.
- They absorb u-v light and show a characteristic absorption spectrum.
- Alkaloids with basic character are very much sensitive to decomposition and create problem during their storage.

Uses:

Alkaloids and their salts are used in pharmaceutical industry for extraction and formulation of many medicines, some of which are as follows:

No.	Biological source	Alkaloids	Pharmacological uses
1.	Poppy – *Papaver somniferum*	Morphine, papaverine, codeine	Analgesics and narcotics
2.	Seeds of *Strychnos nux-vomica*	Strychnine, Brucine	CNS stimulants
3.	Leaves of *Erythroxylon coca*	Cocaine	Local anaesthetics
4.	Leaves and seeds of *Datura metel*	Atropine, Hyoscyamine	Antispasmodics
5.	*Ephedra* (gymnosperm)	Ephedrine	Antihypotensive
6.	Sarpgandha (*Rouwolfia serpentina*)	Reserpine	Antihypertensive
7.	*Cinchona officinalis*	Quinine	Cardiac repressant
8.	*Vinca rosea* / *Catharanthus roseus*	Vincristine	Antitumor
9.	*Holarrhena antidysenterica* (Kuda, kurchi)	Conessine	Antiamoebic
10.	Adulsa (*Adhatoda vasica*)	Vasicine	Expectorant
11.	Ashwagandha (*Withania somnifera*)	Tropine	Antidepressant

- Plants contain alkaloids, which are used as psychoactive substances. Eg., cocaine acts as a stimulant for the CNS. Morphine and codeine act as strong pain-killers.
- Some alkaloids act as a pre-cursor for the production of semi-synthetic psychoactive drugs, eg. Ephedrine is used to produce methcathinone.
- The alkaloids form active principles of many abuse drugs like cocaine, marijuana, hashish, etc.
- Alkaloids are also used in food industry. They are commonly used in refreshing drinks like tea, coffee, cocoa, etc.

- Many synthetic and semisynthetic drugs are structural modifications of the alkaloids, which were designed to enhance or change the primary effect of the drug and also to reduce side effects. For eg., naloxone is a derivative of thebaine, which is present in opium.
- In agriculture too, prior to the development of synthetic pesticides, some alkaloids like salts of nicotine were used as insecticides. But they were found to be highly toxic to humans.

GLYCOSIDES

Sources:

- Glycoside is a molecule formed by joining of sugar to a non-carbohydrate small organic molecule.
- They are organic compounds which on hydrolysis yield one or more sugars and a non-sugar residue.
- They are complex organic molecules containing sugars, mainly monosaccharides.
- Therapeutically glycosides show significant effects on the human body.
- They play an important role in the growth regulatory, protective and excretory functions of plants.
- Pharmaceutically important glycosides are obtained from only vegetable sources.
- Glycosides are mainly found in dicotyledonous plants belonging to families Scrophulariaceae, Rubiaceae, Polygonaceae, Verbenaceae, Rhamnaceae, Lythraceae, Leguminosae and Euphorbiaceae. In monocotyledons, it is found only in family Liliaceae.
- Glycosides occur in various parts of the plants. For example, roots of mulethi (*Glycyrrhiza*), jeshtamadh, liquorice, ginseng; stem of *Thevetia* (yellow oleander); leaves of *Senna*, *Aloe*; flowers of Saffron (*Crocus sativus*); fruits of *Vanilla*; seeds of almond, mustard, etc.
- The first identified glycoside is amygdalin.

Properties:

- Glycosides are organic compounds which on hydrolysis give one or more sugar along with non-sugar component. Glycoside (hydrolysis) → sugar [glucose / mannose / galactose] + non-sugar [alcohol / phenol / amine]
- Glycosides are optically active compounds that are levo-rotatory.
- The sugar component is called glycone and non-sugar component called as aglycone or genin.
- The most commonly occurring sugar as a product of hydrolysis are glucose, mannose and galactose and the most common aglycone may be alcohol, phenol and amine.
- The linkage between glycone and aglycone is called glycoside linkage.
- Glycosides are colourless, crystalline and non-reducing compound.

- They are water soluble as well as soluble in alcohol and insoluble in organic solvents.
- Most of them have little bitter taste, exceptions being populin, glycyrrhizin, stevioside.
- They are easily hydrolysed in acids and enzymes present in the plant.
- Maceration, germination and other physiological conditions of the tissue can cause hydrolysis of glycoside by an enzyme.
- Glycosides are important due to their aglycone content.
- Glycosides exhibit various types of physiological actions and the most common is process of hydrolysis.
- The chemical nature of aglycone compound varies, hence it gives different therapeutic effects. Examples, cardiac glycoside (*Digitalis*); saponin glycoside (*Glycyrrhiza*); anthro quinine glycoside (*Senna*, *Aloe*)

Uses:

Common Name	Botanical Name	Active constituent/s	Uses
Liquorice, Mulethi	*Glycirrhiza glabra*	Glycirrhizin	Expectorant; Improves voice; treats peptic ulcer
Ginseng	*Panax ginseng*	Ginsenoside	Tonic and stimulant
Senna, Sonmukhi	*Cassia angustifolia*	Sennoside A & B	Purgative
Aloe	*Aloe vera*	Aloe - emodin	Purgative for skin
Vanilla	*Vanilla planifolia*	Glucovanillin	Strong flavouring agent
Saffron	*Crocus sativus*	Crocetin	Flavouring agent, stimulant, induces sleep, improves skin complexion

- Various medicines, condiments and dyes obtained from plants occur in the form of glycosides.
- Several glycosides are administered in the form of antibiotics. Eg., Streptomycin.
- Salicin, an alcoholic glycoside is converted into salicylic acid in the body and exhibits analgesic, antipyretic, anticoagulant and anti-inflammatory effects.
- Anthroquinone glycosides have a laxative action.
- Cyanogenic glycosides have disease resistant and anti-cancerous properties.
- Flavonoid glycosides have antioxidant effects.

- Two primary steviol glycosides, namely stevioside and rebaudioside A, found in the leaves of *Stevia rebaudiana* are sweet glycosides, which are 40 to 300 times sweeter than sucrose. In many countries, these are used as natural sweetening agents.

TANNINS

Sources:

- The term 'tannin' is obtained from a German word *tanna* which means Oak or Fir tree (*Quercus* spp.), as this tree is the chief source of tannins.
- Tannins are complex phenolic compounds present in plants.
- They are characterized by their ability to combine with proteins of animal skin / hide to prevent their putrefaction and convert it into leather.
- Tannins are present in solution form in the cell sap and vacuoles.
- They are widely distributed in the different plant parts. For example,
    - Bark – Ashoka (*Saraca indica*), Arjuna (*Terminalia arjuna*), Peepal (*Ficus religiosa*), Pomegranate (*Punica granatum*), etc.
    - Stem – Heartwood of Katha (*Acacia catechu*)
    - Leaves – Tea (*Camellia sinensis*)
    - Flowers – Dried flower buds of Clove (*Syzygium caryophyllus*)
    - Fruits – Harda (*Terminalia chebula*), Beheda (*Terminalia bellerica*), Amla (*Emblica officinalis*)
    - Seeds – Arecanut (*Areca catechu*)
- Plants like tea, coffee, *Cocao, Acacia* contain pseudotannins.
- Tannins are often found in immature fruits and usually disappear during the ripening process.
- They are the sources of fruit-acids.
- They provide protection to the plant by defense mechanism.
- They are finally destroyed and deposited as end products in certain dead tissues like bark, heartwood, 'galls', etc.

Properties:

- Tannins are derivatives of polyhydroxybenzoic acids, capable of combining with proteins.

- Most tannins are complex substances having very large molecular weight ranging from 500 to over 3000 and sometimes up to 20,000 Daltons.
- They are yellowish white to brown in colour. The colour deepens when exposed to light.
- They are amorphous, powder-like non-crystalline substances.
- High contents of tannins give the product their bitter taste.
- Tannins are soluble in water and acetone but insoluble in other inorganic solvents.
- They have high molecular weight and do not contain nitrogen.
- They show acidic reactions due to presence of phenols.
- They show astringent action i.e. makes body proteins resistant to proteolytic enzymes.
- They cause precipitation of proteins and alkaloids.
- When applied to smooth muscles, they cause their contraction.
- They are used in the treatment of burns as they precipitate the proteins of exposed tissues form a protective coating.

Uses:

- Tannins exhibit antibacterial, antifungal, antiviral and antiparasitic properties, which are exploited by pharmaceutical industries in drug production.
- Tannins precipitate the proteins to form solution making it resistant to proteolytic enzymes.
- It is used to treat burns, since the proteins are precipitated forming an antiseptic protective coat, thereby bringing about healing of wounds.
- Tannins are used in the immediate relief of sore throats, diarrhea, dysentery, haemorrhage, fatigue and skin ulcers.
- Tannins are used to detect the presence of gelatin due to its precipitating property.
- Tannins are used as antioxidants to store edible oils.
- Tannins are used in the manufacture of ink.
- The tradition of adding milk to tea has the added benefit of causing the tannins in tea to bind to the proteins in the milk rather than to proteins in the liver and kidneys.

Common Name	**Botanical Name**	**Active constituent/s**	**Uses**
Arjuna	*Terminalia arjuna*	Sitosterol	Cardio-tonic; hypotensive
Ashoka	*Saraca indica*	Catechol	Uterine tonic

Catechu	*Acacia catechu*	Quercetin	Astringent; against skin infection; making commercial ink
Harda	*Terminalia chebula*	Chebulic acid	Astringent, purgative, stomachic, used to prepare 'triphalachurna'
Beheda	*Terminalia bellirica*	Beta cetosterol	Purgative, astringent, laxative
Amla	*Phyllanthus emblica; Emblica officinalis*	Phyllemblin	Source of vitamin C, diuretic, laxative, promotes hair growth; anemia; dyspepsia

VOLATILE OILS

Sources:

- Volatile oils are sweet smelling lipids synthesized and stored in various plant parts.
- Volatile oils are the essential principles found in various plant parts like leaf, bark, flower, fruit, seeds, etc.
- Volatile oils are commonly found in plants of Rutaceae, Myrtaceae, Lamiaceae, Umbelliferae, Zingiberaceae.
- The volatile or essential oils of rose (petals), mint (glandular hair, stem and leaves), clove (flower bud), oranges (fruit rind) and lemon (fruit rind) are very famous.
- Volatile oils are extracted by one of the four methods:
    - Steam distillation – eg. Mint (*Mentha piperita*), cinnamon (*Cinnamomum verum*)
    - Solvent extraction – eg. Jasmine (*Jasminum* spp.)
    - Expression method – eg. Citrus fruits
    - Enfleurage method – eg. Rose (*Rosa gallica*)

Plant part	**Examples of plants**	
Root	*Vetivera zizanoides*	Vetiver
Rhizome	*Zingiber officinale, Curcuma longa, Acorus calamus*	Ginger, Turmeric, Vekhand / Vacha
Wood	*Santalum album, Cinnamomum camphora*	Sandalwood, Camphor
Leaves	*Eucalyptus globulus,*	Nilgiri,

	Ocimum sanctum, *Cymbopogon nardus*, *Mentha piperita*, *Murraya koenigii*	Tulsi, Lemongrass, Mint, Curry leaves
Bark	*Cinnamomum verum*	Cinnamon
Flowers	*Syzygium caryophyllus*, *Crocus sativus*, *Lavendula officinalis*, *Rosa gallica*	Clove, Saffron, Lavender, Rose
Fruits	*Trachyspermum ammi*, *Foeniculum vulgare*, *Cuminum cyminum*, *Citrus sinensis*	Ajwain, Saunf, Jeera, Orange
Seeds	*Elettaria cardamomum*, *Myristica fragrans*	Cardamom, Nutmeg

Properties:

- Volatile oils are the mixtures of hydrocarbons and oxygenated compounds, derived from hydrocarbons.
- They evaporate when exposed to air at ordinary temperatures, hence they are called volatile oil or ethereal oil / essential oil.
- Volatile oils have high refractive indices.
- They are colourless when fresh. On storage, they become dark in colour.
- They are liquids at ordinary room temperatures.
- They possess characteristic strong odour.
- They are lighter than water, hence they float on the water.
- They are immiscible in water, but can impart odour to it.
- These oils are lipophilic and hence are miscible with other oils.
- They are easily soluble in alcohol and organic solvents.

Uses:

Common Name	Botanical Name	Active constituent/s	Uses
Camphor	*Cinnamomum camphora*	Camphor eugenol	Analgesic, carminative, antispasmodic
Cinnamon	*Cinnamomum zeylanicum*	Cinnamaldehyde	Carminative, flavouring agent
Nilgiri	*Eucalyptus globulus*	Cineale	Antiseptic, expectorant, reducing phlegm
Lemongrass	*Citronella / Cymbopogon citratus*	Citral	Insect repellent, flavouring agent
Clove	*Syzygium caryophyllus*	Eugenol	Analgesic, carminative, antiseptic
Mint	*Mentha piperita*	Menthol	Carminative, stimulant, freshener

- Aromatherapy is an alternative medicinal therapy in which essential oils are used for healing of the patients.
- Volatile oil act as insect repellants.
- They also serve as insect attractants helping in pollination.
- These oils are extensively used as flavouring agents in food, beverages, tobacco and in cosmetic industry.
- Due to their exotic aroma, some of them are used in the manufacturing of soaps and perfumes.

SAPONINS

- Saponins are a class of glycosides characterized by their property of producing a frothing aqueous solution.
- As glycosides, they are hydrolyzed by acids to give an aglycone (sapogenin) and various sugars and related uronic acids.
- Two kinds of saponins are recognized – steroidal and triterpenoid.

Sources:

Saponin compounds are found in various plant parts, especially the bark and the roots of different plant species. Examples are:

- *Dioscorea* spp. – Bark
- *Asparagus racemosus* – Roots

- *Panax ginseng* – Roots
- *Glycyrrhiza glabra* – Roots
- *Quillaja Saponaria* – Bark
- *Sapindus laurifolius* – Fruits and seeds (Reetha / Soapnut)

Properties:

- Saponins on hydrolysis give sugars (glucose, galactose, rhamnose or xylose, etc.) and aglycones (sapogenin).
- Several groups of compounds characterized by their steroidal or triterpenoid aglycone and one or more sugar chain.
- Saponin molecule consists of a hydrophilic sugar moiety linked to a hydrophobic aglycone.
- Saponins are mostly amorphous in nature.
- They are soluble in alcohol and water, but insoluble in non-polar organic solvents.
- Both the types of saponins have glycosidal linkage at third carbon and have a common biogenetic origin.
- They produce a soapy lather in water and widely used as detergents since ancient days.

Uses:

Common Name	Botanical Name	Active constituent/s	Uses
Wild Yam	*Dioscorea* spp.	Digitonin, Diosgenin	Estrogen replacement therapy, pre-menstrual syndrome, menstrual cramps, osteoporosis
Nightshade	*Solanum khasianum*	Solasodine	Precursor for production of complex steroidal compounds
Shatavari	*Asparagus racemosus*	Sarsapogenin	Antitumor, Antidepressant
Ginseng	*Panax ginseng*	Ginsenoside	Antioxidative, vasorelaxation, anti-inflammatory, anticancer
Quillaja	*Quillaja saponaria*	Quillaia	Cough, bronchitis, skin problems
Soapnut / Reetha	*Sapindus laurifolius*	Hederagenin	Cleansing agents and detergents

PHENOLICS

- Phenolics are broadly distributed in the plant kingdom and most abundantly present in plants.
- Plant polyphenols have drawn increasing attention due to their potent antioxidant properties and their marked effects in the prevention of various oxidative stress associated diseases such as cancer.
- More than 8000 phenolic structures are known in plants. They account for 40% of organic carbon circulating in biosphere.
- Plant phenolics are generally involved in defense against ultraviolet radiation or aggression by pathogens, parasites and predators, as well as contributing to plants' colors.

Sources:

The phenolic compounds in plants are more commonly stored in the fruits and seeds. Examples are as follows:

- *Olea europea* (Olives) – Fruits
- *Vanilla planifolia* (Vanilla) – Pods
- *Beta vulgaris* (Beetroot) – Fleshy roots
- *Capsicum annum* (Chilli) – Fruits
- *Mallotus philippinensis* (Kamala / Mussoorie) – Fruits
- *Rubus* spp. (Blackberries) – Fruits

Properties:

- Phenolics are compounds possessing one or more aromatic rings with one or more hydroxyl groups.
- They can be simple, low molecular weight, single aromatic ringed compounds to large and complex polyphenols.
- Flavonoids, a type of phenolics, are polyphenolic comprising of 15 carbon with 2 aromatic rings connected with 3 bridges.
- Solubility differs across the various groups of phenolic compounds, most of them being soluble in water and some in organic solvents.
- Phenolics are commonly found conjugated to sugars and organic acids.
- Phenolics exhibit intense absorption in the UV region of the spectrum.

Uses:

Common Name	Botanical Name	Active constituent/s	Uses
Onion	*Allium cepa*	Quercetin	Powerful antioxidant effects

		(Flavonol)	
Citrus fruits	*Citrus* spp.	Naringenin (Flavanone)	Anti-inflammatory, anti-cancer and liver protective
Soybean	*Glycine max*	Isoflavones	Reduce prostate and breast cancer, Anti-inflammatory and cardioprotective
Tea	*Camellia* spp.	Ellagitannins, complex tannins	Antioxidant
Strawberry	*Fragaria* spp.	Non-flavonoids	Astringent
Grapes	*Vitis vinifera*	Stilbens (Non-flavonoids)	Cardioprotective, inhibit LDL oxidation

As a conclusion,

Secondary metabolites were once believed to be waste products. They are not essential to the plants' survival but the plants suffer without them. Secondary metabolites also have many uses for us. Some are beneficial for us while some others are toxic.

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