Review of Literature
Indian sub-continent has a rich biological diversity owing to its vast geographic area, varied topography and climate, and diverse biogeographical regions. Because of its richness in the overall species diversity, India is recognized as one of the 12 mega-diversity centers of the world. Out of 1.7 million species globally described and recorded in the scientific literature, India has about 1,26,200 species (Khoshqaf, 1996) and ranks tenth in the world in respect of the richness of flowering plants (17,000 species) Amongst 49,219 plant species found in a 17,000 sq km strip of forest area along the seaward side, 1,600 (40%) species are considered endemic to the Western Ghats region in Maharashtra, Karnataka, Tamil Nadu and Kerala (Anon., 1992). Forest tracts of up to 500 m in elevation, comprising one-fifth of the entire forest expanse are mostly evergreen, while those in the 500–1500 m range are semi-evergreen (Myers, 1988).

India has the well-documented traditional knowledge of medicinal and aromatic plants used in the primary healthcare of humans and his livestock. In recent years, there is an increasing awareness on the significance of medicinal plants not only in human healthcare but also in other area of science. More than 35,000 plant species are being used around the world for medicinal purposes (Van-Seters, 1997) and about 8,000 medicinal plant species are used by the rural people in India (Tiwari et al., 2000). About 25,000 formulations used in allopathic system of medicine are derived from plant species that are being used as folk medicines throughout the world. Approximately, 166 companies import crude extracts obtained from medicinal and aromatic plants in India. Nearly 90% of plant species used in industries is collected from the wild habitat
(Srivastava, 2000). In India, the traditional healers generally use 2,500 plant species and regularly use 100 species of plants, as source of medicine (Pei, 2001).

The global market for herbal medicine currently stands at over US $ 60 billion, annually. The scale of herbal medicines is expected to get higher at 6.4% on an average annual growth rate (Inamdar, 2008). Indian herbal market is one of the fastest growing market and is expected to attain ₹ 14,500 crore by 2012 and could earn foreign exchange of ₹ 9,000 crore according to findings of ‘The Associated Chambers of Commerce and Industry of India’ (ASSOCHAM) (Saini et al., 2011).

There is a growing concern on diminishing populations, loss of genetic diversity, local extinction and habitat degradation of well-known plant species threatened by harvesting in the wild; and about 4,000 to 10,000 medicinal species might have already been endangered (Edwards, 2004). The major pharmaceuticals exported from India in recent years include isabgol, opium alkaloids, senna derivatives, vinca extract, cinchona alkaloids, ipecac root alkaloids, solasodine, diosgenine, menthol, gudmar herb, mehdi leaves, papain, rauwolfia, guar gum, jasmine oil, agar wood oil, and sandal wood oil (Sharma, 2008). The main active constituents of Artemisia annua are sesquiterpepeid lactone endoperonides named artemisinin and artemisinic acid (Tiwari, 2008). Artemisinin is very effective to Plasmodium falciparum and P. vivax and also to drug resistant parasite races. Digoxin produced by Digitalis purpurea (foxglove) has been used for various medicinal properties. For more than a century, quinine, an alkaloid obtained from the bark of various species of cinchona trees has been used in the treatment of malaria, and interestingly it was one of the first agents used in the treatment of amoebic
dysentery. Reserpine isolated from raw plant extract of *Rauwolfia serpentina* is used as a tranquilizer and in the control of high blood pressure (Tiwari, 2008).

In India during 2006-07, the total production of herbal medicine was approximately ₹ 10,000 crores. There are around 1,000 single drugs and 15,000 compound formulations manufactured by 4,000 registered manufactured units in India (Kamboj, 2000: Sharma et al., 2008). There are also an estimated 9,000 manufacture units in India using 960 botanicals with an annual domestic turn-over of ₹ 8,000 crores and the export of around ₹ 1,000 crores per year. Presently, the US is the largest market for Indian botanical products accounting to about 50% of the total exports.

Today, the herbal medicine trade is a booming business world-wide. The largest global markets for medicinal plants are China, France, Germany, Italy, Japan, Spain, UK and the US. Japan has the highest per capita consumption of botanical medicines in the world (Laird, 1999). Japan, Hong Kong, Korea and Singapore are the major importers of the herbal drugs making 66% share of China’s botanical drug export (Sangita, 2011). Within the European community, botanical medicine represents an important share of the pharmaceutical market (Fig. 1). An estimate of the EXIM Bank puts the International market of medicinal plant related trade at US$ 60 billion per year, growing at the rate of 7%. The global pharmaceutical market was expected to exceed US $ 900 billion by the year 2009 (Aneesh et al., 2009). Aarts (2006) reported that recent global market for medicinal herbs and herbal products is about US $ 62 billion and would touch the level of US $ 5 trillion market by 2050.
With only 2.4% of the total land mass of the world, India shares about 11% of the total floristic diversity and ranks as one of the megadiversity centers having four hot-spots among 34 global hot-spots. The main source of plant products in India are forests. Of the 17,000 species, about 7,500 species (44%) of higher plants in India are reported to possess medicinal value, while the percentage of plants having medicinal value in China, Mexico and North America is 44%, 7% and 13% of their total reported species, respectively. With regard to the habit of medicinal plants, about one third of all species are trees, 32% herbs, 20% shrubs, 12% climbers and 3% species of other categories (Anon., 2000b). Among the plant parts, roots followed by whole plant, bark and fruits are most preferred for medicinal purposes (Fig. 2).
Diseases of medicinal plants

Various plant pathogens adversely affect the medicinal plant species and might cause decrease in the medicine value and productivity; and when consumed, diseased herbs might cause harmful effects on human body. Detailed information on the fungal diseases caused in cultivated and uncultivated medicinal herbs with respect to disease severity and distribution, the seedborne nature and transmission of pathogens and their management is scant in the literature. The literature on the diseases of both wild and cultivated medicinal plants, seed mycoflora and disease severity and disease management, and its impact on secondary metabolite content has been reviewed, with due importance to the recent published information.

Foliar diseases are characterized by the production of very small to large leaf spots that might coalesce to cover the entire leaf lamina causing the leaf blight. Sometimes, shot-holes are also produced following the separation of dead tissue from the leaf. Other very distinct foliar symptoms include powdery and downy mildews, rust and
sooty molds, or ring spots, mosaics and mottles. The foliar diseases are incited by pathogenic forms of fungi, bacteria, viruses or phytoplasma.

Stem diseases are mainly characterized by cankers and rots. A canker is a dead area in the bark or cortex of the stem, especially in woody plants. The surface may be smooth or rough and usually somewhat sunken. In some cases, only the superficial layers of cell are affected, while in others all the tissues except fibers are destroyed. In many cases, the dead bark splits and finally peels away leaving the wood naked. In rot symptoms, the affected tissue dies and decomposes to a great extent and turns brown. In most cases, this condition is brought about by the pathogenic fungi and bacteria, which dissolve the cell walls more or less completely by their enzymes. Rot is the major disease symptom in root system. Depending upon the type of dissolution brought about by the pathogen, rots could be grouped into soft rot, wet rot or dry rot.

Damping-off, a major symptom at seedling stage, is a condition in which the stem is attacked near the soil surface. The affected portion becomes constricted and weak, and incapable of bearing the load of the upper portion, seedlings topple down and die. Damping-off of vegetable and ornamental seedlings are common examples. Crown and collar rots occur at the soil level, where the plant emerges. A crown rot is typically associated with herbaceous plants. The tissue may turn brown to black in the localized area around the soil line. The discoloration may migrate upward and downward around the outside of the tissue from the point of infection.

Some of the diseases expressed in wild and cultivated medicinal plants of different families are briefly reviewed.
Acanthaceae

*Adatoda vasica* is an important medicinal plant used extensively in Ayurvedic medicine, primarily for treating respiratory disorders (Kapoor, 2001). The plant species is affected by foliar pathogens - *Colletotrichum gloeosporioides* and *Curvularia pallescens* (Roy, 1979). Singh et al. (2006) also reported leaf blight of *A. vasica* caused by *Alternata alternata* (Fr.) Keissler that resulted in severe damage to foliages, that were unfit for medicinal purpose. Shreemali (1972) observed the infection of twigs of *A. vasica* by *Phoma vasicae* spec. nov.

*Barleria cristata*, a wild medicinal plant, is used traditionally for the treatment of variety of diseases including anemia, tooth-ache and cough (Rajasekaran and Kanakasabapathi, 2012). Leaves were used to reduce swellings due to inflammation (Gambhire et al., 2009). Purushothaman (1971) reported *Alternaria tenuis* Auct. cause leaf blight of *B. cristata* in Tamil Nadu.

Annonaceae

*Annona squamosa* is a small evergreen tree cultivated throughout India for its edible fruits. Different parts of *A. squamosa* are used in folklore medicine for the treatment of various diseases (Suresh et al., 2006). Reddy (1969) recorded leaf spot disease caused by *Arthriniun phaeospermum* (Corda) Ellis. on leaves of *A. squamosa*.

Amaranthaceae

*Chenopodium album* is a leafy vegetable plant and its seeds are the rich source of protein, vitamin A, calcium, phosphorus, and potassium (Johnson et al., 1995). Mishra (1987) reported the leaf spot disease in *C. album* caused by *Phoma exigua* Desm. The/
disease was controlled by spraying Bavistin 50% WP (@ 0.1%). In 1962, Ganguly et al. described powdery mildew caused by *Erysiphe cichoracearum* DC. in *Chenopodium ambrosioides.*

*Achyranthes aspera* is an ethno-medicinal plant and its leaves and fruits are used as remedy for piles, renal dropsy, pneumonia, cough, kidney stone, skin eruptions, snake bite, gonorrhea, and dysentery (Aziz et al., 2005). Nath et al. (1980) reported *Colletotrichum dematium* (Pers. Ex.Fr.) which caused sub-circular to irregular, grey spots with brown margin and bigger spots.

Sugarbeet (*Beta vulgaris*), one of the most efficient converter of solar energy into stored energy, is an important sugar crop with ethanol production potential (Singh, 2006). *Cercospora* leaf spot has been reported to be a serious problem in sugar beet under intensive cultivation (Vereissen et al., 2007). The pathogen identified as *C. beticola.*

**Amaryllidaceae**

Onion, one of the most popular vegetable that forms the daily diet in India, is an important commercial crop. It is widely grown in different parts of the country (Barakade et al., 2011). The presence of antioxidant, anticancer, antimicrobial, anti-inflammatory, and neuroprotective activities makes *A. cepa* a potential therapeutic agent (Vamshi et al., 2010). Singh (1968) reported *Botrytis allii* Munn. on bulbs of *Allium cepa.* Thind et al. (1982) reported a fungal pathogen *Alternaria porri* (Ellis) Cit. which caused purple blotch infection on onion plants in Punjab, causing 20-25% losses. Leaf blight of onions caused by *Xanthomonas campestris* occur in Barbados and is characterized by the rapid necrosis and die-back of leaves under humid conditions (Paulraj et al., 1993). Deshmukh et al. (2008) reported that purple blotch of onion caused by *A. porri* could be controlled by
foliar application of a mixture of hexaconazole (0.005%) + mancozeb (0.3%) followed by difenoconazole (0.025%) + mancozeb (0.3%). This resulted in the reduced disease intensity (70.72%) and reduction in yield loss by 26.16 and 22.67%, respectively, over control.

**Apiaceae**

*Foeniculum vulgare*, commonly known as fennel, is an important medicinal and aromatic plant widely used as carminative, digestive, lactagogue and diuretic and in treating respiratory and gastrointestinal disorders (Agarwal *et al.*, 2008). *Ramularia* blight caused by *Alternaria alternata* is a serious problem in *F. vulgare* cultivation. Chaudhari and Patel (1987) reported that spraying plants with Bavistin at 10 days interval (0.20) and the same fungicide at 20 days interval (0.42) were useful in controlling the disease. Dithane M-45 stood next to Bavistin in its effectiveness.

All parts of *Coriandrum sativum* plant are edible, but the fresh leaves and the dried seeds are the most common parts used in cooking (Pathak *et al.*, 2011). Agarwal *et al.* (2005) investigated seeds carrying 38-43% incidence of *Fusarium oxysporum* f. sp. corianderi. The disease was asymptomatic or symptomatic with discoloration. In asymptomatic seeds, the fungal inoculum was localized to seed coat. In moderately and heavily discoloured seeds, the infection was found to be extra- as well as intra-embryonal. In heavily discoloured seeds, besides all components, the pathogen colonized the embryo also. Sivaprakasam *et al.* (1992) reported that stem gall disease caused by *Protomyces macrosporus*, is controlled by seed treatment with thiram (2 g kg⁻¹), or collection and destruction of affected plants and selection of disease-free seeds. Wilt caused by *Fusarium oxysporum* f. sp. *coriander* was controlled by seed treatment with
thiram, or carbendazim (2 g kg⁻¹), growing resistant varieties and application of organic manure. Powdery mildew caused by *Erysiphe polygoni* was controlled by dusting with sulphur at 25 kg ha⁻¹ or spraying with wettable sulphur at 2 kg ha⁻¹.

*Anethum graveolens* (Dill) is a popular aromatic herb and spice with a long history of use, going back to more than 2,000 years (Ishikawa *et al.*, 2002). Dill is used as a flavouring agent in food industry and to relieve digestive problems such as stomach-ache, indigestion and flatulence (Gurinder and Daljit, 2010). Janardhanan and Ganguly (1963) reported that fungal flora of seeds predominantly consisted of species of *Alternaria*, *Aspergillus* and *Penicillium*.

**Apocyanaceae**

*Alstonia scholaris* is traditionally important and used in Ayurvedic, Unani and Siddha systems of medicine (Khare, 2007). The plant is used for treating asthma (Vikneshwaran *et al.*, 2008), leucorrhoea (Bhandary *et al.*, 1995), fever (Rajakumar and Shivanna, 2010), cancer, tumour, jaundice, hepatitis, malaria, skin diseases (Mollilj *et al.*, 2010), and diarrhea (Dash and Padhya, 2006). Reddy (1969) recorded *Sordaria humana* (Fuckel) Wint. Balsamand that caused cream coloured leaf spots in *A. scholaris*.

*Tylophora indica* is a folk remedy in certain regions of India for the treatment of bronchial asthma and inflammation (Gopal *et al.*, 1979). This plant is reported to be affected by powdery mildew caused by *Oidum* sp. (Verma and Guptja, 2006).

*Boerhaavia diffusa*, one of the medicinal plants used to treat human ailments, is mentioned in Ayurveda, Charaka Samhita, and Sushrita Samhita. The plant in whole or its aerial parts and roots have numerous medicinal properties such as anti-bacterial, anti-
nociceptive, hepato-protective, hypo-glycemic, anti-proliferative, anti-estrogenic, anti-convulsant, and anti-metastatic activities (Mahesh et al., 2012). Shreemali (1972) observed twig spot disease in B. diffusia caused by Phoma boerhavieae spec.nov.

*Rauwolfia serpentina*, the Indian snake root, is an important Ayurvedic medicinal plant used for centuries for various medicinal properties, in India. The dry root of *Rauwolfia serpentina* contains about 30 indole alkaloids (0.7–2.4%). Among alkaloids, reserpine is the active constituent well known for its anti-hypertensive action. Other alkaloids include ajmalicine, rescinnamine, yohimbine and serpentine (Chopra et al. 1980). The plant is affected by a number of foliar diseases caused by *Alternaria alternata*, *Cercospora rauwolfiae* and *Rhizoctonia solani* which caused considerable damage to plants (Ganguly and Pandhota, 1962; Mohanty and Addy, 1957). Ganguly et al. (1962) also described powdery mildew disease caused by *Leveillula taurica* (Lev.) Arn. Lele et al. (1968) reported die-back of *R. serpentina* Benth. caused by *C. dematium* (Pers. ExFr. Grove). The affected twigs, leaves and flowers expressed numerous spots, lesions coalesced to form larger spots and resulted in defoliation. The die-back disease appeared during high humidity conditions. Spraying with Dithane Z-78 (0.2%) and pruning of the affected parts partially controlled the spread of disease in the field.

**Asparagaceae**

*Asparagus* species are important medicinal herbs. Bakel et al. (1974) described dead stem disease in *Asparagus* caused by two types of *Fusarium culmorum* (W.G. Smith) Sacc. infection. The first one with lesions on the base of the stem at soil level, as a result of which the stem dies-off. In the second type of infection, lesions appear higher up on stems, while stems remain mostly green. Schreuder et al. (1995) reported that
Fusarium oxysporum and F. proliferatum are important pathogens associated with Asparagus decline in South Africa.

Asclepiadaeae

Calotropis procera is an Ayurvedic plant with anticancer, antifungal (Hassan et al., 2006) and insecticidal activities. Flowers, roots and latex have many biological activities. (Markouk et al., 2000; Dewan et al., 2000), including anti-inflammatory (Arya and Kumar, 2005) and antimicrobial (Sehgal et al., 2005), anti-fertility (Kamath et al., 2002) activities. The plant is affected by powdery mildew disease caused by Oidum sp. (Verma et al. 2006).

Plumeria acutifolia (syn. Plumeria rubra) is a native of Mexico and cultivated in gardens throughout India, as an ornamental tree. The root bark of the plant is bitter, pungent, heating, carminative, laxative, cures ulcers and useful in leprosy (Surendra, 2012). Sohi et al. (1968) reported Cercospora plumeriae Chupp. on P. acutifolia in Himachal Pradesh.

Asteraceae

Ageratum houstonianum, native to Mexico and Central America, is an important seed-propagated, annual bedding weed. In addition to its use as an ornamental, A. houstonianum and its closely related species A. conyzoides are used in folk medicine (Johnson, 1971), and as a source of a potential insecticide that acts as an anti-juvenile hormone (Bowers et al., 1976). Forsberg and Crane (1970) reported the stem rot of A. houstonianum caused by Alternaria zinniae in the US. Stems of affected plants had
black areas extending from the ground line 2 to 3 cm up the stem. Some of the stems were girdled and portion of the plant above girdle was dead.

**Brassicaceae**

*Lepidium sativum* (garden cress) is a fast-growing edible herb, used in treating diarrhea, dysentery, leprosy, skin and eye diseases, leucorrhoea, scurvy, liver and renal diseases, dyspepsia, and asthma (Anil, 2006). Rakholiya *et al.* (1998) reported a new downy mildew disease in *L. sativum*, caused by *Peronospora parasitica*.

**Chenopodiaceae**

*Beta vulgaris*, a leafy green vegetable, is considered to be one of the healthiest vegetables available and a valuable addition to the healthy diet (Kugler *et al.*, 2004). *Cercospora beticola* Sacc. is reported to infect leaves of *B. vulgaris* (Lall *et al.*, 1961).

**Convolvulaceae**

*Argyreia nervosa* is a perennial climbing vine which is used in wound healing, syphilis, diuretics, rheumatic affections, leucorrhoea, cerebral disorders, and ulcers as well as for its anti-tumour and contraceptive properties (Krishaveni and Sant, 2011). *Alternaria citri* Ellis was reported to cause leaf blight in *A. nervosa* (Singh *et al.*, 2006).

*Convolvulus arvensis*, also known as wild morning glory or bindweed, is commonly found growing in waste-lands in India. The alcohol extract of *C. arvensis* was demonstrated with anticancer activity (Manibir and Nalia, 2012). This plant is affected by powdery mildew disease caused by *Oidium* sp. (Verma, 1984).
Elaeagnaceae

Sea buckthorn (*Hippophae rhamnoides* L.), a unique and valuable plant, has gained a world-wide attention mainly for its medicinal and nutritional potential. Pharmacological activities such as cytoprotective, anti-stress, immunomodulatory, hepatoprotective, radioprotective, anti-atherogenic, anti-tumor, anti-microbial and tissue regeneration have been reported (Geetha and Asheesh, 2011). Kennedy (1987) reported *Verticillium dahliae* Kleb. causing wilt in *H. rhamnoides* in the UK.

Fabaceae

*Clitoria ternatea*, commonly known as shankapushapam, is a traditional brain tonic believed to promote memory and intelligence (Subramanian and Prathyusha, 2011). *Colletotrichum dematium* (Pers. Ex.Fr.) is a major pathogen affecting foliages of *C. ternatea* in Gorakhpur (Nath and Bhargava, 1980).

*Vicia faba*, a rich source of protein was reported with positive effects on both plasma L-dopa concentration and motor function (Duke, 1981). It has both nutritive and pharmalogical value (Kempster *et al.*, 1993). *Colletotrichum sativum* Horn. was reported to cause ash-brown spots on leaves of *V. faba*.

*Phaseolus mungo* (black gram) is a pulse crop, used in Indian cuisine. The black gram fiber is demonstrated to possesses the significant hypolipidemic, hypoglycemic and anticolon-cancer activities (Indira and Kurup, 2003). Mallaiah *et al.* (1981) recorded a leaf spot disease caused by *Corynespora cassiicola* (Berk. and Curt.) from Nagarjunasagar.
Cassia tora, a well-known anthraquinone containing plant and used in Chinese and Ayurvedic medicine (Smita and Patil, 2010), is reported to be infected by Cercospora occidentalis Ceoke on leaves of C. tora (Lall et al., 1961).

Senna siamea is an evergreen cultivated tree species that finds application in constipation, and childbirth and as a narcotic pain reliever (Hill, 1992). Reddy (1969) recorded Cochliobolus nodulosus Luttrell which caused brown spot in S. siamea.

Glycyrrhiza glabra is an Ayurvedic and a flavoring herb. It is sweet, moist, and soothing herb that detoxifies and protects liver and is also anti-inflammatory, and used in arthritis and mouth ulcers (Vijaya et al., 2011). The fungal pathogen Cylindrosporium glycyrrhizae Harkn caused leaf spot in G. glabra on both surfaces of leaf and covered the entire leaf area during July (Narendra et al., 2002). Severely infected plants defoliated within a short period of time.

Vigna radiata is an important pulse crop reported for the treatment of hepatitis, gastritis, and heat rash (Huijie et al., 2003) and cancer (Kumar and Singhal, 2009). Cercospora leaf spot in V. radiata is a serious disease which could be managed by thiophanate methyl and carbendazin and increase yield (Saxena and Tripathi, 2006).

Vigna unguiculata, another pulse crop, was shown to be therapeutically beneficial in the management of sickle cell disease (Egba et al., 2012). In this crop, Colletotrichum dematium is reported to cause anthracnose disease (Smith et al., 1999).

The whole plant material of Medicago sativa contain steroidal saponins, sterols, coumarins, flavonoids, isoflavones and coumestrol analogues, and sprouts and seeds contain canavanine, a toxic amino acid analogue of arginine derivative of great medicinal

*Cassia angustifolia*, popularly known as senna, is a valuable drug in ayurvedic and modern systems of medicine for the treatment of constipation (Atal and Kapur, 1977; Das *et al.*, 2003; Sharma, 2004). The pharmaceutical preparations involving pods and leaves of senna consisting of containing sennosides A and B are used for their laxative properties. Sharma and Mathur, (2006) reported that *C. angustifolia* is infected with damping-off disease caused by *Fusarium solani*.

**Lamiaceae**

*Mentha arvensis*, commonly known as mint, is used in the treatment of liver and spleen diseases, asthma and jaundice, rheumatic pains, and arthritis (Khan and Khatoon, 2008). Shukla *et al.* (2000) reported the impact of foliar diseases on the yield and major constituents of oil in *M. arvensis*. *Puccinia menthae* and *Alternaria alternata* diseases caused reduced herbage and essential oil yield by 55%. The gas chromatographic analysis of the oil from diseased leaves had 2-7% decrease in menthol, menthone, isomenthone and 4% increase in methyl acetate components of the oil as compared to healthy leaves. Another disease, stolon rot of mint caused by *Rhizoctonia bataticola* was reduced following treatment of stolons with dithane Z-78, dithane M-22 or captan 406.

*Ocimum sanctum* known as ‘Tulsi, Queen of plants’ or “The mother medicine of nature” has been evaluated pharmacologically for antimicrobial, immuno-modulatory, anti-stress, anti-inflammatory, anti-pyretic, anti-asthmatic, hypoglycemic, hypotensive and analgesic activities. Siddaramaiah *et al.* (1982) recorded *Fusarium solani* (Marr.) Sacc. from roots of wilted plants with symptoms of yellowing and dropping followed by

*Ocimum basilicum*, another aromatic and medicinal plant, attracted the attention of ancient Indian medicine men for its therapeutic properties such as insecticidal, anti-ulcer, anti-inflammatory, anti-diabetic and respiratory tract problems (Keita et al., 2001; Abas et al., 2006; Chaha et al., 2006). This plant species is affected by leaf blight disease caused by *Colletotrichum capsici* (Syd.) Butler & Bisy. (Alum et al., 1979), and powdery mildew disease caused by *Oidum* sp. (Verma and Gupta, 2006).

**Malvaceae**

*Hibiscus moschatus* is an annual under-shrub yielding ambrette oil of commerce which finds application both in flavour and fragrance formulations (Rout et al., 2002). Phytophthora leaf blight of *H. moschatus* caused by *Phytophthora nicotianae* var. *nicotianae* was reported in 1981 by Shukla et al. The pathogen produced irregular necrotic, dark-brown patches over the entire leaf surface resulting in defoliation and death of plant.

*Triumfetta rhomboidea* is an under-shrub, in tropical and subtropical India. The root is bitter and acrid, aphrodisiac, tonic, cooling and is useful in dysentery. The leaves and stem are used as poultice on tumors (Kirtikar et al., 1998). A new leaf spot caused by *Cecospora triumfetiae-rhomboidea* Srivastva Narayan and N. Kumari sp.nov.on was reported by Srivastava et al. in this plant (2001).

*Urena lobata*, native to China, is cultivated in many tropical countries including India. The plant species finds application in traditional medicine to cure diarrhea, colic,
skin diseases, boils, pneumonia, rheumatism, cough, and diabetes in India, and south-east nations (Mazumder et al., 2001; Ahmad and Holdsworth, 2003; Pinto et al., 2005). Mallaiah et al. (1981) recorded powdery mildew disease in U. lobata caused by Oidium sp.

**Menispermaceae**

*Tinospora cordifolia*, commonly known as Guduchi, is a herbaceous vine indigenous to tropical India, Myanmar and Sri Lanka. Guduchi is widely used in veterinary folk medicine/ayurvedic system of medicine for its general tonic, anti-periodic, anti-spasmodic, anti-inflammatory, anti-arthritic, anti-allergic and anti-diabetic properties (Nadkarni and Nadkarni, 1976; Chopra et al., 1982; Zhao et al., 1991). *Cercosporidium tinosporae* Kar. & Ray. is reported to cause leaf spot disease in *T. cordifolia* (Kar and Ray, 1985).

Leaves of *Nyctanthes arbor-tristis* are used in Ayurvedic medicine for the treatment of sciatica, chronic fever, rheumatism, and internal worm infections, and as a laxative, diaphoretic and diuretic (Harleen et al., 2011). Srivastava et al. (2001) reported a new leaf spot disease caused by *Cercospora nyctanthidis* Srivastava, Narayan an N. Kumari sp\{Nov\}.

**Oxalidaceae**

*Averrhoa carambola*, evergreen tree commonly known as kamrakh, is a good source of potassium, copper, as well as folate and panthothenic acid (Hansraj et al., 2012). Lall et al. (1961) reported *Cercospora wellesiana* (Welles) Chupp. on living leaves of *A. carambola*.
Oxalis corniculata, indigenous to tropical and subtropical regions of the world is reported in Indian pharmaceutical codex, the Chinese, British and the American pharmacopoeias and in different traditional systems of medicines such as Ayurveda, Unani and Siddha (Ashwani et al., 2012). Oidium oxalidis caused powdery mildew on leaves of O. corniculata (Singh et al., 1968).

Piperaceae

Piper nigrum, (black pepper) is an important spice plant native to India. Prakasm (1992) reported that stem rot due to Rhizoctonia solani in P. nigrum is controlled by treating cuttings with 0.1% carbendazim or 0.2% of copper oxychloride. Dasgupta et al. (2005) managed foot rot of beetelvine caused by Phytophthora sp. by bordeaux mixture, which is also effective against anthracnose and bacterial leaf spot in addition to phytophthora disease.

Phyllanthaceae

Emblica officinalis enjoys a hallowed position in Ayurveda. It is useful in cancer, diabetis, liver treatment, heart trouble, ulcer, and anemia and has application as an antioxidant, immunomodulatory, antipyretic, analgesic, cytoprotective, antitussive and gastroprotective drug. It is useful in memory enhancing, ophthalmic disorders and lowering cholesterol level (Khan et al., 2009). Rust disease caused by Ravenelia emblicae Syd. is reported as a major disease in E. officinalis. Tyagi and Pathak (1987) reported that the rust disease could be controlled effectively with elosal, sulphur dust and ultra sulphur, followed by karathane, thiovit, colloidal sulphur and bordeaux mixture.
Poaceae

Lemongrass (*Cymbopogon citratus*), is a perennial grass native to warm region and grows in all tropical and sub-tropical countries (Cheel *et al.*, 2005). Citral, the biologically active constituent of lemon grass (Huynh *et al.*, 2008) finds application in acne, oily skin, scabies, flatulence, headaches, and blood circulation problems (Pearson, 2010). Santra (1981) reported a leaf spot disease of lemon grass caused by *Helminthosporium leucostylum* Drechs.

*Cymbopogon winterianus*, commonly known for its natural insect repellent properties, is used in aroma-therapy. Alum *et al.* (1994) reported collar rot and wilt disease in *C. winterianus* in Java caused by *Fusarium moniliforme* Sheldon.

*Cynodon dactylon* occupies its unique place in ethnomedicinal practices (Mishra, 2006) and Ayurvedic, Unani, Nepalese, and Chinese medicinal knowledge. Rust caused by *Puccinia cynodontis* Lacroix was reported on leaves of *C. dactylon* (Singh, 1968). Wadsworth *et al.* (1968) reported *Helminthosporium spiciferum* (Bain) Nicot frequently associated with rotten roots in the spring dead spot disease of *C. dactylon*.

Rubiaceae

*Rubia cordifolia*, commonly known as Indian Madder, is extensively prescribed in the treatment of jaundice, visceral obstruction, splenomegaly, in paralysis as deobstruent, and is resolvent, strong diuretic, and antidote (Siddiqui *et al.*, 2012). Singh (1968) reported *Pseudopeziza rubiae* T.S. Ramakr. & K. Ramakr. on leaves and stem of *R. cordifolia*.
A dozen species of *Cinchona* are used in medicine as the source of alkaloids - quinine or quinidine. Cinchona seedling damping-off and wilting of sprouts of vegetatively propagated nurseries have been reported from South India. The disease was reported to be caused by *Pythium vexans* de Bary (Ramakrishnan, 1949).

**Sapotaceae**

*Mimusops elengi*, known as Bakul or Spanish cherry, is an evergreen tree cultivated in India in gardens for its fragrant flowers. The bark, fruit and seeds of *M. elengi* possess several medicinal properties such as astringent, tonic, and febrifuge (Prasad et al., 2012). Chaurasia et al. (1979) reported leaf spot disease in 95% of trees of *M. elengi* in Saugar University Campus. The pathogen was identified as *Pestalotiopsis versicolor* (Speg.) Steyaert.

**Solanaceae**

*Datura innoxia* (thorn-apple) has been found to contain a number of extremely toxic alkaloids; namely atropine, hyoscine, hyoscyamine, and scopolamine. Despite the plant’s high toxicity, appropriate doses of its extract have medicinal effects recognized in traditional medicines around the world (Kaushik and Pankaj, 2008). Ganguly and Pandotra (1962) described leaf spot disease of *D. stramonium*, *D. metel* and *D. innoxia* due to *Alternaria tenuissima* Nees. Ex. Fr. Wiltshire, *A. crassa* (Sacc.) Rands. and *Alternaria* sp., respectively. In 1982, Sattar et al. reported phytophthora leaf blight disease in *D. innoxia*.

*Atropa belladonna*, a perennial herb, is one of the classic poisons of antiquity, but is also significantly used in medicine and cosmetics (Paul and Animesh, 2011). Ganguly
and Pandotra (1962) described leaf necrosis caused by *Ascochyta atropae* Bres. in *A. belladonna*. Collar rot disease caused by *Rhizoctonia solani* J.G. Kuhn mainly affected the collar region of seedlings and girdled the entire stem, resulting in toppling of plants (Sharma and Jandaik, 1979).

*Solanum nigrum* is used in Oriental systems of medicine for anti-tumorigenic, anti-oxidant, anti-inflammatory, hepato-protective, diuretic, and anti-pyretic properties. Various compounds have been identified with diverse activities (Ramya *et al*., 2011). *Cercospora solani* Thuem was identified as one of the pathogens on leaves of *S. nigrum* (Singh, 1968).

*Withania somnifera* is a promising revitalizing medicinal herb known by the name ‘ashwagandha’. Rakesh *et al.* (2003) described root-knot disease and its management with organic materials. Of the organic material tested, neem compound, *Artimisia annua*, mentha and *M. koengii* distillates were found to be highly useful in suppressing root-knot nematode population.

Patra *et al.* (2004) reported that seedling and leaf blight in Ashwagandha could be controlled with seed treatment (Thiram or Deltan at 3-4 g kg⁻¹ seed) coupled with one or two sprays of 0.3% Fytolon, Dithane Z-78 or Dithane M-45.

Karunakara *et al.* (2003) studied perpetuation and host range of *Alternaria alternata* causing brown spot disease of tobacco. The common weeds around tobacco field viz., *Cassia occidentalis*, *Crotolaria calycina*, *C. mucronata*, *Cyperus* spp., *Euphorbia pulcherrima* and *Trianthema decandra* were identified as collateral hosts.
Sapindaceae

*Sapindus emarginatus*, a tropical tree species distributed in India, has activities such as surfactant, mild detergent, anti-inflammatory, antipruritic, antihyperlipidemic, antimicrobial, emetic, hair tonic, and nasal insufflations (Arora *et al*., 2012). *Scopulariopsis cinerea* Emile. Weil. et Gaudin. was recorded on leaves of *S. emarginatus* (Reddy, 1969).

Verbenaceae

*Vitex negundo* is credited with analgesic, anti-inflammatory, anticonvulsant, antioxidant, bronchial relaxant and hepatoprotective activities (Tandon, 2005). Roy (1979) reported that *Cochliobolus specifer* Nelson and *C. geniculatus* Nelson are pathogenic in *Vitex negundo*.

*Lantana camara* is an exotic weed species growing in wastelands. It is well known to cure several diseases and used in various folk medicinal preparations. Leaves are used to treat cuts, rheumatism, ulcer, catarrhal infection, tetanus, rheumatism, malaria, cancer, chicken pox, asthma, ulcer, swelling, eczema, tumour, high blood pressure, bilious fever, ataxy of abdominal viscera, measles, cold and high blood pressure (Sanjeeb *et al*., 2012). Trujillo *et al.* (1995) reported that *Septoria* sp. was isolated from infected leaves of *L. camera* in Ecuador. *Septoria* sp. was identified as a promising biological control of this weed in Hawaiian forests.

Zingiberaceae

Turmeric is a spice derived from the rhizomes of *Curcuma longa*. In addition to its use as a spice and pigment, turmeric has been used in India for medicinal purposes for
centuries. Curcumin from *C. longa* have been shown with anti-inflammatory and anti-cancer activities (Akram *et al.*, 2010). Borborun (1987) reported *Pestalotiopsis* leaf spot in Gauhati. Palarpawar *et al.* (1998) described three strains of *Colletotrichum curcumae* (Syd.) Butler & Bisby from Vidarbha region which produced distinct symptoms on Waigon variety of *C. longa*.

Ginger is a cholesterol-lowering herb primarily used to treat nausea, but it is also used as an anti-inflammatory, a pain remedy, and warming remedy (Kathi, 1999). Roy *et al.* (1988) studied the associated mycoflora of rhizomes of *Zingiber officinale* and their toxin producing potentiality. Sood and Dohroo (2005) studied the influence of air temperature, RH and rainfall on the leaf spot disease development. Rhizome treatment as well as foliar sprays with bordeaux mixture (1%), companion (0.2%), indofil M-45 (0.25%), unilax (0.2%) or baycor (0.05%) were effective in reducing disease severity. Treatment with bordeaux mixture and companion increased the rhizome yield of ginger.

**Seed mycoflora and its management**

Spoilage of seeds in storage and mortality of seedlings in nursery by seedborne fungi are serious problems, which have attracted the attention of plant pathologists. These problems could be tackled effectively through integrated control measures involving quarantine and seed certification, suitable seed production site, proper seed beds, proper storage and seed treatment (Mehrotra and Mehrotra, 2000). Seed treatment is done with the triple purpose, firstly to minimize loss of seeds due to fungal deterioration, secondly to raise healthy seedling stock free from diseases due to seedborne pathogens, and thirdly to prevent or avoid further spread of pathogens in plantations. Seed treatment is possibly
the cheapest and often the safest method of disease control. Seeds may be treated mechanically physically, chemically or biologically (Mehrotra and Mehrotra, 2000). In nurseries, plants are concentrated in limited space. These are watered regularly and nursery soil is usually heavily manured. All these factors together contribute to the development of disease epidemics in nursery seedlings, resulting sometimes in nearly total destruction of nursery stock.

Kumar et al. (2000) reported the effect of some post-harvest treatments viz., sanitation, solarization and pesticides on storage fungi and insect pests associated with seeds of *Acacia nilotica*, *Albizia lebbek*, *Leucaena leucocephala* and *Sesbania sesban*. Sanitation significantly decreased seed infestation by fungi in *A. lebbek*, *L. leucocephala* and *S. sesban* and insect infestation in *A. lebbek* and *S. sesban*. Sanitation + solarization reduced the fungal association in *A. nilotica* and damage by insects in *A. lebbek* and *S. sesbania*. Phenyl mercury acetate and benzene hexachloride eliminated fungal and insect pests associated with seeds. Species of *Aspergillus*, *Alternaria* and *Helminthosporium* were predominantly associated with seed. Activity of bruchids was observed in *A. nilotica*, *A. lebbek* and *S. sesban*.

Singh and Khan (1999) assessed seeds of *Plantago ovata* for seedborne fungi. Stored seeds in general possessed more number of fungi in comparison to freshly collected seeds. Seed treatment with fungicides namely Thiram, Dithane M-45, Bavistin or Emisan was effective in controlling seed mycoflora.

Singh and Khan (1999) reported that seedborne fungi in *Strychnos nux-vomica* could be controlled by seed treatment with fungicides like Thiram, Dithane M-45, Bavistin or Emisan.
Disease epidemiology

Epidemiology deals with the outbreaks and spread of disease in a population. Epidemiology of plant disease is essentially a study of the rate of multiplication of a pathogen, which determines its capacity to spread disease in a plant population. From the practical viewpoint, this is the most important part of study of plant diseases (Singh, 1975). Unless the disease is unknown or under a specialized scientific study, the form of diagnosis that is chosen is generally the quickest, easiest, cheapest and the most accurate method that can confirm the correct identification of casual organisms and its epidemiological studies are very important to management of plant diseases. Some of the epidemiological reports on plant diseases were reviewed and presented hereunder.

Alum et al. (1994) reported collar rot and wilt disease of Cymbopogon winterianus in Java caused by Fusarium moniliforme and the incidence of disease varied between fields from 20 to 30%. The high incidence of disease in the commercial fields during summer indicated that high temperature favoured disease spread.

Amongst a number of fungi reported to cause root-rot disease in Atropa belladonna, and pythium root-rot occurred in epiphytotic proportion in commercial plantations in Jammu and Kashmir. The disease appeared in the beginning of summer when day temperature is beyond 30°C and the disease remained prevalent upto the end of September (Janardhanan et al., 1971).

Barbetti (1991) described that the post-inoculation temperature and humidity conditions were most favourable for the development of Phoma black stem and leaf spot (Phoma medicaginis) and Leptosphaerulina leaf spot (Leptosphaerulina trifolii) disease.
in *Medicago sativa*. *Phoma medicaginis* caused more severe disease at day/night temperatures of 15/10°C, while *L. trifolii* generally was more severe at 18/30°C. Both diseases were always severe with the longest period (168 h) of humidity during incubation.

Bosland *et al.* (1988) studied the influence of soil temperature on disease expression by five pathotypes of *Fusarium oxysporum* in crucifers. Various cabbage cultivars were tested in coastal California field naturally infested with *Fusarium oxysporum* f. sp. *conglutinans* race-2. For all pathotypes, virulence on their respective susceptible hosts was influenced strongly by soil temperature with increase in disease severity as the soil temperature increased.

Anila and Thakare, (2002) observed downy mildew of *Opium* poppy favoured by maximum (20.8 to 26.4°C) and minimum (5-11.4°C) temperature along with maximum RH (37.39%), both in the greenhouse and field.


Mondal *et al.* (2003) reported the environmental factors affecting the release and dispersal of ascospores of *Mycosphaerella citri*. Greasy spot disease caused by *M. citri* in leaves affected all citrus species in Florida and the Caribbean basin; *M. citri* produced pseudothecia and ascospores. The authors used a computer controlled environmental chamber, and found that a single rain event triggered release of most mature ascospores beginning 30 to 60 min after the rain event. High RH without rain triggered release of
less numbers of ascospores, but vibration and red/infrared radiation had little or no effect on ascospore release. After three to four cycles of wetting and drying of leaves, all pseudothecia had matured and released their ascospores. Ascospores were detectable starting about 2h after the beginning of rain or irrigation and most ascospores were released within 16h in field.

Singh et al. (2001) reported the effect of temperature, light/darkness and RH on germination and sporulation of *Alternaria tenuissima*. The conidia germinated at 10-35 ± 2°C. The germination was not discernible at 40 ± 2°C and beyond. Maximum germination (98%), length of germ tubes after 24 h (632.57 μm) and number of germ tubes/conidia (3.61) were observed at 25 ± 2°C. Maximum spores germination and germ tubes length was observed in total darkness followed by 8h light/16h darkness and 16 h light/8h darkness. Maximum germination and number of germ tubes/conidia was observed at 100% RH.

Sood et al. (2005) studied the influence of environmental factors viz., air temperature, RH and rainfall on the ginger leaf spot disease development; the disease occurred to an extent of 85.5%. Rhizome treatment as well as foliar sprays with bordeaux mixture (1%), companion (0.2%), indofil M-45 (0.25%), unilax (0.2%) or baycor (0.05%) were effective in checking the disease severity. However, bordeaux mixture and companion effectively reduced the rhizome yield of ginger.

Surulirajan and Sarbhoy (2000) reported the effect of carbon and nitrogen sources on growth and sporulation of *Fusarium moniliforme*. The potent producer of GA₃, *F. moniliforme* isolate III (ITCC No. 4916) was tested for nutritional requirements. Out of six carbon sources tested, glucose was found to favour good growth. Among
different forms of nitrogen, glycine was the best source causing the maximum growth and sporulation. Among the 36 different combinations and concentrations of C:N ratio tested, 30:10 was the best for maximum growth and sporulation.

Varadarajan (1966) reported the leaf spot and premature defoliation of *Rauwolfia serpentina* under cultivation caused by *Curvularia lunata* (Wakker) Boed. which generally appeared during the first week of August. Two to three sprays per week with bordeaux mixture for about four to six weeks controlled the disease.

**Effect of disease on plant metabolites**

Many higher plants are major sources of natural products which are used as pharmaceuticals, agrochemicals, flavor and fragrance ingredients, food additives, and pesticides (Balandrin and Klocke, 1988). The search for new plant derived chemicals should thus be a priority in current and future efforts toward sustainable conservation and rational utilization of biodiversity (Phillipson, 1990).

Anything that affects the health of plants is likely to affect their growth and yield and also seriously reduce their usefulness to mankind. Affected cells and tissues of diseased plants are usually weakened or destroyed. The ability of such cells and tissues to perform their normal physiological functions, especially the secondary metabolite biosynthesis, is drastically reduced. Several food poisoning problems may occur due to the consumption of infected plant materials that might contain toxins like aflatoxin, fusarial toxins, ergotin and mycotoxins. In some cases, therapeutical values are lost or changed due to infection by phytopathogens. On the other hand, raw crude drug materials are most often degraded by microorganisms before harvesting, during handling and after
prolonged storage (Mathe, 1995; Kenneth, 1989). The presence of sufficient number of microbes could be harmful to consumers. As a result of fungal contamination, the risk of mycotoxin production, especially aflatoxin, should be taken into consideration in the manufacturing process because of the proven mutagenic and immunosuppressive activities (Anon., 2000a; Hohler, 2000).

1. Primary metabolite content in infected plants

The primary metabolites perform metabolic roles that are essential and usually evident. Primary metabolites comprise many different types of organic compounds, including, but not limited to, carbohydrates, lipids, proteins, and nucleic acids. They are found universally in the plant kingdom because they are the components or products of fundamental metabolic pathways or cycles such as glycolysis, Krebs cycle, and Calvin cycle.

Anahosur et al. (1985) reported relationship of stalk sugars with charcoal rot of sorghum incited by *Macrotrichum phaseolina*. Total sugars in the resistant genotypes were more than in susceptible genotypes. The quantity of reducing sugar was more in resistant genotypes than in susceptible genotypes.

Banik and Chatterjee (1995) recorded the total chlorophyll and carbohydrate contents of healthy and *Phytophthora palmivora* infected leaves of rubber plants (*Hevea brasiliensis* var. RRIM 105). Considerable reduction in both the contents was noticed in host tissues during the course of infection, as compared to the healthy ones. The reduced photosynthetic activities as a result of loss of chlorophyll content was evident from the investigation.
Biswas et al. (2003) reported that foliar spray with crude extract of Chaetomium globosum caused biochemical changes in wheat and accounted for high content of total protein, and nitrogen in treated wheat seedlings. Carbon contents also increased but in terms of C: N ratio, the quantity of C proved to be lowest. An increase in proteins and nitrogen levels appears to be indicative of artificial activation of defense mechanism in wheat against Drechslera sorokiniana.

Chakraborty et al. (2002) reported the biochemical response of tea plants growing in Darjeeling hills exposed to biotic stress due to blister blight infection caused by Exobasidium vexans. The levels of proteins, proline, and enzyme activities such as phenylalanine ammonia lyase, polyphenol oxidase and peroxidase altered with infection. Activity of phenylalanine ammonia lyase registered a decline in infected leaves, whereas peroxidase and polyphenol oxidase activity was higher. Proline content increased markedly in blister infected leaves. Proteins declined at the very early stage of infection.

Naik (1995) estimated the biochemical constituents such as total sugars and reducing sugars in Colletotrichum abelmoschii infected Hibiscus species. The quantity of total sugars and reducing sugars reduced in the inoculated leaves of H. canabinus, while the level increased in the inoculated leaves of H. sabdlariffa.

Nema (1991) reported changes in chlorophyll, nitrogen, protein, amino acid and some enzyme content in betelvine leaves infected with Xanthomonas campestris pv. beticola. Reduction in total chlorophyll as well as in chlorophyll ‘a’ and ‘b’ contents was more pronounced in highly susceptible cultivars. The quantity of amino acids in resistant cultivar was about 50% more than in moderately and highly susceptible cultivar and when the leaves were inoculated, amino acids content depleted in all cultivars.
Pandey and Prasad (1993) observed reduction of the total sugar contents (2.17-34.78%), glucose (2.63-32.47%) and starch (32.0-62.0%) in fungal infected seeds of *Pongamia pinnata*. Total sugar and starch contents diminished more than glucose. The amount of protein diminished more prominently within four months of seed infestation.

Rahman *et al.* (2001) observed total sugar, reducing sugar, sucrose, total soluble solid, moisture, protein and lipid content were increased but ash, total titrable acidity and vitamin C content decreased moderately with maturity in both the healthy and *Rhizopus stolonifer* infected moringa fruit. Starch content changed rapidly after maturity stage. All the nutrient contents except protein, reducing sugar and ash decreased after fruit infection. The activities of seven enzymes increased after post-infection of fruits.

Sharma *et al.* (1993) reported biochemical alterations in brinjal leaves and fruits due to infection by *Phomopsis vexans*. Progressive and significant decrease in the quantity of total, non-reducing and reducing sugars, amino acids, phenol and orthodihydroxy phenols was observed with an increase in infection.

### 2. Secondary metabolite content in infected plants

Plants produce a high diversity of secondary metabolites with a prominent function in the protection against predators and microbial pathogens on the basis of their toxic nature and repellence to herbivores and microbes, and some of which are also involved in defense against abiotic stress and also important for the communication of the plants with other organisms (Schafer *et al.*, 2009), and are insignificant for growth and developmental processes (Rosenthal *et al.*, 1991).
Alkaloids were originally defined as pharmacologically active, nitrogen containing basic compounds found in approximately 20% of the species of vascular plants (Hegnauer et al., 1988). Plant alkaloids have also served as models for modern synthetic drugs, such as the tropane alkaloid atropine for tropicamide used to dilate the pupil during eye examinations and the indole-derived antimalarial alkaloid quinine for chloroquine. The role of chemical defense for alkaloids in plants is supported by their wider range of physiological effects on animals and by the antibiotic activities many alkaloids possess. Various alkaloids also are toxic to insects or function as feeding deterrents. For example, nicotine, found in tobacco, was one of the first insecticides used by humans. Generally, most of them, including the pyrrolizidine alkaloids are toxic to some degree and appear to serve primarily in defense against microbial infection and herbivoral attack. They are usually synthesized from one of the few common amino acids, in particular, aspartic acid, lysine, tyrosine and tryptophan (Pearce et al., 1991).

Flavonoids are the low molecular weight polyphenolic secondary metabolic compounds, performing very different functions in plant system including pigmentation and defense (Kondo et al., 1992). In plants, flavonoids have long been known to be synthesized in particular sites and are responsible for color, aroma of flowers, to attract pollinators, consequently fruit dispersion, help in seed, spore germination, growth and development of seedlings. Flavonoids protect plants from different biotic and abiotic stresses and act as unique UV-filter, function as signal molecules, allelopathic compounds, phytoalexins, detoxifying agents, and antimicrobial defensive compounds (Caldwell et al., 1983; Mazid et al., 2011).
Sindhan and Parashar (1996) reported changes in phenolic compounds, and mineral elements in resistant and susceptible cultivars of groundnut. Total phenols and ortho-dihydric phenols were high in resistant cultivars in comparison to susceptible ones.

Kumar and Singh (1996) reported alteration in biochemical constituents of sunflower leaves in relation to the development of leaf blight caused by *Alternaria alternata*. The wax content was considerably reduced, and necrotic tissues contained about 15% of the total wax present in healthy leaves, drastic reduction of chlorophyll a and b content in diseased leaves, and reduced polyphenol content.

Lodha *et al.* (1993) reported the development of bacterial blight and changes in biochemical components in the resistant and susceptible genotypes of clusterbean. The total phenol content was higher in diseased as compared to the healthy leaves, while the reverse was the case for ortho-dihydroxy phenols, irrespective of the genotype and the stage of development. The resistant genotype HG 75 had high amount of total phenols in healthy and diseased leaves. High accumulation of phenols was observed in the diseased leaves.

A hydroxyl functional group on an aromatic ring called phenol is a chemically heterogeneous group and they could be an important part of plant defense system against pests and diseases, including root parasitic nematodes (Wuyts *et al.*, 2006).

Plant steroids are types of natural organic compounds found in plants. Many types of plant steroids exist and play important roles in the biological processes of plants, such as growth and development, cell division, and resistance to damage from environmental stresses (Sun *et al.*, 2010).
Bailey and Burden (1973) described production of many phenolic compounds, some of which were shown to be highly antifungal and compounds like phaseollin, phaseollidin, and Kievitone in tobacco necrosis virus infected Phaseolus vulgaris were recorded. They were also demonstrated in tissue infected with Colletotichum lindemuthianum. The virus infected tissue acted as a source of new phytoalexin and also was involved in the disease resistance.

Dixit et al. (2003) reported changes in the strychnine and brucine contents of Strychnos nux-vomica seeds due to fungal infestation. During storage, a large amount of fruits of S. nux-vomica have been found to be infested by fungal pathogens resulting in fruit rot and heavy loss. Fungi viz., A. flavipes, A. flavus, A. niger, A. sulphureus, Cladosporium herbarum, C. oxysporum, Fusarium roseum and Penicillium spinulosum decreased the quantity of strychnine in S. nux-vomica seeds.

Harmukh and Naik (2008) estimated the total alkaloid content in roots of Cocculus hirsutus in different seasons. November was found to be the good for collection of C. hirsutus for maximum alkaloid yield (1.532%).

Mall and Suresh (1989) reported qualitative and quantitative changes in phenolic compounds in potato host plant due to Rhizoctonia solani infection. Extracts of potato stem tissues as well as tuber tissues contained all the five phenols- chlorogenic acid, caffeic acid, p-coumaric acid, 3,4-dihydroxybenzoic acid and phloroglucinol produced by R. solani in culture. Extracts of healthy stem tissues of the same age had chlorogenic acid, caffeic acid, p-coumaric acid and 3,4-dihydroxybenzoic acid and only one unidentified compound. In healthy tuber tissues, phloroglucinol and unidentified

46
compounds were absent. The phloroglucinol present only in infected tissues was either of pathogen origin or synthesized during pathogenesis.

Pandey and Joshi (1991) reported the altered phenolic content in bitter gourd due to cucumis virus 3 infection. Infection had influenced the phenolic content of the host plant. Leaf, stem and root samples from infected plants had more phenolic content than healthy and infected samples that increased with age.

Seetharam et al. (2001) reported the quantitative and qualitative assessment of phenols in *Argemone mexicana*, *Datura stramonium*, *Papaver somniferum*, *Strychnos nux-vomica*, *Trigonella foenum-graecum* and *Withania somnifera*. Maximum amount of phenol content was observed in *A. mexicana* and minimum quantity in *D. stramonium*.

Sharma et al. (1998) studied the relationship between the phenolic content and incidence of purple blotch disease of garlic in five cultivars which showed varied resistance. The total phenols, orthodihydroxy phenols and flavonol contents were higher in resistant varieties as compared to the susceptible one. The high amount of phenolic contents in resistant varieties are implicated in the defence mechanism of garlic genotypes towards purple blotch infection.

Sukhwal (2003) reported that the accumulation of phenolics was higher in resistant varieties (against *Helminthosporium* sp.) of maize as compared to susceptible ones. The Corresponding increase in the activity of oxidative enzyme suggested active metabolic reaction of the host to pathogenesis and their possible role in the increased level of phenolics.
Vanitha and Balagurunathan (2008) reported that the total alkaloids and solasodine content were considerably reduced due to infection of leaf by blight pathogen *Alternaria chlamydospora* in *Solanum nigrum*.

3. Effect of diseases on enzyme activities

During fungal plant pathogenesis, enzymes play a crucial role and they are involved in the external and internal interactions. To restrict the development of fungal pathogens, the plants expressed many defense mechanisms. Peroxidases were frequently associated with plant defense against pathogens (Lebeda *et al.*, 1999).

Chakraborty *et al.* (2002) reported the biochemical response of tea plants exposed to biotic stress like blister blight infection caused by *Exobasidium vexans*, this changed the levels of proteins, proline, phenols and enzyme activities such as phenylalanine ammonia lyase, polyphenol oxidase and peroxidase. Activity of phenylalanine ammonia lyase registered a decline in infected leaves, whereas that of peroxidase and polyphenol oxidase was higher.

Dohroo (1989) reported peroxidase and polyphenol oxidase activities in rhizome rot of ginger. A rise in the peroxidase activity was recorded in rhizomes affected by the two pathogenic fungi during the initial three days of pathogenesis. A sharp decline in peroxidase activity was observed afterward which was doubled in *Pythium* affected rhizomes than the *Fusarium* affected ones. The peroxidase was thought to involve in importing resistance to ginger plants against *Fusarium* infection.

Rajalakshmi and Ramarethinam (2000) reported biochemical changes in tea infected by *Exobasidium vexans* causing blister blight. Polyphenol oxidase and
peroxidase were activated by 40 and 65%, respectively, in blistered leaves. The activity of phenylalanine ammonia lyase was lowered by 17%

The inhibitory effect of phenolic compounds on activities of both polygalacturonase and pectin methyl esterase indicated their protective role against pathogenesis by *Sclerotinia sclerotiorum*. Results suggested the role of phenolics in disease resistance (Sharma et al., 2001).

**Botanical Descriptions of Select Medicinal Herbs and their Pharmaceutical Importance**

1. *Centella asiatica*

   Order: Apiales
   
   Family: Apiaceae
   
   Species: *Centella asiatica* (L.) Urban

*Centella asiatica* is an important traditional medicinal herb (Devkota and Jha, 2008) native to India, China, Nepal, Indonesia, Sri Lanka, Australia, Madagascar and Southern and Central Africa.

*Centella asiatica* grows in tropical swampy areas. The stems are slender, creeping stolons, green to reddish-green in color, connecting plants to each other. It has long-stalked, green, reniform leaves with rounded apices which have smooth texture with palmately netted veins. The leaves are borne on pericladiad petioles, around 2 cm. The rootstock consists of rhizomes, growing vertically down; they are creamish in color and covered with root hairs. The flowers are pinkish to red in color, borne in small, rounded bunches (umbels) near the surface of the soil. Each flower is partly enclosed in two green
bracts. The hermaphrodite flowers are minute in size (less than 3 mm), with 5-6 corolla lobes per flower. Each flower bears five stamens and two styles. The fruits are densely reticulate, distinguishing it from species of Hydrocotyle, which have smooth, ribbed or warty fruit. The crop matures in three months, and the whole plant, including the roots, is harvested manually (Gamble, 1995; Yoganarasimhan et al., 1982).

Previous work on *C. asiatica* has led to the isolation of more than 70 biochemical constituents including triterpenoid saponins (Jiang et al., 2005; Kuroda et al., 2001), polyacetylenes (Schulte et al., 1973), flavones (Prum et al., 1983), and sterols (Kapoor et al., 2003). Asiaticoside, a trisaccharide triterpene in this plant has been identified as the most active compound associated with the healing of wounds and duodenal ulcers, whilst the triterpene saponins are reported to possess immunomodulatory properties (Plohmman et al., 1994; Coldren et al., 2003). The plant is diuretic and alterative and is used in the treatment of leprosy (Wolfram, 1965; Kartnig, 1988), asthma, bronchitis, dropsy, elephantiasis, gastric catarrh, kidney trouble, leucorrhoea, skin disease and urethritis (Kakkar, 1998). It has been shown with antibacterial, anti-feedent, anti-filarial, anti-stress, anti-tuberculosis (Chakraborty et al., 1996; Srivastava et al., 1997) and anti-viral activities (Yoosook et al., 2000). The drugs from this plant possess anti-epileptic (Moharana and Moharana, 1994), anti-tumor (Babu et al., 1995) and anti-hepatoma activities (Lin et al., 2002).

A survey of literature indicated that *C. asiatica* is infected by fungal pathogens like *Pseudocercospora centelli* and *Cercospora centellae* that cause considerable damage to plants in cultivated land (Dubey and Pandey, 2008; Manoharachary et al., 2003). The plant species is affected by *C. centellae* during different seasons of the year in Bhadra
Wildlife sanctuary (Parashurama et al., 2007). These studies are limited to the symptomatological description of *C. centellae* disease in *C. asiatica* in certain seasons.

2. *Elephantopus scaber*

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<td>Family</td>
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<td>Species</td>
<td><em>Elephantopus scaber</em> L.</td>
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</table>

*Elephantopus scaber* is found in Tropical Africa, Eastern Asia, Indian subcontinent, South-east Asia, and Australia. Its natural habitat is subtropical or tropical moist montane forests.

Plants are erect, root stock short, giving off many stout fibrous roots, stem usually dichotomously branched, strigose, with appressed white hairs. Leaves mostly radical, 12.5-20 by 3.8-5.7 cm., forming a spreading rosette on the ground, obovate oblong, rounded or subacute, coarsely serrate-dentate, more or less hairy on both surface, base tapering into an obscure petiole; main nerves numerous, prominent beneath, with reticulate veins between, cauline leaves smaller that the radical, sessile or nearly so. Heads numerous, sessile, closely packed, forming a terminal inflorescence nearly 2.5 cm across and surrounded at the base by large stiff broadly-ovate cordate conduplicate conspicuously nerved leafy bracts. Involucral bracts in 2 series enclosing 4 flowers, bracts of the outer row half as long as those of the inner, 1-nerved, bracts of inner row usually 3 (rarely 5) nerved, scarious, linear, cuspidate. Corolla violet, exserted, tube long, slender, limb deeply cleft on one side. Style much exserted, the arms recurved.
Pappus white, 1-serrate, consisting of 5 (rarely 4) rigid bristles dilated at the base (Gamble, 1995; Yoganarasimhan et al., 1982).

Since 1970, a number of chemical constituents of *E. scaber* and their pharmacological evaluations are reported. The major constituents include flavonoids, flavonoid esters, triterpenoids and sesquiterpene lactones, in addition to elephantopin, stigmasterol, epifriedelanol and lupeol (Rajkapoorn et al., 2002). The whole plant is used in the treatment of nephritis, dampness, pain in the chest and arthralgia due to wounding (Peer, 1980; Tsai, 1999), diseases of blood, skin and heart, piles, dysuria, urethrorrhea, swelling, filariasis, and haemorrhoids and possesses anti-diarrheal, hepatoprotective, antipoison, alexipharmic, aphrodisiac, expectorant and febrifuge activities (Nadakarni, 1976; Kirtikar and Basu, 1980; Rajesh and Latha, 2001; Sankar et al., 2001; Muthumani et al., 2010; Nair and Anisha, 2011).

There are no comprehensive reports of fungal disease(s) in *E. scaber* plants although the year, or seed transmission of pathogen and its management. A survey of Bhadra Wildlife sanctuary in Karnataka indicated that *E. scaber* occurs in wild and is affected by a foliar fungal disease in mature plants during different seasons of the year in varying severity (Parashurama et al., 2007).

3. *Plumbago zeylanica*

<table>
<thead>
<tr>
<th>Order</th>
<th>Caryophyllales</th>
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<tbody>
<tr>
<td>Family</td>
<td>Plumbaginaceae</td>
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<tr>
<td>Species</td>
<td><em>Plumbago zeylanica</em> L.</td>
</tr>
</tbody>
</table>
Plumbago zeylanica, commonly known as Ceylon Leadwort or Doctorbush, is pantropical in distribution. Commonly known as Citraka in India, the plant grows throughout India, especially in Bengal, Uttar Pradesh, South India and Sri Lanka, in moist places (Kirtikar and Basu, 1998). It is also cultivated commercially.

The plant grows to 0.5-1.0 m in height. It is a perennial shrub. The leaves are simple, alternate, oblong, 8 cm and 3 cm broad. Inflorescences are 3-15 cm in length and have glandular, viscid rachises. Bracts are lanceolate and 3-7 × 1-2 mm long. The flowers are white, 10-25 cm long, inodorous, in terminal spikes. The roots are stout, cylindrical, friable, blackish red in colour, with a pungent odour. The flowering occurs from September to November. The heterostylyous flowers have white corollas 17-33 mm in diameter and tubes 12.5-28 mm in length. Capsules are 7.5-8 mm long and contain are reddish brown to dark brown seeds (5-6 mm) (Gamble, 1995; Yoganarasimhan et al., 1982).

Plumbago zeylanica is one among the endangered species in the north-eastern Karnataka that require immediate conservation (Seetharam et al., 1998). The plant contain plumbagic acid and plumbagin, with expectorant and antimicrobial (Ahmad et al., 2000; Dhale, 2011), anti-inflammatory (Kantha et al., 2010), analgesic (Vineeth et al., 2010), antitussive and anticancer activities (Dhar, 1999). The plant species is being increasingly cultivated for its traditional medicinal value (Rajakumar and Shivanna, 2010).

A literature survey suggested that there is no report of the fungal disease and its effect on secondary metabolite contents in P. zeylanica in wild or under cultivation.
4. *Rauwolfia serpentina*

Order : Gentianales  
Family : Apocyanaceae  
Species : *Rauwolfia serpentina* Benth

*Rauwolfia serpentina* or sarpagandha plant is widely used medicinally both in the modern western medical system and also in Ayurveda, unani and folk medicine. Sarpagandha is an important medicinal plant distributed in the foot-hills of Himalayan range, up to the elevation of 1,300-1,400 m and almost all over the country. It is used in traditional medicine in India, China, Africa and many other countries.

Shrubs 1 m tall, erect, glabrous. Stems usually unbranched, slender, straw colored. Leaves grouped near stem apex, in whorls of 3-5; petiole 1-1.5 cm; leaf blade narrowly elliptic or obovate, membranous, 7-17 x 2-9 cm, base cuneate, apex acuminate or rarely obtuse; lateral veins 7-15 pairs. Cymes congested; peduncle 5-13 cm, red or reddish. Pedicel and calyx red or reddish. Corolla white, tube cylindric, 1-1.8 cm, inflated at middle and pilose inside distal half; lobes obliquely suborbicular, 1.5-3.5 mm. Stamens inserted in the middle of corolla tube. Ovaries connate in basal half. Drupes ellipsoid √√ 8 mm, connate for half their length. Flowes during Feb-Oct, fruits during May-Dec (Gamble, 1995; Yoganarasimhan *et al.*, 1982).

*Rauwolfia serpentina* is a good source of alkaloids and dry root contains about 30 indole alkaloids (0.7 – 2.4%). Among various alkaloids, reserpine is the active constituent and is well known for its anti-hypertensive action. It depletes the stores of catecholamines at nerve endings. Other important alkaloids are ajmalicine, rescinnamine, yohimbine and...
serpentine (Chopra et al., 1980). Pure isolated alkaloids as well as their synthetic derivatives are used as basic medicinal agents for their analgesic, antispasmodic and bactericidal effects (Stary 1998; Okwu and Okwu, 2004). Indian snakeroot is also used for snake and reptile bites (Kokate et al., 2003), feverish intestinal diseases, liver ailments, rheumatism, dropsy (edema), general debilities, mental illness, and epilepsy, nervousness (Ojha and Mishra, 1985), insomnia and insanity in Indian systems of medicine. In view of its sharply rising pharmaceutical value, the large-scale cultivation has been taken up in recent years in order to maintain sustainable supply to the pharmaceutical industries. However, it is threatened with extinction (Singh et al., 2010; Mao et al., 2009) due to its over-exploitation by local people, government agencies and pharmaceutical companies (Mamgain et al., 1998) and its loss in natural habitat (Sukumaran and Raj, 2008) and limited cultivation owing to the poor seed viability and seed germination rate (Dutta et al., 1962).

A survey of forests in the Western ghats of India indicated that R. serpentina occurs in wild in Bhadra Wildlife sanctuary and is affected by foliar fungal diseases in seedlings and mature plants during different seasons of the year in varying severity (Shivanna et al., 2007). Rauwolfia serpentina is affected by a number of foliar diseases caused by Alternaria alternata, Cercospora rauwolfiae and Rhizoctonia solani which cause considerable damage to plants (Ganguly and Pandotra 1962; Mohanty and Addy 1957). These studies are limited to the description of diseases; however a detailed study of foliar diseases althrough the year, and the pathogen transmission and disease control is lacking.
5. *Rubia cordifolia*

<table>
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<tr>
<th>Order</th>
<th>Gentianales</th>
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</thead>
<tbody>
<tr>
<td>Family</td>
<td>Rubiaceae</td>
</tr>
<tr>
<td>Species</td>
<td><em>Rubia cordifolia</em> Linn</td>
</tr>
</tbody>
</table>

*Rubia cordifolia* (Manjistha) is considered to be one of the most valuable herbs in Ayurvedic medicine and has been largely used by physicians, since ancient times. The plant grows throughout India, in hilly districts upto 3,500 m height. It is a perennial, herbaceous climber.

It can grow up to 1.5 m in height. The evergreen leaves are 5–10 cm long and 2–3 cm broad, produced in whorls of 4-7 star like around the central stem. It climbs with tiny hooks at the leaves and stems. The flowers are small (3–5 mm across), with five pale yellow petals, in dense racemes, and appear from June to August, followed by small (4–6 mm dia.) red to black berries. The roots can be over 5 m long, up to 12 mm thick. It prefers loamy soils with a constant level of moisture (Gamble, 1995; Yoganarasimhan et al., 1982).

The alkaloids are major components of this plant and furthermore, anthraquinones exhibit some interesting *in vivo* biological activities, such as antimicrobial, antifungal (Premlatha et al., 2012), hypotensive (Rath et al., 1995), analgesic, antimalarial (Younos et al., 1990), antioxidant (Advankar et al., 1982), antileukemic and mutagenic functions (Tripathi and Sharma, 1997; Singh and Geetanjali, 2005). Apart from its medicinal value, this plant species has also been used as natural food colorant and natural hair dye (Chang, 1995; Ismail et al., 1997; Ramesh et al., 2011). There is a lot of interest in the isolation of
natural dyes and colouring matters and their increased application in food, drug and other commodities (Samatha and Vasudevan, 1996).

A literature survey suggested that there is no information of the fungal diseases occurring in *R. cordifolia* either in wild or under cultivation.

6. *Withania somnifera*

Order : Solanales  
Family : Solanaceae  
Species : *Withania somnifera* (L.) Dunal.

*Withania somnifera* is a xerophytic plant, found in the drier parts of India, Sri Lanka and Afghanistan. It is found in high altitude ascending to 5,500 feet in the Himalayas. This shrub is common in Bombay and Western India, occasionally in Bengal. It is widely cultivated in Bikaner and Pilani areas of Rajasthan, Rajputana, Punjab and Manasa in Madhya pradesh (Chopra et al., 1980; Dey and Bahadur, 1973; Dymock et al., 1976; Kirtikar and Basu, 1980; Nadkarni, 1982).

A dense, hairy erect grayish under shrub. The roots are stout, long tuberous, fleshy, whitish brown and aromatic. The leaves are simple, alternate or sub-opposite, round-oval shaped. The flowers are greenish-yellow and found in few flowered clusters in axils. The fruit is a round orange-red berry, enclosed in green enlarged calyx. The fruit resembles that of red cherries. Seeds are many, yellow kidney shaped and discoid (Gamble, 1995; Yoganarasimhan et al., 1982; Ramaswamy et al., 2001; Saldanha and Nicolson, 1976).
The roots contain several pyrazole alkaloids, withasomnine, and steroids, lactones, withaferin A and withanolides (Arun et al., 1996). The plant is used as a sedative, tonic, stimulant, aphrodisiac, diuretic, antipyretic and anthelmentic (Gupta and Rana, 2007) and for anticancer (Devi, 1996) and inflammatory (Al-Hindawi et al., 1989), antiarthritic (Somasundaram et al., 1983) and antioxidant activities (Bhattacharya et al., 1997). In view of its wide therapeutic potential, it has been the subject of considerable modern scientific attention. Hence, *W. somnifera* is cultivated in India.

Like cultivated medicinal plants, *W. somnifera* is also attacked by a number of phytopathogens which cause considerable damage to plants under cultivation (Sinha, 2002; Pandey, 1988; Nigam, 1984; Gupta et al., 1993). Detailed information on fungal diseases caused in *W. somnifera* with respect to disease severity and distribution, the seedborne nature and transmission of pathogens and their management is lacking in the literature.