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Review Article

ANTIFUNGAL INVESTIGATIONS ON PLANT ESSENTIAL OILS. A REVIEW

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ABSTRACT

Plant essential oils are potential source of antimicrobials of natural origin. Essential oils and extracts obtained from many plants have recently gained a great popularity and scientific interest. Consumer demand for natural preservatives has increased, whereas the safety aspect of chemical additives has been questioned. The plant oil has been reported to have antibacterial, antifungal, antiviral, antiparasitic and antidermatophytic properties. It is now considered as a valuable source of natural products for development of medicines against various diseases and also for the development of industrial products. The present review is a compilation of updated information on plant essential oils with antifungal properties.

Keywords: Plant families, Essential oils, Antifungal activity.

INTRODUCTION

Essential oils are volatile aromatic concentrated hydrophobic oily liquids which are obtained from various plant parts such as flowers, buds, seeds, leaves, twigs, bark, woods, fruits and roots. Essential oils are usually terpenoids responsible for the aroma and flavor associated with herbs, spices and perfumes, also called volatile oils because they easily diffuse into the air. The main constituents of essential oils are mono and sesquiterpenes including carbohydrates, phenols, alcohols, ethers, aldehydes and ketones responsible for the biological activity as well as for their fragrance. Phenolic compounds present in essential oils have also been recognized as antimicrobial bioactive components [1]. Various plant materials are believed to have antifungal activity and many essential oils have been reported to have antifungal activities with no side effects on humans and animals [2]. Previous in vitro and in vivo investigations suggested that the essential oils could be used as effective antifungal agents [3]. The selection of plants for evaluation was based on traditional usage for treatment of infectious diseases [4-6]. However, there are only limited data available on the antifungal activity of essential oils against human and plant fungal pathogens. Fungal species of the genera *Aspergillus, Fusarium* and *Alternaria* have been considered to be major plant pathogens Worldwide [7]. Millions of people throughout the world are affected by superficial fungal infections, which are the most common skin diseases. These infections, which occur in both healthy and immunocompromised persons, are caused mainly by dermatophytes. Increasing social and health implications caused by dermatophytes means there is a constant striving to develop safe and new natural antifungal agents to cure human fungal disorders caused by dermatophytes. Many skin diseases such as, tinea and ringworm caused by dermatophytes are existing in tropical and semitropical areas. In general, these fungi live in the dead and top layer of skin cells of moist areas of the body and cause only a minor irritation. Other types of fungal infections could be more serious. They can penetrate into the cells and cause itching, swelling, blistering and scaling [8]. Essential oils and plant extracts have long been known and used throughout the world for the treatment of many conditions, including skin conditions, and have less deleterious side effects than corresponding synthetic drugs [9].

In general, plant-derived essential oils and extracts are considered as non-phytotoxic compounds and potentially effective against several microorganisms including many fungal pathogens [10, 11]. Therefore, they can be used as a natural therapy to inhibit fungal pathogens causing superficial infections. In recent years, interests have been generated in the development of safer antifungal agents from natural plant products such as, essential oils and extracts to control fungal diseases [11, 12]. In recent years, several researchers have reported the mono- and sesquiterpene hydrocarbons as the major components of plant essential oils with enormous potential to inhibit microbial pathogens [13]. The active antimicrobial compounds of essential oils are generally terpenes, which are phenolic in nature, attack the pathogens through cell wall and cell membrane. Thus, active phenolic compounds might have several invasive targets which could lead to the inhibition of human infectious fungal pathogens.

Essential oils antifungal activity

The increasing resistance to antifungal compounds and the reduced number of available drugs led us to search for the new alternatives among aromatic plants and their essential oils, used for their antifungal properties. The antifungal activity can be attributed to the presence of some components such as carvacrol, α-terpinly acetate, cymene, thymol, pinene, linalool which are already known to exhibit antimicrobial activity [14-17]. A number of scientific investigations have highlighted the importance and the contribution of many plant families i.e. Asteraceae, Liliaceae, Apocynaceae, Solanaceae, Caesalpinaceae, Rutaceae, Piperaceae, Sapotaceae, etc., used as medicinal plants [18].

Several in vitro studies have been published confirming the effect of essential oil and their major compounds on plant and human pathogenic fungi. Some of the plant families, their antifungal activity of essential oil are summarized below. Other significant screening assays comprising other species and therefore, reported in Table 1.

1. Asteraceae

Most members of Asteraceae are herbaceous, but a significant number are also shrubs, vines and trees. The family has a worldwide distribution and is most common in the arid and semi-arid regions of subtropical and lower temperate latitudes [19]. Plants in Asteraceae are medically important in areas that don't have access to Western medicine. They are also commonly featured in medical and phytochemical journals because the sesquiterpene lactone compounds contained within them are an important cause of allergic contact dermatitis. Allergy to these compounds is the leading cause of allergic contact dermatitis [20]. Reports on the antifungal activity and chemical composition of the essential oils from aromatic plants belonging to Asteraceae family have been found in literatures. The antifungal activity of essential oil of flowerheads of garland chrysanthemum *Chrysanthemum coronarium* L. was evaluated against twelve agricultural pathogens [21]. The main compounds in the oil were camphor, α- and β-pinene and lyratyl acetate. Oil was active both in contact and headspace in vitro assays and produced hyphal growth inhibition. The chemical composition and antifungal activity of essential oils from three *Artemisia* species i.e. *Artemisia absinthium* L., *A. santonicum* L. and *A. spicigera* C. Koch. all the oils had potent inhibitory effects over all the fungi tested [22]. The compositions of leaf oils obtained by hydro-

distillation were also studied in Asteraceae [23].The essential oil of *Tagetes patula* L. exerted good antifungal activity against two phytopathogenic fungi, *Botrytis cinerea* and *Penicillium digitatum*, providing complete growth inhibition [24]. The contribution of two main compounds, piperitone and piperitenone to the antifungal efficacy was evaluated and structural modifications in mycelia were observed via electron microscopy, displaying considerable alterations in hyphal morphology and multi-site action mechanism. Examples of other antifungal essential oils from Asteraceae family also included the essential oil of *Chrysactinia mexicana* Grag, which completely inhibited the growth of *Aspergillus flavus* [25] and *Helichrysum italicum* (Roth) Don active against *Pythium ultimum* [26]. Antifungal activity in essential oils from the aerial parts of *Arnica longifolia* D.C.Eaton*., Aster hesperius* A.Gray*., Chrysothamnus nauseosus,* against three plant fungal pathogens of *Colletotrichum* species [27]. Previously reported that carvacrol possesses antifungal activity against *Colletotrichum* species[28,29].

2. Rutaceae

Rutaceae, commonly known as the rue or citrus family generally known for the flowers divided into four or five parts and strong scents. The family is of great economic importance in warm temperate and sub-tropical climates for its numerous edible fruits. In this family, the essential oil from the epicarp of *Citrus sinensis* (L.) Osbeck exhibited absolute fungitoxicity against ten post-harvest pathogens [30]. The chemical composition and antifungal activity of the essential oil of *Haplophyllum tuberculatum* (Forsskal) A. Juss was also analysed [31]. The oil affected the mycelial growth of *Curvularia lunata* and *Fusarium oxysporium* in a dose-dependent manner, but had no effect on the germination of their spores. Thirty compounds, constituting about 99.7% of the total oil, were identified. The most abundant oil components were α- and β-phellandrene, limonene, β-ocimene, β-caryophyllene and myrcene. The antifungal activities of essential oils from *Citrus limon* (L.)Burm.f*., C. paradise* Macfad *, C. sinesis* were reported against five phytopathogenic fungi [32]. Bergamot oil (*Citrus hystrix* DC.) shows the antagonistic activity against seven species of economically important rice pathogenic fungi *Alternaria brassicicola, Aspergillus flavus, Bipolaris oryzae, Fusarium moniliforme, F. proliferatum, Pyricularia arisea* and *Rhizoctonia solani* and found that both the concentration and type of active compound are important factors that determine their potential antifungal activity [33]. The antifungal effectiveness of *Bergamot* essential oil is probably affected by the method of oil extraction and the sensitivity of the strains [34].

3. Liliaceae

It is monocotyledonous family; many plants in the Liliaceae are important ornamental plants, widely grown for their attractive flowers and are native primarily to temperate and subtropical regions. The activity of essential oils from *Allium fistulosum* L.*, A. sativum* L. and *A. cepa* L. were investigated against three *Trichophyton* species responsible for severe mycoses in humans[35]. *A. sativum* oil exhibited strongest inhibition of growth in *T. rubrum* with an IC50 value of 61 µg/ml, while *A. cepa* and *A. fistulosum* were relatively mild [36].

4. Lamiaceae

The family has cosmopolitan distribution. Many members of this family are useful economically for medicinal, culinary, ornamental and various commercial utilizations. Previous studies on the essential oils of many Lamiaceae show that, these plants have a broad range of biological activities, notably their antimicrobial potency [37], and this activity is generally correlated to the chemical composition of the oil. Thus, this biological difference can be partly explained by the variation in their chemical composition. The essential oil of *Ocimum basilicum* L. is known for its wound healing property and hence, is used in the treatment of fungal infections [38]. Major component of this oil was linalool. Antifungal activity in oil of *O. sanctum* L. against pathogenic fungi [39]. The in vitro antifungal activity of essential oil of *O. gratissimum* L. was investigated in order to evaluate its efficacy against *Candida albicans, C. krusei, C. parapsilosis* and *C. tropicalis*. Results demonstrated that the essential oil showed fungicidal activity against all of the *Candida* species [40]. Analysis of the ultra structure of the yeast cells revealed changes in the cell wall and in the morphology of some subcellular organelles. The essential oil from another species of the *Ocimum* genus, basil *Ocimum micranthum* Willd. showed a dose-dependent antifungal activity against pathogenic and food spoiling yeasts [41-45]. Another genus *Nepeta crispa* Willd. oil exhibited a noticeable antifungal activity against all the tested fungi. Twenty three compounds, accounting for 99.8% of the total oil were identified. The main constituents were 1,8-cineole and 4α,7α-abetanepetalactone [46]. The composition and the antifungal activity of the essential oil of *Thymbra capitata* (L.) Cav. on *Candida, Aspergillus* and dermatophyte strains was studied [47]. The oil exhibited antifungal activity against all the strains tested, particularly for dermatophytes, with IC50 values ranging from 0.08 to 0.32µg/ml. All samples were of the carvacrol type with a high content of carvacrol and its biogenetic precursors, γ-terpinene and p-cymene suggesting that the plant essential oils are potentially safe source of antifungal agents. Recently examined the antifungal activity of essential oil of *Thymus daenensis* Celak*., Zataria multiflora* Boiss. and *Thymbra spicata*L*.,* against *A.flavus* and *A. parasiticus* [48]. Previous studies on the antimicrobial activity of the essential oils of some *Thymus* species showed that most of the species which possess large quantities of phenolic monoterpenes have shown activity against viruses, bacteria, food-derived microbial strains and fungi. The volatile oil of *T. striatus* L. exhibited strong inhibitory effects against all the test fungi [49].

In addition, it is known that sage (*Salvia officinalis* L.), lavender (*Lavendula angustifolia* Mill.) always been used to treat various skin diseases and cosmetic products for skin care [50]. Lavender is also used for healing wounds in ethnomedicine and its essential oil possess components like, linalool, linalyl acetate, limonene, cineole and camphor. The efficacy of essential oil can be explained by interactions of individual components like, linalyl acetate and linalool [51]. Anti-inflammatory potential and the possibility of easier passage through mucous membrane of the essential oils of lavender and sage, probably contribute to the overall therapeutic effect [52]. The efficacy of essential oils of lavender and sage, can be explained by the high content of 1,8-cineole, which is capable of changing the structure and moisture of mucous membranes of fungal cells, interfering with the respiratory processes, and therefore comes to the elimination of pathogens[53]. The presence of limonene and 1, 8-cineole which can influence on the changing structure of the lipid layer, the stratum corneum, increased permeability of the epidermis and stratum corneum human, also may be one of the reasons for the good of the essential activities in vivo [54]. The therapeutic potential is very important in the healing of inflammatory wounds incurred as a response to infection, and therefore more quickly master the pathogen by an infected organism. Linalool was more effective than essential oil, although linalyl acetate was almost ineffective. Previously investigated the chemical composition and antifungal activity of essential oil from the stems, leaves and flowers of *Lavandula stoechas* L.[55]. The essential oils were effective on the inactivation of *Rhizoctonia solani* and *Fusarium oxysporum*, and less effective against *Aspergillus flavus*. Fenchone, limonene and myrtenol appeared to be the most effective on the inhibition of *R. solani* growth. The chemical composition of the essential oil of *Rosmarinus officinalis* L. obtained by hydro-distillation was also studied [56]. The major compounds in the essential oil were α-pinene, borneol, camphene, camphor, verbenone and bornyl acetate. An inhibitory effect on fungal growth, especially toward *F. graminearum*, was observed. Essential oils of rosemary exhibited an intermediate antifungal activity (MIC=1.10mg/mL) against *C. albicans*[57].

The antifungal effect of the essential oils from several species of the Lamiaceae family, *Satureja montana* L., *Lavandula angustifolia*, *L. hybrida* Reverchon, *Origanum vulgare* L., *Rosmarinus officinalis* L. and six chemotypes of *Thymus vulgaris* L. on *Candida albicans* growth [58]. The greatest efficiency obtained with the essential oil from the *T. vulgaris* (IC50 of 0.016 µg/ml). From two of these genera, *Lavandula and Rosmarinus*, extensive works on the antifungal activity of their essential oils have been reported. The antifungal activity of the essential oil of *L. angustifolia* (lavender oil) and its main components, linalool and linalyl acetate, was investigated

against fifty clinical isolates of *Candida albicans* (oropharyngeal and vaginal strains) [59]. *O. vulgare* oil alone inhibited all of the phytopathogenic fungi. The main constituents of *O. vulgare* oil were carvacrol, ρ-cymene and thymol and this result is accordance with the previously published reports [60, 61]. Previously reported that the highest and broadest activity was shown by the carvacrol containing oils such as *O. onites* and *S. thymbra* [62]. Carvacrol and thymol as strong inhibitors of *B. cinerea* in vitro [63]. ρ-Cymene, a constituent of *O. vulgare* oil showed synergistic activity with thymol against fungi [64]. A screening assay of essential oils against *T. mentagrophytes* using vapour phase test was carried out [65]. The most active oils were *Origanum vulgare* L.*, Thymus serpyllum* L., *Thymus vulgaris, Lavandula latifolia* Medik*., L. angustifolia. T. vulgaris* inhibited the fungal growth due to the presence of phenolic compounds, namely thymol and carvacrol [66]. Similarly, the essential oil of mint was found to have strong antimycotic activity against *Candida albicans* and dermatophytes[67]. The activity of *Mentha arvensis* L. essential oil was also well studied [41-45,68]. The antifungal activity of essential oils of *Mentha piperita* L. and *T. vulgaris* was evaluated against mycotoxin producers *Aspergillus flavus* and *A. parasiticus*. Menthol and thymol are the major component of essential oils [69]. Many publications have documented the antifungal activity of oregano oil against different microbial species [70-79]. Essential oil from the aerial parts of *Salvia mirzayanii* Rech. F. and Esfand. was determined against *Fusarium solani*, and *Candida albicans* [80]. The inhibitory effect of the essential oil increased when the concentration of essential oil was increased. Major components were linalool, linalyl acetate, α-terpinyl acetate, 1, 8-cineole, α-cadinol and δ-cadinene. Essential oil composition of *S. mirzayanii* showed good antimicrobial activity against pathogens which could be attributed to high amount of major components as 5-neocedranol, α-terpinyl acetate, 1,8-cineol, bicyclogermacrene, α-cadinene and other valuable components in oil.

5. Verbenaceae

Verbenaceae is a family of mainly tropical flowering plants. It constitutes trees, shrubs and herbs notable for heads, spikes, or clusters of small flowers, many of which have an aromatic smell. Some of the medicinal and aromatic plants have been reported to be anti-infectious agents. A study to evaluate the antifungal activity of oregano (*Lippia berlandieri* Shauer) versus food-contaminant fungi was initiated [81]. The oregano essential oil was inhibitory to all fungal strains tested, but there was a differential effect with the fungal strains studied. Previously, reported the antimicrobial activity of *Lippia javanica* (Burm. f.) leaf essential oil against some fungi [82]. The antifungal activity of the essential oils of aerial parts of *Lantana achyranthifolia* Desf. and *Lippia graveolens* Kunth. against *Fusarium sporotrichum, Aspergillus niger, Trichophyton mentagrophytes and Fusarium moniliforme. L. graveolens* presented higher antifungal activity than *L.achyranthifolia* [83].

6. Lauraceae

The Lauraceae are the laurel family of flowering plants, occur mainly in warm temperate and tropical regions, especially Southeast Asia and South America. Most are aromatic evergreen trees or shrubs. Many Lauraceae contain high concentrations of essential oils, some of which are valued for spices and perfumes. Photochemical in the Lauraceae are numerous and diverse. The adaptation of Lauraceae to new environments has followed a long evolutionary journey which has led to many specializations, including defensive or deterrent systems against other organisms. The antifungal activity of the essential oils from several aromatic species from the Lauraceae family, *Aniba rosaedora* Ducke, *Laurus nobilis* L., *Sassafras albidum* (Nutt.) Nees and *Cinnamomum zeylanicum* Blume. were investigated against seventeen micromycetes[84]. Among the fungal species tested for food poisoning and food spoilage fungi, plant and animal pathogens. Linalool was the main component in the essential oil of *A. rosaedora*, while 1, 8-cineole was dominant in *L. nobilis*. Safrole was the major component in *S. albidum* essential oil, and the main component of the oil of *C. zeylanicum* was trans-cinnamaldehyde. The essential oil of *C. zeylanicum* showed strongest antifungal activity. Another antifungal *Cinnamomum* species is *Cinnamomum osmophloeum* Kaneh. has significant antifungal activity against wood decay fungi[85]. The authors were able to establish a correlation between chemical composition and antifungal activity, showing that the strong antifungal activity of the bark and leaf oils of *C. zeylanicum* was related to the high levels of cinnamaldehyde (44.2%) and eugenol (90.2%) while high amounts of benzyl benzoate (>50%) in the leaf oils of *C. rhynchophyllum, C. microphyllum, C. pubescens, C. impressicostatum,* and *C. mollissimum* were responsible for selective toxicity against dermatophytes[86]. Previously, demonstrated that *C. zeylanicum* bark oil has fungitoxic properties against fungi involved in respiratory tract mycoses, such as *A. niger, A. fumigatus, A. nidulans* and *A. flavus* [87]. The inhibitory effect of cinnamom oils on the growth and alfatoxin production by *A. flavus* have also been reported [73,88,89]. Cinnamon oil exhibited strong inhibitory effects on *Botrytis cinerea*. It completely suppressed the mycelial growth of fungus [90, 91].

Essential oil of *Ocimum gratissimum* (L.) had significant fungistatic activity against all the species investigated[92]. *Penicillium* species and *Fusarium poae* were the most sensible to this essential oil. Furthermore, the biological activity of this oil is probably due to its prominent concentration in thymol, which is a phenolic compound. Generally, the essential oils possessing the strongest antimicrobial properties against food borne pathogens contains a high percentage of phenolic compounds such as carvacrol, eugenol (2-methoxy-4-(2-propenyl) phenol) and thymol[93,94]. An important characteristic of thymol is its hydrophobicity, which enables it to partition in the lipids of the fungal cell membrane, disturbing the structures and rendering it more permeable and leakage of ions and other cell contents can then occur [93,95]. Many studies have assessed antifungal activities of essential oil of *O. gratissimum* against different food-borne pathogens. It was reported that volatile oil of *O. gratissimum* had significant antimicrobial effects against both fungi and bacteria [96].

7. Cupressaceae

The Cupressaceae or cypress family is a conifer family with worldwide distribution. From the Cupressaceae family, *Calocedrus formosana* Florin. timber is recognized for its natural resistance to decay. Its leaf essential oil constituents displayed activity against four fungi *namely, Lenzites betulina*, *Pycnoporus coccineus, Trametes versicolor* and *Laetiporus sulphurous*. Two compounds, α-cadinol and murolol, exhibited the strongest antifungal activity [97]. The antifungal activity of essential oil from another coniferous tree, *Chamaecyparis obtusa* (Siebold and Zucc.) Siebold and Zucc. Ex Endl. was also reported [98]. The main component was bornyl acetate. The essential oil from *Juniperus communis* L. was found active against dermatophyte, *Aspergillus* and *Candida* strains [99].

8. Apiaceae

The Apiaceae (or Umbelliferae), commonly known as carrot or parsley family, are a family of mostly aromatic plants with hollow stems. Many plants in this family have been used as a folk medicine. The chemical constituents and antifungal effects of ajwain essential oil, *Trachyspermum ammi* (L.) Sprague was investigated [100]. The oil exhibited a broad spectrum of fungitoxic behaviour against fungi, such as *Aspergillus niger, Fusarium moniliforme* and *Curvularia lunata*, as absolute mycelial zone inhibition was obtained at a 6 µl dose of the oil. Analysis of ajwain essential oil showed the presence of twenty six identified components, which account for 96.3% of the total amount. Thymol was found to be a major component along with p-cymene, γ-terpinene, β-pinene and terpinen-4-ol. High antifungal activity of *Cuminum cyminum* L. reported [39,101], and was toxic to *Aspergillus* [102]. The main constituents were β-pinene, γ-terpinene and cuminaldehyde, identical to report [103]. Both β -pinene and γ-terpinene, showed antifungal activity against various fungi when treated as a sole component [104]. Essential oils from (dill) *Anethum graveolens* L. and (fennel) *Feoniculum vulgare* Mill. oil had considerable antimycobacterial and anticandidal properties[105]. Volatile oil exhibited a broad range of antifungal activity, inhibiting some nail infecting fungi such as *Aspergillus niger, A.flavus, A. fumigatus, A. ustus, Candida albicans, Epidermophyton flooccosum, Microsporum canis, M. audouini. M. nanum, M. gypseum, Rhizopus nigricans, Trichophyton tonsurons and T.violaceum*[106].

Fennel oil showed higher inhibition against *Alternaria alternate, Fusarium oxysporum* and *Aspergillus flavus*. By same oil, evaluated antifungal activity against mycotoxin producers *Aspergillus flavus* and *A. parasiticus* [107]. Trans-anethole is the major component of essential oil of fennel; antifungal effect is directly related to its main component trans-anethole[106]. Essential oil of fennel plant roots, stem, leaves and seeds against commonly encountered *Candida* species and reported that only the essential oil from seeds of fennel displayed anticandidal activity against *C. albicans* and *C. tropicalis* where no inhibition zone was recorded in the case of fennel root, stem and leaves[105]. The aerial parts of *Bupleurum gibraltaricum* Lamarck, which yielded an antifungal essential oil active towards *Plasmopara halstedii*. The main compounds in this oil were sabinene, α-pinene and 2, 3, 4-trimethylbenzaldehyde [108].

9. Poaceae

The Poaceae (also called Gramineae or true grasses) are a large and nearly ubiquitous family of monocotyledonous flowering plants. Poaceae still constitute the most economically important plant family in modern times. Plant oils are important source of fungitoxic compounds and they may provide a renewable source of useful fungicides that can be utilized in antimycotic drugs against *Aspergillus fumigatus* and *A. niger*. Different degrees of antifungal activity of *Cymbopogon martini* (Roxb.) Wats. and *Cymbopogon citratus* (DC.) Stapf. exhibited [39], the maximum antimycotic activity shown by *C. martini*[109]. The antifungal activities of essential oils from *C. citratus* reported[32] against five phytopathogenic fungi and found to be effective against *Cladosporium sp., Aspergillus niger* and *Mucor* at lower concentrations, where as that of *C. martini* was more effective against *Candida sp., Aspergillus fumigatus* and *Trichophyton rubrum* compared with the oil of *C. citrates*. Various volatile oils in plant have been reported to have medicinal values ranging from skin treatment to remedy for cancer [110]. The isolation of volatile oils in *C. citratus* confirms the activity showed against the test organisms [111]. Lemongrass oil was found to be among the most active against human dermatophyte strains inhibiting 80% of strains as reported [112,113], this is confirmed by the antifungal activity of *C. citratus* against strains of fungi species used as test organism *C. albicans* and also confirm reports by traditional users of lemongrass against ring worm infections

10. Moringaceae

The family Moringaceae is the major group of Angiosperms (Flowering plants). Moringa is the sole genus in Moringaceae contains 13 species from tropical and subtropical climates that range in size from tiny herbs to massive trees. Several in vitro studies have been published confirming the effect of essential oil and their major compounds on dermatophytic fungi. Investigations were carried out to evaluate the therapeutic properties of the seeds and leaves of *Moringa oleifera* Lam. as herbal medicines [8]. Ethanol extracts showed antifungal activities *in vitro* against dermatophytes such as *Trichophyton rubrum, T. mentagrophytes, Epidermophyton flooccosum,* and *Microsporum canis.* The TEM images of fungal cells of 70% ethyl alcohol crude extract showed the cytoplasmic membrane of the fungal cell was ruptured and the intracellular components were seriously damaged. About 44 compounds were extracted which interacted with the lipid bilayer in membrane leading to the separation of the two membranes, which causes cell to swell more and leads cell to death.

11. Zingiberaceae

Zingiberaceae is a family of flowering plants consisting of aromatic perennial herbs with creeping horizontal or tuberous rhizomes, distributed throughout tropical Africa, Asia, and America. Many species are important ornamental or medicinal plants. Recently the antifungal activity of essential oils of ginger (*Zingiber officinale* Roscoe), evaluated against mycotoxin producers *Aspergillus flavus* and *A. parasiticus.* The major component is zingiberene, and showed low antifungal activity on the mycelial growth of *A. flavus* [69] and also effective against *F. oxysporum*[114] . The antidermatophytic activity of essential oil on *Curcuma longa* L. studied[115,116] and identified major components such as Terpinolene, α-phellendren and terpinene-4-ol.

12. Ranunculaceae

Ranunculaceae is a family of flowering plants, distributed worldwide. Some members of Ranunculaceae are used as herbal medicines because of their presence of alkaloids and glycosides. *Nigella sativa* L. is regarded as a valuable remedy for a number of diseases [117]. The oil extract of *N. sativa* showed In vitro and In vivo antimicrobial effect against *Candida albicans*[118-120]. The volatile oil of *N. sativa* was found to have excellent antifungal activity, particularly against *Aspergillus* species [121]. Seed oil of *N. sativa* prevent the mycelial growth of *A. flavus* [122]. Furthermore, showed that 6 µl/ml of oil concentration exhibited 73.3% inhibition activity [123]. Thymoquinone was believed to be the responsible constituent to this effect. This assumption was confirmed [124], who reported antifungal activity of thymoquinone at the concentration of 2 µg/ml after one week of incubation with 100% growth inhibition in *A. niger* strain.

13. Theaceae

Theaceae is a family of flowering plants, composed of shrubs and trees. In parts of Asia, other species are used as a beverage. Several species grown widely as ornamentals for their flowers and handsome foliage and includes antifungal essential oil producing *Chamellia sinensis*(L.) Kuntze[125]. Various publications have reported the antimicrobial activity of essential oils and plant extracts of tea tree [41-45]. *In vitro* antagonistic activity of *Melaleuca alternifolia* (Maiden and Betche) Cheel. oil against seven species of economically important rice pathogenic fungi namely, *Alternaria brassicicola, Aspergillus flavus, Bipolaris oryzae, Fusarium moniliforme, F. proliferatum, Pyricularia arisea* and *Rhizoctonia solani* and believed that both the concentration and type of active compound are important factors in determining their potential antifungal activity [33]. Moreover, essential oils are probably affected by the different oil extraction methods and by the different sensitivity of the test strains [34]. The fractional lethal concentration index (FLCI) combinations of Tea tree oil and silver ions (Ag+) exerted a synergistic effect against *C. albicans* (FLCI = 0.663 and 1.197), in combination with other antimicrobial compounds, have been used in the treatment of topical infections[126]. Tea tree essential oils exhibited an intermediate antifungal activity (MIC=2.25mg/mL) against *C. albicans* [57].

14. Meliaceae

The Meliaceae family is a flowering plant family of mostly trees and shrubs with a pantropical distribution and economically important, used for vegetable oil, soap-making and insecticides. Plant oils are important source of fungitoxic compounds and they may provide a renewable source of useful fungicides that can be utilized in antimycotics drugs against *Aspergillus fumigatus* and *A. niger*. Several reports have been made on the fungicidal properties of *Azadirachta indica* (L.)Adelb. (neem) oil[39,127,128], whereas, *Alternaria alternata, Aspergillus niger* and *Fusarium oxysporum* have been completely controlled by using 2-10% neem oil[129].

15. Myrtaceae

Myrtaceae or Myrtle family includes the species of woody plants with essential oils distributed widely in tropical and warm-temperate regions of the world and are typically common in many of the world's biodiversity hotspots. *Syzygium aromaticum* (L.) Merrill and Perry. oil exhibited strong inhibitory effects with complete inhibition of mycelia growth in *Botrytis cinerea*[90,91]. Previously showed that mixing of clove oil and cinnamon oils at appropriate ratios result in an improvement of the efficacy against the postharvest decaying fungi of grapes like, *Aspergillus niger, Alternaria alternata, Colletotrichum gloeosporioides, Lasiodiplodia theobromae, Phomopsis viticola* and *Rhizopus stolonifer*[130].

The antifungal activity of the clove oil and its main component eugenol [131],were investigated against *Candida, Aspergillus* and dermatophyte clinical and American Type Culture Collection strains [132] which showed inhibitory activity against all the tested strains. Mainly, phenolic components of essential oils are considered as

responsible for the antimicrobial activity, followed by aldehydes, ketones, and alcohols[133-135]. It is difficult to attribute the activity of natural essential oils which are complex mixtures to a particular constituent, it is reasonable to assume that the activity of clove oil can be related to the presence of a high concentration (85.3%) of eugenol. Different modes of action are involved in the antimicrobial activity of essential oils. The activity may, in part, be due to their hydrophobicity, responsible for their partition into the lipid bilayer of the cell membrane, leading to permeability alteration and a consequent leakage of cell contents. As typical lipophiles, essential oils can travel through the cell wall and cytoplasmic membrane, disrupt the structure of the different layers of polysaccharides, fatty acids and phospholipids, and permeabilize them[93]. Clove oil significantly suppressed the microbial growth of tested fungal strains displayed greater pathogenicity in case of *A. fumigatus* and *A. acculeatus*.

Essential oil of *Leptospermum petersonii* Bailey. demonstrated strong antifungal activities against the three *Aspergillus* species i.e. *Aspergillus ochraceus*, *A. flavus*, and *A. niger*[136]. Major constituents were citronellal, neral, and geranial show antifungal activity against various dermatophytes, such as *Microsporum canis, Trichophyton mentagrophytes*, and *Microsporum gypseum*[137].

16. Piperaceae

The Piperaceae, also known as the pepper family, is a large family of flowering plants. Members of the family may be small trees, shrubs or herbs. The distribution of this group is best described as pantropical are used as spices. Recently, antifungal activity of essential oil from fruits of *Piper barberi* Gamble. against *Aspergillus foetidus*, *A. fumigates, A. ochraceus, A. flavus* and *Penicillium notatum* reported[138]. Similarly, reported *Piper nigrum* L. volatile oils as effective for *Fusarium graminearum* [139,140].

Table 1: Plants containing antifungal activity

Plant family	Scientific name	Compounds	Reference(s)
Amaranthaceae	*Chenopodium ambrosioides*	m-cymene, myrtenol	[141]
Anacardiaceae	*Pistacia lentiscus*	terpineol, α-terpineol	[142]
Apiaceae	*Crithmum maritimum*	dillapiole, γ-terpinene, sabinene, thymol methyl ether, β-phellandrene	[143]
	Daucus carota subsp. *carota*	Sardinia: β-bisabolene, 11-α-(H)-himachal-4-en-1-β-ol Portugal: geranyl acetate, α-pinene	[144]
	Daucus carota subsp. *halophilus*	Flowering umbels: sabinene, α-pinene, limonene; Ripe umbels elemicin, sabinene	[9]
	Distichoselinum tenuifolium	myrcene, limonene	[145]
	Eryngium duriaei subsp. *juresianum*	α-neocallitropsene, isocaryophyllen-14-al, 14-hydroxy-β-caryophyllen, caryophyllene oxide, E-β-caryophyllene	[146]
	Ferula hermonis	α-pinene, α-bisabolol, 3,5-nonadiyne	[147]
	Trachyspermum ammi	Thymol, p-cymene, γ-terpinene, β-pinene, terpinen-4-ol.	[98]
	Coriandrum sativum	Linalool, geraniol	[148]
	Pimpinella anisum	trans -anethole	[149]
	Foeniculum graveolens	Anethol, Fenchone	[150]
Asteraceae	*Arnica longifolia*	camphor , 1,8-cineole	[27]
	Aster hesperius	carvacrol, α-bisabolol	[27]
	Baccharis latifolia	hexadecanoic acid, carvacrol	[21]
	Chrysothamnus nauseosus	camphor, α- and β-pinene, lyratyl acetate.	[27]
	Elephantopus spicatus	β -phellandrene, β –pinene	[23]
	Eupatorium semialatum	δ-elemene, farnesene, α-curcumene, selina-4,7(11)-diene, β-bisabolene	[23]
	Spilanthes americana	Piperitone, piperitenone	[24]
Euphorbiaceae	*Croton cajucara*	linalool	[151]
Gentianaceae	*Gentiana asclepiadea*	xanthones	[152]
Hypericaceae	*Hypericum perforatum*	terpinen-4-ol	[153]
Labiatae	*Hyptis suaveolens*	Sabinene, -terpinolene, 1, 8-cineole.	[154]
Lamiaceae	*Calamintha nepeta* subsp. *nepeta*.	Sardinia: pulegone Portugal: isomenthone, 1,8-cineole	[155]
	Lavandula viridis	1,8-cineole, camphor, α-pinene, linalool	[156]
	Mentha cervina	pulegone, isomenthone	[157]
	Salvia officinalis	cis-thujone, β-pinene, 1,8-cineole, α-humulene	[158]
	Thymbra capitata	Carvacrol, γ-terpinene, p-cymene.	[47]
	Thymus x viciosoi	carvacrol, p-cymene, thymol	[159]
	Thymus zygis subsp. *sylvestris*	chemotypes: carvacrol, thymol, geranyl acetate/geraniol, linalool	[160]
	Thymus vulgaris	Thymol, ρ-Cymene, γ-Terpinene	[32]
	Origanum vulgare	Carvacrol, ρ-Cymene, Thymol	[32]
	Plectranthus amboinicus	Carvacrol, ρ-Cymene, Thymol	[161]
Lauraceae	*Aniba rosaedora*	Linalool	[31]
	Laurus nobilis	1,8-cineole	[31]
	Sassafras albidum	Safrole	[31]
	Cinnamomum zeylanicum	trans-cinnamaldehyde	[31]
Moringaceae	*Moringa oleifera*	pentacosane, hexacosane	[11]
Myrtaceae	*Eucalyptus citriodora*	Citronellal, Isopulegol	[32]
	Syzygium aromaticum	Eugenol	[150]
Piperaceae	*Piper barberi*	1,8 ceneole, α-pinene , eugenol isomer , camphor	[138]
Poaceae	*Cymbopogon martini*	trans geraniol, β-elemene	[141]
	Cymbopogon citratus	Geranial, Neral, Limonene	[32]
Ranunculaceae	*Nigella sativa*	Nigellone	[150]
Rutaceae	*Citrus aurantiifolia*	Limonene, γ-terpinene, terpinolene.	[162]
	Citrus hystrix	limonene , citronellal, β-pinene	[1]
	Haplophyllum tuberculatum	α- and β-phellandrene, limonene, β-ocimene, β-caryophyllene, myrcene.	[83]
Verbenaceae	*Vitex agnus-castus*	Leaves: bicyclogermacrene , (E)-β-farnesene, 1,8-cineole flowers: bicyclogermacrene, manool, fruits: (E)-β-farnesene, bicyclogermacrene, 1,8-cineole	[163]
	Vitex rivularis	germacrene D , γ-curcumene, ar-curcume, α-copaene, β-caryophyllene	[164]
	Lantana achyranthifolia	Carvacrol, α-bisabolol, isocaryophyllene.	[82]
	Lippia graveolens	Carvacrol, α-terpinyl acetate, m-cymene, thymol.	[82]
Zingiberaceae	*Zingiber officinale*	Zingiberene,geranial, α-curcumene , β-bisabolen, β-sesquiphellandrene	[165]

CONCLUSION

Essential oils are naturally occurring phytochemicals which have various applications and have long been known and used throughout the world for treatment of many diseases, and there is at least some evidence that natural products such as essential oil and extracts may tend to have less deleterious side effects than corresponding synthetic drugs. Also, the resurgence of interest in natural control of human infectious fungal pathogens and increasing demand for effective, safe, natural products, that quantitative data on plant oils and extracts are required and could lead to a new antifungal agent, which could support the use of the plant to treat various infective diseases.

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