CHAPTER-I

INTRODUCTION

1.1. Medicinal plants and traditional medicines

“Jagatyevam anoushadham
na kinchit vidyate dravyam
vashaannyaarthayagayoh”

"There is nothing in this universe, which is non-medicinal, which cannot be made use for many purposes and by many modes" [Eraly, 2011].

This is the traditional definition of medicinal plants given in Ashtaanga Hrdaya, the definitive Ayurvedic text written by the Buddhist monk Vagbhata in 600 A.D. The World Health Organization (WHO) has defined medicinal plants are plants which have been used for medical purposes at one time or another and which, although not necessarily a product available for marketing, is the original material of herbal medicines [WHO, 1998].

Plants have been played an important role in human society for many centuries by providing food, shelter, medicines, clothing, fertilizers, cosmetics, dyes, flavors, fragrances, fibers, pesticides, herbicides and means of transportation [Fakim, 2006]. Plants are the chemical factories of nature, producing vast secondary metabolites, some of which have medicinal properties. Medicinal plants which has high medicinal properties were used traditionally all over the world to treat many ailments such as, diarrhea, fever, cold, cut, wounds, bone fractures, birth control, dental hygiene, cancers and psychic problems etc., [Mitscher et al., 1987; Deans and Svoboda, 1990].

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India is a sub-tropical country harboring rich plant diversity. There are more than 280,000 higher plant species are supposed to be present on the Earth, among them 15,000 plant species were found in India which account for 6% of the total plant species in the world. The flora of India is one of the richest floras of the world due to a wide range of climate, topology and environments in the country. India is one of the 12 mega diversity countries in the world which has 16 different agro-climatic zones which denotes an infinite source of biodiversity that contains nearly 3/4th of the drugs and perfumery products derived from natural habituated plants [Harborne, 1993]. According to WHO (1998), there were about 21,000 plant species having medicinal potential which is used in various medications across India. In India, it is reported that traditional healers use 2,500 plant species and 100 species of plants serve as regular sources of medicine. India exports more than 32,600 tonnes of medicinal plants per annul [Arora et al., 2003].

Historically, dietary intake of certain vegetables and fruits has been believed to bring health benefits. In fact, early medicines revolved largely around the prescription of specific food concoctions for certain ailments. Medicinal plants are rich source of novel drugs that forms the ingredients in traditional systems of medicine, modern medicines, nutraceuticals, food supplements, folk medicines, pharmaceutical intermediates, bioactive principles and lead compounds in synthetic drugs [Ncube, 2008].

Medicinal plants are natural sources for highly valuable medicinal products, which are used to treat various diseases [Sudhakar et al., 2007]. Since, our ancient time we traditionally use the plants in the treatment of several human and animal diseases. Their pharmacological and therapeutic properties have been attributed to
different chemical constituents isolated from their crude extracts. Natural products particularly medicinal plants remain as an important source of new drugs, new drug leads and new chemical entities (NCEs) [Newman et al., 2003; Butler, 2004].

Nowadays, plant based products and their derivatives represent more than 50% of the drugs in clinical use in the world. Higher plants contribute not less than 25% to the total [Fakim, 2006]. Plant products are also a source of highly potent and powerful drugs that have stood the test of times and even modern chemistry has not been able to replace most of them [Farnsworth, 1994]. Many important chemical intermediates necessary for manufacture of modern drugs (mainly in allopathic medicines) are plant based (e.g. diosgenin, solasodine, β-ionone etc..) which form an important segment of the modern pharmacopoeia. About 70% of the Indian population depends on traditional medicinal systems and 80% of world’s population (particularly, Asia, Latin America and Africa) depends on herbal medicine [Bibitha et al., 2002; Maghrani et al., 2005]. According to Meyer et al., (1996) about 12 to 15 million South Africans still depend on their traditional herbal medicine from as many as 700 indigenous plant species.

Medicinal plants are the backbone of traditional medicine. Several hundred plant genera are used in traditional medicine in different countries. The Indian systems of herbal medicine use around 8,000 species of plants which include trees (33%), herbs (32%), shrubs (20%), climbers (12%), epiphytes, grasses, lichens, ferns and algae put together (3%). Among 2,000 drugs are used in curing human ailments in India, only 200 are of animal origin, 300 of mineral origin and the rest 1,500 drugs are extracted from various plants [Agarwal and Ghosh, 1985]. The total numbers of medicinal plants are listed that are used in various indigenous
systems such as Siddha (600), Ayurveda (700), Amchi (600) and Unani (700) which was more than 2,800 plants [Rabe et al., 1997]. Whole plants or different organs of the plant like leaves, stem, root, bark etc., are employed in the preparation of herbal drugs in traditional medicines. Some excretory products like gum, resins and latex can also serve as a source of plant based drugs.

Major pharmaceutical industries depend on the plant products for the preparation of Ayurvedic medicines. In the present context, the Ayurvedic system of medicine is widely accepted and practiced not only in the Indian peninsula but also in the developed countries such as Europe, United States and Japan. Plant derived medicines have been the first line of defense in maintaining health and combating diseases [John, 1984; Veale, 1992]. In the last century, roughly 121 pharmaceutical products have been discovered based on the information obtained from the traditional healers [Anesini et al., 1993].

The WHO’s commission on intellectual property and innovation in public health has also recognized the promise and role of traditional medicine in drug development for affordable health solutions [Patwardhan, 2005]. India, China, Korea, Malaysia, Brazil, South Africa, Australia and many countries are becoming increasingly aware of the value of their traditional knowledge. On the other hand, the global pharmaceutical industry is looking for innovative solutions to expedite the discovery process. Therefore, innovative approaches inspired by traditional knowledge like Ayurveda and folkloric uses may aptly occupy this niche strategy to expedite drug discovery and development process especially in the existing global economic environment [Patwardhan and Mashelkar, 2009].
1.2. Ancient traditional medicine systems

India is the birth place of renewed system of indigenous medicine such as Siddha, Ayurveda and Unani.

1.2.1. Siddha medicine

Siddha medicine (Tamil traditional medicine) is the oldest medicinal system in India, being rooted in its philosophies and practices. Siddha medicine is derived from alchemy, with Chinese alchemy having the greatest influence, involving aurrfaction, elixirs of gold and mercuric sulfide (cinnabar) and herbs of "deathlessness" or immortality [Needham, 1974]. Medicines used, include herbal products, animal products or inorganic substance, with much emphasis on the later. These drugs are classified based on taste, character, potency, class and action [Shukla et al., 2011].

1.2.2. Ayurveda medicine

Ayurveda originated from the Athatva Veda, which mostly pertains to the Hindu religion and contains 114 hymns relating to the treatment of diseases. However, the principle classic reference for Ayurveda is considered to be the Charaka Samhita, authored by Charaka (ca. 700 BC). It provided a rational approach to cause and cure disease and an introduction to objective methods for clinical examination. Charaka described approximately 50 plants, classified in groups of 10 plants each. Ancient Ayurveda were passed on through generations by means of memorised songs and poems. Ayurveda is based on Siddha medicine [Chattopadhyaya, 1977].
A further principle contribution to Ayurveda was made by Sushruta (ca. 800 BC), the "father of surgery", who wrote the Sushruta Samhita. This contains all the major concepts of Ayurvedic medicine and consisted of 184 chapters, describing 1,120 illnesses, 700 medicinal plants, 64 preparations from mineral sources and 57 preparations from animal origin [Dwivedi and Dwivedi, 2007].

1.2.3. Unani medicine

Unani medicine (also known as Unani-tibb or Yunani Medicine) (in Arabic, Hindi-Urdu and Persian, meaning "Greek medicine") originated as a form of traditional medicine widely practiced in Southern Asia. Unani first arrived in India with the establishment of Delhi Sultanate (1206-1527) and during Muslim rule over North India [Rahman, 2011]. The greatest contribution to this medicinal system stems from the Canon of Medicine, written by Avicenna, which relates to the date of origin of this medicinal system (1025 AD). It is based on a tradition of Graeco-Arabic medicine, which has its roots in the teachings of four humours; (Phlegm (Balgham), Blood (Dam), Yellow bile (Safra) and Black bile (Sauda)) and Galen. It was developed into an elaborate medical system by Arab and Persian physicians, such as Rhazes, Avicenna, Al-Zanrawi and Ibn Nafis [Saad et al., 2005].

1.3. Free radicals and antioxidants

Free radical can be defined as chemical species possessing an unpaired electron, which is formed by homolytic cleavage of a covalent bond of a molecule by the loss of a single electron from a normal molecule or by the addition of a single electron to a normal molecule. The chemical compounds of free radicals are referred as pro-oxidants. Free radicals has very short span of half-life, high
reactivity and damaging activity towards macromolecules like proteins, lipids and DNA [Pratico et al., 1998].

1.3.1. Sources of free radicals

Formations of free radicals in living cells are exposed to oxidants originating from a large variety of exogenous or endogenous sources. Free radicals are chiefly generated in biological system via metabolic pathways i.e. free radical leaks from electron transport chain system and radicals produced by the inflammatory cells. A major source of free radicals in biological systems is molecular oxygen. About 1- 4% of oxygen taken up in the body is converted as free radicals [Naphade et al., 2009]. Some enzymes are also involved in the production of free radicals, especially xanthine oxidase, aldehyde oxidase, dihydro orotate dehydrogenase and peroxidases, creating partial reduced oxygen species [Cuzzocrea et al., 2001]. Exogenous free radical sources are pollutants, ozone, radiations (e.g: UV light, X-rays and gamma rays), toxic chemicals (e.g: Paraquat), drugs (e.g: Adriamycin, Bleomycin) and pathogenic microorganisms [Peterhans, 1997].

1.3.2. Types of free radicals

Free radicals are mainly classified into two types based on the source of origin they are Reactive Oxygen Species (ROS) and Reactive Nitrogen Species (RNS). Prime biological reactive oxygen species are superoxide anion (O$_2$•$^-$), hydroxyl radical (•OH), hydrogen peroxide (H$_2$O$_2$), peroxyl (ROO•), alkoxy (RO•) free radicals and RNS are nitric oxide (NO), peroxynitrite (ONOO$^-$), nitrogen dioxide (NO$_2$) and dinitrogen trioxide (N$_2$O$_3$) [Miller et al., 2008].
1.3.3. Reactive oxygen species

All aerobic cells generate ROS either enzymatically or non-enzymatically. Intracellular ROS can be generated from mitochondrial electron transport chain reaction which is a well-known principal site for ROS generation and targets for ROS action. Moreover, ROS is also generated during the course of phagocytosis, ischemia/reperfusion and metabolism of various drugs and other xenobiotic chemicals [Kim et al., 2008]. ROS are useful molecules in signaling
pathways of many animal and plant host defense mechanisms. However, if produced in an uncontrolled manner or in high amount they cause several cellular damages [Pan et al., 2008].

1.3.4. Superoxide radical (O$_2^\cdot$)

The superoxide radical anions are formed when oxygen was reduced by the transfer of a single electron to its outer shell. Superoxide anion is the first reduction product of O$_2$. The important source of production of O$_2^\cdot$ is oxidative enzymes, among which xanthine oxidase (XO), aldehyde oxidase, dihydronic dehydrogenase and NADPH/NADH oxidase produces significant quantities of O$_2^\cdot$ [Cross and Jones, 1991; Mc Cord and Fridovich, 1969]. Superoxide radical anion has a long half-life in the cellular environment which is approximately $10^6$ s [Pryor, 1986].

$$O_2 + e^- \rightarrow O_2^\cdot$$

Previous studies showed that O$_2^\cdot$ directly affects some intracellular enzymes, changing their activities such as epinephrine, creatine phosphokinase [McCord and Russell, 1988], lactate dehydrogenase bound NADH [Bielski and Chan, 1973], aconitase and 6-phosphogluconate dehydratase [Gardner and Fridovich, 1992]. It can cause the peroxidation of unsaturated lipids and oxidation of thiols [Pederson and Aust, 1973]. Superoxide anion radical induces the chromosome breakage, rearrangement and sister chromatid exchanges [Emerit et al., 1982]. Hence, O$_2^\cdot$ may be a possible factor for increased risk of carcinogenesis.

1.3.5. Hydroxyl radical (OH$^\cdot$)

Hydroxyl radical is the most reactive free radical and will probably react with any molecule present in cells. Hydroxide radical is formed from superoxide
anion and hydrogen peroxide in the presence of metal ions, such as Fe$^{2+}$ or Cu$^{2+}$ [Genestra, 2007; Sathish et al., 2007]. The life span of OH$^\bullet$, very low at 37°C is $10^{-9}$s which leads to the insufficient stability and also does not allow it to diffuse through the cells. Therefore, OH$^\bullet$ with near organic substrates with only few collisions from where it is formed. So it’s a site-specific reaction.

$$\text{O}_2^\bullet^- + \text{H}_2\text{O}_2 \rightarrow 2\text{OH}^- + \text{O}_2$$

Hydroxyl radical formation causes the oxidation of lipids, proteins and nucleic acids such as, DNA strand breaks, base modifications and DNA cross linking have also been observed [Battin and Brumaghim, 2009; Mandal et al., 2009]. OH$^\bullet$ reacts induces damage to tumor suppressor genes and enhanced expression of proto-oncogenes, [Halliwel and Aruoma, 1991].

1.3.6. **Reactive nitrogen species**

1.3.6.1. Nitric oxide (NO)

Nitric oxide is a gaseous inorganic free radical, which form a covalent link with other molecules. The NO is synthesized by a family of isoenzymes called nitric oxide synthetase (NOS), located in various tissues particularly in phagocytes and endothelial cells [Felley-Bosco, 1998]. There are three forms of NOS isoenzymes. The NO is formed by the action of NOS on the amino acid arginine. The principal biological target of nitric oxide is guanylate cyclase and/or other iron-containing heme proteins. NO$^\bullet$ plays an important role as a signaling molecule in vascular, nervous and immune systems, free radical and tumour biology [Moncada et al., 1991].
Fig. 1.3. Formation of nitric oxide radical [Moncada et al., 1991].

Prolonged exposure of NO\(^*\) inhibits the activity of number of enzymes such as aconitase, complexes I and II, and cytochrome-C oxidase [Clementi et al., 1998]. The excessive, unregulated production of NO\(^*\) has been inducing many lethal and debilitating diseases [Gross and Wolin, 1995]. The inflamed tissues produced NO and its derivatives which plays a dual role in cancers. The NO\(^*\) at higher concentrations act as cytotoxic agent, and at low concentrations, it promotes tumor growth and metastasis [Jenkins et al., 1995; Tamir and Tannenbaum, 1996]. NO is known to be a potential mutagen [Arroyo et al., 1992]. Moreover, it may have a role in carcinogenesis by impairing the tumor suppressor function of p53 [Wang and Liehr, 1995] and inducing DNA strand breaks [Yoshie and Osmhima, 1998]. It can bind to non-heme iron of ribonucleotide reductase to inhibit DNA synthesis [Lepoivre et al., 1991].

1.3.7. Oxidative stress and their impact in cell damages

The term oxidative stress refers to the situation of serious imbalance between production of reactive species and antioxidant defense [Chung et al., 2007]. In a normal cell, there is an appropriate oxidant-antioxidant balance. However, this balance can be shifted towards the pro-oxidant, when production of oxygen species
is increased or when levels of anti-oxidants are diminished. This state is called oxidative stress and can result in serious cell damage if the stress is massive or prolonged [Frei, 1994, Peterhans, 1997, Domenico et al., 1998].

Free radicals induced oxidative stress play a vital role in damaging various cellular macromolecules, include DNA molecules, proteins and lipids [Cho et al., 2009]. This damage may result in many diseases, including diabetes mellitus, atherosclerosis, myocardial infarction, arthritis, anemia, asthma, inflammation, neurodegenerative diseases, carcinogenesis, ageing and various other pathobiological effects [Oyedemi et al., 2010; Treitinger et al., 2000].

1.4. Antioxidants

An antioxidant or free radical scavenger is defined as a substance, which at low concentrations, can prevent or delay the oxidation of an oxidisable substrate. Such substrates include proteins, carbohydrates, lipids, DNA, and other cell constituents. There are two types of antioxidant they are intracellular enzymes and extracellular chemo agent antioxidants.

1.4.1. Enzymatic antioxidants

Most of the living cells contain variety of enzymes, which remove number of free radicals. Superoxide dismutase, catalase, glutathione peroxidase are prime enzymes which involve in potential removal of free radicals in cells.

1.4.2. Non-enzymatic antioxidant molecules

A second line of defense against free radical attack is constituted by small antioxidant molecules, such as vitamin-E, vitamin-C, ubiquinone or Coenzyme-Q, carotenoids. Some of these compounds are considered as chain-breaking
antioxidants because they effectively interrupt free radical propagation reactions. Anti-oxidative vitamins have a number of biological actions such as immune stimulation, inhibition of nitrosamine formation and an alteration of metabolic activation of carcinogens [Van and Van, 1997]. They can prevent genetic changes by inhibiting DNA damage induced by the reactive oxygen molecules (ROMs) [Sun, 1990].

1.4.2.1. Vitamin E or Tocopherols

Natural vitamin E is a mixture of tocopherols (α, β and γ) and tocotrienols (α, β, and γ) the alpha and gamma isomers are usually the major ones. It is a lipid soluble vitamin, which mainly found in the interior of membranes and blood proteins. Major dietary sources of vitamin E are vegetable oils, margarine, nuts, seeds, whole grains and wheat. It is a major lipid soluble antioxidant in human blood plasma.

Vitamin E reacts at considerable rates with a variety of free radical species. Vitamin E can directly act with a variety of oxy-radicals including the peroxide radicals (ROO•), CC13•, OH•, O2•- [Fukuzawa and Gebicki, 1983] and singlet oxygen [Littarru et al., 1984]. Vitamin E is an important chain breaking antioxidant, with emphasis on lipid peroxyl radicals formed during lipid peroxidation. It plays an important role in various stages of carcinogenesis through its contribution to immuno competence, membrane and DNA repair and decreasing oxidative DNA damage [Kimmick et al., 1997]. Rosemary hydroxytyrosol, a phenol antioxidant
from olives, the tocopherols, tocotrienols, polyphenols and flavonoids are few examples of plant origin antioxidants [Cahill et al., 1991].

1.4.2.2. Vitamin C or Ascorbic acid

Vitamin C is an important water soluble-antioxidant in biological fluids and an essential micronutrient required for many metabolic functions of the body [Jaffe, 1984]. The vitamin C is plentiful in fresh fruits, especially, citrus fruits and vegetables [Bendich et al., 1997]. Vitamin C is a cofactor for several enzymes involved in the biosynthesis of collagen, carnitine and neurotransmitters [Burri and Jacob, 1997]. Plasma is devoid of vitamin C, which is extremely vulnerable to oxidative stress and susceptible to peroxidative damage of lipids [Frei et al., 1989].

\[
\text{AH} + \text{HO}^* \rightarrow \text{A}^* + \text{H}_2\text{O}
\]

Antioxidant Free radical Radical form of antioxidant

Vitamin C readily scavenges ROS, ozone and RNS [Noroozi et al., 1998]. Vitamin C neutralizes ROMs and reduces oxidative DNA damage and genetic mutations [Frie, 1994]. It prevents carcinogenic nitrosamine formations in cancers and decreases the risk of colon, breast and stomach cancers [Tannenbaum and Wishnok, 1991; Block, 1991]. Vitamin C can act as a co-antioxidant in the regeneration of \( \alpha \)-tocopheroxyl radicals produced during scavenging of ROMs [Packer, 1997].

1.5. Antimicrobial agents

Infectious diseases comprise clinically evident illness resulting from the infections, presence and growth of pathogenic biological agents in an individual host organism. Infectious diseases caused by bacteria, fungi, viruses and parasites are still a
major threat to public health. Transmission of pathogen can occur in various ways including physical contact, contaminated food, body fluids, objects, airborne inhalation or through vector organisms [Ryan and Ray, 2004]. Infectious diseases are the world’s leading cause of premature deaths, killing almost 50,000 people every day [Ahmad and Beg, 2001]. The rise in multi-drug resistant strains of pathogens has become a world-wide public health concern [Mohanasundari et al., 2005].

1.5.1. Gram positive bacteria

_Bacillus subtilis_ (B. subtilis) is only known to cause disease in severely immune compromised patients and can conversely be used as a probiotic in healthy individuals [Ryan and Ray, 2004]. _Staphylococcus aureus_ (S. aureus) is a common organism found in nosocomial and postoperative infections and it can cause Enterocolitis rarely it leads to fatal, wound infection, food poison, etc. [Okii et al., 2006]. _Enterococcus faecalis_ (E. faecalis) can cause endocarditis and bacteremia, urinary tract infections (UTI), meningitis and other infections in humans. Enterococci have rapidly emerged as important nosocomial and community acquired pathogens [Kapoor et al., 2005] and responsible for 90% of enterococcal infection. _E. faecalis_ has been frequently found in root canal-treated teeth [Molander et al., 1998].

1.5.2. Gram negative bacteria

_Klebsiella pneumoniae_ (K. pneumoniae) can cause Pneumonias. It is difficult to control and also cause bacillary meningitis, brain and lung abscess, thoracic emphysema, prostatic abscess, deep neck infection, complicated skin and soft tissue infections [Chang et al., 2008]. _Salmonella typhi_ (S. typhi) causes systemic infections and typhoid fever in humans [Den et al., 2003]. Capsules are not formed. Symptoms of _S. typhi_ infection are mild to severe fever, headache, loss of appetite,
constipation or diarrhea and non productive cough. *Shigella flexneri* (*S. flexneri*) is a species of Gram-negative bacteria in the genus *Shigella* that can cause diarrhea in humans. *S. flexneri* infections can usually be treated with antibiotics although some strains have become resistant. Less severe cases are not usually treated because they become more resistant in the future [Ryan and Ray, 2004].

### 1.5.3. Fungus

*Aspergillus niger* (*A. niger*) is a filamentous ascomycete fungus ubiquitous in the environment and has been implicated in opportunistic infections to humans. *A. niger* is less likely to cause human disease than some other Aspergillus species, but, if large amounts of spores are inhaled, a serious lung disease, aspergillosis can occur. Aspergillosis is, in particular, frequent among horticultural workers that inhale peal dust, which can be rich in Aspergillus spores. *A. niger* is one of the most common causes of otomycosis (fungal ear infections), which can cause pain, temporary hearing loss, and, in severe cases, damage to the ear channel and tympanic membrane.

*Candida albicans* (*C. albicans*) can exist in three forms that have distinct shapes: yeast cells (also known as blastospores), pseudohyphal cells and true hyphal cells. It colonizes mucosal surfaces of the oral and vaginal cavities and the digestive tract and is also able to cause a variety of infections, depending on the nature of the underlying host defect. It can cause infections under altered physiological and pathological conditions such as infancy, pregnancy, diabetes, prolonged broad spectrum antibiotic administration, steroidal chemotherapy as well as AIDS [Sallah, 1999].
Cryptococcus neoformans (C. neoformans) is an environmental yeast distributed worldwide and is the most common cause of fungal meningoencephalitis in immune compromised hosts [Casadevall and Perfect, 1998]. C. neoformans is a facultative intracellular pathogen. Infection is initiated upon inhalation of spores or desiccated yeast. In the lung, the fungus proliferates in the alveolar space, and in immune competent subjects the infection is normally contained in this organ.

1.5.4. Antibiotics

Antibiotics are molecules that kill, or stop the growth of microorganisms, including both bacteria and fungi. Antibiotics work in one of the following two ways they are bactericidal and bacteriostatic.

During the last two decades, the development of drug resistance as well as the appearance of undesirable side effects of certain antibiotics has led to the search of new antimicrobial agents mainly among plant extracts with the goal to discover new chemical structures, which overcame the above disadvantages. Plants are used in traditional medicine in different countries to treat infectious diseases. Plant based antimicrobial compounds have great therapeutic potential, cheap, safe and lesser side effects when compared with synthetic drugs for the treatment of microbial infections and has modest probability of developing resistance. Due to emergence of drug resistance, it triggers the search for new antibacterial compound with improved activity in plant sources.

1.6. Elemental analysis

Minerals are inorganic substances, present in all tissues and body fluids and their presence is necessary for the maintenance of certain physicochemical processes
which are essential to life. Since ancient times, minerals have been used in several clinical treatments including loss of memory, defective eyesight, infertility, overall body weakness and incidence of early aging. Several mineral nutrition such as, Ca, Fe, Mg, Na, K, Zn, Ni, Co etc. have been added to Ayurvedic Pharmacopoeia of India [The Ayurvedic Pharmacopoeia of India, 1999].

Usually minerals are required in small amounts from less than 1 to 2500mg per day, depending on the mineral. If a mineral is required at a level greater than 100mg per day, it is considered to be a major mineral. The major minerals are calcium (Ca), chloride (Cl), magnesium (Mg), phosphorus (P), potassium (K), sodium (Na) and sulfur (S). If a mineral is required at a level less than 100mg per day, it is considered to be a minor mineral which includes, chromium (Cr), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se) and zinc (Zn) [Albion Research Notes, 1996]. Minerals yield no energy; they have important roles to play in many bioactivities in the cells [Malhotra, 1998; Eruvbetine, 2003].

The inorganic mineral content in the soil was absorbed by growing plants which forms complexes with organic molecules. Plants incorporate minerals from the soil into their own tissues, such as, fruits, vegetables, grains, legumes, nuts and seeds are often excellent sources for minerals [Prabhat, et al., 2008]. The development of technologies in food processing was raising the quality of the foods. The quality of many foods depends on the concentration and type of minerals. The lack of inadequate information about the composition of varied feed resources also leads to the deficiency of the minerals. Data on mineral contents of human foods and
animal feeds are essential for formulation of feeding regimes and food processing
techniques.

There is very limited information on the mineral elements of some plants
used as human food and animal feeds. Some of the earlier information on mineral
elements was based on analysis employing less sensitive methods, which may not be
reliable. Modern analytical techniques like Laser Induced Breakdown Spectroscopy
(LIBS) led to the detection of trace elements and this is an active area of current
research [Aletor and Omodara, 1994].

**1.7. Phytochemistry**

Phytochemistry is an integrated distinct discipline of organic chemistry and
plant biochemistry which deals with a variety of organic substances accumulated in
plants and its biological and economical uses [Kokate, 1994].

**1.7.1. Phytochemicals**

Plants are considered to be a biosynthetic laboratory for a variety of
bioactive compounds. Phytochemicals (phyto=plant) are chemical compounds
formed during normal metabolic processes in plants. These chemicals are often
referred to as metabolites. Phytochemicals are important in both human and animal
life by providing nutritional diets, fibers, defense system against diseases. These
include vegetables, fruits, medicinal plants, aromatic plants, leaves, flowers and
roots [Okwu, 2005]. Based on the functions of plant metabolites, they are divided
into two groups primary metabolites and secondary metabolites. Primary metabolites
are fundamental components of plants which play an important role in metabolisms
and reproduction of the plants. These compounds include common carbohydrates,
amino acids, proteins, nucleic acid and chlorophylls [Krishnaiah et al., 2009].
1.7.2. Secondary metabolites

Secondary metabolites are non-nutritive chemicals produced by plants which have no role in their growth, photosynthesis, reproduction or other primary functions [Dixon, 1999]. Secondary metabolites are consisting of alkaloids, flavonoids, coumarins, glycosides, gums, phenols, tannins, terpenes, terpenoids, saponins, steroids and so on. Numerous plant derived secondary metabolites were used in human civilization for multipurpose benefits since ancient times [Jigna and Sumitra, 2007; Kumar et al., 2009; Harborne, 1973; Okwu and Okwu., 2004].

In many plants, secondary metabolites act as deterrents serve as defense compounds against herbivores [Hartman, 1996; Bernays and Chapman, 1994; Harborne, 1993], antibacterial, antifungal and antiviral to protect plants from pathogens [Wink, 1999b; Rhodes, 1994] and precursors for the synthesis of phytohormones [Croteau et al., 2000]. Besides, they constitute important UV absorbing compounds, thus preventing serious leaf damage from the sun light [Facchini, 1999].

1.7.3. Types of secondary metabolites

Secondary metabolites can be classified on the basis of chemical structure, composition, solubility and pathway by which they were synthesized. Most well-known major types of secondary metabolites are

1. Phenols and polyphenols
2. Alkaloids
3. Terpenoids and essential oils
1.7.3.1. Phenol and polyphenol compounds

Plant phenols are aromatic chemical compounds with weak acidic properties and are characterized by one or more acidic hydroxyl (OH) groups attached directly to an aromatic (phenyl) ring. The simplest of phenols derived from benzene is also known as phenol and has the chemical formula C₆H₅OH. Phenol compounds constitute about 40% of organic carbon and are primarily derived from phenylpropanoid, phenylpropanoidacetate and related biochemical pathways leading to hydralizable tannins. Many phenols act as defense compounds against herbivores, insects, fungi, bacteria, viruses, signaling molecules, pigments, flavors and others function in mechanical support, attracting pollinators and in absorption of UV radiation. Phenol compounds are present as esters or glycosides unit rather than as free compounds. Naturally occurring polyphenols scavenges peroxy radicals. Many phenol compounds are potent quenchers of free radical reactions and also react quite rapidly with singlet oxygen.

1.7.3.2. Flavonoids

Most phenol compounds belong to the flavonoids which are non-toxic dietary constituents. Most of the flavonoids possess anticarcinogenic activity and found to stabilize the basement membrane against the activity of proteolytic enzymes. They are ubiquitous and commonly found in fruits, vegetables, nuts, tea, wine, honey, etc. Several herbal preparations contain many phenol compounds which have antimeiastic and anticarcinogenic activity. The basic structure of flavonoids is derived from the C₁₅ body of flavone which has the C₆-C₃-C₆ structure. Flavonoids have an A, B and C-ring, and are typically depicted with the A-ring on the left-hand side. The A-ring originates from the condensation of three malonyl-
CoA molecules, and the B-ring originates from p-coumaroyl-CoA. These origins explain why the A-ring of most flavonoids is either meta-dihydroxylated or meta-trihydroxylated.

Flavonoids are differing from other phenol substances in the degree of oxidation of their central pyran ring. Some classes of flavonones are colorless, the members of other classes (anthocyanidins) are always colored and known as pigments of flowers or other plant parts. Anthocyanidins are normally red or yellow, their color is pH-dependent. Blue pigments are achieved by chelate formation with certain metal ions. The variability of the flavonoids is largely based on the hydroxylation and/or methylation pattern of the three ring systems.

Flavonoids are further classified into anthocyanidins, flavan-3-ols, flavones, flavanones, flavonols, isoflavonones and neoflavonoids. They all have the C₆-C₃-C₆ structure, but the B-ring is in a different position on the oxygen heterocycle ring. Examples are isoflavone and the neoflavonoid dalbergin.
1.7.3.3. Flavanones

The heterocycle of flavanones also contains a ketone group, but there is no unsaturated carbon-carbon bond. The A- and B-ring can be substituted analogous to the flavones, as in naringenin.

![Naringenin](image)

1.7.3.4. Flavanols

Flavanols are also known as dihydroflavonols and often occur in association with tannins in heartwood. An example of flavanol is taxifolin also known as dihydroquercitin.

![Taxifolin](image)

1.7.3.5. Flavones

The heterocycle of flavones contains a ketone group and has an unsaturated carbon-carbon bond. Flavones are common in angiosperms. The most widely distributed flavones in nature are kaempferol (5,7,4′ hydroxyflavone;), quercetin (5,7,3′,4′ hydroxyflavone;) and myricetin (5,7,3′,4′,5′ hydroxyflavone).
1.7.3.6. Biflavonoids

Biflavonoids have a C\textsubscript{30} skeleton. They are dimers of flavones such as apigenin or methylated derivatives and are found in gymnosperms. Few compounds are known. The most familiar is ginkgetin from \textit{Ginkgo biloba} (fossil tree of Japanese silver apricot).

1.7.3.7. Leucoanthocyanidins

Leucoanthocyanidins are also referred to as flavan-3, 4-cis-diols. They are synthesized from flavanonols via a reduction of the ketone moiety on C\textsubscript{4}. Examples of leucoanthocyanidins are leucocyanidin and leucodelphinidin. These compounds are often present in wood and play a role in the formation of condensed tannins.
1.7.3.8. Anthocyanidins and deoxyanthocyanidins

The heterocycle of anthocyanidins is a pyrilmation. Anthocyanidins are typically not found as free aglycones, with the exception of the following widely distributed, colored compounds like pelargonidin (orange-red), cyanidin (red), peonidin (rose-red), delphinidin (blue-violet), petunidin (blue-purple) and malvidin (purple). The most common anthocyanidin is cyanidin. Anthocyanins are watersoluble glycosides of anthocyanidins. The most common glycoside is the 3-glycoside. These compounds are present in the vacuoles of colored plant tissues such as leaves or flower petals. The color of the pigment depends on the pH, metal ions present, and the combination of substituted sugars and acylesters.

1.7.3.9. Chalcones

Chalcones and dihydrochalcones have a linear C₃-chain connecting the two rings. The C₃-chain of chalcones contains a double bond, whereas the C₃-chain of dihydrochalcones is saturated. Chalcones, such as butein, are yellow pigments in flowers. An example of a dihydrochalcone is phloridzin (phloretin-2’-O-D-glucoside) a compound found in apple leaves, and which has been reported to have anti-tumor activity [Nelson and Falk, 1993].
1.7.3.10. Aurones

Aurones are formed by cyclization of chalcones, whereby the meta-hydroxyl group reacts with the α-carbon to form a five-member heterocycle. Aurones are also present as yellow pigments in flowers.

1.7.3.11. Lignans

Lignans are dimers or oligomers of phenols that result from the coupling of monolignols-\(p\)-coumaryl alcohol, coniferyl alcohol and sinapyl alcohol with coniferyl alcohol being the most common monolignol used in lignan biosynthesis. Lignans are present in ferns, gymnosperms and angiosperms. They are localized in woody stems and in seeds and play a role as insect deterrents. Some of these compounds have medicinal properties.

1.7.3.12. Lignin

Lignin is a phenol polymer. It is the second most abundant biopolymer on the Earth (after cellulose) and plays an important role in providing structural support
to plants. Its hydrophobicity also facilitates water transport through the vascular tissue. The chemical complexity and apparent lack of regularity in its structure make lignin extremely suitable as a physical barrier against insects and fungi [Pillonel et al., 1991; Ralph et al., 2001].

1.7.3.13. Tannins

Tannin is a general descriptive name for a group of polymeric phenol substances capable of tanning leather. Tannin tastes are astringency, molecular weights range from 500 to 3,000 [Haslam, 1996]. They are found in almost every part of plant tissues such as, bark, wood, leaves, fruits and roots [Scalbert, 1991]. Tannins are abundant in many plant species, particularly in euphourbaciae family. They are divided into two main groups, hydrolyzable and condensed tannins [Egunyomi et al., 2009].

Tannins are used commercially as dyes, astringents and lignin accounts for structural rigidity of cells and tissues and essential to vascular development. Tannins were applied in the wine and beer production to precipitate proteins. They have used to treat a wide range of illnesses, including diarrhea and tumors in the stomach or duodenum [Khanbabaee and Van Ree, 2001]. Many human physiological activities, such as stimulation of phagocytic cells, host-mediated tumor activity and a wide range of antiinfective actions have been assigned to tannins [Haslam, 1996].

1.7.3.14. Biological and pharmaceutical activities of phenol compounds

Phenol compounds are effective antimicrobial agents against a wide variety of microorganisms [Cushnie and Lamb, 2005]. Flavonoids have the ability to make complex with extracellular proteins as well as with bacterial cell walls, rendering them inactive [Cushnie and Lamb, 2005]. More lipophilic flavonoids may also have the ability to disrupt microbial membrane [Tsuchiya et al., 1996; Martindale, 1996].
Catechins are the most extensively studied flavonoids for their possible antimicrobial activity due to their occurrence in green tea [Toda et al., 1989].

Polyphenols are important antioxidants, because they have high redox potential, which permit them to act as reducing agents, hydrogen donors, singlet oxygen quenchers and metal chelator [Kahkonen et al., 1999] and alleviate free-radical mediated cellular injury [Shahidi and Wanasundara, 1992]. The antioxidant activity of a polyphenol compound is chiefly determined by its structure, in particular electron delocalization over an aromatic nucleus [Tsao and Akhtar, 2005].

Flavonoids are potent water-soluble super antioxidants and free radical scavengers, which prevent oxidative cell damage, have strong anti-cancer activity and protects against all stages of carcinogens. Flavonoids have been shown to be highly effective scavengers of most types of oxidizing molecules, including singlet oxygen and various free radicals [Bravo, 1998], which are possibly involved in DNA damage and tumor promotion [Cerutti, 1985]. In terms of anti-cancer activity, they inhibit the initiation, promotion and progression of tumors [Urquiaga and Leighton, 2000; Okwu and Okwu, 2004].

1.7.3.15. Alkaloids

Alkaloids (alkali+oid means alkali like substance) are defined as a basic nitrogenous compound which produces salt when combines with acid and is physiologically active in plants and animals. Names of alkaloids are end in “ine” [Harborne, 1973]. Generally alkaloids are crystalline in nature but a few are liquid at room temperature. Alkaloids have bitter tastes, insoluble in water but its salt preparation is highly soluble in water and soluble in alcohol, ether, chloroform and oil. Usually, alkaloids are basic in nature which contains secondary, tertiary or cyclic amines [Harborne, 1973].
Approximately, more than 16,000 alkaloids are known, comprising the largest single class of secondary plant substances. The majority of the alkaloids were extracted from the flowering plants abundant in seeds and roots. About 20-30% all plant species accumulate alkaloids. They are more common in Solanaceae and Apocynaceae families contains as many as 60-70% alkaloids.

1.7.3.16. Pharmacological activities of alkaloids

Alkaloids have important biological activity, which affect the nervous system, particularly the action of mechanical transmitters, e.g. acetylcholine, epinephrine, GABA, dopamine, and serotonin [Harborne, 1973]. Alkaloids have many other pharmacological activities including haemolytically, analgesic, antispasmodic and bactericidal effects [Stray, 1998], antihypertensive effects (many indole alkaloids), antiarrhythmic effects (quinidine, ajmaline, planeine), antimalarial activity (quinine) and anticancer actions (dimeric indolest vincrisiine, vinblastine) [Okwu, 2005]. Antibiotic activities are common for alkaloids and some are even used as antiseptics in medicine, e.g., berberine in ophthalrnics and sanguinarine in toothpastes [Noble, 1990]. Alkaloids are widely used as therapeutic agents in the management of cancer [Caner and Horwitz, 1990]. Alkaloids also interfere with cell division, alkaloid from Hibiscus sabdariffa demonstrated to prevent mutagenesis [Chewonarin et al., 1999].

1.7.3.17. Terpenoids and essential oils

The terpenes are compounds that are built up from isoprene units. Their structures are divisible into the C₅ isoprene units. Isoprene units are linked in a head-to-tail manner. Terpenes has several important biological roles such as flavour, fragrance,
scent, antibiotics, hormones, membrane lipids, insect attractants, insect antifeedants and mediate the electron transport processes (in respiration and photosynthesis).

Essential oils are secondary metabolites that are highly supplemented in compounds based on isoprene structures which also contain extra elements such as oxygen [Cowan, 1999]. They are usually occurring as di, tri, tetra, hemi and sesquiterpenes. Camphor, farnesol, artemisin and capsaicin are common examples of terpenoids. Terpenes and terpenoids are active against an array of bacteria [Habtemariam et al., 1993] and fungi [Rana et al., 1997]. Previous research showed that terpenoids present in the essential oils of plants could be useful in the control of Listeria monocytogenes [Aureli et al., 1992]. The mechanism action of terpenes is not yet established precisely, but is speculated to be due to disruption of bacterial cell membrane by lipophilic terpenoids [Mendoza et al., 1997].

1.7.3.18. Plants as leads to the discovery of new drugs

Phytochemicals are chemical compounds formed during the plants normal metabolic processes. Phytochemicals are present in a variety of plants/parts utilized as important components of both human and animal diets [Okwu, 2005]. The constituents are playing a significant role in the identification of crude drugs [Savithramma et al., 2011]. Phytochemicals are responsible for medicinal activity of plants [Savithramma et al., 2011]. The presence of these secondary metabolites in plants probably explains the various uses of plants in traditional medicine [Soetan, 2008]. Most of these phytochemical constituents are potent bioactive compounds found in medicinal plant parts, which are precursors for the synthesis of useful drugs of several pharmaceutical industries [Sofowora, 1993].
Based on the scientific and traditional knowledge, a rational approach is being the phytochemicals from established herbals were also used as chemical models to synthesize modern drugs. Nowadays, new drug discovery processes uses plants as sources of active molecules. An attempt for chemical synthesis of few plant metabolites is being undertaken commercially but a great majority are still extracted and purified directly from plants. Chemical synthesis of plant products is commercially not available because of the complexity in their biosynthetic pathway. Presently, modern therapy contains 120 plant derived compounds obtained from 90 plants species. Plants have synthesized limitless of secondary metabolic substances of which less than 10% of the total has been isolated and studied [Schultes, 1978; Geissman, 1963].

The whole medicinal plant, was extracted then to purify the bioactive compounds was the first step in the led molecule search. This approach has led to successful development of many drug molecules from plants. From these purified compounds, molecules are used to develop/derive a number of new compounds which used to treat a variety of diseases. At present, hundreds of plant based pharmaceutical products and synthetic analogues from herbal plants were prepared and available in the market. Several plant based semisynthetic drugs have been used as major drugs for many diseases. Bromhexine, a synthetic mucolytic agent for cough preparation has been developed from viscine an alkaloid obtained from Adathoda vasica. The entire field of hormonal steroids has come out as chemical modification of diosgenin, a product obtained from Dioscorea tubers or the Mexican yam. In the discovery of new derivatives from plant extracts were possible, only due to the fact that original plants had shown activity, even if it is low it was only a lead.
[Darshan and Doreswamy, 1998]. There are several standard methods used for the phytochemical screening and isolation from medicinal plants.

1.8. Plant details
1.8.1. Terminalia genus

The family Combretaceae is comprised of 20 genera and about 475 species [Thiombiano et al., 2006]. Of these, about 200 belong to the genus Terminalia, making it the second largest genus of the family after Combretum [McGaw et al., 2001]. The family is distributed throughout the tropical and sub-tropical regions of the world [Lamb and Ntima, 1971]. The genus Terminalia (T.) derives its Latin name (Terminalis = end) from the position of the leaves, which are crowded at the ends of the shoots [Lamb and Ntima, 1971; Rogers and Verotta, 1996].

1.8.2. Economic importance of Terminalia species

Terminalia spp. provides economical, medicinal, spiritual and social benefits. Terminalia trees are planted in several countries in the tropics as a source of high quality solid timber for fine carpentry, joinery, building, flooring and plywood manufacture [Schmidt et al., 2002; Smith et al., 2004]. The wood of Terminalia spp. is highly appreciated as constructional timber. It is currently used for light construction, door and window frames, coffin boards, mouldings, beams, rafters, joists, flooring, furniture, carts, tool handles, spindles, shuttles, picker sticks, walking sticks, bowls, boat building, masts, mine props, foundation piles, veneer and plywood [Irvine 1961; Lemmens et al., 1995; Schmidt et al., 2002; Smith et al., 2004].

The fruits and bark of T. sericea and T. catappa are important sources of tannin, as well as gum and resins for glazing pottery [Irvine, 1961; Lemmens and Wulijarni-Soetjipto, 1991; Ellery and Ellery, 1997]. Dyes of various colours (black,
red, orange, yellow, brown) are extracted from the leaves, fruits, bark and roots of species such as T. mollis, T. ivorensis, T. laxiflora, T. catappa and T. superba and used for decorating the walls of houses and buildings with murals, for dyeing clothes, mattings, rattan, spoons and walking sticks [Dalziel, 1937]. The seed of some species is edible and considered one of the best flavoured tropical nuts. Furthermore, consumable oil can be extracted from the seed of T. catappa and used as a substitute for groundnut (Arachis hypogea L.), cotton seed (Gossypium spp.) and silk cotton seed (Ceiba spp.) oils [Irvine 1961].

**Terminalia chebula Retz.**

**Synonym names**

*Terminalia parviflora* Thwaites

*Terminalia tomentella* Kurz;

*Terminalia zeylanica* van Heurck & Muell. Arg

**Common name:** Kadukkaay (Tamil)

**Botanical classification (taxonomy)**

- **Domain**: Eukaryota
- **Kingdom**: Plantae
- **Division**: Mannoliphyta
- **Class**: Mangolipsida
- **Order**: Myrtates
- **Family**: Combretaceae
- **Genus**: *Terminalia*
- **Species**: *chebula*

**Botanical name:** *Terminalia chebula* Retz.

*Fig. 1.4. Terminalia chebula*
1.8.3. Geographical distribution

Terminalia chebula (T. chebula) is a native plant of India also found in wet lands of tropical Myanmar, Bangladesh, Sri Lanka, Malaysia, Vietnam, Iran, Egypt, Turkey, Africa, China, etc. It primarily occurs in deciduous forests and areas of light rain fall but occasionally in slightly moist forests grow upto about 1500m elevation and medium altitudes [Suryaprakash et al., 2012].

Habit: It is a moderate sized (or) large deciduous tree (30-80 feet in height) usually short cylindric bole of 5-10m length, 60-80cm in diameter at breast height; younger stems glabrescent, woody. It has round crown and spreading branches. The bark is dark brown with some longitudinal cracks.

Root system: The root system of T. chebula is fairly shallow. As the trees ages, the tap roots disappear.

Flowers: The flowers are monoecious, many and crowded at the apices of the numerous peduncles, normally dull white to yellow or orange in color with red streak in the center of each of the five petals with a strong unpleasant odour.

Fruits: It is a drupe, glabrous, sub globose to ellipsoid, 2.5–5.0cm by 1.5-2.5cm in size, usually smooth or frequently 5-angulate (five ribs on the outer skin), ridged, wrinkled. Fruit is green when unripe and yellowish grey when ripe and turning blackish when dry.

Seeds: One, rough, ellipsoidal, 1-2cm by 0.2 -0.7cm and without ridges.

Flowering: Flowers appear from April–August and fruits ripen from October-January.

1.8.4. Ethnobotanical uses/biological activities

T. chebula is a most popular medicinal plant in traditional herbal medicine not only in India and also in several countries of Asia and Africa regions [Lawes et al., 2004]. The different parts (barks, leaves, flowers, roots, fruits and seeds) of
*T. chebula* has been extensively used in Siddha, Unani, Ayurveda and Homeopathic medicine [Criagg and David, 2001]. *T. chebula* was used in traditional medicine due to the wide spectrum of pharmacological activities which posses several biologically active chemicals (secondary metabolites). *T. chebula* is an economically important plant in tanning and pharmaceutical industries [Chadha, 1989].

It is used for the treatment of number of diseases like asthma, sore throat, vomiting, hiccough, diarrhea, dysentery, bleeding piles, cancer, paralysis, cardiovascular diseases, ulcers, leprosy, arthritis, gout, epilepsy, constipation, parasites, malabsorption syndrome, hepatomegaly, vesicular ophthalmia, renal calculi, urinary discharges, tumours, skin disease, intermittent fever, rheumatism, neuropathy, paralysis, memory loss, diabetes, anorexia, fever, cough, gastroenteritis, candidiasis, inflammation, brain dysfunction, urinary tract infection and wound infections *etc.*, [Suryaprakash et al., 2012; Bharat Reddy et al., 2010; Thakur et al., 1998; Dash and Bhagwan 1991].

*T. chebula* has been reported to possess many pharmacological, biological and medicinal activities such as, antioxidant, antimicrobial, antidiabetic, hepatoprotective, antiinflammatory, antimutagenic, antiproliferative, radioprotective, cardioprotective, antiarthritis, anticaries, antiviral, anticancerous, antiulcer, gastrointestinal motility and wound healing activity *etc.*, [Suryaprakash et al., 2012; Anwesa Bag et al., 2013; Suchalatha and Devi, 2009; Kim et al., 2001; Kannan et al., 2009].

**1.9. Pteridophytes and their importance**

The name *Pteridophyta* was derived from the Greek words (*pteron=*feather and *phyta=*plant), due to feather-like leaves of pteridophytes. The ferns and fern-allies together form the pteridophytes. In the plant world, pteridophytes are supposed to be oldest and primitive vascular plants. Pteridophytes constitute an important part of the
flora of the world and they are second largest component of this world flora, next to the
flowering plants [Rashid, 1976]. They are found scattered all over the globe and quite
many of them occur in India. About 12,000 species of pteridophytes occur in the world
flora of which about more than 1,200 species are promising as reported from India.

Pteridophytes have been playing a vital role (for food, fuel, fiber, oils,
medicines, ornamentation and shelter) in the life and economy of many tribal
societies around the world. The tribal communities, ethic groups and folklore
throughout the world are utilizing different parts (rhizome, stem, fronds, pinnae and
spores) of pteridophytes in various ways for the treatment of several ailments since
ancient time. The pteridophytes are known to man for more than 2000 years for their
medicinal values. Theophrastus (327-287 BC) and Discorides (50 AD) had referred
the medicinal attributes of certain ferns. Nowadays, pteridophytes are used in many
traditional medicine systems such as, Homeopathic, Ayurvedic and Unani medicines
and other systems of medicines which provided insecticides, antibiotics and food.

1.9.1. Dryopteris

Dryopteris is now considered as synonym of Oreta. Dryopteris, commonly
called as wood fern, male fern or buckler fern. Dryopteris is a large and widespread
genus containing about 230 species, which are often found in forests and open
vegetation or sometimes in rocky and alpine zones from temperate to tropical regions.
Dryopteris is distributed on all the continents except Antarctica, but the abundance and
diversity is temperate Northern Hemisphere and centered in Asia, especially in South-
Western China and adjacent regions [Fraser-Jenkins 1986; Wu, 2000].

The relationship among these Dryopteris species remain poorly understood.
Fraser-Jenkins (1986) briefly reviewed the history of the infrageneric classification of
Dryopteris and presented the first subdivision for the global Dryopteris species based on morphology. His classification for Dryopteris included four subgenera: Pycnopteris, Dryopteris, Erythrovariae and Nephrocystis, all of which except the Pycnopteris contain several sections, particularly in the subgenus Dryopteris [Fraser-Jenkins, 1986].

Many of the species have stout, slowly creeping rootstocks that form a crown, with a vase-like ring of fronds. The sori are round, with a peltate indusium. The stipes have prominent scales. Hybridisation is a well-known phenomenon within this group, with many species formed by this method.

**Dryopteris cochleata** (Buch. -Ham.ex D. Don) C. Chr.

**Synonym name**

*Nephrodium cochleatum* D. Don.

**Common name:** Nandukuthi

**Botanical classification (taxonomy)**

- **Domain:** Eukaryota
- **Kingdom:** Plantae
- **Subkingdom:** Viridaeplantae
- **Phylum:** Tracheophyta
- **Subphylum:** Euphyllophytina
- **Infraphylum:** Moniliformopses
- **Class:** Polypodiopsida
- **Order:** Polypodiales
- **Family:** Dryopteridaceae
- **Genus:** *Dryopteris*
- **Species:** *cochleata*

Botanical name: *Dryopteris cochleata* (Buch. -Ham.ex D. Don) C. Chr.
1.9.2. Geographical distribution

Dryopteris cochleata (D. cochleata) is commonly grows along the sides of streams and nalas in the forest floor in laterite soil at low to medium altitudes (up to 2,000m). Found in almost all countries especially in the mixed forests of India, Burma, China, Philippines, Java, Myanmar, Malaysia, Thailand, Laos and Cambodia [Heena and Achaleshwar, 2010].

1.9.4. Morphological Description

Rhizome: Rhizome are short creeping, densely clothed by scales all over, scales lanceolate, pale brown, thin, memberanaceous, translucent, apex long acuminate, margin with tooth like or glandular hair like out growths or with long lateral branches, size about 10 by 1mm.

Leaves: Leaves/ Frond are bipinnate, distinctly dimorphic, sterile lamina oblong- subdeltoid, acuminate at apex, upto 45 by 30cm; rachis glabrescent or minutely scaly, grooved above; lateral pinnae upto 10 pairs, basal pinnae the largest or slightly smaller than the next above, slightly falcate, oblong-lanceolate, caudately acuminate at apex, narrowing towards stalked base, pinnate, upto 25 by 7cm; pinnarachis grooved above, winged throughout; pinnules oblong, falcate, acute to moderately acute at apex, upto 4 by 1.3cm, shallowly lobed at margin; lobes oblique, slightly toothed; herbaceous to softly papyraceous, light green, glabrous, veins bipinnate; fertile lamina oblong or narrowly subdeltoid, upto 50 by 15cm; pinnae ascending, linear, upto 10 by 1.5cm; pinnules oblong, round at apex, truncate and shortly stalked or adnate at base, upto 10 by 5mm; veins pinnate, veinlets simple or forked. Sori in one row between midrib and margin; indusia large, upto 2mm diam., very close to each other or slightly imbricate, glabrous.
Fig. 1.5. *Dryopteris cochleata* leaves (a), spores (b) and rhizome (c)
1.9.4. Ethnobotanical uses/biological activities

*D. cochleata* has been reported in the use of traditional herbal medicine to cure various diseases and possess many important biological properties like, antifungal [Asolkar et al., 1992], antibacterial, antiepileptic [Thomas, 2011] and antioxidant [Kathirvel et al., 2012]. Extracts of rhizome were taken twice daily to treat rheumatism, epilepsy, leprosy, throat problems, blood purification and also used as tonic for strength [Manandhar et al., 1998; Shah et al., 1990]. The paste of fresh rhizome, stem and stipe is externally applied on cuts, wounds, ulcers, swelling and pains. A teaspoonful root juice was given twice a day before meal to treat amoebic dysentery [Singh, 1999; Verma et al., 1995; Shah et al., 1990; Shanker et al., 1994].

Whole plant extract was given twice daily orally for snake and dog bites as an antidote. Fresh paste of rhizome and fronds is externally applied on the wound site of snake and dog bites to prevent infections [Singh et al., 2010]. The fresh juice of fronds is used to treat muscular and rheumatic pain [Kunjani and Ananda, 2008]. *D. cochleala* shoots are edible when cooked as a vegetable curry. When boiled with salt then eaten, the plant has a powerful medicinal use in combating diarrhoea with blood in the stool. The whole plant extract is used as gonorrhea [Sigh et al., 2003].