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Aspects of Antifungal Potential of Ethnobotanically Known Medicinal Plants

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INTRODUCTION

Human and animal fungal infections pose serious medical and veterinary issues, whereas fungal infection of plants represents significant losses of agricultural products. Up to now, more than 1,00,000 fungal species are considered as natural contaminants of agricultural and food products (Kacaniova, 2003). There is a general consensus among researchers, clinicians and companies (pharmaceutical and agrochemical) that new, potent, effective and safe antifungal drugs are needed (Selitrennikoff, 1992). Historically, most of the substances have been part of natural product. Therefore, it is quite logical that any recent search for new prototype antifungal products should also include a variety of plant part or extract.

In designing a search for novel prototype antifungals, it seems reasonable to assume that if new agents are to be found that have different structures and different activities from those in current use, sources other than the more traditional plant extracts must also be investigated. In particular, higher plants are a logical choice, chiefly because of their seemingly infinite variety of novel molecules, which are often referred to as secondary metabolites (Clark and Hufford, 1992). Antifungal agents are widely distributed among higher plants (Caceres *et al*., 1991), but only a few have been evaluated for their activity against human, animal and plant pathogenic fungi.

In the past few decades, a worldwide increase in the incidence of fungal infections has been observed as well as a rise in the resistance of some species of fungi to different fungicidals used in medicinal practice. Therefore, new prototype antimicrobial agents are needed to address this situation (Sati and Joshi, 2010). Fungi are one of the most neglected pathogens, as demonstrated by the fact that the amphotericin B, a polyene antibiotic discovered as long ago as 1956, is still used as a gold standard for antifungal therapy (Abad *et al*., 2007). The fungal growth may cause decrease in germinability, discolouration of grain, loss in weight, biochemical changes and production of toxins (Sinha *et al*., 1993). Exploitation of naturally occurring compounds from plants and microbes has also been suggested by Sati and Arya (2010). Climatic conditions are most conducive for mould invasion, elaboration of mycotoxins. Unseasonal rains and floods enhances the moisture content of the grain making them more vulnerable for fungal attack (Srivastava, 1987). The majority of clinically used antifungals have various drawbacks in terms of toxicity, efficacy as well as cost and their frequent use has also led to the emergence of resistant strains. Additionally, in recent years public pressure to reduce the use of synthetic fungicides in agriculture has increased. Concerns have been raised about both the environmental impact and the potential health risk related to the use of synthetic fungicides (Khulbe and Sati, 2009).

Hence, there is a great demand for novel antifungals belonging to a wide range of structural classes, selectively acting on new targets with least side effects. The testing of plant (extracts or compounds), traditionally used for their antifungal activities might be a potential sources for drug development. Plants are not only important to the millions of people for whom traditional medicine is the only opportunity for health care and to those who use plants for various purposes in their daily lives, but also as a source of new pharmaceuticals. Natural products, either as pure compounds or as standardised plant extracts, provide unlimited opportunities for new drug leads because of their having normally matchless chemical diversity.

This study is an attempt to review the work done in the field of antifungal activities of plant extracts as well as compounds which will facilitate to unravel the potentiality of plants and plant products for workers engaged in the line of bioactivities of natural products and new drug discoveries.

ANTIFUNGAL ACTIVITY OF MEDICINAL PLANTS

Now days the use of botanicals for the management of the phytopathogens is being more popular practices. The plant extracts and volatile oils may have an important role to play in the preservation of foodstuffs against fungi, in fungicidal application against plant diseases and in the fight against various human fungal infections. Various research groups have initiated antifungal screening programmes for plants used all over the world as anti-infectious agents in traditional medicine. Recent literature has shown the biological activities of plant-extracts, essential oils and their individual pure components. It has been well documented for the inhibitory activity of these substances against the growth of various fungi.

Antifungal activity of crude extracts of plants: Hussain *et al.* (1992) reported that leaf extracts of *Datura stramonium* reduced the development of rust pustules on the leaves of wheat. Mughal *et al.* (1996) observed that aqueous leaf extracts of *Allium sativum*, *Datura alba* and *Withania somnifera* inhibited the growth of *Alternaria alternata, A. brassicola* and *Myrothecium roridum*. According to Khan *et al.* (1998) aqueous extract of *Allium cepa* exhibited antifungal activity against *Helminthosporium turcicum* and *Ascochyta rabiei* and that of *Calotropis procera* against *Alternaria redicina*.

Nineteen plant species belonging to fourteen families used by some Indian living in North America were tested for their fungicidal activity (Bergeron *et al.* 1996). Of the species investigated by them, nine were active against *Cladosporium cucumerinum* and nine against *Candida albicans*. A programme was designed for the pharmacological screening of species used by the Mayan people in the highlands of Chiapas in southern Mexico to treat gastrointestinal and respiratory diseases (Meckes *et al.*, 1995). It demonstrated that 63% of the botanical species showed antifungal properties against *Candida albicans*. Herbal products such as D-limonene, neem seed extract, tea tree oil, eugenol, hinokitiol, citral and allyl-isothiocyanate have an antifungal activity against fish water mold, e.g., *Saprolegnia*, *Aphanomyces* and *Achlya* (Hussein *et al.*, 2002; Campbell *et al.*, 2001; Mori *et al.*, 2002).

A survey of literature shows that a number of higher plants belonging to different families and genera have been screened for their antifungal activity. The families reported to contain strong fungitoxic activity are listed in Table 1. It provides complete information on antifungal activity of crude extracts of various medicinal plants.

Table 1: Antifungal activities of crude extracts from plants

Plants	Family	Plant part	Plant extracts
A. galanga	Zingiberaceae	Whole plant	Crude extract (Khattak *et al*., 2005)
Acacia auriculiformis	Leguminoseae	Heartwood	Crude extract (Mihara *et al*., 2005)
Acacia mangium	Leguminoseae	Heartwood	Crude extract (Mihara *et al*., 2005)
Aglaia roxburghiana	Rutaceae	Leaves, fruit	Ethanol extract (Janaki *et al*., 1998)
Allium cepa	Amaryllidaceae	Bulb	Aqueous extract (Khan *et al*., 1998)
Allium sativum,	Amaryllidaceae	Leaves	Aqueous extract (Sharma and Jandaik,1994; Mughal *et al*., 1996)
Arnebia benthamii	Boraginaceae	Root	Ethanol extract (Dabur *et al*., 2007)
Azadirachta indica	Meliaceae	Leaves	Crude extract (Sharma and Jandaik,1994; Jain *et al*., 1996)
Bauhinia racemosa	Caesalpiniceae	Stem bark	Crude extract (Kumar *et al*., 2005)
Berberis aristata	Berbaridaceae	Root	Ethanol extract (Dabur *et al*., 2007)
Blumea gariepina	Asteraceae	Leaves, stem	Dichloromethane extract (Queiroz *et al*., 2005).
Boenninghausenia albiflora	Rutaceae	Leaves	Hexane, chloroform, methanol, aqueous (Khulbe and Sati, 2006)
Calotropis procera	Asclepiadaceae	Root bark	Ethanol extract (Jain *et al*., 1996)
Curcuma longa	Zingiberaceae	Whole plant	Crude extract (Khattak *et al*., 2005)
Curcuma malabarica	Zingiberaceae	Tubers	Crude extract (Wilson *et al*., 2005)
Curcuma zedoaria	Zingiberaceae	Tubers	Crude extract (Wilson *et al*., 2005)
Cynara scolymus	Asteraceae	Whole plant	Crude extract (Zhu *et al*., 2005)
Datura alba	Solonaceae	Leaves	Aqueous extract (Mughal *et al*., 1996)
Datura metel	Solonaceae	Seed, leaf	Aqueous extract (Kumudini *et al*., 2001)
Datura stramonium	Solonaceae	Leaves	Crude extract (Hussain *et al*., 1992)
Desmostachya bipinnata	Poaceae	Leaves	Aqueous extract (Bajwa *et al*.,2002)
Dicanthium annulatum	Tylenchidae	Leaves	Aqueous extract (Bajwa *et al*., 2002)
Eichhorinia crossipes	Pontedriaceae	Leaves	Crude extract (Sharma and Jandaik, 1994)
Enterobacter cloacae	Enterobacteriaceae	Stem bark	Ethanol extract (Jain *et al*.,1996)
Eucalyptus tereticornis	Myrtaceae	Leaves	Crude extract (Sharma and Jandaik, 1994; Gupta and Govindaiah, 1996).
Ficus microcarpus	Moraceae	Leaves	Crude extract (Taira *et al*., 2005a, b)
Gentianella nitida	Gentianaceae	Whole plant	Methanol extracts (Rojas *et al*., 2004)
Hypericum ternum	Gutiferaceae	Leaves	Methanol Chloroform and hexane extract (Fenner *et al*., 2005).
Imperata cylindrical	Poaceae	Leaves	Aqueous extract (Bajwa *et al*.,2002)
Jacquinia ruscifolia	Theophrastaceae	Leaves, petals	Ethanol extract (Dabur *et al*., 2007; Sharma *et al*., 2008)
Juglans regia	Juglandaceae	Bark	Crude extract (Dabur *et al*., 2007)
Larrea divaricata	Zygophyllaceae	Leaves	Crude extract (Queiroz *et al*., 2004)
Parthenium hysterophorous	Asteraceae	Leaves	Crude extract (Gupta and Govindaiah, 1996)
Phyllanthus amarus	Euphorbiaceae	Leaves	Chloroform extract (Agrawal *et al*., 2004)
Pinus pinaster	Pinaceae	Leaves	Pycnogenol extract (Torras *et al*., 2005)
Pongamia pinnata	Fabaceae	Leaves	Crude extract (Gupta and Govindaiah, 1996)
Pseudarthria viscida	Leguminoseae	Leaf, root, stem, callus	Crude extract (Deepa *et al*., 2004)
Rumex nepalensis	Polygonaceae	Root	Ethanol extract (Dabur *et al*., 2007; Sharma *et al*., 2008)
Senecio vulgaris	Asteraceae	Whole plant	Methanol, ethyle acetate, hexane, butanol and chloroform extract (Loizzo *et al*., 2004)
Spilanthes calva	Asteraceae	Whole plant	Aqueous and petroleum ether extracts (Rai *et al*., 2004)
Tagetes erecta	Asteraceae	Leaves	Aqueous extract (Sharma and Jandaik, 1994)
Tapinanthus sessilifolius	Loranthaceae	Leaves	Crude extract (Tarfa *et al*., 2004)
Taxus wallichiana	Taxaceae	Bark	Crude extract (Dabur *et al*., 2007)
Withania somnifera	Solanaceae	Leaves	Aqueous extract (Mughal *et al*., 1996)

Loizzo *et al.* (2004) investigated the antifungal activity of methanol, ethyl acetate, dichloromethane, n-hexane, n-butanol and chloroform extracts of *Senecio inaequidens* D.C. and *Senecio vulgaris* L. (Asteraceae). The hexane extract of *S. vulgaris* showed significant activity against *Trichophyton tonsurans* (IC50 of 0.031 mg mL^{-1}). The antifungal activity of other crude extracts of the Asteraceae family also includeds *Cynara scolymus* L. extracts, (Zhu *et al.*, 2005) the dichloromethane extract of the aerial part of *Blumea gariepina* D.C. which is shown to be active against the phytopathogenic fungus *Cladosporium cucumerinum* (Queiroz *et al.*, 2005).

Some plant species known to antifungal medicinal plants belong to the Leguminoseae, Rutaceae, Myrtaceae and Lamiaceae families. The effect of heartwood extracts from two Leguminoseae species, *Acacia mangium* Willd and *Acacia auriculiformis* A. Cunn., was examined on the growth of woodrotting fungi in *in vitro* assays (Mihara *et al.*, 2005), *A. auriculiformis* heartwood extracts had higher antifungal activity than *A. mangium*.

In the Zingiberaceae family, the ethanol extract of *Curcuma longa* L. and *Alpinia galanga* were also found to possess good antifungal activities against *Trichophyton longifusus* (Khattak *et al.*, 2005). Other species of *Curcuma* (Zingiberaceae), *C. zedoaria* Rosc. and *C. malabarica* Vel., also posses antifungal activity which supports the use of their tubers in traditional medicine for the treatment of bacterial and fungal infections (Wilson *et al.*, 2005).

Pycnogenol, a standardised extract of *Pinus pinaster* Ait. (Pinaceae), was tested for its antifungal activity towards twenty three different yeast and fungi microorganisms (Torras *et al.*, 2005). Pycnogenol inhibited the growth of all the tested microorganisms in minimum concentrations ranging from 20 to 250 μg mL^{-1}. These results conform with clinical oral healthcare studies describing the prevention of plaque formation and the clearance of candidiasis by pycnogenol.

Crude methanol extracts and fractions from the aerial parts of seven species of *Hypericum* (Gutiferaceae) growing in southern Brazil were analysed for their *in vitro* antifungal activity against a panel of standardised and clinical opportunistic pathogenic yeasts and filamentous fungi, including dermatophytes (Fenner *et al.*, 2005). Chloroform and hexane extract of *Hypericum ternum* A. St.-Hill. showed the greatest activity among the extracts tested. Rojas *et al.* (2004) investigated the antifungal activity of *Gentianella nitida* Griseb. (Gentianaceae). The most susceptible microorganisms were *Candida albicans*, *Trichophyton mentagrophytes* and *Microsporum gypseum*. The antifungal activity was conducted in the 90% methanol and non-soluble fractions.

The latex of gazyumaru (*Ficus microcarpus* L., Moraceae), (Taira *et al.*, 2005a) *Larrea divaricata* Cav. (Zygophyllaceae) which presented fungitoxic activity against yeasts and fungi, (Queiroz *et al.*, 2004). Tarfa *et al.* (2004) studied leaf extracts of *Tapinanthus sessilifolius* (P. Beauv) Van Tiegh. (Loranthaceae) and found it active towards *Candida albicans*.

In India, Sharma and Jandaik (1994) found the leaves of *Azadirachta indica*, *Eucalyptus tereticornis*, *Eichhorinia crossipes*, *Tagetes erecta* and cloves of *Allium sativum* positively active against a few test fungi. While studying antimicrobial activity, Jain *et al.* (1996) observed the maximum inhibitory activity of ethanolic extract of root bark of *Calotropis procera* against *Enterobacter cloacae* and stem bark against *Fusarium moniliforme*. Similarly, Gupta and Govindaiah (1996) observed the effectiveness of leaf extracts of *Azadirachta indica*, *Calotropis gigantea*, *Eucalyptus* sp., *Parthenium hysterophorous* and *Pongamia pinnata* in controling *Fusarium pallidoroseum* and *F. oxysporoum*, causal organisms of leaf spot disease in mulberry. Ethanolic extracts of aerial parts and fruits of *Aglaia roxburghiana* were tested for *in vitro* antifungal activities against dermatophytes (Janaki *et al.*, 1998).

Bajwa *et al.* (2001) found inhibitory potential in aqueous extracts of three Asteraceous allelopathic species on growth of *Aspergillus niger*. More recently, Bajwa *et al.* (2002) have observed that the aqueous extracts of *Dicanthium annulatum, Imperata cylindrical, Cenchrus pennisetiformis* and *Desmostachya bipinnata* have potential to control *Fusarium moniliforme* and *F. oxysporum*.

In an approach toward the development of ecofriendly antifungal compounds for controlling major foliar fungal diseases of tea, ethanol and aqueous extracts of 30 plants belonging to 20 different families collected from sub-Himalayan West Bengal (India) were tested against the fungal pathogens (Saha *et al.*, 2005). The extracts of leaf, root, stem and the callus obtained from Leguminoseae species, *Pseudarthria viscida* (L.) Wight and Arn., showed significant inhibitory activity against some fungal pathogens causing major diseases in crop plants and stored food grains (Deepa *et al.*, 2004). Examples of other antifungal crude extracts from medicinal species also included *Bauhinia racemosa* L. (Caesalpiniceae) stem bark (Kumar *et al.*, 2005).

Another member of the Euphorbiaceae family, *Phyllanthus amarus* Schumach and Thonn., was also tested against the dermatophytic fungus *Microsporum gypseum* (Agrawal *et al.*, 2004). The chloroform extract of the aerial part of the plant showed a significant inhibitory effect against this dermatophytic fungus. One member of the Nyctaginaceae family, *Boerhavia diffusa* L., was active against the dermatophytic species of *Microsporum gypseum, Microsporum fulvum* and *Microsporum canis* (Agrawal *et al.*, 2003, 2004). Aqueous and petroleum ether extracts of *Spilanthes calva* D.C. were also found active towards *Fusarium oxysporum* and *Trichophyton mentagrophytes* (Rai *et al.*, 2004).

There are some other workers (Dixit and Tripathi, 1975; Dikshit *et al.*,1979, Dubey *et al.*, 1982, 1983, 2000; Pandey *et al.*, 1982a, b; Swaminathan *et al.*, 1990; Meena *et al.*, 2009) also reported the antifungal activity of some higher plants.

Kumudini *et al.* (2001) found a positive result in the treatment of susceptible pearl millet seeds with aqueous leaf extracts of *Datura metel* tested against the downey mildew pathogen *Sclerospora graminicola*. Khulbe and Sati (2006) investigated antifungal activity of the hexane, chloroform, methanol and aqueous extract of *Boenninghausania albiflora* Reichb. (Rutaceae) against various plant pathogenic fungi and found that the methanol extract had a broad spectrum antifungal activity. Recently, Dabur *et al.* (2007) investigated the antimicrobial potential of seventy-seven extracts from twenty-four plants against four pathogenic fungi. Similarly, Sharma *et al.* (2008) were tested root extracts of *Rumex nepalensis, Berberis aristata, Arnebia benthamii*, bark of *Taxus wallichiana, Juglans regia* and petals of *Jacquinia ruscifolia* for their antifungal activity against twelve different fungal pathogens. They found the ethanolic extracts of *R. nepalensis* and *J. ruscifolia* had a broad spectrum antifungal activity.

Antifungal activity of compounds isolated from plants: As evident from the available literature there are various workers who isolate individual active compounds from the plants which exert antifungal activity against various plants and human pathogens. Plant produces chemical compounds as part of their normal metabolic activities. These compounds are alkaloids, saponins, flavanoids, essential oils, terpenes, glycosides as well as proteins and peptides. The plants compounds (Phytochemicals) reported to contain antifungal activity have been listed in Table 2.

Essential oils: Meena and Sethi (1994) investigated the antimicrobial effect of 32 essential oils on 13 food-spoilage and industrial yeasts. They found that oregano was the most effective

Table 2: Antifungal compounds (Phytochemicals) isolated from different parts of plants

Plants	Family	Plant part	Phytochemicals
Aegle marmelos	Rutaceae	Leaves	Essential oils (Rana *et al*., 1997)
Alpinia galangal	Zingibearceae	Seeds	Diterpenes (Morita and Itokawa, 1988)
Ananas comosus	Bromeliaceae	leaves	Protein (Taira *et al*., 2005a, b)
Anaphalis adanata	Asteraceae	Leaves	Essential oil (Bisht and Joshi, 2009)
Aquilegia vulgari	Ranunculaceae	Leaves, stem	Flavonoid (Bylka *et al*., 2004)
Artemisia giraldii	Asteraceae	Whole plant	Sesquiterpene lactones (Tan *et al*., 1999)
Artocarpus nobilis	Moraceae	Stem bark	Stilbene (Javasinghe *et al*., 2004)
Baseonema acuminatum	Asclepiadaceae	Leaves	Phenolic compounds (De Leo *et al*., 2004)
Blumea balsamifera	Asteraceae	leaves	Flavonoid luteolin (Ragasa *et al*., 2005)
Calocedrus formosana	Cupressaceae	leaves	Essential oils (Cheng *et al*., 2004)
Camptotheca acuminata	Nyssaceae	Leaves	Flavonoid (Li *et al*., 2005).
Capsicum frutescens	Solanaceae	Whole plant	triterpene saponin (Renault *et al*., 2003)
Cassia tora	Leguminoseae	Whole plant	Emodin, physcion and rhein (Kim *et al*., 2004)
Centaurea sp.	Asteraceae	Whole plant	Sesquiterpene lactones (Skaltsa *et al*., 2000)
Cyathobasis fruticulosa	Chenopodiaceae	Aerial part, root	Alkaloid (Bahceeuli *et al*., 2005)
Datura metel	Solanaceae	Whole plant	Alkaloid (Dabur *et al*., 2005)
Detarium microcarpum	Leguminoseae	Fruit pulp	Diterpenes (Cavin *et al*., 2006)
Dioscorea cayenensis	Dioscoreaceae	Rhizome	Saponins (Sautour *et al*., 2004)
Erythrina burtii	Leguminoseae	Stem bark	Flavonoid (Yenesew *et al*., 2005)
Evonymus europaeus	Celastraceae	Leaves	Protein (Vanden Bergh *et al*., 2004)
Haloxylon salicornium	Chenopodiaceae	Aerial part	Alkaloid (Ferheen *et al*., 2005)
Haplophyllum sieversii	Rutaceae	Aerial part	Alkaloid (Cantrell *et al*., 2005)
Juniperus comunis	Cupressaceae	leaves	Essential oils (Cavaleiro *et al*., 2006)
Juniperus thurifera	Cupressaceae	wood	Sesquiterpene (Barrero *et al*., 2005),
Khaya ivorensis	Meliaceae	Stem bark	Triterpenes (Abdelgaleil *et al*., 2005).
Lavandula sps.	Lamiaceae	Stem, leaves	Essential oils (Angioni *et al*., 2006)
Lycium chinense	Solanaceae	Root bark	Phenolic compounds (Lee *et al*., 2004)
Musa acuminata	Musaceae	banana	Protein (Leone *et al*., 2006)
Ocimum gratissimum	Lamiaceae	Bark	Essential oils (Nakamura *et al*., 2004)
Phaseolus vulgaris	Fabaceae	Seeds	Peptide (Wong and Ng, 2005)
Pinus pinaster	Pinaceae	leaves	Pinosylvin (Lee *et al*., 2005)
Polygonum punctatum	Polygonaceae	Whole plant	Sesquiterpene (Fujita and Kubo, 2005)
Serjania satzmanniena	Sapindeceae	Whole plant	Saponins (Ekabo *et al*., 1996)
Smilax medica	Liliaceae	Root	Saponins (Sautour *et al*., 2005)
Solanum abutiloides	Solanaceae	root	Sesquiterpene (Yokose *et al*., 2004).
Solanum tuberosum	Solanaceae	Tubers	Protein (Park *et al*., 2005)
Thymus vulgaris	Lamiaceae	Whole plant	Essential oil (Giordani *et al*., 2006)
Trachyspermum ammi	Apiaceae	Leaves, flowers	Essential oils (Singh *et al*., 2004)
Trigonella graecum	Fabaceae	Whole plant	Peptides (Olli and Kirti, 2006)
Zingiber officinalis	Zingiberaceae	Rhizome	Protein (Wang and Ng, 2005)

inhibitor against yeast. The antifungal activity of essential oil isolated from the leaves of bael (*Aegle marmelos* L. Correa ex Roxb., Rutaceae) has been evaluated using spore germination assay. The oil exhibited variable efficacy against different fungal isolates and 100% inhibition of spore germination of all the fungi tested was observed at 500 ppm (Rana *et al*., 1997).

The *in vitro* antifungal activity of the essential oil of *Ocimum gratissimum* was investigated in order to evaluate its efficacy against *Candida albicans*, *C. krusei*, *C. parapsilosis* and *C. tropicalis* (Nakamura *et al*., 2004). These results demonstrated that the essential oil show a good fungicidal activity against all of the *Candida* species studied.

Singh *et al.* (2004) investigated the chemical constituents and antifungal effects of ajwain essential oil, *Trachyspermum ammi* (L.) Sprague (Apiaceae). The oil exhibited a broad spectrum of fungitoxic behaviour against all tested fungi, such as *Aspergillus niger*, *Fusarium moniliforme* and *Curvularia lunata*, as absolute mycelial zone of inhibition was obtained at a 6 μL dose of this oil.

An endemic tree species in Taiwan *Calocedrus formosana* Florin. (Cupressaceae) whose timber is recognised for its natural resistance to decay, is studied for antifungal activity by Cheng *et al.* (2004) they found the essential oil isolated from leaf displayed activity against four fungi: *Lenzites betulina*, *Pycnoporus coccineus*, *Trametes versicolor* and *Laetiporus sulphurous*. Examples of other antifungal essential oils from the Cupressaceae family including *Juniperus comunis* L. essential oil which was reported active against the dermatophyte *Aspergillus* and *Candida* strains (Cavaleiro *et al.*, 2006).

The antifungal effect of the essential oils isolated from several species of the Lamiaceae family, *Satureja montana* L., *Lavandula angustifolia* Mill., *Lavandula hybrid* Reverchon, *Origanum vulgare* L., *Rosmarinus officinalis* L. and six chemotypes of *Thymus vulgaris* L. were studied on *Candida albicans* growth (Giordani *et al.*, 2004) and the greatest efficiency was obtained with the essential oil from the *T. vulgaris* thymol chemotype (IC50 of 0.016 μg mL^{-1}).

Angioni *et al.* (2006) investigated the chemical composition and antifungal activity of the essential oil from the stems, leaves and flowers of some *Lavandula* species growing wild in southern Sardinia. The essential oils tested were found effective on the inactivation of *Rhizoctonia solani* and *Fusarium oxysporum*.

The *in vitro* antifungal activity of essential oil of *Anaphalis adnata* DC. was investigated in order to evaluate the efficacy aganist *Pyricularia oryzae, Fusarium oxysporum, Rhizoctonis solani, Sclerotium rolfsii* and *Sclerotinia sclerotiorum* (Bisht and Joshi, 2009). The result shown that the *Pyricularia oryzae* was the most sensitive pathogen tested.

Terpenoid: Morita and Itokawa (1988) isolated two new skeletal diterpenes, named galanal A and B and two new labdane-type diterpenes, named galanolactone and (E)-8 (17), 12-labddiene-15,16-dial, from *Alpinia galanga* (Zingiberaceae) together with (E)-8β(17)-epoxylabd-12-ene-15,16-dial and found cytotoxic and antifungal activities of these compounds.

A new antimicrobial eudesmanolide, 1-oxo-8-hydroxy-11H-eudesm-4-en-12, 6-olide (1), was isolated by Tan *et al.* (1999) from a medicinal plant *Artemisia giraldii*. Antimicrobial bioassay conducted by them indicated that this compound inhibited the growth of human opportunistic pathogenic fungi *Candida tropicalis, Gecotrichum candidun, Aspergillus flavus and A. nigers* as well as human pathogenic bacteria.

Skaltsa *et al.* (2000) isolated three sesquiterpene from some *Centaurea* species. The *in vitro* antifungal activity of these sesquiterpene lactones was tested against nine fungal species using the micro-dilution method and all the compounds were found with considerable antifungal effect.

Polygodial, a sesquiterpene isolated from *Polygonum punctatum* Elliot. (Polygonaceae), was found to exhibit a fungicidal activity against a food spoilage yeast, *Zygosaccharomyces bailii* (Fujita and Kubo, 2005). The time-kill curve study showed that polygodial is fungicidal at any stage of growth.

Antifungal sesquiterpenes from the root exudates of *Solanum abutiloides* (Griseb.) Bitter and Lillo inhibited the spore germination of *Fusarium oxysporum* (Yokose *et al.*, 2004). Similarly, antifungal sesquiterpenes was also isolated from wood of *Juniperus thurifera* L. (Barrero *et al.*, 2005).

A fruit pulp extract of *Detarium microcarpum* Guill. et Perr. (Leguminoseae) show inhibition of the growth of a plant pathogenic fungus *Cladosporium cucumerinum* (Cavin *et al*., 2006). Fractionation of this extract led to the isolation of four new clerodane diterpenes having the antifungal activity.

Chemical investigation of the diethyl ether extract of the stem bark of *Khaya ivorensis* A Chev (Meliaceae) resulted that it has ten highly oxygenated triterpenes (Abdelgaleil *et al*., 2005). These compounds were evaluated for their antifungal activity against a plant pathogenic fungus *Botrytis cinerea*. Methyl angolensate and 1,3,7-trideacetylkhivorin displayed the highest antifungal activity, with 62.8 and 64% mycelial growth inhibition at 1000 mg L^{-1}, respectively (Abdelgaleil *et al*., 2005).

Saponin: Two novel saponins, named salzmannianosides A and B and 2 known saponins (pulsatilla saponin D and 3-O-[[beta-D-glucopyranosyl-(1->4)]-[alpha-L-rhamnopyranosyl-(1->2)]-alpha-L-arabinopyranosyl] oleanolic acid) were recovered by Ekabo *et al*. (1996) from the methanol extract of the stems of *Serjania salzmanniana*. The saponins showed antifungal activity against *Cryptococcus neoformans* and *Candida albicans* (MIC values of 8 and 16 μg mL^{-1}, respectively).

CAY-1, a novel triterpene saponin from the *Capsicum frutescens* L. (Solanaceae) plant commercially known as cayenne pepper has been investigated to determine its *in vitro* antifungal activity by Renault *et al*. (2003). It was found active against sixteen different fungal strains, including *Candida* sp. and *Aspergillus fumigatus* and was active against *Cryptococcus neoformans*. Importantly, they noted that it appears to be active in disrupting the membrane integrity of fungal cells.

From the rhizomes of *Dioscorea cayenensis* Lam. Holl (Dioscoreaceae), a steroid with antifungal activity against the human pathogenic yeasts *Candida albicans*, *Candida glabrata* and *Candida tropicalis* has been isolated (Sautour *et al*., 2004), while three new antifungal steroidal saponins have been recovered from the root of *Smilax medica* L. (Liliaceae) (Sautour *et al*., 2005).

Phenolic compounds: The fungicidal activities of *Cassia tora* L. (Leguminoseae) and its active principles are determined against *Botrytis cinerea*, *Erysiphe graminis*, *Phytophthora infestans*, *Puccinia recondita*, *Pyricularia grisea* and *Rhizoctonia solani* (Kim *et al*., 2004). Three flavanoids Emodin, physcion and rhein which were isolated by Kim *et al*. (2004) from the chloroform extract showed fungicidal activity against the microorganisms tested. Among these emodin showed strong and moderate fungicidal activity against *Botrytis cinerea* and *Phytophthora infestans*, respectively.

Three new phenolic compounds were isolated from the leaves of *Baseonema acuminatum* P. Choux (Asclepiadaceae) (De Leo *et al*., 2004). The compounds showed antifungal activity against two clinically isolated *Candida albicans* strains with IC50 values in the range of 25-100 μg mL^{-1}. Lee *et al*. (2004) isolated four phenolic acid derivatives from an ethyl acetate extract of the root bark of *Lycium chinense* Miller (Solanaceae) and found that all phenolic derivatives had antifungal effect against *Candida albicans*.

Later, Lee *et al*. (2005) found Pinosylvin, a constituent of pine, (*Pinus pinaster*) Pinaceae, with growth-inhibitory activity against *Candida albicans* and *Saccharomyces cerevisiae* The antifungal activity of a series of prenylated flavonoids which were purified from five different medicinal plants belonging to Moraceae family were evaluated against two fungal microorganisms (*Candida albicans* and *Saccharomyces cerevisiae*) by determination of IC50 using the broth microdilution method (Sohn *et al*., 2004). These results support the use of prenylated flavonoids in Asian traditional medicines to treat fungal infections. n-butanol extract of the stem bark of

Artocarpus nobilis Thw. (Moraceae) also furnished two stilbene derivatives (Javasinghe *et al.*, 2004). Both compounds show strong antifungal activity against *Cladosporium cladosporioides*.

Other examples of antifungal flavonoids from medicinal plants include the stem bark of *Erythrina burtii* Ball. a Leguminous plant (Yenesew *et al.*, 2005) and the main flavonoid 4'-methoxy-5, 7-dihydroxyflavone 6-C-glucoside (isocytisoside) from the leaves and stems of *Aquilegia vulgaris* L. a Ranunculous plant, which showed activity against the mould *Aspergillus niger* (Bylka *et al.*, 2004).

The leaves of *Blumea balsamifera* (L.) D.C. (Asteraceae) afford the flavonoid luteolin (Ragasa *et al.*, 2005). Antifungal tests indicated that luteolin had moderate activity against the fungi *Aspergillus niger*, *Trichophyton mentagrophytes* and *Candida albicans*. The flavonoids trifolin and hyperoside isolated from *Camptotheca acuminata* Decne (Nyssaceae) effectively control fungal pathogens *in vitro*, including *Alternaria alternata*, *Epicoccum nigrum*, *Fusarium avenaceum*, *Pestalotia guepinii* and *Drechslera* sp. (Li *et al.*, 2005).

Alkaloids: Cantrell *et al.* (2005) performed a preliminary screening data indicated that the presence of growth-inhibitory compounds in bioassay-guided fractionation of the hexane/ethyl acetate/water crude extract of the aerial parts of *Haplophyllum sieversii* Lincz et Wed. (Rutaceae) against *Colletotrichum fragariae*, *C. gloeosporioides* and *C. acutatum*. Their fractionation resulted in the isolation of bioactive alkaloids, flindersine, anhydroevoxine and haplamine. Of them, flindersine and haplamine were found with the highest level of antifungal activity.

A novel alkaloid, 2-(3,4-dimethyl-2,5-dihydro-1H-pyrrol-2-yl)-1-methylethyl pentanoate was isolated by Dabur *et al.* (2005) from the plant *Datura metel* L. (Solanaceae) The *in vitro* activity of this dihydropyrrole derivative against *Candida albicans*, *Candida tropicalis*, *Aspergillus fumigatus*, *A. flavus* and *A. niger* was evaluated and found active against all the species tested.

Examples of other antifungal alkaloids from medicinal plant also include a β-carboline, a tryptamine and two phenylethylamine-derived alkaloids from the aerial parts and roots of *Cyathobasis fruticulosa* (Bunge) Aellen (Chenopodiaceae)) and haloxylines A and B, new piperidine alkaloids from the chloroform extract of *Haloxylon salicornium* L. (Chenopodiaceae), which display good antifungal potentials (Bahceeuli *et al.*, 2005; Ferheen *et al.*, 2005).

Peptides and proteins: Park *et al.* (2005) purified an antifungal protein, AFP-J from potato tubers, *Solanum tuberosum* cv L. Jopung (Solanaceae). AFP-J strongly inhibited yeast fungal strains, including *Candida albicans*, *Trichosporon beigelii* and *Saccharomyces cerevisiae*. Similarly, Taira *et al.* (2005b) purified three proteins, designated pineapple leaf chitinase-A,-B and -C, from the leaves of pineapple, *Ananas comosus* L. (Bromeliaceae). Pineapple leaf chitinase-B exhibits strong antifungal activity toward *Trichoderma virida*.

Other antifungal peptides and proteins from the medicinal plants are two chitin-binding proteins from spindle tree *Evonymus europaeus* L. (Vanden Bergh *et al.*, 2004), a thaumatin-like protein from banana *Musa acuminata* Colla. (Leone *et al.*, 2006) and a protein from ginger rhizomes *Zingiber officinalis* L. (Wang and Ng, 2005).

Wong and Ng (2005) purified an antifungal peptide from the seeds of haricot beans, *Phaseolus vulgaris* L. (Fabaceae). This peptide, named vulgarinin, displayed antifungal activity toward *Fusarium oxysporum*, *Mycosphaerella arachidicola*, *Physalospora piricola* and *Botrytis cinerea*. Another Fabaceae species, *Trigonella foenum-graecum* L., yielded defensins, small cysteine rich peptides, which exhibited antifungal activity against the broad host range fungus *Rhizoctonia solani* and the peanut leaf spot fungus *Phaeoisariopsis personata* (Olli and Kirti, 2006).

CONCLUSIONS

The reconnaissance of available literature on antimicrobial activity indicates that a variety of plant species possess different antimicrobial activities. The crude plant extracts in various organic solvents as well as aqueous extract comprises of different types of compounds-essential oils, alkaloids, saponins, terpenes, flavanoids, peptides and proteins etc. Among these, essential oils have frequently been screened for their antifungal activities against a number of plant pathogenic and animal pathogenic fungi. Majority of these have shown a significant inhibitory effect.

Though the crude extract have also been frequently screened for their antifungal activities with positive results but it can not be attributed that which plant compound (Phytochemical) is responsible to what extent for its effectiveness towards the tested fungi. Thus it gives a preliminary data and should be followed by isolation of phytochemicals.

It can fairly be concluded that such studies are paramount importance in the discovery of new classes of antibiotics that could serve in the maintenance of human and plant health. The spread of multidrug-resistant strains of fungi and the reduced number of drugs available makes it necessary to discover new classes of antifungal compounds that inhibit these resistant microorganisms. Plant based antifungals may represents an unlimited sources for modern medicines. Therefore, a continued and regular exploration of plant antifungals is required. The studies on plant extracts or chemicals have shown remarkable antifungal activity against different strains of fungi and highlighted its significance to human and plants.

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