

UNIT 10

SECONDARY METABOLITES |

Structure

10.1 Introduction	10.6 Terpenoids
Expected Learning Outcomes	Classification of Terpenoids
10.2 Secondary Metabolism	Structure and Source of Representative Terpenoids
10.3 Major Classes of Secondary Metabolites	Biological Role of Terpenoids
10.4 Alkaloids	10.7 Applications of Plant Secondary Metabolites
Representative alkaloid Groups	10.8 Summary
Functions of Alkaloids	10.9 Terminal Questions
10.5 Phenolics	10.10 Answers
Major Phenolic Groups	10.11 Further Readings
Biological Roles of Phenolics	

10.1 INTRODUCTION

Plants are sessile (fixed) organisms so they have to constantly monitor their immediate surroundings. They are faced with both biotic (competition for space and nutrients from other plants, pathogens, herbivores) and abiotic (drought, salinity) stresses at all times. Since plants cannot avoid these potential enemies by simple relocation, they have developed efficient strategies for detecting potential dangers and defending themselves.

In addition to simple protective coverings like cuticle and periderm, plants are known to produce a vast array of biochemical compounds in response to environmental cues and threats. These plant products are categorized as secondary metabolites. They also include plant volatiles such as isoprene, β -

myrcene and α -pinene which in some cases have been shown to participate in inter- and intra-communication.

At this point it is worth mentioning that an increasing number of primary metabolites, for example phytohormones (gibberellins and abscisic acid), are also produced by so called secondary metabolism. Therefore the clubbing of metabolites of unknown function as 'secondary' is indicative of our ignorance. Logically evolution would not have selected thousands of metabolites with no benefit to the host. An improved understanding of their role and biosynthesis has made the distinction between primary and secondary metabolites seem arbitrary.

In this unit we shall concentrate on three classes of secondary metabolites, namely terpenoids, alkaloids and phenolics. The emphasis would be on the role of representative members from each class in plant survival and communication; biosynthetic precursors; structures (not to memorise) and their applications in pharmaceutical and other industries.

Expected Learning Outcomes

After studying this unit you should be able to:

- ❖ define secondary metabolism;
- ❖ differentiate between primary and secondary metabolism;
- ❖ describe the major groups of secondary metabolites;
- ❖ indicate the biosynthetic precursor(s) for each of the three groups included in this unit;
- ❖ tell the plant sources and structure of representative isoprenoids, alkaloids and phenolics;
- ❖ elaborate the role of secondary metabolites, with examples; and
- ❖ highlight the medicinal properties of secondary metabolites.

10.2 SECONDARY METABOLISM

Every living cell is engaged in a complex array of enzyme catalyzed reactions, many of which are part of metabolic sequences that culminate in one / more end products. The intermediates of a pathway are invariably starting points for anabolism. These intermediates / end products are known as metabolites.

In 1891, German biochemist **Albrecht Kossel** proposed that those metabolites that are involved in basic processes of a cell such as growth, development and reproduction are primary metabolites. The pathways producing them constitutes primary metabolism and is indispensable for survival. For instance, plants reduce CO_2 in presence of sunlight to synthesise carbohydrates. The latter is utilised to

provide energy and carbon skeleton for other biomolecules. On the other hand metabolites that are not essential for performing basic functions of plants and are of less general importance, although extremely diverse among plants were called secondary (specialised) metabolites. They were believed to be byproducts / wastes of primary metabolism. They are synthesised from precursors derived from primary metabolism. Many of them are also medically active phytochemicals. We shall now describe the three major classes of secondary metabolites.

SAQ 1

Indicate whether the following statements are true or false:

- All secondary metabolites are dispensable for plant survival.
- Primary and secondary metabolism operates in separate compartments of plant cells.
- The pathways of primary metabolism are generally conserved among plants.
- The term 'secondary metabolites' is a 'misnomer'.
- Some phytohormones are products of secondary metabolism.
- A number of secondary metabolites are pharmaceuticals.

10.3 MAJOR CLASSES OF SECONDARY METABOLITES

With advancements in biochemical separation techniques such as High-performance liquid chromatography (HPLC), Gas liquid chromatography (GLC) and Mass spectrometry (MS) the number of known secondary metabolites has increased tremendously; more than 50% are derived from plants (approx. 100,000). A large percentage of these metabolites belong to three major groups, viz, phenolics terpenoids and alkaloids.

Many plant derived compounds were named either by plant source or its activity and hence the initial nomenclature was botanical. The existing nomenclature of plant secondary metabolites is a mix of chemical and botanical nomenclature. The secondary metabolites are not only important to the producer but from time immemorial plant extracts have been used to treat various ailments.

10.4 ALKALOIDS

Alkaloids are a diverse group of nitrogen containing secondary metabolites, generally as part of a heterocyclic ring of variable structure. They are also defined as compounds derived from amino acids' or 'nitrogen containing bases having pharmacological activities' Most of them (true alkaloids) are synthesised from a handful of amino acids, primarily aromatic

(tyrosine, tryptophan and phenylalanine) and positively charged amino acids, arginine, ornithine (non protein) and lysine. Those alkaloids which are not derived from amino acids and without a heterocyclic ring such as terpenoid alkaloids (actinidine) are grouped as pseudoalkaloids. Between the two extremes are protoalkaloids that are derived from amino acids but lack a heterocyclic ring.

The name 'alkaloids' is derived from an Arabic word (al-qali for alkaline salts originally isolated from the ashes of plant material). Most alkaloids are alkaline, bitter tasting, sparingly soluble in water and soluble in organic solvents. The names of alkaloids end in "ine", for example morphine.

10.4.1 Representative Alkaloid Groups

Alkaloids are generally colourless, non volatile, laevorotatory, low molecular weight, white crystalline solids. The structure of the carbon ring is usually used to classify them. They can also be classified according to the biological source (opium alkaloids from opium) or based on the amino acid precursor (with the exception of pseudoalkaloids).

The biosynthetic pathways of alkaloids are complex, branched and incompletely understood. As is often the case in metabolism, much of the diversity of alkaloids is created by only few types of reactions, namely decarboxylation, methylation, acylation, oxidation / reduction and glucosylation. Generally alkaloids are synthesised at a different site than where it is stored. For example, nicotine is produced in roots and then transported to leaves for storage. They are most often stored in the vacuole (acidic pH), in protonated form. We present here representative groups of alkaloids based on the structure of N-heterocycle (Table 10.1; Fig.10.1).

Table 10.1: Classification of alkaloids

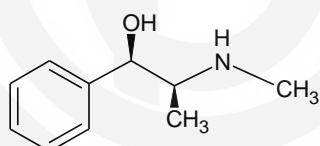
Alkaloid group	Amino acid precursor	Example(s)	Plant source
Isoquinoline	L-tyrosine	Morphine, codeine	<i>Papaver somniferum</i>
Terpenoid indole	Tryptophan (and Geraniol)	Quinine ; vinblastine / vincristine	<i>Cinchona officinalis</i> ; <i>Catharanthus roseus</i>
Pyridine and Pyrrolidine	L-Aspartic acid (Asp) Ornithine	Nicotine	Predominantly <i>Nicotiana tabaccum</i>
Tropane	L-ornithine / arginine	Cocaine;	<i>Erythroxylum coca</i>
Pyrrolizidine	L-ornithine	Senecionine; jacobine	<i>Senecio species</i>
		Anabasine;	<i>Anabasis aphylla</i> / <i>Nicotiana glauca</i> ;

Piperidine	L-lysine	coniine	<i>Conium maculatum</i>
Terpenoid alkaloids	Nitrogen is not derived from an amino acid.	Actinidine (Pseudoalkaloid)	<i>Actinidia polygama</i>
Purine	Asp, glutamine, glycine	Caffeine	<i>Coffea arabica</i>
Phenethylamine	Phenylalanine	Ephedrine (protoalkaloid)	<i>Ephedra sinica</i>
Phenethyl-isoquinoline	Tyrosine	Colchicine	<i>Colchicum ; Gloriosa</i>

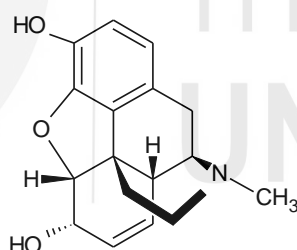
Alkaloids represent an extremely diverse group of nitrogen containing compounds that are mostly derived from a handful of amino acids. Almost all of them are alkaline in solution.

More than 12,000 have been isolated. Examples of true alkaloids include quinine, morphine and cocaine.

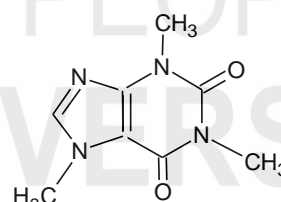
The first alkaloid to be isolated and crystallized was morphine from opium poppy (*Papaver somniferum*). Almost 50% of all known alkaloids are produced from precursors of isoquinoloid or terpene indole alkaloids. Alkaloids are stored in tissues mainly involved in active growth and reproduction. Dead and senescing tissues are often devoid of alkaloids. They are found in a few fungi (*Claviceps* or ergot fungus), pteridophytes (*Huperzia serrata*), gymnosperms (*Ephedra*) and particularly common in certain families of flowering plants such as Rubiaceae (Coffee), Papaveraceae (Poppy family), Solanaceae (nightshades) Ranunculaceae (buttercups), Fabaceae (legumes), Rosaceae (Rose family), Asteraceae (Compositae or sunflower family) and Lamiaceae (mint family). Generally a given species produces only few types of alkaloids.



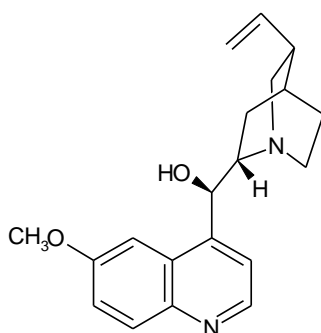
Caffeine



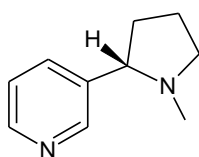
Ephedrine



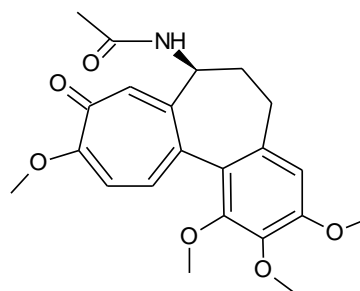
Morphine



Quinine



Nicotine



Colchicine

Fig. 10.1: Structures of some common alkaloids.

10.4.2 Functions of Alkaloids

Alkaloids were long considered as waste products of plant metabolic processes similar to urea and uric acids in animals. In this section we shall describe our current understanding of their specific role in plants and animals although there is no concrete evidence for alkaloid biosynthesis in the animal kingdom. There are well documented examples of animals that accumulate alkaloids from dietary sources.

In plants alkaloids perform a variety of roles ranging from feeding deterrents, anti microbial defense, poisons and germination inhibitors. These roles along with specific examples of alkaloids and plant sources are summarised in Table 10.2.

Table 10.2: Functions of alkaloids in plants

Alkaloid	Plant source	Role	Remark(s)
Senecionine; Nicotine; Solanine	<i>Senecio species</i> ; <i>Nicotiana</i> ; <i>Solanum tuberosum</i>	Feeding deterrents	Bitter tasting & toxic; repel herbivores / insects; herbivory / wounding induces nicotine synthesis.
Strychnine and brucine; coniine;	<i>Strychnos nux-vomica</i> ; <i>conium</i> ;	Highly toxic poisons	Poisoning is dose and host dependent
Caffeine; Quinolizidine alkaloids	<i>Coffea arabica</i> ; Legumes	Germination inhibitors	Reduces competition from other plants*.
Berberine Sanguinarine Palmatine	<i>Berberis vulgaris</i> ; <i>Sanguinaria</i> ; <i>Coptis chinensis</i>	Anti microbial defense	Protects plants from bacterial and fungal infection.
Most alkaloids		Storage reservoirs of nitrogen	
Purine alkaloids		Growth regulators	Some have resemblance to plant regulators.

***Alleolopathy** is an interaction between two plants in an ecosystem such that a chemical, for example an alkaloid, released from one plant affects the development (inhibit germination) of another plant, thereby reducing competition.

Herbivore pressure drives the evolution of alkaloids (and other secondary metabolites) as predators tend to evolve resistance. At any given point of time one of them is ahead in this arms race. There are specialist herbivores that have evolved ways to overcome the toxic effects of plant defenses, for instance, the tobacco hornworm caterpillar (*Manduca sexta*) usually feeds on Solanaceae plants like tobacco without harmful effects because they can detoxify nicotine by cytochrome P₄₅₀ system. They also emit some of the nicotine from the hornworms' spiracles (small holes on their sides) to ward off predators (spiders).

In animals there is lack of clear cut evidence for alkaloid biosynthesis. Their presence, specifically in some groups of insects is either directly from plants or indirectly from other herbivores (Fig.10.2). Very few vertebrates have been reported to accumulate alkaloids. They are put to different uses like feeding deterrents against predators, attractants and courtship pheromones. Let us now consider some specific examples.

The poison dart frog (*Phylllobates* species) accumulates steroidal alkaloids (batrachotoxins) in their skin. They are powerful neurotoxins which help in deterring predator. The toxin is acquired indirectly from plants via insects that feed on such plants.

The Monarch butterfly (*Danaus plexippus*) sequesters pyrrolizidine alkaloids in their bodies for defense. It migrates every winter from central Mexico to eastern America and Canada to breed. The larvae acquire pyrrolizidine alkaloids by feeding on milkweed leaves that are retained through adult life. The bitter tasting alkaloids serve as effective deterrents against predatory birds.



Fig. 10.2: Animals acquire alkaloids from their diet to defend against predators.

The males of scarlet bodied wasp moth (*Cosmosoma myrodora*) accumulate systemically pyrrolizidine alkaloids by feeding on excremental fluid of certain plants (*Eupatorium capillifolium*) which protect them against spiders. During courtship the males discharge the alkaloids from the abdominal pouches that covers the female topically. They also transmit the alkaloid to the female by seminal infusion to protect fertilised eggs from predators.

Evidence of evolutionary adaptation is observed for pyrrolizidine and quinolizidine compounds which are used by host-specific insects to store and exploit these dietary alkaloids for their own chemical defense. Pyrrolizidine alkaloids are toxic when broken down to pyrroles. Moths are tolerant as compared to mammals and birds because they lack the enzymes to metabolise them.

SAQ 2

- a) Which of the following are not secondary nitrogen metabolites?
- Alkaloids
 - Purines
 - Cyanogenic glycosides
 - Glucosinolates
- b) Match the alkaloid in column (A) with its role / medicinal property in column (B)

S. No.	Column A	S. No.	Column B
i.	Morphine	a.	Stimulant
ii.	Batrachotoxins	b.	Narcotic analgesic
iii.	Caffeine	c.	Sedative (reduces anxiety)
iv.	Quinine	d.	Neurotoxin
v.	Nicotine	e.	Anti-malarial drug

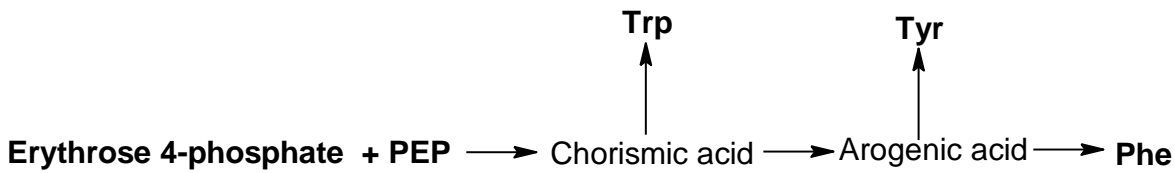
- c) Which of the following is the best description for alkaloids?
- Nitrogen containing phenol
 - Heterocyclic ring with nitrogen
 - Aliphatic compounds with nitrogen
 - Highly water soluble compounds

10.5 PHENOLICS

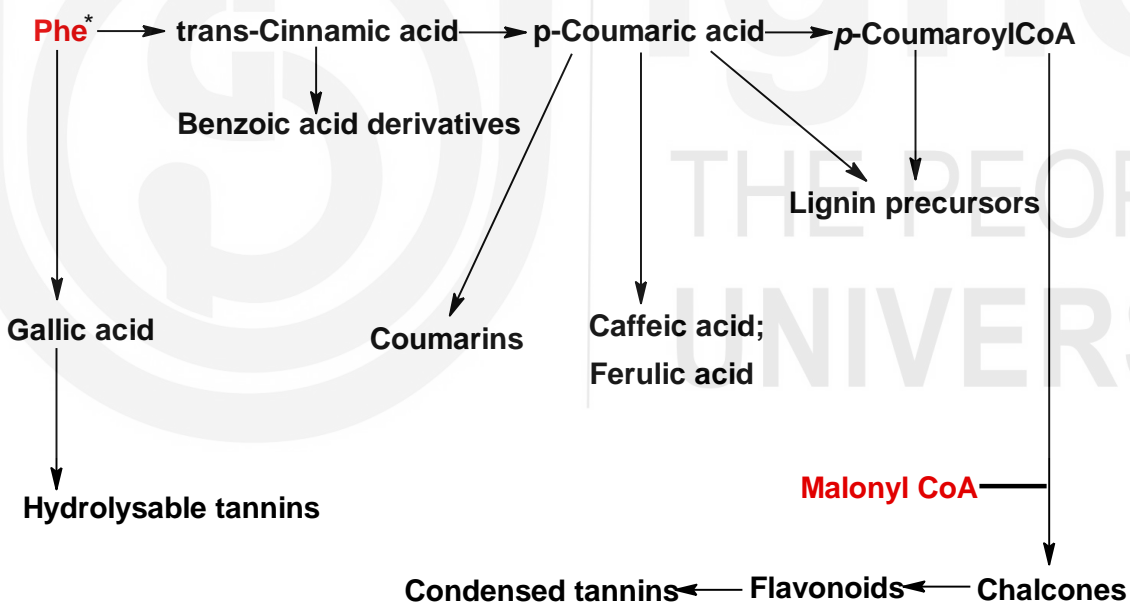
Phenolics are characterized by presence of at least one aromatic ring (C_6) with one or more hydroxyl groups. In general they are relatively more soluble in water (except polymers) than other secondary metabolites. Phenolics are present in most plants (lower plants like liverworts, mosses and ferns to angiosperms) and many microorganisms.

Phenylalanine is the major aromatic amino acid precursor for phenolic biosynthesis and most of them are made from products of the **phenylpropanoid (C₆-C₃) pathway**. Another pathway utilised for the synthesis of some plant phenolics is the **malonic acid / acetate pathway**. It provides the ring B of flavonoids. Basically phenolic synthesis can be divided into two major stages:

(a) The synthesis of phenylalanine (Phe) by shikimic acid pathway, starting from erythrose 4-phosphate (from oxidative pentose pathway) and glycolytic intermediate, phosphoenol phosphate (PEP). The immediate precursor of Phe is arogenic acid. The pathway produces all three aromatic amino acids:



(b) Phenylalanine is the precursor for simple phenylpropanoids - trans-Cinnamic acid, *p*-Coumaric acid and *p*-Coumaroyl CoA that are fed to different branches for the synthesis of most plant phenolics (Fig.10.3).



(*- phenylalanine ammonia lyase or PAL)

Fig. 10.3: An overview of major phenolic biosynthesis pathways in plants.

10.5.1 Major Phenolic Groups

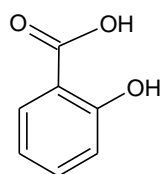
Phenolics are divided into different classes according to their carbon skeleton (Table 10.3). The most abundant phenolic groups include simple phenolics (simple phenylpropanoids, coumarins and benzoic acid derivatives), flavonoids, lignin and tannin.

Table 10.3: Classification of phenolics*

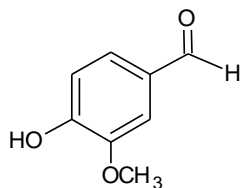
Carbon skeleton	Class	Examples	Remark(s)
(C_6-C_3)	Simple phenylpropanoids	Caffeic acid, ferulic acid, cinnamic acid.	Side chain is linear.
	Coumarins (phenylpropanoid lactones)	Coumarin; hydroxy derivatives: esculetin, umbelliferone,	The side chain is cyclised to form a ring.
(C_6-C_1)	Benzoic acid derivatives (hydroxy benzoates)	Vanillin, salicylic acid, Gallic acid,	Some are components of tannins.
$(C_6-C_3-C_6)$ (aglycone part)	Flavonoids are divided into subgroups:Chalcone,flavones, isoflavone, flavin-3-ol, flavonol and anthocyanins	Quercetin (flavonol) Delphinidin,cyanidin, pelargonidin petunidin in brightly colored anthocyanins	In chalcones the C-ring is open. Anthocyanins are anthocyanidin glycoside.
$(C_6-C_3-C_6)n$	(a)Tannins (condensed) / proanthocyanidins	(a) Flavonoid based polymers; do not contain sugar.	(a). Not readily hydrolysable; in woody plants.
	(b) Hydrolysable tannins	(b) Mixed polymers of phenolic acids - gallic acid (gallotannins) and ellagic acids (ellgitannin) / esters of simple sugars.	(b). Readily hydrolysed in dilute acid / hot water; smaller than condensed tannins
$(C_6-C_3)n$	The main monolignols of lignin are p-coumaryl, coniferyl and sinapyl alcohol. It is next to cellulose in abundance.	Gymnosperms have guaiacyl lignins derived from coniferyl alcohol. Angiosperm (hardwood): Guaiacyl-syringyl lignins, derived from sinapyl alcohol.	Branched and heterogeneous. The proportion of monolignols varies between species. Interwoven with cellulose and hemi-cellulose.

*The simplest compound with a phenolic hydroxyl is phenol itself. Although free phenol is not found in plants but present in many plant phenolic compounds.

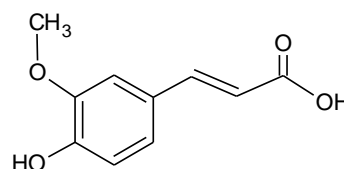
The structures of selected phenolic classes are given in Fig.10.4.



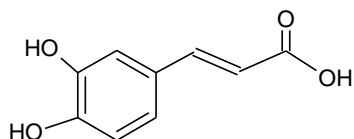
a) Salicylic acid



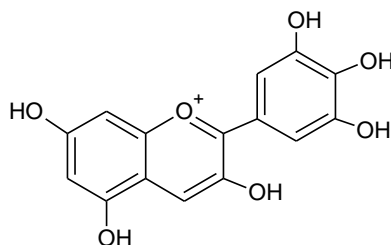
b) Vanillin



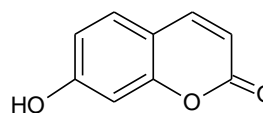
c) Ferulic acid



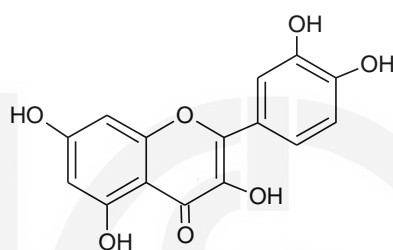
d) Caffeic acid



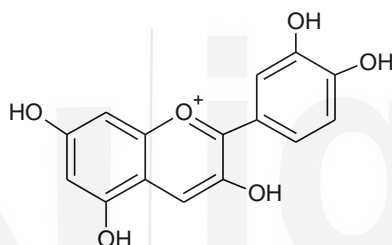
e) Delphinindin



f) Umbelliferone



g) Quercetin



h) Cyanidin

Fig.10.4: Structures of representative phenolics.

10.5.2 Biological Role of Phenolics

Phenolics represent a diverse group of chemicals with varying complexity that serve a range of biological functions in plants including defense against pathogens, herbivore deterrents and attract pollinators. In some plants they function as ultraviolet B (UV) protectants, signaling compounds & allelopathy.

An overview of their biological functions is encapsulated in Table 10.4.

Table 10.4: Biological functions of plant phenolics

Role	Phenolics	Plant source(s)	Remark(s)
Feeding deterrents	Lignin / tannins / other simple phenolics such as gingerols (in ginger) or capsiacin (in capsicum pepper)	Lignin is present in all vascular plants. Most legumes contain tannins; oak and willow tree bark / red mangrove roots are tannin rich.	Many herbivores avoid lignified tissue (indigestible & hard) and plants with high tannin content / other phenolics (bitter and astringent). Generally unripe fruits have more tannin. <i>Acacias</i> produce more tannin following browsing damage.

Poisons	Tannins		Tannins are toxic to many insects, birds and mammals. They bind proteins and inhibit enzymes.
Attract pollinators towards pollen and nectar	(a) Flavonoids (anthocyanins and other accessory flavonoids) (b) Volatile benzoic acid derivatives.	<i>Papaver rhoeas</i> (red- cyanidins); <i>Delphinium occidentale</i> (blue-delphinidin) Vanillin	Water soluble floral pigments in cell vacuole; color varies with pH, structure & presence of metals. Some co-pigments absorb UV light & are visible to insects (bees) that can see in UV range. Floral scents of vanilla orchids
Structural components	Lignin	All vascular plants.	Mechanical strength to stem and conducting vessels; impermeable / protect from microbes.
Allelopathy	Simple phenolics: (Caffeic / ferulic acids)-water soluble.	<i>Coffea arabica</i> / corn bran, egg plant, artichoke	Germination inhibitors
Fruit / seed dispersal	*Flavonoids confer vivid colors to flowers and fruits.		Aroma / pigmentation of fruits attract animal consumers and assist in seed dispersal.
Signaling molecules	(a) Salicylic acid (b) Flavonoids	Tobacco; <i>Arabidopsis</i> ; etc Legumes	(a) Plant defense (b) Specific Legume- <i>Rhizobium</i> symbiosis.
Phytoalexins (broad spectrum antibiotics)	Tannins; lignin; isoflavonoids such as medicarpin; rotenone stilbenes (viniferin)	<i>Acacia</i> leaves <i>Alfalfa</i> ; members of <i>Fabaceae</i> ; Grapevine	Many phenolics protect plants against fungal / bacterial attack; made <i>de novo</i> following browsing damage.
Protection from UV B (280-320nm)	Flavonoids such as Quercetin / Kaempferol Apigenin	Bark of <i>Quercus</i> / <i>Delphinium</i> Parsley, celery, chamomile tea	Absorb UV radiation; protect the plants by reducing its penetration and as antioxidants.
Blooming	Salicylic acid	Voodoo lily (thermogenic)	It induces heat production in the spadix of the lily, prior to flowering.

*The vivid colors of flowers and fruits and pattern are developed by flavonoids and carotenoids (tetraterpenes). In addition aroma of essential oils (mostly monoterpenes) also works along with flavonoids.

SAQ 3**a) Fill in the blanks:**

- i) All phenolics have an.....orring that usually has at least onegroup.
- ii) The two broad classes of lignin areand.
- iii) Flavonoids are group of compounds with two aromatic rings (A and B) connected bycarbon bridge that usually forms ring C.
- iv) An example of a phenolic compound involved in allelopathic interaction between plants is
- v) is a widespread signalling molecule, synthesized in response to pathogen attack in plants.

b) Pick the best option:

- i) A common biosynthetic precursor of plant phenolics is
 1. Glycine
 2. Phenylalanine
 3. Tryptophan
 4. Cysteine
- ii) Lignin present in plant cell wall confers which of the following characteristics?
 1. Mechanical strength
 2. Allelopathic effect
 3. Fragrance
 4. Insecticidal
- iii) Astringent taste of apple, tea and betel nut is due to.....
 1. Flavones
 2. Anthocyanin
 3. Phenylpropanoids
 4. Tannins

10.6 TERPENOIDS

Terpenoids represent the largest and extremely diverse group of secondary metabolites (SM) in plants that belong to a class of non saponifiable lipids. They were originally obtained from turpentine oil, produced from steam distillation of plant oleoresins, primarily conifers (pines), hence the name

'terpenoids'. Turpentine oil is a mixture of terpenes (α -pinene, β -pinene, limonene, camphene, etc) and terpenoids such as anethole (anise camphor). The two names terpene and terpenoid are not interchangeable; the former are hydrocarbons and the latter are oxygen containing analogs of terpenes. These metabolites are synthesised from a five carbon precursor, isopentenyl - pyrophosphate ('active isoprene') which in higher plants is made by two independent pathways, localised in different sub cellular compartments (cytosol and chloroplast). Therefore, they are also referred to as isoprenoids. Even animals, bacteria and fungi can synthesise terpenoids though they are not as diverse as in plants.

10.6.1 Classification of Terpenoids

All isoprenoids are made up of one or more isoprene units. The complex terpenoids are assembled by joining isoprene units using specific transferases and then modified. The final product may not always have carbon atoms in multiples of five and many are cyclised. They are classified on the basis of the number of isoprene units they are assembled from.

The terpenoids having ten carbon atoms were the first to be identified and were named monoterpene (single terpene) as they were believed to be the simplest. With the discovery of isoprene in natural plant emissions (in 1961), the simplest terpenoid was termed hemiterpene (half terpene). There are many compounds in which only part of their structure is derived from isoprene such as zeatin (cytokinin) and chlorophyll. They are classified as meroterpenes. The nomenclature of terpenoid classes based on number of isoprene units and examples is given in Table 10.5.

Table 10.5: Classification of terpenoids

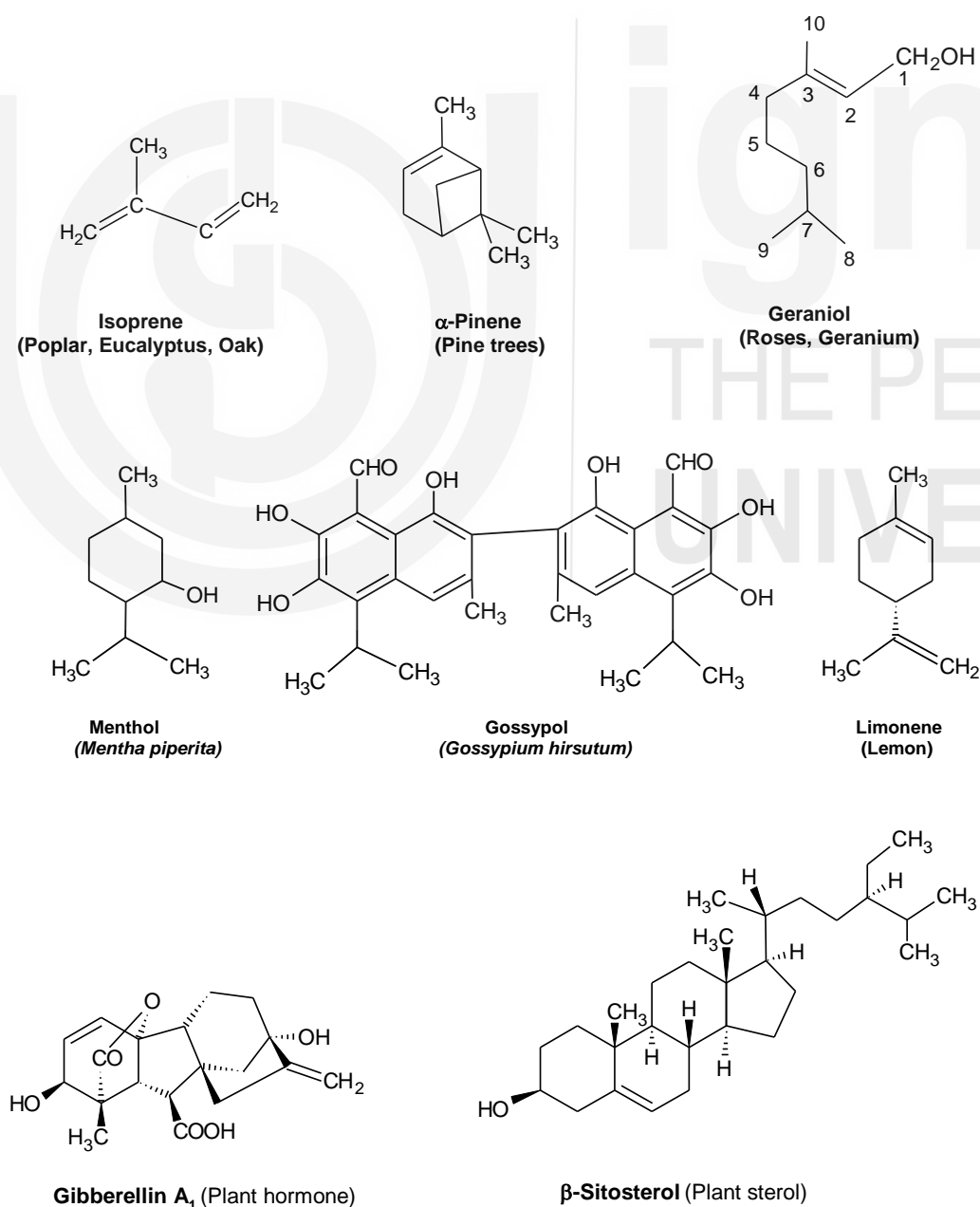
Class	No. of isoprene (C5) units	Example(s)
Hemiterpene	One	Isoprene
Monoterpene	Two	α -pinene; limonene; menthol, geraniol
Sesquiterpene	Three	Gossypol, capsidiol
Diterpene	Four	Gibberellins; taxol;
Sesterterpene	Five (rare)	(-) retigeraninB
Triterpene	Six	Brassinosteroids; sitosterol, juvabione
Tetraterpene	Eight	β -carotene; lycopene; lutein (xanthophyll)
Polyterpene	Very large	Natural rubber (cis 1,4-polyisoprenoid)
Meroterpene	Variable	Phytol chain of chlorophyll (C-20); zeatin (one isoprene + purine); Plastoquinone A (9 isoprene +quinone)

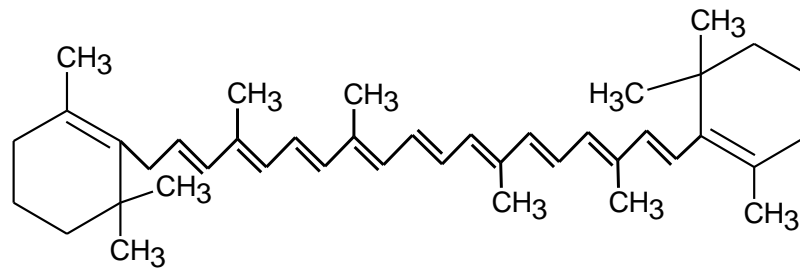
In 1887 **Otto Wallach**, a German biochemist recognised that the basic unit of all naturally occurring terpenoids is isoprene. The isoprene units can be joined in different orientations to form complex terpenes / terpenoids. According to the isoprene rule, they are joined in a head to tail fashion (C-1 of one unit is bonded to the C-4 of the next unit) but it is not a fixed rule (β -carotene has head to head linkage at their centre). Terpenes that do not obey isoprene rule are irregular terpenes.

10.6.2 Structure and Source of Representative Terpenoids

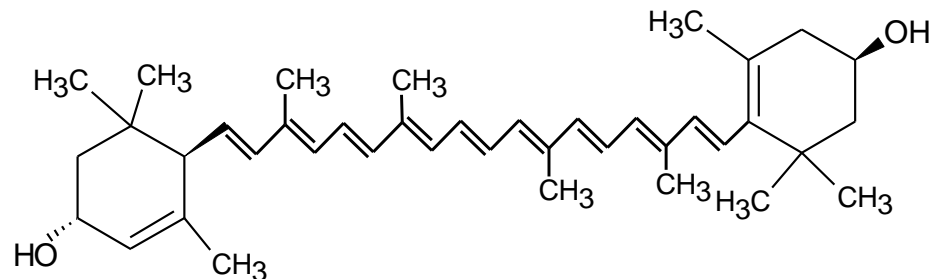
This section deals with the structure and biological source(s) of terpenes and terpenoids beginning with the simplest member, isoprene (Fig 10.5). Terpenes exist in liquid and crystalline form to extreme colloidal states. Lower terpenes form the major component of **essential oils**. Terpenoids are more polar and slightly more soluble and less volatile than terpenes. Most of them are optically active, colourless fragrant liquids, lighter than water.

Essential oils are generally a mixture of open or cyclic isoprenoids, many of which are volatile. They are hydrophobic & responsible for the characteristic aroma of flowers, seeds or leaves that are utilised to attract insect pollinators; as herbivore deterrents and in host-parasite associations.

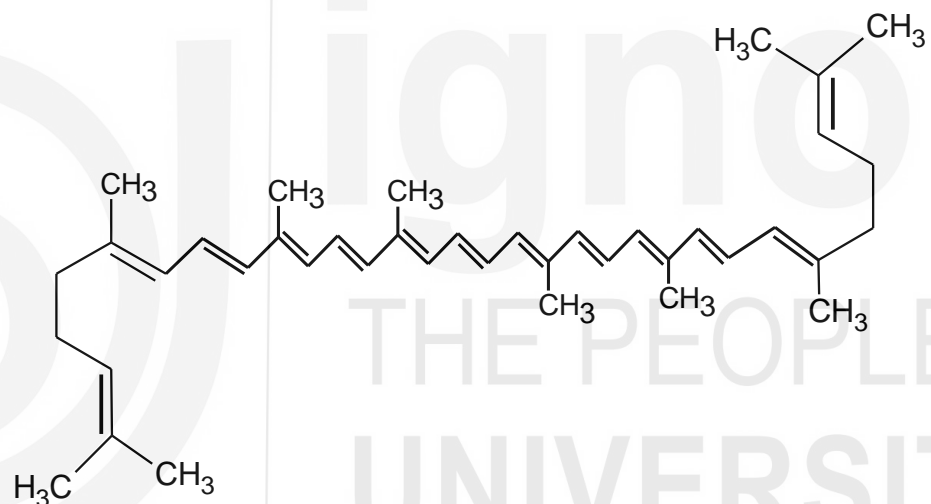




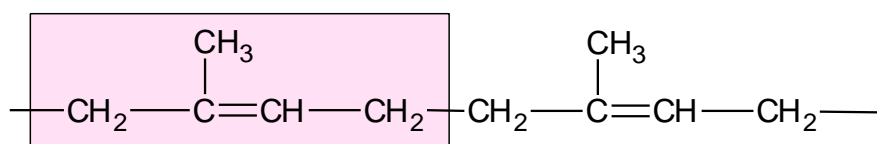
β -Carotene (Provitamin A) from carrots



Lutein; A xanthophyll from corn and green leafy vegetables



Lycopene (red pigment from ripe tomato; an acyclic tetraterpene)



Natural rubber (cis-1,4-polyisoprenoid) >300 isoprene units) obtained from the latex of rubber trees (*Hevea brasiliensis*).

Fig. 10.5: Structure and source of representative terpenes and terpenoids.

10.6.3 Biological Role of Terpenoids

Terpenoids function both as primary and secondary metabolites. Their structural diversity has been exploited in nature for diverse roles, some of which are summarised in Table 10.6. Despite our improved understanding of their roles in plants we still have a long way to go.

Table 10.6: Role of terpenoids with special reference to plants

Function	Example of terpenoid (s)	Remark(s)
Light absorption in photosynthesis	Chlorophyll and carotenoids	Carotenoids also protect from oxidative damage.
Electron carriers	Plastoquinone and ubiquinone	Photosynthetic and mitochondrial ETC, respectively.
Growth regulators	Abscisic acid; cytokinins and brassinosteroids	Phytohormones regulate various plant processes.
Membrane lipids	Sitosterol; stigmasterol; campesterol	Functionally similar to cholesterol in controlling membrane fluidity.
Sugar carrier	Dolichol-phosphate (poly-prenol)	For protein glycosylation in ER
Protection from heat stress	Isoprene (and monoterpene) emissions.	The release of isoprene is substantial at high temperatures; cools the leaf by evaporative heat loss / decomposes rapidly.
Plant-animal interactions	Sesquiterpenes (α -farnesene & germacrene) / oleoresins, Azadirachtin / phytoecdysone / volatile terpenoid mix from tomato.	Insect pollinators (bees for Kiwifruit) / herbivore deterrents or both / affect insect development / finding the right host (<i>Cuscuta</i> finds tomato)
Protein anchors	Farnesyl or geranyl are linked to the cysteine residues of proteins.	Protein is anchored to the membrane; possibly also in plants.
Phytoalexins	Casbene (C-20 from <i>Ricinus</i> ; capsidiol (C-15; from pepper)	Defense (anti bacterial / anti fungal agents)

SAQ 4

a) Ticks [\surd] mark the correct option:

- i) Terpenoids were first isolated from turpentine oil.
- ii) Terpenoids are always cyclic compounds without nitrogen.
- iii) Sitosterol is a growth promoting secondary metabolite.
- iv) Monoterpenes are isoprenoids having two isoprene units.

b) Match the items in column A with those in column B:

Sr. No.	Column A	Sr. No.	Column B
i.	Phytol	a.	Natural rubber
ii.	<i>Digitalis</i>	b.	Chlorophyll tail
iii.	<i>Brassica</i> spp.	c.	Turpentine oil
iv.	<i>Havea brasiliensis</i>	d.	Arrow toxin
v.	<i>Pinus</i> species.	e.	Brassinosteroids

10.7 APPLICATIONS OF PLANT SECONDARY METABOLITES

Secondary metabolites not only play important role(s) in overall plant survival they find a wide range of industrial applications, especially in pharmaceutical sector. The list of potentially useful chemicals is ever increasing as the search for novel metabolites from untapped sources continues. Even today a significant proportion of prescribed drugs are of plant origin and in developing countries most treatments are based on use of plant extracts by applying the knowledge gained through experience. Table 10.7 is divided into two sections; the first part deals with medicinal uses and the second is on other applications of SM.

Table 10.7: (a) Medicinal uses of secondary metabolites(SM)

Secondary metabolite	Medicinal properties	Plant source (s)	Remark(s)
Quinine; Artemisinin	Anti malarial	<i>Cinchona officinalis</i> ; <i>Artemisia annua</i>	
Vinblastine & vincristine; Taxol Kaempferol	Anti cancer	<i>Catharanthus roseus</i> ; <i>Taxus brevifolia</i> ; <i>Delphinium</i> .	Effective against childhood leukemia; Taxol: versatile drug
Colchicine	Against Gout	<i>Colchicum</i>	mitotic inhibitor
Nicotine	Reduces anxiety / induces sleep.	<i>Nicotiana tabaccum</i>	Sedative.
Morphine	Narcotic analgesic (relieves pain)	<i>Papaver somniferum</i>	Addictive and induces sleep
Ephedrine	Treatment of bronchial asthma and low blood pressure;	<i>Ephedra sinica</i>	Bronchodilator; blood vessel constrictor.

Atropine	Dilation of pupils; antidote for nerve gas poisoning; treatment for low heart rate.	<i>Atropa belladonna</i> and many members of Solanaceae.	
Reserpine, serpentine	Snake / insect bites	<i>Rauwolfia serpentina</i>	More than 50 alkaloids are known from this plant.
Yamonin	Raw material for oral contraceptive	<i>Dioscorea</i> (Yam plant)	Glycosylated steroid
Diosgenin	Antifertility; anti-proliferative, anti oxidant.	<i>Dioscorea sp.</i>	Phytosteroid sapogenin (soap like)
Salicylates	Antipyretic	Broccoli, Zucchini spinach, radish	Aspirin is (acetyl salicylic acid)
Sanguinarine	Anti-plaque / anti-bacterial	<i>Sanguinaria canadensis</i> ; <i>Eschsholzia</i>	Relieves pain especially tooth ache; added to toothpastes
Cocaine	Topical anesthetic	<i>Erythroxylon coca</i>	CNS stimulant in controlled doses
Codeine/ mint / eucalyptus / etc	Relief from cough	<i>Papaver / Mentha / Eucalyptus</i>	Controlled doses.
Ajmalicine; scopolamine	Antihypertensive	<i>Catharanthus sp</i> ; <i>Datura sp</i>	
(b) Other applications of SM			
Nicotine; pyrethrin; Rotenone	Insecticide / pesticide	<i>Nicotiana / Chrysanthemum / Lonchocarpus</i> spp.	Effective against aphids & other insects / used also in combination.
Essential oils	Perfume industry, soap making, food flavors; Ex. vanillin, menthol, linalool, eugenol	Vanilla orchid; <i>Mentha</i> ; Lavender and citrus fruits; <i>Syzygium aromaticum</i> (clove)	Mono- and sesquiterpenoids; phenolics; Volatile oils

Turpentine oil	Paints & varnishes	<i>Pinus</i> species	
Tannin (vegetable)	Leather industry	Many types / parts of plants	Converts raw animal hide into leather.
Antioxidants	Added to fuels, lubricants, drugs, cosmetics, food	Many flavonoids	Protect against heart diseases / cancer
Phorbol esters	Tumour promoting	<i>Croton tiglium</i>	Medical research

SAQ 5

Indicate two medicinal properties for each of the three major groups of secondary metabolites (alkaloids, terpenoids and phenolics).

Alkaloids: (a) (b)
 Terpenoids (a) (b)
 Phenolics: (a) (b)

10.8 SUMMARY

- Metabolites that are involved in basic cellular processes such as growth, development and reproduction are primary metabolites. The pathways producing them constitutes primary metabolism and is indispensable for survival.
- Plants also synthesise a vary array of compounds that are grouped as secondary (specialised) metabolites. They were believed to be byproducts / wastes of primary metabolism. A large percentage of these metabolites belong to three major groups, viz, phenolics terpenoids and alkaloids. SM are synthesised from precursors derived from primary metabolism.
- Now we know that an increasing number of primary metabolites, for example phytohormones (gibberellins and abscisic acid), are also produced by so called secondary metabolism. Therefore the clubbing of metabolites of unknown function as 'secondary' is indicative of our ignorance. The distinction between primary and secondary metabolites is getting blurred and seems arbitrary.
- Many secondary metabolites often have an ecological role such as attract pollinators; deter herbivores; adaptation to stress; defence against pathogens and allelopathic interactions. A given plant genera synthesises few such chemicals unlike products of primary metabolism.

- Alkaloids are a diverse group of nitrogen containing secondary metabolites, generally as part of a heterocyclic ring of variable structure. Most of them (true alkaloids) are derived from amino acids. They are generally colourless, non volatile, laevorotatory, low molecular weight, white crystalline solids.
- Phenolics are characterized by the presence of at least one aromatic ring (C_6) having one or more hydroxyl groups. In general they are relatively more soluble in water (except polymers) than other secondary metabolites.
- Terpenoids are aliphatic or cyclic compounds derived from isoprene. They represent the largest and extremely diverse group of secondary metabolites (SM) in plants that belong to a class of non saponifiable lipids.
- Secondary metabolites find a wide range of industrial applications, especially in pharmaceutical sector. The list of potentially useful chemically is exponentially increasing.

10.9 TERMINAL QUESTIONS

1. Differentiate primary vs. secondary metabolism in plants.
2. Indicate the role of flavonoids with specific examples.
3. Describe role of alkaloids in plants.
4. Compare the following pairs:
 - a) Condensed and hydrolysable tannins.
 - b) Carotenoids and anthocyanins.
 - c) Anthocyanidin and anthocyanin
5. What are isoprenoids? Indicate the various classes of isoprenoids with examples.

10.10 ANSWERS

Self Assessment Questions

1.
 - a) False
 - b) False
 - c) True
 - d) True
 - e) True
 - f) True

2. a) i)
- b) i-b; ii-d; iii-a; iv-a; v-c
- c) ii)
3. a) i) Phenyl / benzyl; hydroxyl
- ii) Condensed; hydrolysable
- iii) Three
- iv) Ferulic acid
- v) Salicylic acid
- b) i) 2.
- ii) 1.
- iii) 4.
4. a) i) True
- ii) False
- iii) False
- iv) True
- b) i – a; ii – d; iii – e; iv – b; v – c
5. Refer to table 10.5 / any other

Terminal Questions

1. Primary metabolism: Synthesises metabolites that are involved in basic processes such as growth, development and reproduction / indispensable for survival / conserved pathways.

Secondary metabolism: It refers to reactions / pathways involved in the synthesis of secondary / specialised metabolites. They are synthesised from precursors derived from primary metabolism and exhibit enormous diversity; a given plant species produces only some of them. These metabolites participate both in basic cell functions (primary metabolism) and specialised ecological roles (secondary metabolism).

2. Role of flavonoids (Refer to Table 10.4)
- i) Anthocyanins: attract pollinators and seed dispersers;
- ii) Signalling molecules: In establishing specific legume-*Rhizobium* symbiotic association.
- iii) Phytoalexins (broad spectrum antibiotics)
- iv) Protection from the harmful effects of UV B radiations and against excessive light.

3. Refer to Table 10.2
4. Compare the following pairs:
 - a) Condensed tannins: Flavonoid based polymers / do not contain sugar /not readily hydrolysable / found in woody plants.
Hydrolysable tannins: Mixed polymers of phenolic acids / esters of simple sugars / readily hydrolysed in dilute acids / oak wood / chestnut wood /smaller than condensed tannins.
 - b) Carotenoids: Tetraterpenoids / lipid soluble / present in plastid membranes or as crystalloids in stroma / Ex. lycopene, β -carotene, zeaxanthin / role in light absorption; antioxidant; impart colours to fruit, flowers & some roots.
Anthocyanin: Phenolics (glycosides of anthocyanidins) / water soluble pigments / dissolved in the vacuolar sap /examples: pelargonidin anthocyanin and delphinidin anthocyanin (flower pigments).
 - c) Anthocyanidin: aglycone part of an anthocyanin; Ex. delphinidin, cyanidin / more soluble in alcohol than anthocyanins; unstable.
Anthocyanin: glycosides of anthocyanidins; Ex. cyanidin3-O-glucoside / soluble in water and alcohol; stabilised by glycosylation / other modifications.
5. Isoprenoids are compound derived from isoprene. They are classified based on the number of isoprene units they are made up of. Refer to Table 10.5 for classification and examples.

10.11 FURTHER READINGS

1. Heldt, H. Walter Plant Biochemistry, 3rd Ed, 2005, Elsevier Academic Press, USA.
2. Bowsher, C; Steer, M. and Tobin, A, Plant Biochemistry, 1st Ed, 2008, Garland Science, Taylor and Francis Group, LLC.
3. [www. Britannica.com / science/ alkaloids](http://www.Britannica.com/science/alkaloids)
4. <http://Learn.genetics.utah.edu>; Go to the home page and select insect herbivores Vs plants.



ignou
THE PEOPLE'S
UNIVERSITY