

# Antifungal Essential Oils of Lamiaceae

Subjects: Biology

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The incidence of fungal infections has been steadily increasing in recent years. Systemic mycoses are characterized by the highest mortality. At the same time, the frequency of infections caused by drug-resistant strains and new pathogens e.g., *Candida auris* increases. An alternative to medicines may be essential oils, which can have a broad antimicrobial spectrum. Rich in the essential oils are plants from the Lamiaceae family.

Keywords: Labiateae ; fungi ; Aspergillus ; Cryptococcus ; Penicillium ; dermatophytes ;  $\beta$ -caryophyllene ; sesquiterpene ; monoterpenes ; minimal inhibitory concentration (MIC)

## 1. Introduction

Fungal infections belong to the most often diseases of humans. It is estimated that about 1.7 billion people (25% of the population) have skin, nail, and hair fungal infections [1]. The development of most of these infections is affected by dermatophytes, namely *Trichophyton* spp., *Microsporum* spp., and *Epidermophyton* spp. [2]. Simultaneously, mucosal infections of the oral and genital tracts caused by *Candida* spp. are very common. About 0.13 billion of women suffer from vulvovaginal candidiasis. On the other hand, oral candidiases are common in babies and denture wearers. Fungi also cause life-threatening systemic infections, with mortality reaching >1.6 million, which is >3-fold more than malaria [3]. Among life-threatening fungal infections prevail cryptococcosis (*Cryptococcus neoformans*) with >1,000,000 cases and mortality rate 20–70%, candidiasis (*Candida albicans*) with >400,000 cases and mortality rate 46–75%, pneumocystosis (*Pneumocystis jirovecii*) with >400,000 cases and mortality rate 20–80%, and aspergillosis (*Aspergillus fumigatus*) with >200,000 cases and mortality rate 30–95% [1][4][5]. In Table 1 are presented diseases caused by some of the most often fungal pathogens among people.

**Table 1.** Fungal pathogens of humans and most often observed mycoses (based on [6][7]).

	<ul style="list-style-type: none"><li>• <i>Hortae werneckii</i> (Tinea nigra)</li><li>• <i>Malassezia furfur</i> (Pityriasis versicolor)</li></ul>
<b>Superficial mycoses</b>	<ul style="list-style-type: none"><li>• <i>Piedraia hortae</i> (Black piedra)</li><li>• <i>Trichosporon</i> spp. (White piedra)</li></ul>

- *Aspergillus* spp. (Onychomycosis, Keratitis)
- *Candida* spp. (Tinea pedis, Tinea cruris, Onychomycosis, Keratitis)
- *Chaetomium* spp. (Subcutaneous phaeohyphomycosis)
- *Curvularia* spp. (Subcutaneous phaeohyphomycosis)
- *Epidermophyton* spp. (Tinea pedis, Tinea cruris, Onychomycosis)
- *Exophiala* spp. (Chromoblastomycosis, Subcutaneous phaeohyphomycosis)
- *Fonsecaea* spp. (Chromoblastomycosis)
- *Fusarium* spp. (Onychomycosis, Keratitis, Eumycotic mycetoma)
- Cutaneous and subcutaneous mycoses**
  - *Geotrichum* spp. (Onychomycosis)
  - *Microsporum* spp. (Tinea corporis, Tinea capitis)
  - *Phaeoacremonium* spp. (Eumycotic mycetoma)
  - *Phialophora* spp. (Chromoblastomycosis, Subcutaneous phaeohyphomycosis)
  - *Scopulariopsis brevicaulis* (Onychomycosis)
  - *Sporothrix schenckii* (Lymphocutaneous sporotrichosis)
  - *Trichophyton* spp. (Tinea pedis, Tinea corporis, Tinea cruris, Tinea capitis, Onychomycosis)
  - *Trichosporon* spp. (Onychomycosis)
  - *Blastomyces dermatitidis* (Blastomycosis)
  - *Histoplasma capsulatum* (Histoplasmosis)
- Endemic mycoses**
  - *Coccidioides immitis/posadasii* (Coccidioidomycosis)
  - *Penicillium marneffei* (Penicilliosis)
  - *Paracoccidioides brasiliensis* (Paracoccidioidomycosis)

- *Acremonium* spp. (Hyalohyphomycosis-cutaneous, disseminated infection)
- *Alternaria* spp. (Phaeohyphomycosis-subcutaneous, sinusitis, disseminated infection)
- *Aspergillus* spp. (Allergic reactions, Aspergillosis-nasal, sinusitis, bronchial, pulmonary, systemic dissemination)
- *Bipolaris* spp. (Phaeohyphomycosis-subcutaneous, sinusitis, brain abscess)
- *Candida* spp. (Candidiasis-superficial mucosal, cutaneous, widespread hematogenous distribution involving target organs)
- *Cryptococcus* spp. (Cryptococcosis-cutaneous, pulmonary, meningitis)
- *Curvularia* spp. (Phaeohyphomycosis-subcutaneous, sinusitis, disseminated infection)
- *Fusarium* spp. (Hyalohyphomycosis-cutaneous, disseminated infection)

**Opportunistic mycoses**

- *Lichtheimia* spp. (Mucormycosis-cutaneous, invasive)
- *Mucor* spp. (Mucormycosis-cutaneous, invasive)
- *Paecilomyces* spp. (Hyalohyphomycosis-cutaneous, disseminated infection)
- *Pneumocystis jirovecii* (Pneumocystosis-pneumonia, extrapulmonary manifestations)
- *Rhizomucor* spp. (Mucormycosis-cutaneous, invasive)
- *Rhizopus* spp. (Mucormycosis-cutaneous, invasive)
- *Scedosporium* spp. (Hyalohyphomycosis-cutaneous, disseminated infection)
- *Trichosporon* spp. (Trichosporonosis-invasive disease)
- *Wangiella* spp. (Phaeohyphomycosis-subcutaneous, sinusitis, brain abscess)

The big problem is growing drug-resistance amid fungi. Among *Candida* and *Aspergillus* species is observed resistance to azoles, e.g., to fluconazole, voriconazole, and posaconazole. Some *Candida* species, especially *C. glabrata* and *C. parapsilosis*, can be echinocandin- and multidrug-resistant [8][9]. Acquired resistance to echinocandins has also been reported for yeasts *C. albicans*, *C. tropicalis*, *C. krusei*, *C. kefyr*, *C. lusitaniae*, and *C. dubliniensis* [10]. More than 3% of *Aspergillus fumigatus* isolates are resistant to one or more azoles [11]. Polyene resistance mainly concerns amphotericin B. Resistance to this drug is observed in *Fusarium* spp., *Trichosporon* spp., *Aspergillus* spp., and *Sporothrix schenckii* [12][13]. Resistance to amphotericin B has also been reported for *C. albicans*, *C. glabrata*, and *C. tropicalis* [14][15][16]. Cultures of some *Candida* species and *Cryptococcus neoformans* are presented in [Figure 1](#).





**Figure 1.** Cultures of selected yeast fungi on Sabouraud agar (Author of photos: Tomasz M. Karpiński).

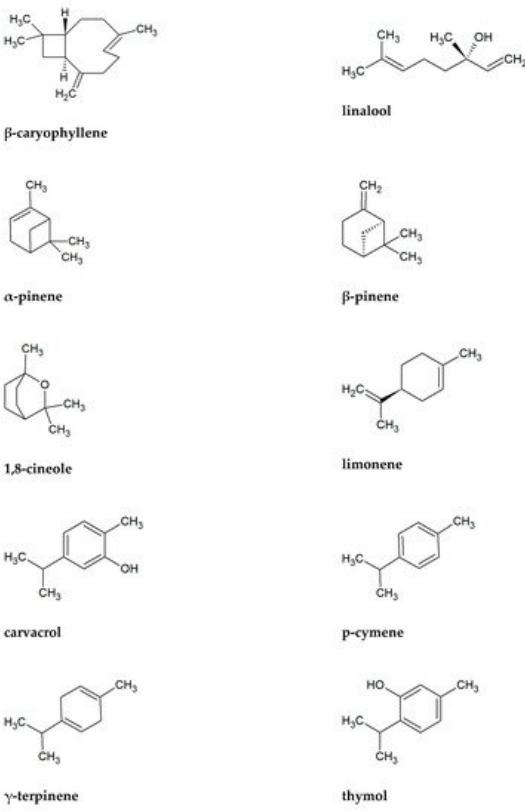
The new epidemiological problem is *C. auris*, a multidrug-resistant organism first described in Japan in 2009 [17]. Recently, *C. auris* has been reported from 36 countries from six continents [18]. About 30% of isolates demonstrate reduced susceptibility to amphotericin B, and 5% can be resistant to the echinocandins [19][20]. The estimated mortality from *C. auris* fungemia range from 28% to 60% [21].

Fundamental issues are also the costs of treatment and hospitalization of patients with invasive fungal diseases. According to Drgona et al., all costs range from around €26,000 up to over €80,000 per patient [5].

## 2. Components of Essential Oils of Lamiaceae Family

The family Lamiaceae or Labiateae contains many valuable medicinal plants. In the family are 236 genera and between 6900 and 7200 species. To the most abundant genera belong *Salvia* (900 species), *Scutellaria* (360), *Stachys* (300), *Plectranthus* (300), *Hyptis* (280), *Teucrium* (250), *Vitex* (250), *Thymus* (220), and *Nepeta* (200). Lamiaceae plants rich in essential oils have great worth in natural medicine, pharmacology, cosmetology, and aromatherapy [22]. The essential oils are mostly present in leaves, however, they can be found in flowers, buds, fruits, seeds, rind, wood, or roots [23]. Essential oils are mixtures of volatile compounds, which are secondary plant metabolites. They play a role in the defense system of higher plants [24]. Essential oils may contain over 300 different compounds, mainly of molecular weight below 300 [25]. Some oils, e.g., obtained from *Lavandula*, *Geranium*, or *Rosmarinus*, contain 450 to 500 chemicals [26]. Among the active compounds of essential oils are various chemical classes, e.g., alcohols, ethers, aldehydes, ketones, esters, phenols, terpenes (monoterpenes, sesquiterpenes), and coumarins [27][28].

To the chemical components most commonly found as the main ingredients in essential oils, among plants presented in Table 2, include  $\beta$ -caryophyllene (41 plants), linalool (27 plants), limonene (26),  $\beta$ -pinene (25), 1,8-cineole (22), carvacrol (21),  $\alpha$ -pinene (21), p-cymene (20),  $\gamma$ -terpinene (20), and thymol (20) (Figure 2). Sesquiterpene  $\beta$ -caryophyllene seems particularly important antifungal component in the Lamiaceae family. Its activity and its derivatives, such as caryophyllene oxide is well known [29][30][31]. According to Bona et al. [32], essential oils containing high concentrations of phenolic monoterpenes (e.g., carvacrol, p-cymene, thymol) have great antifungal activities. Rich in these substances are, among others *Origanum* and *Thymus* plants. Important antifungal chemicals often presented in Lamiaceae are also other monoterpenes as alcohol linalool and cyclic 1,8-cineole, limonene, pinenes, and terpinenes [33][34][35][36][37][38][39][40][41]. Table 1 shows that all of these antifungal substances are common in presented plants.



**Figure 2.** Chemical formulas of ten substances the most commonly found in essential oils of Lamiaceae plants presented in [Table 1](#).

### 3. Antifungal Activity of Essential Oils of Lamiaceae Family

In [Table 3](#) are shown the antifungal activities of selected Lamiaceae essential oils. More than half of the essential oils have good activity ( $<1000 \mu\text{g/mL}$ ) against fungi. In some cases are observed significant discrepancies between different studies. An example could be the action of essential oils from Italian *Calamintha nepeta* against *Candida albicans*. In the work of Marongiu et al. [\[42\]](#), minimal inhibitory concentrations amounted to 1.25–2.5  $\mu\text{g/mL}$ , while in Božović et al. [\[43\]](#) MICs were between 780 to 12,480  $\mu\text{g/mL}$ . Differences may be related to the different biochemical composition of the examined essential oils. In results presented by Marongiu et al. [\[42\]](#) the main components of essential oils were pulegone (39.9–64.4%), piperitenone oxide (2.5–19.1%) and piperitenone (6.4–7.7%), while in Božović et al. [\[43\]](#) three main substances were pulegone (37.7–84.7%), crysanthenone (1.3–33.9%) and menthone (0.5–35.4%). Some authors have described that the content of active substances varies depending on the season. In studies of Gonçalves et al. [\[44\]](#) in *Mentha cervina* during the flowering phase in August amount of isomenthone and pulegone in essential oil amounted 8.7% and 75.1% respectively. Simultaneously, in the vegetative phase in February, the content of both components changed significantly and amounted to 77.0% for isomenthone and 12.9% for pulegone. Similarly, Al-Maskri et al. [\[45\]](#) presented essential changes in some compounds of *Ocimum basilicum* essential oil between winter and summer. In the summer essential oil, there is significantly more of linalool, p-allylanisole and  $\beta$ -farnesene, and at the same time much less content of limonene and 1,8-cineole. In this work, a seasonal variation of chemical composition is directly related to other antifungal activities. It is particularly evident in action against *Aspergillus niger*, which was lower in the summer season. Zone of growth inhibition (ZOI) for winter essential oil was 21 mm and MIC  $> 50 \mu\text{g/mL}$ , while for summer essential oil-ZOI was 13 mm and MIC  $> 100 \mu\text{g/mL}$  [\[45\]](#). Influence on the content of chemical substances in essential oils also has a method of obtaining them. Ćavar et al. [\[43\]](#) compared the composition of oils obtained from *Calamintha glandulosa* using three methods: Hydrodistillation (HD), steam distillation (SD) and aqueous reflux extraction (ARE). For example, the level of menthone was 3.3% in ARE, 4.7% in HD, and 8.3% in SD method, while for shisofuran was only 0.1% in HD and SD, and even 9.7% in ARE [\[43\]](#). Additionally, many other factors can affect antimicrobial activity, such as amount and concentration of inoculum, type of culture medium, pH of the medium and incubation time. All these factors can affect the value of MIC [\[40\]](#). Differences are visible in [Table 2](#). Generally, it can be assumed that the best activity (MICs  $< 100$ ) have essential oils from *Clinopodium* spp. (excluding *C. nepeta* subsp. *glandulosum* and *C. umbrosum*), *Lavandula* spp., *Mentha* spp. (excluding *M. piperita*), *Thymbra* spp., and *Thymus* spp. (excluding *T. migricus* and *T. vulgaris*). The highest values of MICs are presented among others for *Aeollanthus suaveolens*, *Agastache rugosa*, *Lepechinia mutica*, *Mentha × piperita*, and *Salvia sclarea*. Simultaneously, some essential oils have a very different activity, and MIC values differ depending on the region, chemical composition,

research methodology, etc. Significant variations can be observed even in *Ocimum basilicum* (MICs 1–10,000), *O. sanctum* (MICs 0.1–500), *Origanum majorana* (MICs 0.5–14,400) or in *Thymus vulgaris* (MICs 0.08–3600).

**Table 3.** Minimal inhibitory concentrations (MICs) of essential oils against fungi.

Source of the Essential Oil	Targeted Fungus	MICs (µg/mL; µl/mL)	Reference(s)
<i>Aeollanthus suaveolens</i> Mart. ex Spreng. = <i>A. heliotropioides</i> Oliv.	<i>Candida albicans</i>	1200–5000	[46]
	<i>Candida glabrata</i>	5000	[46]
	<i>Candida krusei</i>	2500	[46]
	<i>Candida parapsilosis</i>	2500	[46]
	<i>Candida tropicalis</i>	1200	[46]
	<i>Cryptococcus neoformans</i>	600–5000	[46]
	<i>Aspergillus flavus</i>	10,000	[47]
	<i>Aspergillus niger</i>	5000	[47]
	<i>Blastoschizomyces capitatus</i>	5000	[47]
<i>Agastache rugosa</i> (Fisch. and C.A.Mey.) Kuntze	<i>Candida albicans</i>	28–5000	[47][48]
	<i>Candida utilis</i>	5000	[47]
	<i>Candida tropicalis</i>	5000	[47]
	<i>Cryptococcus neoformans</i>	10,000	[47]
	<i>Trichoderma viride</i>	5000	[47]
	<i>Trichophyton erinacei</i>	780	[47]
	<i>Trichophyton mentagrophytes</i>	3120	[47]
	<i>Trichophyton rubrum</i>	1560	[47]
	<i>Trichophyton schoenleinii</i>	1560	[47]
<i>Ballota nigra</i> subsp. <i>foetida</i> (Vis.) Hayek	<i>Trichophyton soudanense</i>	1560	[47]
	<i>Trichophyton tonsurans</i>	10,000	[47]
	<i>Trichosporon mucoides</i>	5000	[47]
	<i>Alternaria solani</i>	750	[49]
	<i>Botrytis cinerea</i>	600	[49]
	<i>Fusarium coeruleum</i>	350	[49]
	<i>Fusarium culmorum</i>	300	[49]
	<i>Fusarium oxysporum</i>	300	[49]
	<i>Fusarium solani</i>	350	[49]
	<i>Fusarium sporotrichioides</i>	350	[49]
	<i>Fusarium tabacinum</i>	350	[49]
	<i>Fusarium verticillioides</i>	300	[49]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
	<i>Aspergillus niger</i>	0.4	[50]
	<i>Aspergillus ochraceus</i>	0.4	[50]
	<i>Cladosporium cladosporioides</i>	0.4	[50]
<i>Clinopodium dalmaticum</i> (Benth.) Bräuchler and Heubl = <i>Micromeria dalmatica</i> Benth.	<i>Fusarium tricinctum</i>	0.4	[50]
	<i>Penicillium ochrochloron</i>	0.4	[50]
	<i>Phomopsis helianthi</i>	0.2	[50]
	<i>Trichoderma viride</i>	0.4	[50]
<i>Clinopodium nepeta</i> subsp. <i>glandulosum</i> (Req.) Govaerts = <i>Calamintha glandulosa</i> (Req.) Bentham = <i>Calamintha officinalis</i> Moench	<i>Aspergillus niger</i>	1250	[42]
	<i>Candida albicans</i>	2500	[42]
	<i>Aspergillus flavus</i>	1.25–10	[51]
	<i>Aspergillus fumigatus</i>	0.64–5	[51]
	<i>Aspergillus niger</i>	0.32–10	[51]
	<i>Candida albicans</i>	1.25–12,480	[51][52]
	<i>Candida guillermondii</i>	1.25–2.5	[51]
	<i>Candida krusei</i>	1.25–2.5	[51]
<i>Clinopodium nepeta</i> (L.) Kuntze = <i>Calamintha nepeta</i> (L.) Savi	<i>Candida parapsilosis</i>	1.25–2.5	[51]
	<i>Candida tropicalis</i>	1.25–2.5	[51]
	<i>Cryptococcus neoformans</i>	0.32–1.25	[51]
	<i>Epidermophyton floccosum</i>	0.64–2.5	[51]
	<i>Microsporum canis</i>	0.64–2.5	[51]
	<i>Microsporum gypseum</i>	1.25–5	[51]
	<i>Trichophyton mentagrophytes</i>	0.64–5	[51]
	<i>Trichophyton rubrum</i>	0.64–5	[51]
	<i>Aspergillus niger</i>	2	[50]
	<i>Aspergillus ochraceus</i>	2	[50]
	<i>Cladosporium cladosporioides</i>	2	[50]
<i>Clinopodium thymifolium</i> (Scop.) Kuntze = <i>Micromeria thymifolia</i> (Scop.) Fritsch	<i>Fusarium tricinctum</i>	2	[50]
	<i>Penicillium ochrochloron</i>	2	[50]
	<i>Phomopsis helianthi</i>	0.4	[50]
	<i>Trichoderma viride</i>	2	[50]
	<i>Alternaria solani</i>	3000	[53]
<i>Clinopodium umbrosum</i> (M.Bieb.) Kuntze = <i>Calamintha umbrosa</i> Benth.	<i>Fusarium oxysporum</i>	2000	[53]
	<i>Helminthosporium maydis</i>	1500	[53]

Source of the Essential Oil	Targeted Fungus	MICs (µg/mL; µl/mL)	Reference(s)
<i>Dracocephalum heterophyllum</i> Benth.	<i>Alternaria solani</i>	625	[54]
	<i>Candida albicans</i>	625–1000	[55][54]
	<i>Epidermophyton floccosum</i>	2500	[54]
	<i>Fusarium semitectum</i>	313	[54]
<i>Hymenocrater longiflorus</i> Benth.	<i>Aspergillus niger</i>	480	[56]
	<i>Candida albicans</i>	240	[56]
	<i>Microsporum canis</i>	15.6–1000	[57][58]
<i>Hyptis ovalifolia</i> Benth.	<i>Microsporum gypseum</i>	7.8–1000	[57][58]
	<i>Trichophyton mentagrophytes</i>	15.6–1000	[57][58]
	<i>Trichophyton rubrum</i>	7.8–1000	[57][58]
	<i>Aspergillus niger</i>	52,200	[59]
	<i>Aspergillus ochraceus</i>	26,100	[59]
	<i>Aspergillus versicolor</i>	10,440	[59]
	<i>Candida albicans</i>	128–1000	[55][60]
	<i>Candida glabrata</i>	512–1024	[60]
	<i>Candida krusei</i>	128–256	[60]
<i>Hyssopus officinalis</i> L.	<i>Candida parapsilosis</i>	256–512	[60]
	<i>Candida tropicalis</i>	512–1024	[60]
	<i>Cladosporium cladosporioides</i>	10,440	[59]
	<i>Cladosporium fulvum</i>	26,100	[59]
	<i>Penicillium funiculosum</i>	52,200	[59]
	<i>Penicillium ochrochloron</i>	26,100	[59]
	<i>Trichoderma viride</i>	10,440	[59]
	<i>Candida albicans</i>	0.125–512	[61][62][63]
	<i>Malassezia furfur</i>	>4	[64]
<i>Lavandula angustifolia</i> Mill.	<i>Trichophyton rubrum</i>	1–512	[64][62]
	<i>Trichosporon beigelii</i>	2	[64]

Source of the Essential Oil	Targeted Fungus	MICs (µg/mL; µl/mL)	Reference(s)
<i>Lavandula multifida</i> L.	<i>Aspergillus flavus</i>	0.64	[65]
	<i>Aspergillus fumigatus</i>	0.32	[65]
	<i>Aspergillus niger</i>	0.32	[65]
	<i>Candida albicans</i>	0.32	[65]
	<i>Candida guilliermondii</i>	0.32	[65]
	<i>Candida krusei</i>	0.64	[65]
	<i>Candida parapsilosis</i>	0.32	[65]
	<i>Candida tropicalis</i>	0.32	[65]
	<i>Cryptococcus neoformans</i>	0.16	[65]
	<i>Epidermophyton floccosum</i>	0.16	[65]
	<i>Microsporum canis</i>	0.16	[65]
	<i>Microsporum gypseum</i>	0.16	[65]
	<i>Trichophyton mentagrophytes</i>	0.16	[65]
	<i>Trichophyton mentagrophytes</i> var. <i>interdigitale</i>	0.16	[65]
<i>Lavandula pedunculata</i> (Miller) Cav.	<i>Trichophyton rubrum</i>	0.16	[65]
	<i>Trichophyton verrucosum</i>	0.16	[65]
	<i>Aspergillus flavus</i>	5–10	[66]
	<i>Aspergillus fumigatus</i>	2.5–5	[66]
	<i>Aspergillus niger</i>	5	[66]
	<i>Candida albicans</i>	2.5	[66]
	<i>Candida guilliermondii</i>	1.25	[66]
	<i>Candida krusei</i>	1.25– 2.5	[66]
	<i>Candida parapsilosis</i>	2.5–5	[66]
	<i>Candida tropicalis</i>	1.25– 2.5	[66]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
<i>Lavandula stoechas</i> L.	<i>Aspergillus flavus</i>	1.25–10	[67]
	<i>Aspergillus fumigatus</i>	0.64–1.25	[67]
	<i>Aspergillus niger</i>	0.32–1.25	[67]
	<i>Candida albicans</i>	0.64–512	[62][67]
	<i>Candida guillermondi</i>	1.25	[67]
	<i>Candida krusei</i>	2.5	[67]
	<i>Candida parapsilosis</i>	2.5	[67]
	<i>Candida tropicalis</i>	2.5	[67]
	<i>Cryptococcus neoformans</i>	0.64	[67]
	<i>Epidermophyton floccosum</i>	0.16–0.32	[67]
	<i>Microsporum canis</i>	0.16–0.64	[67]
	<i>Microsporum gypseum</i>	0.32–0.64	[67]
	<i>Trichophyton mentagrophytes</i>	0.32–0.64	[67]
	<i>Trichophyton mentagrophytes</i> var. <i>interdigitale</i>	0.16–0.64	[67]
	<i>Trichophyton rubrum</i>	0.16–256	[62][67]
	<i>Trichophyton verrucosum</i>	0.32	[67]

Source of the Essential Oil	Targeted Fungus	MICs (µg/mL; µl/mL)	Reference(s)
<i>Lavandula viridis</i> L'Her.	<i>Aspergillus flavus</i>	5	[68]
	<i>Aspergillus fumigatus</i>	2.5	[68]
	<i>Aspergillus niger</i>	2.5	[68]
	<i>Candida albicans</i>	1.25– 2.5	[68]
	<i>Candida guillermondi</i>	0.64– 1.25	[68]
	<i>Candida krusei</i>	1.25– 2.5	[68]
	<i>Candida parapsilosis</i>	1.25	[68]
	<i>Candida tropicalis</i>	1.25– 2.5	[68]
	<i>Cryptococcus neoformans</i>	0.64	[68]
	<i>Epidermophyton floccosum</i>	0.32	[68]
	<i>Microsporum canis</i>	0.32	[68]
	<i>Microsporum gypseum</i>	0.64	[68]
	<i>Trichophyton mentagrophytes</i>	0.32– 0.64	[68]
<i>Lepechinia mutica</i> (Benth.) Epling	<i>Trichophyton mentagrophytes</i> var. <i>interdigitale</i>	0.32– 0.64	[68]
	<i>Trichophyton rubrum</i>	0.32	[68]
	<i>Trichophyton verrucosum</i>	0.32	[68]
	<i>Candida albicans</i>	>9000	[69]
	<i>Fusarium graminearum</i>	>9000	[69]
	<i>Microsporum canis</i>	2200– 4500	[69]
	<i>Pyricularia oryzae</i>	>9000	[69]
	<i>Trichophyton rubrum</i>	2200– 4500	[69]
	<i>Aspergillus niger</i>	>1180	[70]
	<i>Botrytis cinerea</i>	>1100	[70]
<i>Marrubium vulgare</i> L.	<i>Fusarium solani</i>	>1190	[70]
	<i>Penicillium digitatum</i>	>1120	[70]
	<i>Aspergillus niger</i>	313	[71]
	<i>Candida albicans</i>	30–313	[72][71]
	<i>Cryptococcus neoformans</i>	78	[71]
	<i>Epidermophyton floccosum</i>	30	[72]
	<i>Microsporum canis</i>	30	[72]
<i>Melissa officinalis</i> L.	<i>Penicillium verrucosum</i>	125	[73]
	<i>Trichophyton mentagrophytes</i> var. <i>mentagrophytes</i>	15	[72]
	<i>Trichophyton rubrum</i>	15	[72]
	<i>Trichophyton tonsurans</i>	15	[72]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
<i>Mentha cervina</i> L.	<i>Aspergillus flavus</i>	2.5–5	[44]
	<i>Aspergillus fumigatus</i>	1.25–2.5	[44]
	<i>Aspergillus niger</i>	1.25–2.5	[44]
	<i>Candida albicans</i>	1.25–2.5	[44]
	<i>Candida guillermondii</i>	1.25–2.5	[44]
	<i>Candida krusei</i>	1.25–2.5	[44]
	<i>Candida parapsilosis</i>	1.25–2.5	[44]
	<i>Candida tropicalis</i>	1.25–2.5	[44]
	<i>Cryptococcus neoformans</i>	1.25	[44]
	<i>Epidermophyton floccosum</i>	0.64–1.25	[44]
	<i>Microsporum canis</i>	1.25	[44]
	<i>Microsporum gypseum</i>	1.25–2.5	[44]
	<i>Trichophyton mentagrophytes</i>	1.25–2.5	[44]
	<i>Trichophyton rubrum</i>	1.25	[44]
<i>Mentha × piperita</i> L.	<i>Aspergillus flavus</i>	1450–5000	[74][75]
	<i>Aspergillus niger</i>	625–10,000	[75][71]
	<i>Aspergillus parasiticus</i>	2500	[75]
	<i>Candida albicans</i>	225–1125	[76][71][77]
	<i>Candida glabrata</i>	225	[74]
	<i>Candida tropicalis</i>	225–230	[74]
	<i>Cryptococcus neoformans</i>	313	[71]
	<i>Fusarium oxysporum</i>	125	[78]
	<i>Penicillium chrysogenum</i>	1250	[75]
	<i>Penicillium minioluteum</i>	2050–2200	[74]
	<i>Penicillium oxalicum</i>	1300–2050	[74]
	<i>Penicillium verrucosum</i>	2500	[79]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
<i>Mentha pulegium</i> L.	<i>Aspergillus niger</i>	0.25–1.25	[80][81]
	<i>Aspergillus flavus</i>	1.25	[81]
	<i>Aspergillus fumigatus</i>	1.25	[81]
	<i>Candida albicans</i>	0.94–3.75	[80][82][81][83]
	<i>Candida bracarensis</i>	3.75	[83]
	<i>Candida guillermondii</i>	1.25	[81]
	<i>Candida krusei</i>	0.94–1.25	[81][83]
	<i>Candida parapsilosis</i>	1.25	[81]
	<i>Candida tropicalis</i>	1.25	[81]
	<i>Cryptococcus neoformans</i>	0.64	[81]
<i>Mentha requienii</i> Bentham	<i>Epidermophyton floccosum</i>	1.25	[81]
	<i>Microsporum canis</i>	1.25	[81]
	<i>Microsporum gypseum</i>	1.25–2.5	[81]
	<i>Saccharomyces cervisiae</i>	<0.3–0.94	[82][83]
	<i>Trichophyton mentagrophytes</i>	1.25–2.5	[81]
	<i>Trichophyton mentagrophytes</i> var. <i>interdigitale</i>	2.5	[81]
	<i>Trichophyton rubrum</i>	1.25	[81]
	<i>Trichophyton verrucosum</i>	1.25	[81]
	<i>Alternaria</i> spp.	>40	[84]
	<i>Aspergillus fumigatus</i>	>60	[84]
	<i>Candida albicans</i>	0.94–40	[84][83]
	<i>Candida bracarensis</i>	3.75	[83]
	<i>Candida krusei</i>	0.94	[83]
	<i>Fusarium</i> spp.	>40	[84]
	<i>Penicillium</i> spp.	>60	[84]
	<i>Rhodotorula</i> spp.	45	[84]
	<i>Saccharomyces cerevisiae</i>	0.94	[83]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
<i>Mentha spicata</i> L.	<i>Aspergillus flavus</i>	1.25	[81]
	<i>Aspergillus fumigatus</i>	0.64	[81]
	<i>Aspergillus niger</i>	0.64–313	[71][81]
	<i>Candida albicans</i>	1.25–625	[62][71][81]
	<i>Candida guillermondi</i>	1.25	[81]
	<i>Candida krusei</i>	1.25	[81]
	<i>Candida parapsilosis</i>	1.25	[81]
	<i>Candida tropicalis</i>	1.25	[81]
	<i>Cryptococcus neoformans</i>	0.32–313	[71][81]
	<i>Epidermophyton floccosum</i>	0.64	[81]
	<i>Fusarium graminearum</i>	2.5	[85]
	<i>Fusarium moniliforme</i>	2.5	[85]
	<i>Malassezia furfur</i>	>4	[64]
	<i>Microsporum canis</i>	0.64–2	[86][81]
	<i>Microsporum gypseum</i>	0.64–3	[81]
	<i>Penicillium corylophilum</i>	0.625	[87]
	<i>Penicillium expansum</i>	2.5	[85]
	<i>Trichophyton erinacei</i>	3	[86]
<i>Mentha suaveolens</i> Ehrh.	<i>Trichophyton mentagrophytes</i>	0.64–3	[86][81]
	<i>Trichophyton mentagrophytes</i> var. <i>interdigitale</i>	0.64	[81]
	<i>Trichophyton rubrum</i>	0.25–512	[64][62][81]
	<i>Trichophyton terrestre</i>	3	[68]
	<i>Trichophyton verrucosum</i>	0.32	[81]
	<i>Trichosporon beigelii</i>	0.25	[64]
	<i>Candida albicans</i>	0.34–1250	[88][89][90]
	<i>Candida glabrata</i>	0.69–2.77	[88]
	<i>Cryptococcus neoformans</i>	300	[91]
	<i>Microsporum canis</i>	1250	[91]
	<i>Microsporum gypseum</i>	1250	[91]
	<i>Trichophyton mentagrophytes</i>	600–1250	[91]
	<i>Trichophyton rubrum</i>	5000	[91]
	<i>Trichophyton violaceum</i>	600	[91]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
	<i>Aspergillus niger</i>	0.2	[50]
	<i>Aspergillus ochraceus</i>	0.2	[50]
	<i>Cladosporium cladosporioides</i>	0.2	[50]
<i>Micromeria albanica</i> (Griseb. ex K. Maly) Silic	<i>Fusarium tricinctum</i>	0.4	[50]
	<i>Penicillium ochrochloron</i>	0.2	[50]
	<i>Phomopsis helianthi</i>	0.2	[50]
	<i>Trichoderma viride</i>	0.4	[50]
	<i>Aspergillus niger</i>	50	[92]
<i>Moluccella spinosa</i> L.	<i>Candida albicans</i>	100	[92]
	<i>Fusarium oxysporum</i>	100	[92]
	<i>Alternaria solani</i>	3000	[53]
	<i>Candida albicans</i>	0.78	[93]
<i>Nepeta ciliaris</i> Benth. = <i>Nepeta leucophylla</i> Benth.	<i>Fusarium oxysporum</i>	1000	[53]
	<i>Trichophyton rubrum</i>	0.19	[93]
	<i>Helminthosporium maydis</i>	1500	[53]
	<i>Alternaria solani</i>	3000	[53]
<i>Nepeta clarkei</i> Hook. f.	<i>Fusarium oxysporum</i>	2000	[53]
	<i>Helminthosporium maydis</i>	2000	[53]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
<i>Ocimum basilicum</i> L.	<i>Aspergillus flavus</i>	10,000	[64]
	<i>Aspergillus fumigatus</i>	>50	[45]
	<i>Aspergillus niger</i>	>50– 10,000	[64,75,158]
	<i>Aspergillus parasiticus</i>	5000	[64]
	<i>Candida albicans</i>	30–625	[73,74,158]
	<i>Candida guilliermondii</i>	3.125– 6.25	[76]
	<i>Cryptococcus neoformans</i>	313– 1250	[158,169]
	<i>Debaryomyces hansenii</i>	6.25	[76]
	<i>Epidermophyton floccosum</i>	15	[74]
	<i>Microsporum canis</i>	1–15.2	[68,74]
	<i>Microsporum gypseum</i>	3	[68]
	<i>Penicillium chrysogenum</i>	10,000	[64]
	<i>Penicillium italicum</i>	>50	[45]
	<i>Rhizopus stolonifer</i>	>50	[45]
	<i>Rhodotorula glutinis</i>	86	[94]
	<i>Trichophyton erinacei</i>	2.5	[68]
<i>Ocimum × africanum</i> Lour. = <i>Ocimum × citriodorum</i>	<i>Trichophyton mentagrophytes</i>	2.5–8.3	[68,74]
	<i>Trichophyton terrestrre</i>	3	[68]
	<i>Saccharomyces cerevisiae</i>	28	[94]
	<i>Schizosaccharomyces pombe</i>	86	[94]
	<i>Trichophyton rubrum</i>	8.3	[74]
	<i>Trichophyton tonsurans</i>	8	[74]
	<i>Yarrowia lipolytica</i>	57	[73]
<i>Ocimum campechianum</i> Mill. = <i>Ocimum micranthum</i> Willd.	<i>Candida guilliermondii</i>	3.125	[76]
	<i>Debaryomyces hansenii</i>	1.56	[76]
	<i>Candida albicans</i>	69	[94]
	<i>Rhodotorula glutinis</i>	139	[94]
	<i>Saccharomyces cerevisiae</i>	69	[94]
	<i>Schizosaccharomyces pombe</i>	104	[94]
	<i>Yarrowia lipolytica</i>	69	[94]
<i>Ocimum forskolei</i> Benth.	<i>Candida albicans</i>	35.3– 8600	[77,170]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
<i>Ocimum gratissimum</i> L.	<i>Aspergillus fumigatus</i>	>1000	[78]
	<i>Candida albicans</i>	350–1500	[78,171]
	<i>Candida krusei</i>	750	[171]
	<i>Candida parapsilosis</i>	380	[171]
	<i>Candida tropicalis</i>	1500	[171]
	<i>Cryptococcus neoformans</i>	250–300	[78,79]
	<i>Fusarium oxysporum</i> f. sp. <i>cubense</i>	62.5	[95]
	<i>Fusarium oxysporum</i> f. sp. <i>lycopersici</i>	31.25	[95]
	<i>Fusarium oxysporum</i> f. sp. <i>tracheiphilum</i>	62.5	[95]
	<i>Fusarium solani</i>	62.5	[95]
	<i>Macrophomina phaseolina</i>	62.5–125	[95]
	<i>Malassezia pachydermatis</i>	300	[78]
	<i>Microsporum canis</i>	200–500	[78,172]
	<i>Microsporum gypseum</i>	150–250	[78,172]
	<i>Rhizoctonia solani</i>	31.25	[95]
	<i>Scopulariopsis brevicaulis</i>	400	[78]
	<i>Trichophyton interdigitale</i>	250	[78]
	<i>Trichophyton mentagrophytes</i>	200–250	[78,172]
	<i>Trichophyton rubrum</i>	150–250	[78,172]
	<i>Aspergillus flavus</i>	300	[83]
	<i>Candida albicans</i>	0.1–300	[81,82]
	<i>Candida glabrata</i>	0.15–300	[81,82]
<i>Ocimum tenuiflorum</i> L. = <i>Ocimum sanctum</i> L.	<i>Candida krusei</i>	0.35–450	[81,82]
	<i>Candida parapsilosis</i>	0.25–500	[81,82]
	<i>Candida tropicalis</i>	0.1–300	[81,82]
	<i>Alternaria alternata</i>	300	[96]
	<i>Bipolaris oryzae</i>	300	[96]
	<i>Fusarium equiseti</i>	300	[96]
<i>Origanum compactum</i> Benth.	<i>Fusarium graminearum</i>	300	[96]
	<i>Fusarium verticillioides</i>	300	[96]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
<i>Origanum majorana</i> L.	<i>Aspergillus flavus</i>	450–650	[62]
	<i>Aspergillus niger</i>	625	[158]
	<i>Botrytis cinerea</i>	5000	[87]
	<i>Candida albicans</i>	625	[158]
	<i>Cryptococcus neoformans</i>	313	[158]
	<i>Fusarium delphinoides</i>	1800–14,400	[85]
	<i>Fusarium incarnatum-equiseti</i>	450–3600	[85]
	<i>Fusarium napiforme</i>	3600–14,400	[85]
	<i>Fusarium oxysporum</i>	900–3600	[85]
	<i>Fusarium solani</i>	900–3600	[85]
	<i>Fusarium verticillioides</i>	14,400	[85]
	<i>Microsporum canis</i>	0.5	[68]
	<i>Microsporum gypseum</i>	2	[68]
	<i>Penicillium expansum</i>	10,000	[87]
	<i>Penicillium minioluteum</i>	400–500	[62]
	<i>Penicillium oxalicum</i>	350–400	[62]
	<i>Sporothrix brasiliensis</i>	≤2250–9000	[86]
	<i>Sporothrix schenckii</i>	≤2250–9000	[86]
	<i>Trichophyton erinacei</i>	1	[68]
	<i>Trichophyton mentagrophytes</i>	1.5	[68]
	<i>Trichophyton terrestrre</i>	2	[68]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
<i>Origanum vulgare</i> L.	<i>Aspergillus flavus</i>	0.64–2500	[64,89,91]
	<i>Aspergillus fumigatus</i>	0.32–0.64	[89]
	<i>Aspergillus niger</i>	0.32–623	[62,89,91,158]
	<i>Aspergillus ochraceus</i>	470	[91]
	<i>Aspergillus parasiticus</i>	2500	[64]
	<i>Candida albicans</i>	0.32–700	[74,88,89,91,158]
	<i>Candida glabrata</i>	350	[88]
	<i>Candida guillermondii</i>	0.64–1.25	[89]
	<i>Candida krusei</i>	0.64–700	[88,89]
	<i>Candida parapsilosis</i>	0.64–170	[88,89]
	<i>Candida tropicalis</i>	0.32–700	[88,89]
	<i>Cladosporium</i> sp.	0.05–0.3	[173]
	<i>Cryptococcus neoformans</i>	0.16–78	[89,158]
	<i>Epidermophyton floccosum</i>	0.32–2	[74,89]
	<i>Fusarium</i> sp.	0.1–0.5	[173]
	<i>Malassezia furfur</i>	1–780	[49,174]
<i>Origanum vulgare</i> L.	<i>Microsporum canis</i>	0.025–2	[68,74,89]
	<i>Microsporum gypseum</i>	0.025–1.25	[68,89]
	<i>Penicillium</i> sp.	0.1–0.5	[173]
	<i>Penicillium chrysogenum</i>	625	[64]
	<i>Penicillium corylophilum</i>	0.625	[165]
	<i>Penicillium funiculosum</i>	610	[91]
	<i>Penicillium ochrochloron</i>	710	[91]
	<i>Penicillium verrucosum</i>	1.1719	[90,91]
	<i>Trichophyton mentagrophytes</i>	0.32–1.25	[74,89]
	<i>Trichophyton rubrum</i>	0.16–1.25	[49,74,89]
	<i>Trichophyton tonsurans</i>	1	[74]
	<i>Trichosporon beigelii</i>	0.25	[49]
<i>Origanum vulgare</i> L.	<i>Trichophyton erinacei</i>	0.5	[68]
	<i>Trichophyton mentagrophytes</i>	0.5	[68]
	<i>Trichophyton terrestrre</i>	0.25	[68]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
<i>Pogostemon cablin</i> (Blanco) Benth.	<i>Aspergillus flavus</i>	>1500	[92]
	<i>Aspergillus niger</i>	156	[158]
	<i>Aspergillus oryzae</i>	>1500	[92]
<i>Pogostemon cablin</i> (Blanco) Benth.	<i>Candida albicans</i>	32–625	[158,175]
	<i>Candida krusei</i>	64–257	[175]
	<i>Candida tropicalis</i>	32–257	[175]
	<i>Cryptococcus neoformans</i>	20	[158]
	<i>Candida albicans</i>	6000	[176]
	<i>Candida glabrata</i>	6000	[176]
<i>Pogostemon heyneanus</i> Benth.	<i>Candida tropicalis</i>	10,000	[176]
	<i>Aspergillus niger</i>	>500	[94]
	<i>Candida albicans</i>	>500	[94]
<i>Premna microphylla</i> Turcz.	<i>Fusarium oxysporum</i>	>500	[94]
	<i>Aspergillus flavus</i>	330	[91]
	<i>Aspergillus ochraceus</i>	590	[91]
	<i>Aspergillus niger</i>	380–10,000	[91,98,158]
	<i>Botrytis cinerea</i>	2500	[87]
	<i>Candida albicans</i>	30.2–1000	[51,91,96,98,158]
	<i>Cryptococcus neoformans</i>	313	[158]
	<i>Epidermophyton floccosum</i>	30	[96]
	<i>Microsporum canis</i>	2.5–30.2	[68,96]
	<i>Microsporum gypseum</i>	2.5	[68]
<i>Rosmarinus officinalis</i> L.	<i>Penicillium expansum</i>	5000	[87]
	<i>Penicillium ochrochloron</i>	470	[91]
	<i>Penicillium funiculosum</i>	570	[91]
	<i>Trichophyton erinacei</i>	1.5	[68]
	<i>Trichophyton mentagrophytes</i>	5–15.3	[68,96]
	<i>Trichophyton rubrum</i>	15–256	[51,96]
	<i>Trichophyton terrestrre</i>	5	[68]
	<i>Trichophyton tonsurans</i>	15.2	[96]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
<i>Salvia fruticosa</i> Miller	<i>Candida albicans</i>	512	[51]
	<i>Fusarium oxysporum</i> f. sp. <i>dianthi</i>	>2000	[97]
	<i>Fusarium proliferatum</i>	>2000	[97]
	<i>Fusarium solani</i> f. sp. <i>cucurbitae</i>	>2000	[97]
	<i>Malassezia furfur</i>	>4	[97]
	<i>Rhizoctonia solani</i>	>2000	[97]
	<i>Sclerotinia sclerotiorum</i>	>2000	[97]
	<i>Trichophyton rubrum</i>	2–256	[49,99]
	<i>Trichosporon beigelii</i>	4	[49]
	<i>Candida albicans</i>	0.5–2	[98]
<i>Salvia mirzayanii</i> Rech. f. and Esfand	<i>Candida krusei</i>	1	[98]
	<i>Candida dubliniensis</i>	0.06–0.5	[98]
	<i>Candida glabrata</i>	0.06–1	[98]
	<i>Candida parapsilosis</i>	0.25–1	[98]
	<i>Candida tropicalis</i>	0.25–2	[98]
	<i>Trichosporon</i> sp.	1	[98]
	<i>Aspergillus flavus</i>	5–10	[101]
	<i>Aspergillus fumigatus</i>	2.5–5	[101]
	<i>Aspergillus niger</i>	5–1250	[101,158]
	<i>Candida albicans</i>	2.5–2780	[96,101,158,177]
<i>Salvia officinalis</i> L.	<i>Candida guillermondii</i>	1.25–2.5	[101]
	<i>Candida krusei</i>	2.5–5	[101]
	<i>Candida parapsilosis</i>	5	[101]
	<i>Candida tropicalis</i>	5	[101]
	<i>Cryptococcus neoformans</i>	0.64–625	[101,158]
	<i>Epidermophyton floccosum</i>	0.64–100	[96,101]
	<i>Microsporum canis</i>	1.25–100.2	[96,101]
	<i>Microsporum gypseum</i>	1.25–2.5	[101]
	<i>Trichophyton mentagrophytes</i>	1.25–60	[96,101]
	<i>Trichophyton mentagrophytes</i> var. <i>interdigitale</i>	1.25	[101]
	<i>Trichophyton rubrum</i>	0.64–60	[96,101]
	<i>Trichophyton tonsurans</i>	60	[96]
	<i>Trichophyton verrucosum</i>	1.25–2.5	[101]

Source of the Essential Oil	Targeted Fungus	MICs (µg/mL; µl/mL)	Reference(s)
<i>Salvia sclarea</i> L.	<i>Aspergillus niger</i>	1250	[158]
	<i>Candida albicans</i>	1250	[158]
	<i>Cryptococcus neoformans</i>	313	[158]
	<i>Fusarium delphinooides</i>	1800–3600	[85]
	<i>Fusarium incarnatum-equiseti</i>	1800–3600	[85]
	<i>Fusarium napiforme</i>	1800–3600	[85]
	<i>Fusarium oxysporum</i>	1800–3600	[85]
	<i>Fusarium solani</i>	3600–7200	[85]
	<i>Fusarium verticillioides</i>	1800	[85]
	<i>Alternaria alternata</i>	62.5	[103]
<i>Satureja hortensis</i> L.	<i>Aspergillus flavus</i>	31.25–500	[103,104,117]
	<i>Aspergillus niger</i>	471	[99]
	<i>Aspergillus ochraceus</i>	423	[99]
	<i>Aspergillus parasiticus</i>	373	[99]
	<i>Aspergillus terreus</i>	389	[99]
	<i>Aspergillus variecolor</i>	125	[100]
	<i>Candida albicans</i>	200–400	[103,178]
	<i>Fusarium culmorum</i>	125	[100]
	<i>Fusarium oxysporum</i>	250	[100]
	<i>Microsporum canis</i>	62.5	[100]
<i>Satureja montana</i> L.	<i>Monilinia fructicola</i>	31.25	[100]
	<i>Penicillium</i> spp.	125	[100]
	<i>Rhizoctonia solani</i>	125	[100]
	<i>Rhizopus</i> spp.	250	[100]
	<i>Sclerotinia minor</i>	250	[100]
	<i>Sclerotinia sclerotiorum</i>	125	[100]
	<i>Trichophyton mentagrophytes</i>	62.5	[100]
	<i>Trichophyton rubrum</i>	31.25	[100]
	<i>Microsporum canis</i>	0.5	[68]
	<i>Microsporum gypseum</i>	2	[68]
	<i>Trichophyton erinacei</i>	2	[68]
	<i>Trichophyton mentagrophytes</i>	2	[68]
	<i>Trichophyton terrestrre</i>	3	[68]

Source of the Essential Oil	Targeted Fungus	MICs (µg/mL; µl/mL)	Reference(s)
<i>Satureja thymbra</i> L.	<i>Aspergillus flavus</i>	25	[105]
	<i>Aspergillus fumigatus</i>	1.25–25	[105,179]
	<i>Aspergillus niger</i>	2.5–25	[105,179]
	<i>Aspergillus ochraceus</i>	2.5–25	[105,179]
	<i>Aspergillus versicolor</i>	1.25	[179]
	<i>Candida albicans</i>	25–128	[51,105]
	<i>Penicillium funiculosum</i>	2.5–25	[105,179]
	<i>Penicillium ochrochloron</i>	1–1.25	[105,179]
	<i>Trichoderma viride</i>	1.25–25	[105,179]
	<i>Trichophyton rubrum</i>	128	[51]
<i>Stachys cretica</i> L.	<i>Candida albicans</i>	625	[106]
<i>Stachys officinalis</i> (L.) Trevis	<i>Aspergillus niger</i>	2500	[107]
	<i>Candida albicans</i>	5000	[107]
	<i>Alternaria alternata</i>	1	[101]
<i>Stachys pubescens</i> Ten.	<i>Aspergillus flavus</i>	0–5	[101]
	<i>Fusarium oxysporum</i>	1	[101]
	<i>Aspergillus fumigatus</i>	>1000	[102]
	<i>Candida albicans</i>	>1000	[102]
	<i>Cryptococcus neoformans</i>	>1000	[102]
	<i>Epidermophyton floccosum</i>	850	[102]
	<i>Microsporum canis</i>	800	[102]
	<i>Microsporum gypseum</i>	900	[102]
	<i>Scopulariopsis brevicaulis</i>	>1000	[102]
	<i>Scytalidium dimidiatum</i>	>1000	[102]
<i>Teucrium sauvagei</i> Le Houerou	<i>Trichophyton mentagrophytes</i> var. <i>interdigitale</i>	950	[102]
	<i>Trichophyton mentagrophytes</i> var. <i>mentagrophytes</i>	900	[102]
	<i>Trichophyton rubrum</i>	800	[102]
	<i>Trichophyton soudanense</i>	800	[102]
	<i>Aspergillus niger</i>	313	[103]
	<i>Botrytis cinerea</i>	313	[103]
	<i>Candida albicans</i>	1250	[103]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ l/mL)	Reference(s)
	<i>Aspergillus flavus</i>	0.32	[104]
	<i>Aspergillus fumigatus</i>	0.16– 0.32	[104]
	<i>Aspergillus niger</i>	0.1– 0.16	[104][105]
	<i>Aspergillus oryzae</i>	0.2	[105]
	<i>Candida albicans</i>	0.16– 128	[62][106][104][107]
	<i>Candida glabrata</i>	0.32	[104][107]
	<i>Candida guilliermondii</i>	0.16– 0.32	[104][107]
<i>Thymbra capitata</i> (L.) Cav. = <i>Thymus capitatus</i> (L.) Hoffmanns. and Link = <i>Coridothymus capitatus</i> (L.) Rchb.f. Solms	<i>Candida krusei</i>	0.32	[104]
	<i>Candida parapsilosis</i>	0.32	[104][107]
	<i>Candida tropicalis</i>	0.32	[104][107]
	<i>Epidermophyton floccosum</i>	0.08	[104]
	<i>Fusarium solani</i>	0.2	[105]
	<i>Microsporum canis</i>	0.08	[104]
	<i>Microsporum gypseum</i>	0.08	[104]
	<i>Penicillium digitatum</i>	0.5	[180]
	<i>Trichophyton mentagrophytes</i>	0.08	[104]
	<i>Trichophyton rubrum</i>	0.16–64	[62][104]
	<i>Aspergillus fumigatus</i>	0.3	[108]
	<i>Aspergillus niger</i>	0.6	[108]
	<i>Aspergillus versicolor</i>	0.3	[108]
	<i>Aspergillus ochraceus</i>	0.6	[108]
	<i>Candida albicans</i>	1.12– 3750	[62][109][110]
<i>Thymbra spicata</i> L.	<i>Candida krusei</i>	1.12	[110]
	<i>Candida parapsilosis</i>	0.6– 1.12	[110]
	<i>Penicillium funiculosum</i>	0.3	[108]
	<i>Penicillium ochrochloron</i>	0.3	[108]
	<i>Trichoderma viride</i>	0.3	[108]
	<i>Trichophyton rubrum</i>	64	[62]
<i>Thymus bovei</i> Benth.	<i>Candida albicans</i>	250	[111]
	<i>Alternaria alternata</i>	>8	[101]
<i>Thymus daenensis</i> Celak.	<i>Aspergillus flavus</i>	1	[101]
	<i>Fusarium oxysporum</i>	4	[101]
	<i>Alternaria alternata</i>	1	[101]
<i>Thymus kotschyianus</i> Boiss. and Hohen.	<i>Aspergillus flavus</i>	0.5	[101]
	<i>Fusarium oxysporum</i>	0–5	[101]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
<i>Thymus mastichina</i> (L.) L.	<i>Candida albicans</i>	1.25– 2.5	[112]
	<i>Candida glabrata</i>	1.25– 1.5	[112]
	<i>Candida guilliermondii</i>	1.25	[112]
	<i>Candida krusei</i>	1.25– 2.5	[112]
	<i>Candida parapsilosis</i>	2.5–5	[112]
	<i>Candida tropicalis</i>	2.5–10	[112]
	<i>Aspergillus flavus</i>	452	[99]
	<i>Aspergillus niger</i>	460	[99]
	<i>Aspergillus ochraceus</i>	430	[99]
	<i>Aspergillus parasiticus</i>	581	[99]
<i>Thymus migricus</i> Klokov et Des.-Shost.	<i>Aspergillus terreus</i>	447	[99]
	<i>Aspergillus flavus</i>	0.32	[113]
	<i>Aspergillus fumigatus</i>	0.16	[113]
	<i>Aspergillus niger</i>	0.32	[113]
	<i>Candida albicans</i>	0.32– 0.64	[113]
	<i>Candida glabrata</i>	0.32– 0.64	[113]
	<i>Candida guilliermondii</i>	0.32	[113]
	<i>Candida krusei</i>	0.32– 0.64	[113]
	<i>Candida parapsilosis</i>	0.64	[113]
	<i>Candida tropicalis</i>	0.32– 0.64	[113]
<i>Thymus pulegioides</i> L.	<i>Epidermophyton floccosum</i>	0.16	[113]
	<i>Microsporum canis</i>	0.16	[113]
	<i>Microsporum gypseum</i>	0.16	[113]
	<i>Trichophyton mentagrophytes</i>	0.16	[113]
	<i>Trichophyton rubrum</i>	0.32	[113]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
<i>Thymus schimperi</i> Ronninger	<i>Aspergillus minutus</i>	0.512–2	[114]
	<i>Aspergillus niger</i>	0.16	[115]
	<i>Aspergillus tubingensis</i>	1–4	[114]
	<i>Beauveria bassiana</i>	0.128–1	[114]
	<i>Candida albicans</i>	0.16	[115]
	<i>Microsporum</i> spp.	0.08	[115]
	<i>Microsporum gypseum</i>	0.128–1	[114]
	<i>Penicillium chrysogenum</i>	0.512–2	[114]
	<i>Rhodotorula</i> spp.	0.08	[115]
	<i>Trichophyton</i> spp.	0.08–0.31	[115]
	<i>Verticillium</i> sp.	0.512–2	[114]
	<i>Aspergillus carbonarius</i>	1.25	[116]
	<i>Aspergillus ochraceus</i>	0.625	[116]
	<i>Aspergillus niger</i>	2.5	[116]
<i>Thymus serpyllum</i> L.	<i>Microsporum canis</i>	0.025	[86]
	<i>Microsporum gypseum</i>	0.25	[86]
	<i>Trichophyton erinacei</i>	0.1	[86]
	<i>Trichophyton mentagrophytes</i>	0.2	[86]
	<i>Trichophyton terrestre</i>	0.1	[86]
	<i>Alternaria alternata</i>	1	[117]
	<i>Aspergillus flavus</i>	1.5	[117]
	<i>Aspergillus niger</i>	1	[117]
	<i>Aspergillus ochraceus</i>	1	[117]
	<i>Aspergillus terreus</i>	1	[117]
	<i>Aspergillus versicolor</i>	1	[117]
	<i>Cladosporium cladosporioides</i>	0.5	[117]
	<i>Epidermophyton floccosum</i>	1	[117]
	<i>Microsporum canis</i>	1.5	[117]
<i>Thymus striatus</i> Vahl.	<i>Penicillium funiculosum</i>	2	[117]
	<i>Penicillium ochrochloron</i>	2	[117]
	<i>Phomopsis helianthi</i>	0.5	[117]
	<i>Trichoderma viride</i>	2	[117]
	<i>Trichophyton mentagrophytes</i>	1	[117]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
<i>Thymus vulgaris</i> L.	<i>Absidia</i> spp.	7 ± 4	[118]
	<i>Alternaria</i> spp.	9.4 ± 4.5	[118]
	<i>Alternaria alternata</i>	4.7–500	[118][119]
	<i>Aspergillus</i> spp.	3.2	[118]
	<i>Aspergillus flavus</i>	9.35–1500	[64,104,122,125,184]
	<i>Aspergillus fumigatus</i>	144–1000	[124,184]
	<i>Aspergillus niger</i>	9.35–1250	[64,122,158,184]
	<i>Aspergillus ochraceus</i>	2.5–750	[85][120]
	<i>Aspergillus parasiticus</i>	1250	[75]
	<i>Aspergillus sulphureus</i>	10.88 ± 3.1	[118]
	<i>Aspergillus versicolor</i>	9.6 ± 9.25	[118]
	<i>Botrytis cinerea</i>	312	[87]
	<i>Candida albicans</i>	0.16–313	[94][121][112][71]
	<i>Candida glabrata</i>	0.16–0.32	[112]
	<i>Candida krusei</i>	0.08–0.16	[112]
	<i>Candida guillermondii</i>	0.16	[112]
	<i>Candida parapsilosis</i>	0.16–0.32	[112]
	<i>Candida tropicalis</i>	0.16–0.32	[112]
	<i>Chaetomium globosum</i>	1.6	[118]
	<i>Cladosporium</i> spp.	12.8	[118]
	<i>Cladosporium sphaerospermum</i>	19.6	[118]
	<i>Cryptococcus neoformans</i>	78	[71]
	<i>Epidermophyton floccosum</i>	4	[121]
	<i>Fusarium</i> spp.	62.5	[122]
	<i>Fusarium delphinoides</i>	900–1800	[123]
	<i>Fusarium incarnatum-equiseti</i>	450–3600	[123]
	<i>Fusarium napiforme</i>	900	[123]
	<i>Fusarium oxysporum</i>	5–900	[123][124]
	<i>Fusarium solani</i>	1800–3600	[123]
	<i>Fusarium verticillioides</i>	900	[123]
	<i>Malassezia furfur</i>	920	[125]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
	<i>Microsporum canis</i>	2.2	[121]
	<i>Mortierella</i> spp.	250	[122]
	<i>Mucor</i> spp.	50.2 $\pm$ 8.4	[118]
	<i>Penicilium</i> spp.	18.95– 500	[118][122]
	<i>Penicilium brevicompactum</i>	19.6	[118]
	<i>Penicillium chrysogenum</i>	312.5– 1750	[75][120]
	<i>Penicillium chrysogenum</i>	19.6	[118]
	<i>Penicillium citrinum</i>	1250	[120]
	<i>Penicillium expansum</i>	625	[126]
	<i>Penicillium griseofulvum</i>	19.6	[118]
	<i>Rhizopus</i> spp.	12.6	[118]
	<i>Rhodotorula glutinis</i>	72	[94]
	<i>Rhizopus oryzae</i>	256– 512	[127]
	<i>Saccharomyces cerevisiae</i>	72	[94]
	<i>Schizosaccharomyces pombe</i>	36	[94]
	<i>Stachybotrys chartarum</i>	6.2	[118]
	<i>Trichoderma</i> spp.	16.8	[118]
	<i>Trichophyton mentagrophytes</i>	2.2	[121]
	<i>Trichophyton rubrum</i>	2–72	[121][128]
	<i>Trichophyton tonsurans</i>	2.2	[121]
	<i>Ulocladium</i> spp.	5.45 $\pm$ 1.5	[118]
	<i>Yarrowia lypolytica</i>	36	[94]
	<i>Candida albicans</i>	0.16– 0.32	[112]
	<i>Candida glabrata</i>	0.32	[112]
	<i>Candida krusei</i>	0.16– 0.32	[112]
<i>Thymus zygis</i> L.	<i>Candida guillermondii</i>	0.16	[112]
	<i>Candida parapsilosis</i>	0.32	[112]
	<i>Candida tropicalis</i>	0.16– 0.32	[112]
	<i>Penicillium corylophilum</i>	0.3125– 0.625	[87]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
<i>Vitex agnus-castus</i> L.	<i>Candida albicans</i>	0.53–512	[62][129]
	<i>Candida dubliniensis</i>	0.27	[129]
	<i>Candida famata</i>	2.13	[129]
	<i>Candida glabrata</i>	0.27	[129]
	<i>Candida krusei</i>	0.27	[129]
	<i>Candida lusitaniae</i>	2.13	[129]
	<i>Candida parapsilosis</i>	1.06	[129]
	<i>Candida tropicalis</i>	0.13	[129]
	<i>Epidermophyton floccosum</i>	0.64–2.5	[130]
	<i>Microsporum canis</i>	0.64–5	[130]
<i>Zataria multiflora</i> Boiss.	<i>Microsporum gypseum</i>	1.25–10	[130]
	<i>Trichophyton mentagrophytes</i>	1.25–10	[130]
	<i>Trichophyton rubrum</i>	0.64–512	[62][130]
	<i>Aspergillus flavus</i>	358	[99]
	<i>Aspergillus niger</i>	358	[99]
	<i>Aspergillus ochraceus</i>	341	[99]
	<i>Aspergillus parasiticus</i>	367	[99]
	<i>Aspergillus terreus</i>	447	[99]
	<i>Microsporum canis</i>	0.125–0.25	[131]
	<i>Microsporum gypseum</i>	0.03–0.06	[131]
<i>Ziziphora clinopodioides</i> Lam.	<i>Trichophyton mentagrophytes</i>	0.03	[131]
	<i>Trichophyton rubrum</i>	0.03–0.06	[131]
	<i>Trichophyton schoenleinii</i>	0.125–0.6	[131]
	<i>Aspergillus flavus</i>	48.82	[120][132]
	<i>Aspergillus fumigatus</i>	1750	[120]
	<i>Aspergillus niger</i>	3000	[120]
	<i>Aspergillus ochraceus</i>	1500	[120]
	<i>Aspergillus parasiticus</i>	48.82	[132]
	<i>Penicillium chrysogenum</i>	3000	[120]
	<i>Penicillium citrinum</i>	1750	[120]

Source of the Essential Oil	Targeted Fungus	MICs ( $\mu$ g/mL; $\mu$ L/mL)	Reference(s)
<i>Ziziphora tenuior</i> L.	<i>Aspergillus flavus</i>	1.25	[133]
	<i>Aspergillus fumigatus</i>	0.64	[133]
	<i>Aspergillus niger</i>	0.64	[133]
	<i>Candida albicans</i>	1.25	[133]
	<i>Candida guillermondi</i>	1.25	[133]
	<i>Candida krusei</i>	1.25	[133]
	<i>Candida parapsilosis</i>	1.25	[133]
	<i>Candida tropicalis</i>	1.25	[133]
	<i>Cryptococcus neoformans</i>	0.16	[133]
	<i>Epidermophyton floccosum</i>	0.64	[133]
<i>Thymus vulgaris</i>	<i>Microsporum canis</i>	0.64– 1.25	[133]
	<i>Microsporum gypseum</i>	1.25	[133]
	<i>Trichophyton mentagrophytes</i>	1.25	[133]
	<i>Trichophyton mentagrophytes</i> var. <i>interdigitale</i>	1.254	[133]
	<i>Trichophyton rubrum</i>	0.64	[133]
	<i>Trichophyton verrucosum</i>	0.64	[133]

The mode of action of essential oils is multidirectional. Essential oils lead to disruption of the cell wall and cell membrane through a permeabilization process. The lipophilic compounds of essential oils can pass through the cell wall and damage polysaccharides, fatty acids, and phospholipids, eventually making them permeable [41][134]. Change of the permeability for H<sup>+</sup> and K<sup>+</sup> cations affects cellular pH and damage of cellular organelles [135][136]. Additionally, essential oils inhibit the synthesis of fungal DNA, RNA, proteins, and polysaccharides [137]. Essential oils can also disintegrate mitochondrial membrane [138][139]. It has also been shown that essential oil from *Thymus vulgaris* inhibits the production of aflatoxins by *Aspergillus flavus* and leads to the reduction of ergosterol production [127].

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