ABSTRACT

Nature is a treasure hunt of novel molecules which are extensively used by humans for their medicinal values for millennia. Herbal medicines have emerged as life savers all over the world due to their multifunctional and diverse array of activities on the human body. Plants supply numerous bioactive molecules which are capable of treating disease conditions. Plants produce varieties of phytochemicals which are commonly recognized as primary and secondary metabolites. Secondary metabolites are inimitable resources for exploitation for pharmaceuticals, food additives e.t.c. They are often involved in the control of abiotic or biotic stress. They play distinctive roles in the defense mechanism of plants, act as insect repellent, regulate signaling pathways, and also exhibit varied range of pharmacological actions such as antibacterial, antioxidant, anticancer anti-diabetic and others. Secondary metabolites are derived from one or mixed pathways that give rise to formation of various compounds i.e., alkaloids, volatile oils, tannins, glycosides and resins etc. which have great importance in modern medicine. Isopentenyl diphosphate and Shikimic acid pathway serve as primary precursors for the synthesis some of types of secondary metabolites. The present review deals with the brief introduction, significance of secondary metabolites in the plants, biosynthetic pathways, and therapeutic importance of some commonly known secondary metabolites.

*Corresponding author: E-mail: ashwini20armarkar@gmail.com;
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1. INTRODUCTION

Nature is widespread and vast in its diversity with the evolution of several billion years ago. The total number of reported plant species is 25,000, 30,000 million species of insects, and millions of prokaryotes are still in existence [1]. Plants have been vital and stunning source of medicines to mankind since ancient periods and they have provided humanity with numerous bioactive compounds. These structurally diverse bio-active compounds are capable of treating pathological conditions. With the efficiency in recent extraction methods, it has made possible for man to extract and isolate various secondary metabolites which are found in both plants and microbes. Herbal medicines have received much more attention in the recent past and are used as medicine all over the globe [2]. Half of the total populations in all the developing countries are still reliant upon herbal drugs for the cure or treatment of several diseases. The massive utilization of herbal products described in ancient books such as Vedas and by the tribal community are mainly obtained from medicinal plants and traditional herbs that are traced for their biogenetic origin [3].

2. SECONDARY METABOLITES AND THEIR ROLE IN PLANTS

Secondary metabolites are considered as the by-products of plant metabolism. Plants synthesize a diverse chemical compounds or phytochemicals known as primary or secondary metabolites. The primary metabolites are involved mainly in growth, reproduction, and photosynthesis [3]. Unlike primary metabolites, secondary metabolites are not involved in growth but found to plays major roles in plant defense mechanisms and are also utilized by a human for their medicinal value. Evidences shows that the production of secondary metabolites increases when a plant is attacked by herbivores or pathogens [4]. Numerous types of secondary metabolites are produced by plants, which have been subsequently utilized by humans for their valuable roles in diverse array of applications i.e., used as colorants, medicine and flavoring agents [5]. These secondary metabolites have been found to play major roles in plant defense mechanisms, many of them act as insect repellents and also serve as attractants for pollinators, specific odors, tastes, and impart color to plants, Fig.1. Some are involved in the control of biotic and abiotic stress, signaling, and regulation of primary metabolites [6].

![Fig. 1. Schematic representation of plant synthesizing primary and secondary metabolites and their significant role](image-url)
2.1 Classification of Secondary Metabolites and their Biosynthetic Pathways

Secondary metabolites can be categorized based on their chemical nature and the biosynthetic pathway involved in their synthesis. Most of the secondary metabolites are formed from just a few building blocks; the phenylalanine/tyrosine-derived C9-unit (phenylpropanoids), the acetate C2-unit (polyketides) and the isopentenyl diphosphate C5-unit. The Shikimic acid pathway is the key precursor for the biosynthesis of various amino acids and also serves as an intermediate in the formation of flavones, coumarins, and tannins Scheme.1 [7].

2.1.1 Alkaloids

A German scientist “Meissner” coined the term alkaloids for the first time in 1819. The term “alkaloids” represents alkaloid-like substances which are basic compounds containing nitrogen incorporated in their heterocyclic ring. The alkaloids are widespread in various families like Liliaceae, Solanaceae, Apocynaceae, etc. In plants, alkaloids act as a reservoir of nitrogen supply [8]. They are mostly colorless except berberine which is yellow coloured and are crystalline solids except for nicotine and coniine which are liquid and volatile. Alkaloids are soluble in organic solvents but insoluble in water [9]. The first-ever isolated alkaloid was Narcotine in 1803 by a French scientist followed by isolation of Morphine from opium in the same year by Serturner which was then marketed by Merck in 1827. Alkaloids have broad spectrum of therapeutic activities like antimalarial, anticancer, stimulant and analgesic. Based on their biosynthetic pathway and heterocyclic ring system; the compounds have been classified into different classes including purine, imidazole, pyrrolizidine, pyrrolidine, indole, tropane, piperidine, quinolizidine, and isoquinoline alkaloids [8].

Scheme 1. Production of amino acids via Shikimic acid pathway
Alkaloids are classified into the following types:

a) **True alkaloids**: They originate from amino acids and contain nitrogen in their heterocyclic ring and exert physiological activity. Their examples include opium and atropine.

b) **Proto alkaloids**: They are simple amines in which nitrogen is not part of their heterocyclic ring, examples include colchicine and ephedrine among others.

c) **Pseudoalkaloids**: They are not derived from amino acids but respond to standard qualitative tests of alkaloids, examples are conessine and caffeine.

Based on the above classification, the structures of some isolated alkaloids are shown in Fig. 2.

Table 1 summarizes various alkaloid containing crude drugs obtained from various parts of plant and their therapeutic activity.

**2.1.1.1 Biosynthetic pathway of Alkaloids**

The biosynthesis of different groups of alkaloids have been studied to some extent using radioactively labeled precursors. Most alkaloids are derived from decarboxylation of amino-acid precursors (i.e. tyrosine, tryptophan, ornithine, lysine, and histidine) to yield their respective precursors (i.e. tyrosine, tryptophan, ornithine, etc.). The plausible biosynthetic pathways involved in the production of some important classes of the alkaloid are discussed below.

**2.1.1.2 Biosynthetic pathway of Papaverine**

Benzylisoquinoline alkaloid, “Papaverine” is isolated from the latex of opium poppy and used for its vasodilatory and spasmytotropic activity. 3,4-dihydroxy phenyl pyruvic acid serve as starting precursor for the biosynthesis of papaverine, which is followed by the formation of Norlaudanosoline carboxylic acid that yields Norlaudanosoline (tetrahydro papaverine). The Norlaudanosoline is a key intermediate in the biosynthesis of papaverine, Scheme. 2. In the final step of the synthesis, tetrahydro papaverine is aromatized to papaverine [11].

**2.1.1.3 Biosynthetic pathway of Tropane alkaloids**

Ornithine acts as a primary precursor in the synthesis of tropine, a class of tropane alkaloids that are chiefly distributed in plants like Datura, belladonna acting on the central nervous system. In the first step of atropine synthesis, ornithine undergoes methylation to form N-methyl ornithine its further decarboxylation yields N-methylputrescine compound that on oxidation results into formation of 4-(methyl-1-amino) butanal, which under normal physiological conditions is thought to spontaneously rearrange into N-methyl-Δ¹-pyrroline the five-membered ring compound shown in Scheme. 3 [12].

![Fig. 2. Structures of isolated alkaloids](image-url)
| Sr. No | Crude Drug | Part of plant used | Chemical constituents isolated | Therapeutic activity Reported |
|--------|------------|---------------------|--------------------------------|-------------------------------|
| 1.     | Rauwolfia  | Roots               | Reserpine, Rescinnamine        | Hypotensive, tranquilizers    |
| 2.     | Belladonna | Leaves              | Atropine, l-hyoscyamine        | Antispasmodic                 |
| 3.     | Nux-vomica | Seeds               | Strychnine, brucine            | CNS stimulant                 |
| 4.     | Opium      | Latex               | Morphine, codeine, papaverine  | Narcotic analgesic            |
| 5.     | Vinca      | Entire plant        | Vincristine, vinblastine       | Anticancer                    |
| 6.     | Cinchona   | Root or stem bark   | Quinine, quinidine             | Antimalarial, Bitter tonic    |
| 7.     | Kurchi     | Bark                | Conessine, isoconessien        | Antiamoebic                   |
| 8.     | Datura     | Leaves              | Scopolamine, hyoscyamine       | Anticholinergic               |
| 9.     | Vasaka     | Leaves              | Vasicine and vasicinone        | Antitussives and expectorant |
| 10.    | Coffee     | Ripe seeds          | Caffeine                       | Stimulant                     |
| 11.    | Ashwangdha | Roots               | Withanolides, withaferine      | Sedative                      |
| 12.    | Ephedra    | Stems               | Ephedrine, pseudoephedrine     | Antiasthmatic                 |
| 13.    | Berberis   | Roots and rhizomes  | Berberine                      | Astringent                    |
| 14.    | Hyoscyamus | Flowering top and dried leaves | Hyoscine | Antispasmodic |
| 15.    | Lobelia    | Dried leaves and tops | Lobelanidine, lobeline        | Respiratory stimulant         |
| 16.    | Colchicum  | Corm and seeds      | Colchicine                     | Induction of polyploidy and antirheumatic |
| 17.    | Ipecacuanha| Roots and rhizomes  | Emetine, cephalin              | Antiamoebic, emetic           |
| 18.    | Aconite    | Roots               | Aconitine                      | Antirheumatic                 |
| 19.    | Duboisia   | Leaves              | Scopolamine                    | Anticholinergic               |
| 20.    | Pilocarpus | Leaves              | Pilocarpine                    | Anticholinergic               |
| 21.    | Tea        | Leaves              | Theophylline, theobromine      | Diuretic, CNS stimulant       |
| 22.    | Phyostigma | Seeds               | Phystostigmine                 | Hypotensive, In glaucoma      |
| 23.    | Coca       | Leaves              | Cocaine                        | Local anesthetic              |

### 2.1.1.4 Biosynthetic pathway of l-hyoscyamine

L-hyoscyamine belongs to a class of tropane alkaloids which exerts anticholinergic and diuretic effect. The plausible biosynthetic pathway involved in the synthesis of l-hyoscyamine uses phenylalanine as starting precursor that converts phenyl pyruvic acid into tropic acid followed by the addition of tropine which is biosynthesized from ornithine, that leads to the formation of l-hyoscyamine as shown in Scheme. 4 [7].

### 2.1.2 Flavonoids

The word flavonoid was derived from Latin word ‘flavus’ which means yellow. Flavonoids are a class of low molecular weight polyphenolic compounds having 15 carbon atoms present in the form of a C6-C3-C6 skeleton. Flavonoids exist in a free-state or glycoside form in plants [13]. They are mostly yellow-colored substances except anthocyanins which are blue, red or purple in color. They are widely distributed in seeds, vegetable fruits, herbs, spices, stems, and flowers. Flavone, flavone, flavan-3-ols, isoflavones, anthocyanidins and flavanones, naringin are some of the commonly known flavonoids which are produced by plants and are abundant in families of Umbelliferae, Rutaceae, Leguminosae, and Compositae [14]. Flavonoids are associated with a broad spectrum of health-promoting effects and play crucial roles in
nutraceutical, pharmaceutical, medicinal and cosmetic applications [15]. They show a wide range of biological activities like antioxidant, antimicrobial, anticancer, etc. The natural sources of flavonoids include fruits, vegetables, legumes, etc. In plants, flavonoids play major roles in protection against different abiotic and biotic stresses. They are also involved in the pigment or aroma of flowers and attract pollinators. The structures of some important classes of flavonoids can be seen below Fig. 3.

The flavonoids can be classified according to their dietary sources, from which they are obtained; chemical constituents isolated and therapeutic activity reported which is illustrated in Table 2.

2.1.2.1 Biosynthetic pathway of Flavonoids

Flavonoids are produced in the plant by the shikimic acid pathway and acetate pathway. The first step in the biosynthesis of flavonoids involves condensation of two molecules of acetate phenyl propanoid precursor along with 3 malonyl coenzyme-A units to derive polyketide as an intermediate which results in the formation of chalcone, Scheme 5. The chalcone acts as a key intermediate in the synthesis of the majority of flavonoids like flavones, flavanones, isoflavone, etc. in the plant kingdom [13].

Table 2. Flavonoids, chemical constituents, therapeutic potential and their dietary sources

| Sr. No | Class       | Chemical Constituents | Dietary sources                                      | Pharmacologic activity                  | References |
|--------|-------------|-----------------------|------------------------------------------------------|-----------------------------------------|------------|
| 1.     | Flavones    | Luteolin              | Broccoli, olive oil green pepper, rosemary, thyme,   | Anticancer and antioxidant              | [16]       |
|        |             |                       | dandelion, perilla, chamomile tea, carrots,          |                                         |            |
|        |             |                       | peppermint, carrots, peppermint, carrots             |                                         |            |
| 2.     | Flavonols   | Rutin                 | Apple, citrus fruits, Green tea, grape seeds        | Antioxidant and anti-inflammatory       | [17]       |
| 3.     | Chalcone    | Catharine             | Safflower                                            |                                         | [15]       |
| 4.     | Flavones    | Apigenin              | Milk, chocolate, commercial, reduced fat             | Anticancer, antibacterial and antioxidant | [18]       |
| 5.     | Flavanones  | Hesperedin, Naringenin| Oranges, grapes, lemons                              | Anti-inflammatory and analgesic         | [19]       |
| 6.     | Isoflavone  | Genistein             | Psoralea, beans, fats, oils, beef, red clover,       | Antidiabetic and anticancer            | [20]       |
|        |             |                       | soybeans, kudzu                                      |                                         |            |
| 7.     | Coumarin    | Scopoletin            | Coffee, Vinegar                                      | Antidepressant and antidepressant      | [21]       |
| 8.     | Flavan-3-ols| Epicatechin           | Chocolate, commercial reduced fat, milk              | Antioxidant, antiabetic                | [22]       |
| 9.     | Anthocyanidin| Pelargonidin, Cyanidin| Grapes, Blueberry                                    | Antioxidant, neuroprotective and anticancer | [23,24]   |
| 10.    | Isoflavone  | Daidzein              | Soybeans, tofu                                       | Anticancer, cardioprotective          | [25]       |
| 11.    | Flavonols   | Kaempferol            | Grapes, apples, potatoes, onions, tomatoes, green   | Antioxidant, antimicrobial, anticancer, | [26]       |
|        |             |                       | tea, cucumbers, blackberries, raspberries, spinach  | cardioprotective,                    |            |
2.1.3 Terpenoids

Terpenoids comprises of a large class of natural products with around 64000 known compounds. The term “terpene” originated from the German word turpentine. They are usually hydrocarbon molecules and their basic building block is the isoprene unit. Terpenoids are formed by oxidation or rearrangement of their carbon skeleton. Terpenoids are a prominent class of secondary metabolites produced by plants, fungi, and animals and are mostly volatile in nature, responsible for aroma of various compounds. They are chiefly distributed in Umbelliferae, Rutaceae, Zingiberaceae, and Labiatae families. They display various pharmacological actions including carminative, antiallergic, antihyperglycemic, anti-inflammatory, etc. They also play a diverse role in plants like phytol and carotenoids function as photosynthetic pigments [27] Fig. 4 represents the structures of some commonly isolated terpenoids from natural sources [7].

Terpenoids can be classified on the basis of isoprene unit and number of carbon atoms present in their structure as shown Table 3.

The list of terpenoid obtained from natural drugs, their chemical constituents and uses are briefly summarized in Table 4.

![Scheme 2. Biosynthesis of Papaverine](image)

![Scheme 3. Biosynthetic pathway of Tropine](image)
Scheme 4. Biosynthetic pathway of l-hyoscyamine

Fig. 3. Structures of the different class of flavonoids

Scheme 5. Biosynthetic pathway of Flavonoids
### Table 3. Classification of terpenoids based on isoprene unit [9]

| Sr.No | Class of terpenoids | No. of carbon atoms | No. of isoprene unit | General formula |
|-------|---------------------|---------------------|----------------------|-----------------|
| 1     | Homoterpenoids      | 5                   | 1                    | C₅H₈            |
| 2     | Monoterpenoids      | 10                  | 2                    | C₁₀H₁₆           |
| 3     | Sesquiterpenoids    | 15                  | 3                    | C₁₅H₂₄           |
| 4     | Diterpenes          | 20                  | 4                    | C₂₀H₃₂           |
| 5     | Sesterpenes         | 25                  | 5                    | C₂₅H₄₀           |
| 6     | Triterpenoids       | 30                  | 6                    | C₃₀H₄₈           |
| 7     | Tetraterpenoids     | 40                  | 8                    | C₄₀H₆₄           |
| 8     | Polyterpenoids      | >40                 | >8                   | (C₅H₈)ₙ          |

**Fig. 4. Structures of some commonly known terpenoids**

**Scheme 6. Biosynthesis of Terpenoids**
### Table 4. Crude drugs containing terpenoids and their application in medicine [28,29]

| Sr.No | Natural product | Class of terpene | Chemical constituent | Application in medicine |
|-------|-----------------|------------------|----------------------|-------------------------|
| 1.    | Camphor oil     | Monoterpenes     | Camphor, d-pinene, saffrole | Rubefacient, counter-irritant |
| 2.    | Lemongrass oil  | Monoterpenes     | Citral, citronella    | In perfumery, a flavoring agent |
| 3.    | Cumin           | Monoterpenoids   | Cuminaldehyde, phellandrene | Carminative, dyspepsia |
| 4.    | Orange peel     | Monoterpenes     | Hesperidin, Vit. C, citral | Stomachic, flavoring, and carminative |
| 5.    | Caraway         | Monoterpenes     | Carvone, carvacrol    | Stimulant, flavoring agent |
| 6.    | Fennel          | Monoterpenes     | Fenchone, anethole    | Stimulant, flavor & expectorant |
| 7.    | Coriander       | Monoterpenes     | Coriandrol            | Carminative, stimulant |
| 8.    | Garlic          | Monoterpenes     | Allin, Allicin        | Disinfectant, condiment, expectorant, rubefacient |
| 9.    | Cinnamon        | Monoterpenes     | Eugenol, cumin aldehyde | Antiseptic, carminative |
| 10.   | Musk            | Monoterpenes     | Muskone, cholestrin   | Perfumery |
| 11.   | Black pepper    | Monoterpenes     | Piperine, pipericidine| Aromatic, bioenhancer, carminative |
| 12.   | Taxus           | Diterpenes       | Taxol, deacetyl baccatin | Antitumour |
| 13.   | Coleus          | Diterpenes       | Forskolin             | Cardiostimulant, Vasodilator |
| 14.   | Annatto         | Tetraterpenes    | Bixin                 | Hepatoprotective, coloring agent |
| 15.   | Saffron         | Polyterpenes     | Crocin, picrococcin   | Flavour, antispasmodic |
| 16.   | Feverfew        | Sesquiterpenes   | Chrysanthemin A & B, patholide | In the treatment of migraine, fever, and arthritis |
| 17.   | Artemisia       | Sesquiterpenes   | Artemisin, cineole    | Anthelminitic |
| 18.   | Clove           | Sesquiterpenes   | Eugenol, Eugenia      | Dental analgesic, carminative |
| 19.   | Acorus          | Sesquiterpenes   | Acorine, asarone      | Vermifuge, carminative |
| 20.   | Sandalwood oil  | Sesquiterpenes   | α,β-santalol, santene | In dysuria, perfumery |
| 21.   | Valerian        | Sesquiterpenes   | Valerine, borneol     | In cough, antispasmodic, carminative |
| 22.   | Saussurea       | Sesquiterpenes   | Resinoids, inulin     | In asthma, disinfectant |
| 23.   | Davana oil      | Sesquiterpenes   | Davanone,non-davanone | Perfume, flavour |
| 24.   | Ambargas        | Triterpenes      | Amberin. Coprostemone | Perfumery |

#### 2.1.3.1 Biosynthetic pathway of Terpenoids

Terpenoids are biosynthesized from the precursors isopentenyl pyrophosphate (IPP) and dimethylallyl pyrophosphate (DMAPP). They undergo multiple steps of rearrangement, and cyclization reactions [29]. Two main and distinct biosynthetic pathways involved in the production of these universal precursors have been reported, the classical mevalonate (MVA) pathway and the most recently characterized 1-deoxy-D-xylulose-5-phosphate (DXP) pathway also known as 2C-methyl-D-erythritol-4-phosphate (MEP) pathway. The MEV pathway occurs in eukaryotes, cyanobacteria whereas the MVP pathway is associated with the cytosol and mitochondria of plants. The MEP pathway converts pyruvate (precursor) and glyceraldehyde-3-phosphate, to IPP and DMAPP through eight enzymatic reactions, while the
MVA pathway undergoes seven enzymatic reactions to convert the precursor acetyl-CoA to IPP and DMAPP, Scheme 6. In the biosynthetic pathway of terpenoids, there is head-to-tail addition of active isoprene unit C-5 i.e., isopentenyl diphosphate (IPP) to its isomer dimethylallyl diphosphate (DMAPP) resulting in the synthesis of geranyl diphosphate (GPP, C10). Further, condensation of enzyme-bound geranyl diphosphate with additional IPP units forms sequentially larger prenyl diphosphates e.g. farnesyl diphosphate (FPP, C15), Geranylgeranyl pyrophosphate synthase (GGPPS) and farnesyl geranyl pyrophosphate synthase (FGPPS) resulting in the synthesis of geranyl diphosphate (GPP, C10). The starting material of GPP, FPP, GGPP, and FGPP might undergo cyclization and/or rearranged by different terpene synthase enzymes to produce the different classes of terpenoids [30].

2.1.4 Glycosides

Glycosides are the most abundant secondary metabolites found in plants. They are derived from the plant through post modification of secondary metabolites which is accelerated by plant enzymes, glycosyltransferases followed by oxidation, acylation, and degradation. These are organic compounds that on acid or enzymatic hydrolysis yield sugar moiety (glycone) and aglycone (non-sugar moiety) also called genin [31]. They are widely distributed in families of the plants including Liliaceae, Leguminosae, and Polygonaceae. They exert wide range of therapeutic actions, and are used as a laxative, cardiotonic, bitter tonic, and antidiabetics. The glycone part of a glycoside is water-soluble whereas the genin or aglycone part is water-insoluble. The pharmacological actions of glycosides are attributed to aglycone moiety while saccharide influences water solubility, pharmacokinetics, and pharmacodynamics properties. Glycosides play prominent action in plants converting toxic material to non-toxic, also act as a source of energy, regulation of growth [32].

2.1.4.1 Classification of Glycosides

Glycosides are categorized based on the types of linkage present across glycone and aglycone part such as O-glycosides, C-glycosides, N-glycosides, and S-glycosides. The C-glycoside linkage is found in anthraquinone glycosides such as aloe, cascara whereas O-glycoside linkage is predominately present in plants like Senna, rhubarb, etc. The other two types of linkages present in plants is S-glycoside which is present in black mustard.

Glycosides are also classified on the basis of sugar part attached to glycone moiety. The sugars present are mostly rhamnose, fructose, and glucose and are termed as rhamnoside, fructoside, and glucoside.

Another approach for the classification of glycosides is based upon the chemical nature of genin or aglycone moiety which is depicted in the Table 5.

2.1.4.2 Biosynthetic pathway of Glycosides

The principal route of glycoside formation in plants occurs via two steps. In the first step of glycoside synthesis uridylyl group is transferred from uridine triphosphate to sugar-1-phosphate under the presence of enzyme uridylyl transferases followed by subsequent reaction of UDP i.e uridine triphosphate with aglycone moiety and the enzyme catalyzing reaction is known as glycosyltransferases which finally results in the formation of glycosides, Scheme 7 [28].

The sugar attached in glycosides is mainly fructose, rhamnose or fucose, and digitoxose in cardiac glycosides. Phenylalanine an amino acid acts as key precursor in synthesis or formation of different class of glycosides i.e., (Coumarin, Phenolic, and aldehyde glycosides) Scheme 8 [8].
Table 5. Classification of glycosides based on the chemical nature and therapeutic uses of aglycone moiety [8,33]

| Sr. No | Nature of aglycone moiety present | Example of crude drugs | Chemical constituents | Therapeutic uses |
|--------|----------------------------------|-----------------------|----------------------|-----------------|
| 1.     | Anthraquinone glycosides         | Aloe                  | Alo-emodin, barbaloin | Purgative, antibacterial |
|        |                                  | Rheubarb              | Rhein, aloe-emodin    | Purgative        |
|        |                                  | Cascara               | Cascarosides A,B,C,D,E & F | Purgative |
|        | Senna                            | Sennosides A & B      | Laxative              |                 |
|        | Hypericum                        | Hyperforin, hypercin  | Anti-depressant       |                 |
|        | Cochineal                        | Carminic acid         | Colouring agent       |                 |
| 2.     | Saponin glycosides               | Liquorice             | Glycyrrhizin           | Expectorant     |
|        | Ginseng                          | Ginsenosides, panaxosides | Adaptogen            |                 |
|        | Gokhru                           | Gilogen, diosgenin    | Diuretic              |                 |
|        | Momordica                        | Charantin, Momordicin | Hypoglycemic          |                 |
|        | Brahim                           | Bacosides A & B       | Nerve tonic           |                 |
|        | Centella asiatica                | Asiaticoside, Asiaticoside A | Adaptogen, antidepressive |             |
|        |                                   | Milk vetch            | Isoastragalosides I and II, cycloartanes | Antiviral, hepatoprotective & adaptogenic |
|        | Senega                           | Senegin, polygallic acid | Stimulant expectorant |             |
|        | Dioscorea                        | Diosgenin, smilagenin | Synthesis of corticosteroids, rheumatic arthritis |                 |
| 3.     | Isothiocyanate glycosides        | Black mustard         | Sinigrin              | Emetic, counter-irritant |
| 4.     | Flavonoid glycosides             | Gingko                | Gingkolide A,B, C & ginkgetin | In asthma, vascular disorders |
|        | Buck wheat                       | Rutin                 | Retinal hemorrhages   |                 |
|        | Milk thistle                     | Silymarin             | Hepatoprotective      |                 |
|        | Knotweed herb                    | Quercetin, hyperoside | Diuretic, anti-rheumatic |             |
|        | Citrus fruits                    | Hesperidin            | In capillary fragility |                 |
| 5.     | Phenol glycosides                | Melissa Leaf          | Chlorogenic and rosmarinic acid | Antispasmodic, anti-inflammatory |
|        | Bearberry                        | Arbutin, ursone       | Diuretic and in cystitis |                 |
|        | Meadowsweet                      | Monotropitin          | Anti-inflammatory     | Anti-microbial Anti-rheumatic |
|        | Populi folium                    | Salicin, populin      | Anti-microbial        | Anti-rheumatic Anti-pyretic |
|        | Willow Bark                      | Salicortin, tremulacinn, | Antipyretic effect Anti-rheumatic |             |
| 6.     | Aldehyde glycosides              | Vanilla               | Vanillin, glucovanillic acid | Perfumery and flavoring agent |
| Sr. No | Nature of aglycone moiety present | Example of crude drugs | Chemical constituents | Therapeutic uses |
|--------|----------------------------------|------------------------|----------------------|-----------------|
| 7.     | Coumarin glycosides              | Angelica Root          | Angelicin, bergapten | Used in dyspeptic, spasms |
|        |                                  | Horse-Chestnut Bark    | Esculin, scopoletin  | Antioxidant     |
|        |                                  | Tonka bean             | Coumarin             | Flavoring agent |
|        |                                  | Ammi                   | Xanthotoxin          | In the treatment of vertigo |
|        |                                  | Cantharides            | Cantharidin          | Counter-irritant, rubefaciency |
|        |                                  | Psoralea               | Psoralen, corylifolin | In the treatment of leucoderma |
|        |                                  | Visnaga                | Khellin, visnagin    | Coronary vasodilator |
| 8.     | Cardiac glycosides               | Digitalis              | Digitoxin, Purpurea glycoside | Cardiotoxic |
|        |                                  | Indian squill          | Scillaren A & B      | Cardiotoxic     |
|        |                                  | Ouabain                | Ouabagenin           | Carditonic      |
|        |                                  | Thevetia               | Theventin, Thevenerin | Cathartic, Emetic |
|        |                                  | Strophanthus           | K-strophanthoside,   | Cardiotoxic     |
|        |                                  |                        |                      |                 |
| 10.    | Steroidal-Glycoalkoids           | Solanum                | Solasodine           | Synthesis of steroidal Drugs |

Scheme 8. Biosynthetic route for the formation of Coumarin, aldehyde, and phenolic glycosides
3. CONCLUSION

Nature is a remarkable source of wonderful complex molecules which has been exploited by humans to alleviate disease or ailments. Plants are a proven source for producing medicinally active compounds known as primary and secondary metabolites. Secondary plant metabolites are 'bioactive compounds showing pharmacological or toxicological effects in man and animals. Secondary metabolites synthesize numerous phyto compounds which have diverse range of therapeutic activities. Several life-saving drugs manufactured and supplied by pharmaceutical companies are semi-synthetic derivatives of natural products which serve as valuable drug entities. They are considered as products of 'biochemical sidetracks' in the plant cells that help in the growth and development of plants, with no essential role in the maintenance of life processes. Several of them are found to play role in protection, attraction, or signaling. Numerous crude drugs such as cinchona, taxol, and many more have received high market value since the last decade for their ability to treat several infectious and non-infectious diseases like malaria, cancer, diabetes and leprosy, etc. Researchers need to focus more on recent extraction techniques which will aid in the faster extraction, isolation and genetic bioengineering methods to improve yield of these vital secondary metabolites. More herbal plants need to be explored to discover their hidden therapeutic potentialities. The cure to the ingress of new and several deadly diseases in the human population could also be found in plants we never know. Therefore, the fundamental biogenetic pathway for the formation of various secondary metabolites using radioactive labeled isotope tracer studies should be investigated.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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