CHAPTER - I

INTRODUCTION

History of traditional medicinal system, Global Herbal Market, Natural Products in the field of Drug Development, Types of Natural Products, Chemistry of Gums and Resins, Physical properties of gums and resins, Important Gums and Resins Available and Traded in India, Chemistry of Natural occurring compounds.
Chapter-I

I-1 INTRODUCTION

“There is no man on this earth who is incompetent and there is no plant which has no medicinal use. Where everything is present, in fact, a man to manage them properly is seldom available”.

“There is no substance in the universe which cannot be used as a drug for rational objectives”.

[Charak Samhita: su: 26: R] 10,30

Ayurveda, which is known as the ancient healing system of India, flourished in the Vedic era. According to historical facts, the classical texts of Ayurveda, “Charaka Samhita” and “Sushruta Samhita” were written around 1000 B.C.

The planet Earth is known to be 4.7 billion years old, on which the basic organisms evolved around 3.5 billion years ago. The first terrestrial plant appeared about 425 million year ago on the Earth.
The *Homo sapiens* appeared about 30,000 to 40,000 B.C. on the earth. Apart from hunting, food gathering, food producing, the human being also started looking for the possibilities of health care for longevity and control of diseases\(^1,^2\).

The **Ayurvedic Material Medica** includes 600 medicinal plants along with therapeutics. Herbs like turmeric, fenugreek, ginger, garlic and holy basil are integral parts of Ayurvedic formulations.\(^3\) The formulations incorporate single herb or more than two herbs (poly-herbal formulations).

The history of traditional medicine system, which incorporates plant materials as main constituent, traced back in the middle Paleolithic age. Millions of households have been traditionally using medicinal plants for cure of humans and animal diseases and also used as food supplement.\(^8,^{44}\) About 8000 species of medicinal plants are used by 4,635 ethnic communities’ curse for meeting the needs and aspiration of present and future generation.

**I-2 Global Herbal Market:**

Indian system of medicine has documented 1800 species of medicinal value, in which nearly 880 species are being traded in India.\(^{16,22}\) Out of these 880, species 538 (61%) are procured from forest, 88 species (10%) are from
cultivation, 212 species (25%) are sourced both from forest as well as cultivation and 42 species (4%) are imported from different countries.

The **World Health Organization** has estimated that the herbal market will grow up to 5 trillion dollars by 2050 A.D. at growth rate of 20% per annum from present level of 76 billion dollar. Out of this, European Union accounts for about 50%, Japan 16% and USA 11% of share. Asian countries together share is only 19%, in which India accounts for less than 0.3% of total herbal medicines market.\(^{48}\)

The **World Conservation Union Medicinal Plant Specialist Group** has globally assessed 2,70,000 plant species out of which 33,798 species identified as being at risk of extinction and 380 plant species are registered as extinct in the wild vegetation.

In present scenario the pressure on forest wealth of medicinal plant is too much because, Epidemiological surveys show preferences by pharmaceutical companies, practitioner and consumers for wild gathered species on the belief that wild vegetation plants are more powerful.

To ease the existing pressure on traditional forests it is significant to do monitoring of abundance and distribution, assessment of annual yields and records of the harvest practices.\(^{49}\)
Assessment of crude herbal demand in the market has become an extremely difficult task, which requires pre-planned strategies and methods, after involving several possibilities including government policies, public perceptions, and product efficacy based on scientific basis and building excellent organizational structures.

Five strategic areas have been identified for global herbal market such as phyto-pharmaceuticals, Botanical medicinal extracts, Nutraceuticals, Cosmeceuticals and Herbal raw materials.

The medicinal plants required in crude form in above industries can be procured either from forest or by cultivation outside the forest on large scale. Due to unorganized herbal market the middleman play key role in procuring the raw plant material from forest to meet 90% of their total demand. Only 10% of the herbal plant material demand is met from cultivation.

This situation must be changed by promoting cultivation of medicinal plants on large scale by extending various incentives and subsidies to the farmers and also by creating awareness about it. This will lead to check on depleting forest resources and also exploitation of tribal people who actually gather raw plant material from wild.²⁹
I-3 Natural Products in the Field of Drug Development:

Natural products coming from various source materials including plants, micro-organism, marine organisms, vertebrates and invertebrates have importance as they provide an outstanding source of new drugs as well as new drug leads and new chemical entities for further drug development.\textsuperscript{26} 

**Morphine, Vincristine, Codeine, Digitoxin, Quinine, Galantamine** and **Taxol** are just some of the typical examples of drugs that have been introduced from natural sources.\textsuperscript{39, 57}

Plants produce primary and secondary metabolites which encompass a wide array of functions.\textsuperscript{14, 59} Plant secondary metabolites may be referred to as plant natural products, in this case them illicit effects on other organisms.

A natural product is a chemical compound or substance produced by a living organism, found in nature, that usually has a pharmacological or biological activity for use in pharmaceutical drug discovery and drug design.

Natural products often have an ecological role in regulating the interaction between animals, insects, plants and other micro-organism. They can be defensive substance, attractants, pheromones and anti-feedants.
DIGITOXIN

MORPHIN

CODIENE

GALANTAMINE

QUININE
VINCRISTINE

PACLITAXEL (TAXOL)
Average import of Ayurvedic, Unani, Homeopathic and Alkaloid from India (During year 1999-2003).

User profile of Medicinal Plants in Percentage.
Table: 1

Import of Ayurvedic Unani Homeopathic and Alkaloid

<table>
<thead>
<tr>
<th>Year</th>
<th>Ayurvedic &amp; Unani</th>
<th>Homeopathic</th>
<th>Alkaloid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996-1997</td>
<td>3640.05</td>
<td>3395.02</td>
<td>126.21</td>
</tr>
<tr>
<td>1997-1998</td>
<td>1637.19</td>
<td>507.04</td>
<td>102.13</td>
</tr>
<tr>
<td>1998-1999</td>
<td>3761.57</td>
<td>1863.54</td>
<td>171.63</td>
</tr>
<tr>
<td>1999-2000</td>
<td>3934.49</td>
<td>3956.77</td>
<td>146.06</td>
</tr>
</tbody>
</table>


I-4 Types of Natural Products:

Naturally occurring compounds may be divided into three major categories⁶ these are:-

1. Primary metabolites:

These are that compounds which occur in all living cells and play vital role in those cells. Primary metabolites, which include amino acids, simple sugars, nucleic acids, and lipids, are compounds that are necessary for cellular processes.
2. High Molecular Weight Polymeric Compounds:

These are the high molecular weight polymeric compounds such as the Proteins, the Lignins and Cellulose which form cellular structure.

3. Secondary Metabolites:

These are those compounds which have a characteristic of being limited to range of species. Most primary metabolites exert their biological effects within the cell or organisms that are responsible for their production. On the other hand, Secondary metabolites attract towards interest because of their biological effect on the other organisms.

Secondary metabolites include compounds, produced in response to stress, such as the case when acting as a deterrent against herbaceous.\textsuperscript{25, 26} Plants can manufacture many different types of secondary metabolites, which have been subsequently exploited by humans for their beneficial role in a diverse array of applications.

Secondary metabolites, small molecules which are not essential for the growth and development of the producing organism have importance because of their biological activities on other organisms.
“Natural product” term refers to any naturally occurring compounds but in most cases mean secondary metabolite\textsuperscript{15, 18}.

Secondary metabolites mainly consist of these following groups: \textsuperscript{59}

- Terpenoids and Steroids
- Fatty acid derivatives
- Alkaloids
- Phenylpropanoids
- Non-ribosomal polypeptides
- Enzyme cofactors. etc

I-5 Chemistry of Gums and Resins:

Gums and resins are one of the important non-timber forest products (NTFP) of India.\textsuperscript{18} Their importance can be observed in many areas like livelihood security of forest dependant people especially in the tribal economy, its usage in the traditional system of medicine and industrial productions.

Their use in traditional medicine and cosmetics was very popular during early days. Particularly importance is attached to gums in Unani and Ayurvedic systems of medicine for curing many diseases such as fevers,
sexual debilities, cough and cold, dysentry and diarrhoea etc. Similarly in
the modern day gums are used in paper, textile, confectionaries and cosmetic
industries, due to their ability to stabilize emulsions, retain moisture and
impert a smooth texture. Some of the well-known gums of the world in
terms of market capitalization nationally and internationally such as Karaya,
Ghatti and katira are solely obtained from India.

I-5.1 Definition of Gums and Resins:

The word gums and resins are one of the most confusing and ill-defined
terms among NTFPs. Most often both the terms used interchangeably to a
substance or plant exudation that is sticky, smooth and elastic in nature.
However, experts differentiate between the two terms on the basis of the
yield. According to them, some plants yield only gums, some others only
resin and some other both gums and resins.  

I-5.2 Gums:

Different theories have been documented on the formation and removal of
the gums, but none of them has been accepted unanimously. The most
common theories say that gums and resins are formed as a natural
phenomenon of the plant in which internal plant tissues disintegrate through
a process, called Gummosis.
This in turn form cavities, which exudes transformed carbohydrates, called gums. Secondly, it is caused as a result of injury to the bark or stem.

Thirdly, some others attribute to fungi and bacteria attack to the plant. Majority of the gums are exuded from the stem. Only a few gums are obtained from roots, leaves and other parts of the plant. The normal compositions of gums are carbon, hydrogen, and oxygen with small quantities of mineral matter ash constituents, nitrogen and small quantities of tannin. Gums can be derived into two types, soluble and insoluble.

Soluble gums dissolve in water or form transparent, adhesive and viscous solutions as like Indian gum arabic. Insoluble gums do not dissolve in water like gum karaya. A third group is also known which can be termed as semi-insoluble gums. These gums on heating decompose completely without melting. Gums are found in large number of families. Notable among them are Leguminosae and Sterculiaceae. Other important gum-yielding families are Anacardiaceae, Combretaceae, Meliaceae, Rosaceae and Rutaceae.

I-5.3 Characteristic Features of Gums:

*Some gums are edible.  
*Normally these are not fragrant.  
*Mostly does not burn
I-5.4 Resins:

Resins can be generalized as oxidation products of various essential oils. They are chemically related to the terpenes or the essential oils. The process of formation and removal of resins is almost similar to gums. All the natural resins are vegetable in origin with the exemption of lac, which is a natural resin and comes from an insect *laccifer lacca*. This insect during its reproductive cycle feeds on the sap from their twigs. The bug secretes an amber coloured resin which is lac. Resins are found in large number of families. Notable among them are *Pinaceae, Fabaceae, Burseraceae*, and *Dipterocarpaceae*.

I-5.5 Characteristic Features of Resins:

* Resins are not edible.

* Resins are aromatic.

* Resins are flammable.

* With heat they soften fast and then melt to a more or less clear, sticky fluid.

* They are insoluble in water but usually dissolve readily in alcohol, ether and certain other solvents.
I-5.6 Types of Resins:

Resins can be broadly classified into three types. They are Oleoresins, gum resins and hard resins.

1. Oleoresins: These are soft and oily resins with distinct aroma and contain considerable amount of essential oil.

2. Gum resins: These are mixtures of gums and resins and contain small amount of essential oils. These are usually produced by plant species in dry regions. Myrrh, Frankincense, Asafoetida and Galbanum are important gum resins.

3. Hard resins: These contain very little essential oils and are usually solid, more or less transparent, brittle substances with no peculiar odour or taste. The most important commercial resins in this category are Copals, Dammers, Amber, Lacquer, Shellac and Mastic.

I-5.7 Physical properties of gums and resins:

Physical properties of gums and resins are the most important factors in determining their use and commercial value. Viscosity, gel forming tendency, colloidal nature and adhesiveness are some of the important physical properties of gums. The physical properties of various gums
depending on botanical origin, climatic conditions, harvesting period, age of
the tree, post-harvesting practices and storage conditions. The following are
details of physical properties of gums.

1. **Viscosity:** Viscosity or the thickness of a solution that a gum forms with
water, is of paramount importance in determining the quality of gum. It is
said that “higher the viscosity, better is the gum” for medicinal use.

2. **Shape:** Gums are available in two shapes; majority of them are tear
shaped, except few, which are globular.

3. **Colour:** It is a very important in the commercial valuation of gums. It is
believed that colour is mainly due to the presence of impurities.

However, the concrete reasons have not been researched properly. But as per
the traders good market is always there for light coloured gums, the darker
the colour, the commercial value decreases. Majority of the good gums are
almost water white with traces of yellow. The other colours that are found
among gums are amber, orange, dark brown, black and brownish.

4. **Colloidal nature:** This property makes gums valuable in manufacturing
processes, notably in the textile, cosmetic, pharmaceuticals and food
industry. Colloidal nature exhibits swelling pressures and form gel structures
at very low concentrations and over a wide range of concentrations. They have low surface tension, do not crystallize and act as protective colloids and stabilizing agents. In fact they prevent the agglomeration.

**5. Taste and Smell:** The true gums are nearly scentless and in this case differ markedly from some of the resins and oleo-resins that are so distinctive in smell. They may be tasteless, and are in fact generally devoid of any characteristic taste. But some are slightly sweet or bitter, according to botanical origin. In some gums there is distinctively bitter taste. This is a serious disadvantage in a gum required for edible purposes.

**6. Hardness:** Gums vary in hardness; it is obviously governed partly by the amount of moisture present. The density also provides variable in one and the same gum according to the amount of air that may have been incorporated in it when it was formed. Most gums break with a clear glassy fracture when properly dried, and may be readily pulverized.

**I-5.8 Tapping and Collection:**

Collection of gums in India is mostly done during **February** to **June**, as best exudation is said to be possible in the dry season. Collection can also be made after the rains i.e. during **September** to **October** as some trees exude in this season only. There are also some trees, which exude in both the
seasons. Artificial incision or tapping is done of the tree in order to obtain gum from the plant. Even the plants, which exude gum without mechanical injury, are subjected to tapping so as to get maximum production. After making incision, it takes a few days, sometimes even a month, for the exudation to start. The incision should be made very carefully otherwise it may have injurious effect on the plant and may lessen the productivity. Collection of gum is done through hand picking. A labourer can approximately collect 1-1.5 kg of gum in a day. There are certain trees, which produce, only for a few seasons during their lifetime, others every two years and some almost every year.

I-5.9 Important Gums and Resins Available and Traded in India:

There are numerous trees, found in India, exude gum and resins. However, some of these gums have gained commercial importance. The important gums that have gained importance over the years are

1. Gum Karaya (*Sterculia urens*)

2. Gum Babul (*Acacia arabica*)

3. Gum Tragacanth (*Astragalus species*)

4. Gum Kumta (*Acacia senegal*)
5. Gum Dhawara (*Anogeissus latifolia*)

6. Gum Khair (*Acacia catechu*)

7. Gum Guggal (*Commiphora mukul*)

8. Gum Salai (*Boswellia serrata*).

9. Gum Katira (*Cochlospermum religiosum*)

**I-6 Chemistry of Natural Products:**

**I-6.1 Terpenoids:**

Plants produce a vast array of volatiles that mediate their interaction with the environment. A large portion of these volatiles consist of the terpenoids, also known as the isoprenoids. Terpenoids and isoprenoids are a structurally diverse group of natural products. Terpenoids constitute the largest family of natural plant products, more than 30,000 members in the plant kingdom.

Carotenoids serve as light-harvesting and light-protecting pigments, sterols play important roles as modulators of membrane properties, the phytol side chain of chlorophyll (the most abundant organic pigment) is of terpenoids origin, and a wide variety of plant terpenoids function as insect attractants or
repellents. Various terpenoids have attracted commercial interest as pharmaceuticals or nutraceuticals. Thus, Paclitaxel (Taxol), a diterpenes from yew (Taxus baccata), has been established as a major cytostatic agent. Lycopene and lutein were recently registered as on co-preventive agents. Chemical and biological studies have shown that the terpenoids possess a variety of chemical, physical and biological activities.

The biological activity profiles of the terpenoids are diverse and have simple categorization, with the possible exception of the sesquiterpenes lactones, which are well known for being cytotoxic natural products. However, artemisinin, a sesquiterpenes, lactones, endoperoxide, is an important anti-malarial drug with high activity against the multidrug-resistant form of Plasmodium falciparum. A number of diterpenoids are well known for their biological, pharmacological, therapeutic effects. 53

Among the bioactive diterpenes are ginkgolides (PAF inhibitors), gibberellins (plant growth hormones), phorbol esters (tumor promoters), and the anti-cancer agent paclitaxel. 36 Members of the triterpenoids are biologically active, among which are the ginsenosides (adaptogens), betulinic acid (anti-melanoma), brusatol (chemo preventive), and boswellic acids (anti-inflammatory and anti-arthritic).
As cited in the sections to follow, many other terpenoids possess interesting and diverse biological activities and therapeutic potentials, biological tools or lead compounds for drug discovery research.

### Table 2:
**Type of Terpenoids**

<table>
<thead>
<tr>
<th>Type</th>
<th>No's of isoprene</th>
<th>Molecular formula</th>
<th>General formula</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemiterpene</td>
<td>1</td>
<td>C₅H₈</td>
<td>C₅H₈</td>
<td>Isoprene detected in <em>Hamamelis japonica</em></td>
</tr>
<tr>
<td>Monoterpenoids</td>
<td>2</td>
<td>C₁₀H₁₆</td>
<td>(C₅H₈)₂</td>
<td>Essential oils (Menthol from mint)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*Monoterpenes lactones</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*Nepeta lacone from Nepeta</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*Tropolone from gymnospermous woods</td>
</tr>
<tr>
<td>Sequiterpenoids</td>
<td>3</td>
<td>C₁₅H₂₄</td>
<td>(C₅H₈)₃</td>
<td>Essential oils (farnesol, neroleol &amp; caryophyllene)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lactones</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(santonine, xanthinine and in family compositae)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Abscisins (abscisic acid)</td>
</tr>
<tr>
<td>Diterpenoids</td>
<td>4</td>
<td>C₂₀H₃₂</td>
<td>(C₅H₈)₄</td>
<td>Diterpenes acids in plant resins</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gibberellins (gibberelic acid)</td>
</tr>
<tr>
<td>Sesterpenoids</td>
<td>5</td>
<td>C₂₅H₄₀</td>
<td>(C₅H₈)₅</td>
<td>Plants and Insects (defensive agents, pheromones)</td>
</tr>
<tr>
<td>Triterpenoids</td>
<td>6</td>
<td>C₃₀H₄₈</td>
<td>(C₅H₈)₆</td>
<td>Sterols (sitosterol), Triterpene (amyrins)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Saponins (yamogenin), Cardiac glycosides</td>
</tr>
<tr>
<td>Tetraterpenoids</td>
<td>8</td>
<td>C₄₀H₆₄</td>
<td>(C₅H₈)₈</td>
<td>Carotenoids (carotenes)</td>
</tr>
<tr>
<td>Polyterpene</td>
<td>N</td>
<td>Rubber</td>
<td>(C₅H₈)ₙ</td>
<td>Polyisoprene (rubber from <em>Hevea brasiliensis</em>)</td>
</tr>
</tbody>
</table>

### I-6.2 Alkaloids:

Alkaloids are derived from plant sources, which are basic in nature and contain one or more nitrogen atoms (usually in a heterocyclic ring). They usually have a marked physiological action on man or other animals.
Alkaloids are commonly found in the orders:-

- **Centrospermae** (*Chenopodiaceae*),
- **Magnoliales** (*Lauraceae*, *Magnoliaceae*),
- **Ranunculales** (*Berberidaceae*, *Menispermaceae*, *Ranunculaceae*),
- **Papaverales** (*Papaveraceae*, *Fumariaceae*),
- **Rosales** (*Leguminosae*, *subfamily Papilionaceae*),
- **Rutales** (*Rutaceae*),
- **Gentiales** (*Apocynaceae*, *Loganiaceae*, *Rubiaceae*),
- **Tubiflorae** (*Boraginaceae*, *Convolvulaceae*, *Solanaceae*)
- **Campanulales** (*Campanulaceae*, *sub-family Lobelioidae*; *Compositae*, *subfamily Senecioneae*).

Many natural products of alkaloids are of great biological interest, morphine (painkiller), vincristine (anticancer agent), cocaine (anaesthetic, drug of abuse), and nicotine (tobacco, poison) caffeine (stimulant).\(^7\) There are three broad categories of plant secondary metabolites as natural products:-

1. Terpenes and terpenoids (~25,000 types).
2. Alkaloids (~12,000 types).
3. Phenolic compounds (~8,000 types).

According to Croteau et al.\(^{14}\), Based on their numbers and diversity, terpenes offer much potential in an array of industrial and medicinal applications.
I-6.3 Flavonoids:
Flavonoids are a group of about 4000 naturally occurring polyphenolic compounds, found universally in foods of plant origin. These are primarily recognized as the pigments responsible for the colours of leaves, especially in autumn.

Flavonoids are widely distributed in fruits, vegetables, nuts, seeds, herbs, spices, stems, flowers as well as tea and red wine. They are usually subdivided according to their substituents into flavonols (kaempferol, quercetin), anthocyanins, flavones, flavonones and chalcones.

Flavonoids display a remarkable array of biochemical and pharmacological actions viz., anti-inflammatory, antioxidant, anti-allergic, hepatoprotective, anti-thrombotic, anti-viral and anti-carcinogenic activities. These compounds appear to play vital roles in defense against pathogens and predators and contribute to physiological functions such as seed maturation and dormancy. They are synthesized from phenyl propanamide and acetate derived precursors. Flavonoids are important for human beings due to their antioxidative and radical hazardous effects as well as their potential estrogenic and anticancer activities.
Π-chart representing the major groups in % of plant as secondary metabolites\textsuperscript{14}
**Quercetin** belongs to this group of plant pigments called, flavonoids that are largely responsible for the colours of many fruits, flowers and vegetables. Quercetin works as anti-inflammatory, antioxidant, anticancer agents.\textsuperscript{41}

*Citrus colocynthis* (Linn.), Schrad (*Cucurbitaceae*), one of the most important medicinal plant species are locally known as **Tumba** or **Indrayan**. The present study deals with the isolation and identification of flavonoids "quercetin" from *in vivo* (leaf, stem, fruit and root) and *in vitro* callus samples of *Citrus colocynthis* (Linn.).
Flavonoid structure (Adapted from Aoki et al., 2000). A: Chemical structure of selected subclasses and biologically active flavonoid. B: General Structure of flavonoids compounds. The different flavonoids classes are defined according to the structure of the C-ring and the functions carried by C₃ and C₄ (in bold).
I-6.4 Carbohydrate:

A carbohydrate is an organic compound with general formula $C_{m}(H_2O)_n$, [where $m \geq 3$ ] i.e, it consists carbon, hydrogen and oxygen(H and O is 2:1 atom in ratio). Carbohydrates, as their name suggests can be viewed as hydrates of carbon. While the scientific nomenclatures of carbohydrates are complex, the names of carbohydrates end with the suffix – “ose”.

The term saccharide (Latin word: Saccharum, sugar) is most commonly used in biochemistry for carbohydrates, a large family of natural carbohydrates that fill numerous roles in living things, such as the storage and transport of energy (e.g., starch, glycogen) and structural components (e.g., cellulose in plants and chitin in arthropods). Saccharides and their derivatives include many other important biomolecules that play key roles in the immune system, fertilization, pathogenesis, blood clotting, and development of organism.\(^{40}\)

In food science and in many informal contexts, the term carbohydrate often means any food that is particularly rich in starch (such as cereals, bread and pasta) or sugar (such as candy, jams and desserts).
I-6.5 Amino Acids:

Amino acids are the organic compounds building blocks of proteins. Amino acids having both the \(-\text{NH}_2\) and \(-\text{COOH}\) groups attached to the \(\alpha\)-carbon atom. The term \(\alpha\)-amino carboxylic acids are often used for amino acids. Amino acids contain both a carboxyl group (-COOH) and an amino group (-NH\(_2\)). The general formula for an amino acid is \(\text{RCH (NH}_2\) COOH.\)

Although, the neutrally charged structure is commonly written, it is not accurate because the acidic -COOH and basic -NH\(_2\) groups react with one another to form an internal salt called a zwitter ion. The zwitter ion has no net charge; But there is one negative (-COO\(^-\)) and one positive (-NH\(_3^+\)) charge.\(^{40}\)

There are 20 amino acids derived from proteins. The amino acids are classified generally in two categories, on the basis of their synthesis in human body (Table -3).

1. **Essential amino acids**: Essential component of diet, since they are not synthesized by human body.

2. **Non-essential amino acids**: Synthesized in human body.
### Table 3:

**Type of Amino acids**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Name</th>
<th>Essential/Non-Essential</th>
<th>Structure</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alanine (Ale)</td>
<td>Non-Essential Amino Acid</td>
<td><img src="image1" alt="Structure" /></td>
<td>Neutral</td>
</tr>
<tr>
<td>2</td>
<td>Arginine (Arg)</td>
<td>Essential Amino Acid</td>
<td><img src="image2" alt="Structure" /></td>
<td>Basic in nature</td>
</tr>
<tr>
<td>3</td>
<td>Asparagine (Aspe)</td>
<td>Non-Essential Amino Acid</td>
<td><img src="image3" alt="Structure" /></td>
<td>Basic in nature</td>
</tr>
<tr>
<td>4</td>
<td>Aspartic acid (Aspa)</td>
<td>Non-Essential Amino Acid</td>
<td><img src="image4" alt="Structure" /></td>
<td>Acidic in nature</td>
</tr>
<tr>
<td>5</td>
<td>Cysteine (Cys)</td>
<td>Non-Essential Amino Acid</td>
<td><img src="image5" alt="Structure" /></td>
<td>R-configuration, Thiol group</td>
</tr>
<tr>
<td>6</td>
<td>Glutamic acid (Glu)</td>
<td>Non-Essential Amino Acid</td>
<td><img src="image6" alt="Structure" /></td>
<td>Acidic in nature</td>
</tr>
<tr>
<td>7</td>
<td>Glutamine (Glu)</td>
<td>Non-Essential Amino Acid</td>
<td><img src="image7" alt="Structure" /></td>
<td>Glutamic acid amide</td>
</tr>
<tr>
<td>8</td>
<td>Glycine (Gly)</td>
<td>Non-Essential Amino Acid</td>
<td><img src="image8" alt="Structure" /></td>
<td>Achiral, Neutral</td>
</tr>
<tr>
<td>9</td>
<td>Histidine (His)</td>
<td>Essential Amino Acid</td>
<td><img src="image9" alt="Structure" /></td>
<td>N-containing heterocyclic ring, Basic in nature</td>
</tr>
<tr>
<td>10</td>
<td>Iso-leucine (Ile)</td>
<td>Essential Amino Acid</td>
<td><img src="image10" alt="Structure" /></td>
<td>Chiral, Neutral</td>
</tr>
<tr>
<td>11</td>
<td>Leucine (Leu)</td>
<td>Essential Amino Acid</td>
<td><img src="image11" alt="Structure" /></td>
<td>Neutral</td>
</tr>
<tr>
<td>12</td>
<td>Lysine (Lye)</td>
<td>Essential Amino Acid</td>
<td><img src="image12" alt="Structure" /></td>
<td>Basic in nature</td>
</tr>
<tr>
<td>13</td>
<td>Methionine (Met)</td>
<td>Essential Amino Acid</td>
<td><img src="image13" alt="Structure" /></td>
<td>Sulphide group</td>
</tr>
<tr>
<td>14</td>
<td>Phenyl alanine (Pha)</td>
<td>Essential Amino Acid</td>
<td><img src="image14" alt="Structure" /></td>
<td>Neutral</td>
</tr>
<tr>
<td>15</td>
<td>Proline (Pro)</td>
<td>Non-Essential Amino Acid</td>
<td>Neutral, 2° Amine</td>
<td></td>
</tr>
<tr>
<td>----</td>
<td>---------------</td>
<td>--------------------------</td>
<td>------------------</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Serine (Ser)</td>
<td>Non-Essential Amino Acid</td>
<td>Hydroxyl group</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Threonine (Threo)</td>
<td>Essential Amino Acid</td>
<td>Hydroxyl group</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Tryptophan (Try)</td>
<td>Essential Amino Acid</td>
<td>N-containing heterocyclic ring Basic in nature</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Tyrosine (Tyr)</td>
<td>Non-Essential Amino Acid</td>
<td>Hydroxyl group</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Valine (Val)</td>
<td>Essential Amino Acid</td>
<td>Neutral</td>
<td></td>
</tr>
</tbody>
</table>

While there are several methods of categorizing them, one of the most common is to group them according to the nature of their side chains. Plant cells possess multiple highly regulated metabolic networks that play central regulatory roles in their growth.

Among the various metabolic networks, those leading to the synthesis of amino acids have gained considerable interest not only because the amino acids are vital for the synthesis of proteins but also because amino acids serve as precursors for a large array of metabolites with multiple functions in plant growth and response to various stresses. Just to mention a few examples, the aromatic amino acids are used as precursors for numerous
metabolites, such as hormones, cell wall components, and a large group of multiple functional secondary metabolites (Radwanski and Last, 1995; Wittstock and Halkier, 2002; Pichersky et al., 2006; Tempone et al., 2007); Met is a precursor for the synthesis of the hormone ethylene, polyamines, cellular energy glucosinolates, and also provides a methyl group to DNA methylation, chlorophyll biosynthesis, cell wall biosynthesis, and to a large number of secondary metabolites (Amir et al., 2002; Wittstock and Halkier, 2002; Rebeille et al., 2006; Goyer et al., 2007); Thr conversion into Gly is important for seed development (Jander et al., 2004; Joshi et al., 2006); Ile catabolism leads to the production of cellular energy (Mooney et al., 2002); and Pro catabolism is important for the recovery of plants from various abiotic stresses (Rontein et al., 2002).

Biochemical studies of plant amino acid metabolism have so far been mostly devoted to the biosynthesis of the amino acids. These studies showed that the biosynthesis of plant amino acids is largely regulated by end product feedback inhibition loops in which specific enzymes in a given amino acid biosynthesis pathway (called allosteric enzymes) are feedback inhibited by the amino acids that they synthesize (Galili, 1995; Radwanski and Last, 1995).
Eliminations of feedback inhibition traits in specific allosteric/biosynthetic enzymes generally resulted in increased levels of the corresponding amino acids (Widholm, 1972; Galili, 1995, 2002; Radwanski and Last, 1995; Li and Last, 1996), leading to the notion that the biosynthetic/allosteric enzymes represent major regulatory factors determining the rate of the fluxes in metabolic pathways of amino acids. Consequently, the potential roles of downstream enzymes that convert amino acids into other metabolites (defined as catabolic enzymes of the amino acids) in the regulation of fluxes of amino acid metabolism under specific physiological conditions have been largely ignored. Nevertheless, direct experimental evidence (Dixon and Paiva, 1995; Moulin et al., 2000; Galili et al., 2001; Galili, 2002; Mikkelsen et al., 2003; Stepansky and Galili, 2003; Jander et al., 2004) and results of publicly available microarray results (H. Less and G. Galili, unpublished data) support such regulatory roles by showing that the transcript level of many of the catabolic enzymes of the amino acids is highly regulated by developmental, metabolic, and environmental cues.
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