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Review

Antimicrobial Activity of Basil, Oregano, and Thyme Essential Oils

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For centuries, plants have been used for a wide variety of purposes, from treating infectious diseases to food preservation and perfume production. Presently, the increasing resistance of microorganisms to currently used antimicrobials in combination with the appearance of emerging diseases requires the urgent development of new, more effective drugs. Plants, due to the large biological and structural diversity of their components, constitute a unique and renewable source for the discovery of new antibacterial, antifungal, and antiparasitic compounds. In the present paper, the history, composition, and antimicrobial activities of the basil, oregano, and thyme essential oils are reviewed.

Keywords: Essential oils, basil, oregano, thyme, antimicrobial activity

Introduction

One of the actions to counter the emergence of the drug resistance problem is the development of new antimicrobials. Plant essential oils are explored as a promising substitute to currently used antimicrobials, and to date, many plant essential oils have been reported to present considerable antimicrobial activity. This activity is attributed to their ability to synthesize aromatic substances, the majority of which are phenols or oxygen-substituted derivatives.

The antimicrobial, antiseptic, and other therapeutic applications of plants are well recognized since the prehistoric times, widely used by all civilizations throughout the millennia [1]. Interestingly, according to the World Health Organization, approximately 80% of the world population, mostly in developing countries, still relies on medicinal plants and their extracts for primary health care [2, 3]. The contemporary pharmaceutics, cosmetics, and food industries are founded on the knowledge of the properties of medicinal plants that can be used for applications from treating infectious, systematic, and inflammatory diseases to food preservation and perfume production [4]. The aim of the present paper is to review the antimicrobial activities of three essential oils; namely, the basil, oregano, and thyme essential oils.

Historical Review

In ancient Greece, medicinal plants were extensively used by rhizotomists, the persons related to therapeutic herb collection and supply [3]. The Chinese, Indians, Egyptians, Romans, and Arabs also relied on herbalism, which was assimilated into the philosophical principles, traditions, and practices of their culture. Consequently, therapeutics developed from being empirical and instinctive to being magical and theocratic. The theocratic viewpoint constituted an element of all ancient civilizations, including the Greeks, until the advent of the Hippocratic School, which was based on observation and experiment. Hippocrates himself (late 5th century BC) mentioned 300−400 medicinal plants [5]. Plant-derived therapeutic oils are mentioned on clay findings of cuneiform writing (2600 BC) in Mesopotamia [1], while about 30 medicinal plants are described in the Bible [5]. In Dioscourides' work *De Materia Medica* (1st century AD), herbal medicaments are described, providing the knowledge for most of the later medicinal preparations [1].

The great empires controlled the medicinal plants' production and trade for centuries, while in the Middle Ages their cultivation in abbeys and monasteries facilitated the development of knowledge on their therapeutic properties.

During the Ottoman Empire, many Orthodox monasteries established hospitals within their premises, where remedies were prepared from medicinal plants cultivated by the monks. In a monastic script of this period in the island of Cyprus (1571–1878), 494 herbal prescriptions and 231 plants belonging to 70 different botanical families were described [6]. In Greece, for centuries, a large part of the native population health problems was encountered by empirical doctors such as the renowned "Vikoyiatroi" of the Zagori region in Epirus (17th–19th century), who collected and used medicinal plants from the nearby Vikos Canyon [7]. Eventually, with the advancement of modern medicine, traditional remedies were gradually abandoned in the developed world [5].

However, medicinal plants are nowadays being re-examined, their extracts are thoroughly studied, and their properties are revised in an effort to complement or replace the existing synthetic chemical substances used in the modern food and drug industries.

Essential Oils

Composition

The term "essential oil" was used for first time by Paracelsus (16th century), who named the effective component of each drug "quinta essentia" [8]. The components of essential oils, a total of about 500 compounds, include terpenes (monoterpenes and sesquiterpenes), terpenoids (isoprenoids), and aliphatic and aromatic compounds such as aldehydes and phenols [9–11]. It is possible for the predominant components to constitute 85% of the total concentration of the oil [12]. It is estimated that there are about 3,000 well-recognized essential oils, of which 300 are widespread traded [9]. The composition of the essential oils depends on various factors, including environmental conditions, the soil composition and cultivation method, the season and time of the day when the plant was picked, the storage and processing conditions, the oil extraction method, and analysis of the chemical components [2, 8]. Essential oils are produced from plants by means of distillation, fermentation, crushing, extraction, hydrolysis, and airing, but the most frequent method is steam distillation [2, 12]. Distillation as an essential oil production method was used by the Egyptians, Indians, and Persians two millennia ago and was improved by the Arabs in the 9th century AD [12]. The isolation of the constituting components is achieved by chromatographic methods, mostly with the use of gas chromatography–mass spectrometry [12]. Thin layer chromatography, [13] and high performance liquid chromatography are used as well [14].

Bioactivities

The use of essential oils is extensive, since they are used as main ingredients in cosmetics, perfumes, body and hair care products, antiseptic oral solutions, and toothpastes, as well as in domestic cleaning products and air fresheners [15, 16]. Aromatherapy, which was a common therapeutic practice in antiquity, particularly in Egypt and India, still remains widespread under the supervision of official authorities, such as the Aromatherapy Organizations Council in the United Kingdom. It is based on the use of essential oils, which, due to their ability to get easily absorbed by the skin, are used for the relief of symptoms in allergic and rheumatic conditions, displaying anti-aging, revitalizing, and anti-inflammatory activities [17, 18]. Over the past years, the emergence of drug-resistant pathogens drew the attention on essential oils for their potential antimicrobial properties. Owing to the large biological and structural diversity of their components, they are believed to constitute a unique and renewable source for the discovery of much needed new antimicrobials. Based on a recent search in the PubMed database, the published studies on their antimicrobial activities exceed by far the number of studies related to other bioactivities (Table 1). This fact signifies the importance of the antimicrobial potential among various bioactivities of the essential oils.

Although there are many studies on the antibacterial

Table 1. Publications related to various bioactivities of essential oils (PubMed search 9/29/2016).

Activity	Number of publications[a]
Antimicrobial	2671
Antioxidant	1186
Anti-inflammatory	587
Analgesic	388
Anticancer	108
Sedative	102
Spasmolytic	73
Wound healing	44
Immunomodulatory	34
Anti-allergic	22
Gastroprotective	13
Anti-aging	5
Antidepressive	5
Pain relief	4

[a]Keywords used: "name of activity," "essential oil" (*e.g.*, antioxidant activity, essential oil).

activities of essential oils, the results of these studies differ greatly, which is attributed to the heterogeneous chemical structure of the essential oils, the qualitative and quantitative differences of their compounds, and the diverse plant cultivation and gathering conditions. Gram-positive bacteria are more sensitive to essential oils than gram-negatives [12, 19−22], due to the complexity of their outer membrane, which gives the bacterial surface a powerful hydrophilic character, acting as a barrier regarding the cell membrane permeability [12, 21, 23]. Essential oils can directly impair the cell membrane of gram-positive bacteria, causing rupture of the cell membrane, blocking of enzyme systems, and disruption of ion exchange [24]. This kind of damage of the cell membrane permeability is usually lethal for the bacterial cells (cellular death) [12, 21].

Considering the different groups of essential oil compounds, it is most likely that their antibacterial activity is not attributable to one mechanism but that there are several modes of targeting the microbial cell. Important properties of the essential oils, such as hydrophobicity, disturbance of the cytoplasmic membrane, disruption of the electron flow, active transport, and coagulation of cell contents, can be considered as possible mechanisms of their antimicrobial action [12]. Other mechanisms that probably can cause membrane malfunction include disturbances of the pH gradient and the electric potential of the proton motive force [25]. The essential oils that have the most powerful antibacterial properties contain a high percentage of phenolic compounds, like carvacrol, eugenol, and thymol [26], which cause structural and functional disturbances in the cellular membrane [27], and act on cellular proteins that are stuck into the cytoplasmic membrane too [28].

Essential oils are also considered to be natural alternatives to the chemical preservatives in foods, although their practical application is limited because of their aromatic characteristics [19]. Many essential oils that have been internationally characterized by the USA Food and Drug Administration as "Generally Regarded as Safe" are classified among natural products and can be safely used by consumers [26, 29]. However, an overdose of essential oils can cause local or systematic disorders. Instructions for the correct use of essential oils are provided by many international organizations such as the Flavor and Extract Manufacturers Association, the British Essence Manufacturers Association, the International Organization of Flavour Industries, the Research Institute for Fragnance Materials, the International Fragrance Association, the International Federation of Essential Oils and Aroma Trades, and the British Essential Oil Association. The International Standards Organization has laid down rules for the correct management of oils, which include product packaging, standardization, and trading specifications [15].

Basil, Oregano, and Thyme

Basil Essential Oil

Basil is the common name for the culinary herb *Ocimum basilicum* of the family Lamiaceae (Labiatae). The Lamiaceae family is one of the most important families, numbering over 5,000 medicinal and aromatic plant species with extracted essential oils for multiple applications [1]. The genus *Ocimum* L. consists of 70 species and subspecies found in tropical and subtropical regions of Asia, Africa, and Central and Southern America [30−32], as well as in the Mediterranean, represented by the species *O. americanum*, *O. canum*, *O. gratissimum*, *O. tenuiflorum*, *O. trichodon*, *O. citriodorum*, *O. minimum*, *O. micranthum*, *O. grandiflorum*, and *O. urticifolium* [33−35]. Its name is derived from the Greek word βασιλεύς, meaning "king," and according to the tradition, basil grew on the site where the Holy Cross was buried, and it was basil's presence and scent that guided Saint Helen to its discovery [36].

Basil leaves contain essential oil at a percentage of 0.2−1%, with the main components being linalool and estragole (methyl chavicol), as well as *o*-cymene, citral, alpha-pinene, camphene, beta-pinene, geraniol, and geranial [37, 38]. The major components of basil oil vary extensively, depending on genetic factors, geographical origins, nutritional status, the extracted plant parts (stem, leaf, and flower), and the extraction methods [31]. However, because of the variations of the plant and oil composition, several chemotypes have been described with the basic components of linalool and estragole, either alone or in the form of a mixture, as well as in combinations with linalool and eugenol or estragole and methyl eugenol [39, 40]. For instance, six chemotypes for *O. basilicum* and three for *O. gratissimum* have been reported [35]. There are two main types of basil oil, which are widespread in trade: the Reunion Type, mostly composed of estragole (80%), and the European Type coming from France, Italy, Egypt, and South Africa, which is mostly composed of linalool (35−50%) and estragole (15−25%) [33] (Fig. 1).

Basil has long been used in popular medicine as an anti-inflammatory and analgesic and for the treatment of symptoms such as cephalalgia, diarrhea, constipation, indigestion, and cough [41]. It has an antioxidizing effect [34], so it has been used as a spice in cooking [38], as an additive to tomato-based products of high acidity, and as

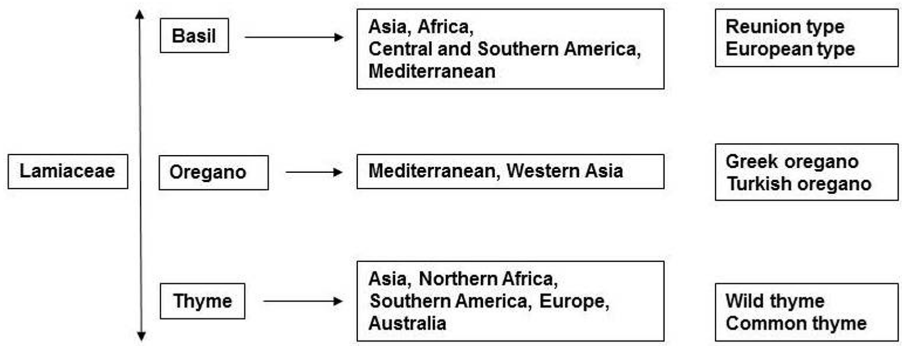

Fig. 1. Distribution and commercial representative species of basil [30–33], oregano [45, 48, 51], and thyme [58, 59].

an inhibitor to contamination by acid-resistant bacteria [19] in foods, particularly in pastry items, tinned meat products, and sausages. Additionally, it is an ingredient of various dental preparations and oral solutions owing to its antiseptic effects [42]. Furthermore, because of the linalool and its insect repulsive effects, it is used in the manufacture of insect repellants particularly suitable for children [43]. Regarding the basil oil toxicity, it has been reported that methyl eugenol and estragole are responsible for cytotoxic damage and cancerogenesis, and according to the Council of Europe, the former must not be detectable, and the latter must not exceed the limit of 0.05% mg/kg in food products [33].

Oregano Essential Oil

This herb belongs to the family Lamiaceae and its main representative species is *Origanum vulgare*. Etymologically, the name *Origanum* comes from the plant's Greek name ορίγανον (origanon), which derives from the words όρος (oros = mountain) and γάνος (ganos = brightness, beauty), since oregano grows at altitudes of 400–1,800 m and sunny places [44]. The *O. vulgare* content of essential oil fluctuates from 0.5–2% [45] up to 7% [46], and its main components are the isomer phenols carvacrol and thymol, as well as their precursor monoterpenes *p*-cymene and γ-terpinene at a lower proportion [45]. Diverse concentrations of the main constituents are reported, coming up to 80% and 64% for carvacrol and thymol, respectively, and up to 52% for each of their precursor molecules [47]. The carvacrol content of different chemotypes of *O. vulgare* is variable and it can be up to 95% [46]. Generally, the essential oil concentration depends on the species, the season of picking the plant, the geographical position, the plant part that is used, and the oil extraction method [47]. Despite the variability of the concentrations of the main components within different species, their total amounts up to 90% of the whole oil composition according to studies on Greek oregano species collected from different geographical regions [45].

The genus *Origanum* L. includes several species of morphological and chemical diversity, and most of them come from the Mediterranean region [48, 49]. The most important species are *O. vulgare* with the subspecies *O. vulgare* subsp. L. *vulgare, O. vulgare* subsp. L. *glandulosum, O. vulgare* subsp. L. *gracile* [45], *O. heracleoticum*, which is mentioned by Dioscourides, and *O. dictamnus* (*Amaracus dictamnus*), which is growing on the mountainous areas of the island of Crete, well known as "Dittany of Crete" for its aphrodisiac and healing properties [19]. Other species include *O. microphyllum* (Crete), *O. scabrum* (Central and Southern Greece) [48], the Turkish oregano *O. onites* that is found in Sicily and Eastern Mediterranean, *O. symes* (Greece), *O. akhdarense* and *O. cyrenaicum* (Libya), *O. libanoticum* (Lebanon), *O. bargyli* (Syria), *O. dayi* and *O. ramonense* (Israel), *O. elongatum* and *O. grosii* (Morocco), *O. floribundum* (Algerie), and *O. petraeum*, *O. punonense*, and *O. jordanicum* (Jordan). The species *O. acutidens, O. solymicum, O. bilgeri, O. minutiflorum* (wild oregano), *O. boissieri, O. saccatum, O. hypericifolium, O. brevidens, O. haussknechtii, O. leptocladum, O. rotundifolium, O. amanum,* and *O. micranthum* are indigenous to Turkey [44, 45, 50]. Closely related species are *O. syriacum* (called za'atar by the Arabs), growing in Southern Europe, Western Asia, and Eastern Mediterranean, and composed of carvacrol, *p*-cymene and γ-terpinene at almost equal concentrations [51], and *O. majorana*, growing in Eastern Mediterranean and Asia, well-known as "marjoram," referred to in Theophrastus' and Dioscourides' scripts, which contains mainly monoterpenes and phenols in smaller concentration [52, 53]. The two most noted commercial oregano species are the Greek *O. vulgare* subsp. *hirtum* and the Turkish *O. onites* [45].

Oregano has been a widespread condiment since antiquity, and its essential oil is recognized for its antiseptic and antispasmodic effects [54]. Members of the genus are widely used as aromatics in food and alcoholic drink products [48]. According to studies related to the antioxidant properties of the oregano essential oil, it has the most intense antioxidant power with remarkable effects in preventing fat oxidation owing to its high content of thymol and carvacrol [55]. However, the use of this essential oil as a food preservative is rather limited because of its strong smell, which affects the food organoleptic properties negatively [25]. The oregano essential oils have been reported to contain highly bioactive compounds that have acaricidal and insecticidal effects [56], as well as promising antibacterial effects against foodborne and food-spoilage bacteria [57, 58].

Thyme Essential Oil

Thyme belongs to the family Lamiaceae and, so far, 928 species of the genus *Thymus* have been identified in Europe, Northern Africa, Asia, Southern America, and Australia. It is an aromatic and medicinal plant of increased commercial interest, with representative species *T. serpyllum* (wild thyme) and *T. vulgaris* (common thyme) [58, 59]. Other species widely spread in the Mediterranean basin are *T. satureioides* (Morocco), *T. willkomii, T. carnosus* (Iberian), *T. moroderi* (Spain), *T. grandulosus* (Spain and North Africa), *T. villosus, T. capitellatus, T. camphoratus* (Portugal), *T. longicaulis, T. poulegioides* (Italy), *T. lotocephalus,* and *T. herba-barona* [60]. The *T. vulgaris* essential oil may contain up to 30 monoterpenes, resulting in a diverse chemical composition of the oils derived from plants of the same species, leading to different chemotypes. For example, in Southern France, there are oil chemotypes of the species *T. vulgaris* with geraniol, alpha-terpineol, thuyanol-4, linalool, carvacrol, and thymol being the prevailing components, whereas in Spain, there is a report of a chemotype with 1,8-cineol being the main component [61]. Thyme oil is one of the 10 most commercial oils worldwide, since it is used as a natural food preservative, has considerable antioxidant, antibacterial, and antifungal effects [62, 63], and is used as an aromatic additive to a variety of foods and drinks, as well as in personal care products (perfumes, cosmetics, soaps, oral solutions) [20, 64].

Antibacterial Activities of Oregano, Thyme, and Basil Essential Oils

The oregano and thyme essential oils have remarkable antibacterial effects, which are associated with the presence of their phenolic components, carvacrol and thymol. In a study by Yamazaki *et al.* [65], carvacrol had the most powerful effect against *Listeria monocytogenes*, followed by thymol, eugenol, cinnamaldeyde, and isoeugenol. In comparative studies including the oregano and thyme essential oils, the two oils demonstrated remarkable antibacterial activity. In a study including four essential oils, the oregano and thyme oils showed the greatest antibacterial effect against *Escherichia coli* O157:H7 [66]. Among 11 essential oils tested against *Bacillus cereus*, the oregano and thyme essential oils were only second to cinnamon essential oil, which showed the most powerful effect [67]. A study including 21 essential oils and five pathogenic bacteria, demonstrated that the thyme, laurel, cinnamon, and clove essential oils had the most potent bacteriostatic and bactericidal effects against *Campylobacter jejuni*, *E. coli*, *Salmonella enteritidis*, *L. monocytogenes*, and *S. aureus* [23]. Among 45 essential oils derived from 13 aromatic plants, the oils of *Satureja montana* and *T. vulgaris*, with the former having carvacrol as its main component and the latter having carvacrol and thymol as its main components, showed the most potent inhibitory effect against the gram-positive *L. monocytogenes* and *S. aureus*, and the gram-negative *S. enteritidis*, *E. coli* O157:H7, *Yersinia enterocolitica*, and *Shigella flexneri* [10]. The essential oils of three species of *Origanum* (*O. vulgare* L., *O. onites* L., *O. majorana* L.) and of two species of *Thymus* (*T. vulgaris* L., *T. serpyllum* L.) showed sufficient inhibitory effect against reference strains of *E. coli*, *E. coli* O157:H7, *S. aureus*, and *Y. enterocolitica* [52]. From 52 essential oils studied against nine gram-positive and gram-negative bacteria (*S. aureus, E. coli, Pseudomonas aeruginosa, Klebsiella pneumoniae, Acinetobacter baumannii, Aeromonas sobria, Enterococcus faecalis, Salmonella* Typhimurium, *Serratia marcescens*), oregano was one of the most effective, inhibiting the growth of all microorganisms at a concentration <2% (v/v) [4]. The *Ocimum micranthum* essential oil, rich in eugenol, showed antibacterial effect against *E. faecalis*, *P. aeruginosa,* and *E. coli*, and was found to be more powerful than that of *O. basilicum* (a chemotype of linalool) and equal to that of *T. vulgaris* (a chemotype of thymol) [68]. The *Origanum scabrum* essential oil, with a high carvacrol content, was effective against *S. aureus*, *Staphylococcus epidermidis, E. coli, Enterobacter cloacae, P. aeruginosa,* and *K. pneumoniae*, whereas *O. acutidens*, also rich in carvacrol, was effective in 27 out of 35 tested bacteria [69]. *O. syriacum*, with carvacrol, *p*-cymene, and γ-terpinene as its main constituents, inhibited the growth of all the tested bacteria [51], whereas *O. microphyllum*, which is inferior in phenolic compounds, was less effective and completely inactive against *P. aeruginosa* and *K. pneumoniae* [48]. In another study including five essential oils and

15 gram-positive and gram-negative bacteria, the oregano oil showed a powerful bacteriostatic and bactericidal effect, compared with sage, peppermint, chamomile, and hyssop oils, which presented a weaker and bacteriostatic-only effect [22]. The *O. vulgare* and *T. vulgaris* oils demonstrated bacteriostatic effect against five gram-positive and eight gram-negative bacterial strains, which was more potent than that of the *Ocimum basilicum* oil, because the latter contained estragole, which lacks the antibacterial properties of thymol and carvacrol contained in the former oils [70]. Schelz *et al.* [71] observed that the essential oil of *T. vulgaris* inhibited the growth of *S. epidermidis* and *E. coli* more efficiently than the essential oils of orange, eucalyptus, fennel, geranium, cedar, ginger, turpentine, rosemary, and tea tree, whereas of 15 essential oils used against foodborne (*L. monocytogenes*, *S. typhimurium*, *E. coli* 0157:H7) and food spoilage bacteria (*Brochothrix thermosphacta* and *Pseudomonas fluorescens*), the oregano, thyme, and cinnamon oils demonstrated the most powerful antibacterial effect [57]. Additionally, the oregano, thyme, and basil oils exhibited sufficient to moderate effects against multi-resistant clinical isolates of *A. baumannii*, *E. coli*, *K. pneumoniae*, and *P. aeruginosa* [72] (Table 2).

Table 2. Various chemotypes of basil, oregano, and thyme essential oils with antibacterial activity.

Common name	Botanical name	Chemotype	Ref.
Basil oil	*O. micranthum*	Eugenol	[68]
	O. basilicum	Linalool	[38, 68]
	O. basilicum	Estragole	[70, 72]
Oregano oil	*O. vulgare*	Thymol	[22]
	O. vulgare	Carvacrol, thymol	[70]
	O. scabrum	Carvacrol	[69]
	O. acutidens	Carvacrol	[69]
	O. syriacum	γ-Terpinene, carvacrol, *p*-cymene	[51]
	O. compactum	Carvacrol	[57]
	O. heracleoticum	Carvacrol	[57]
	O. majorana	Terpinene-4-ol	[57]
Thyme oil	*T. vulgaris*	Carvacrol, thymol	[10, 70]
	T. vulgaris	Thymol	[68]
	T. vulgaris	Thymol, *p*-cymene	[72]

Antifungal Activity of Oregano, Thyme, and Basil Essential Oils

The antifungal activity is directly dependent on the phenolic alcohol content of the oil, which confirms the general acceptance that their antimicrobial potency is determined by their chemical composition [73, 74]. The findings of the relative studies are not always comparable, due to several reasons, such as the divergence in the quality of the herbs, the qualitative and quantitative variations of the essential oils' compounds, differences between the tested fungal strains, and methodological disparities [75]. In a study including 16 essential oils, which were tested against fungi isolated from bakery products, thyme was one of the oils that showed the most powerful inhibitory effect [26]. Giordani *et al.* [74] reported that *Candida albicans* was inhibited by the essential oil of thyme (*T. vulgaris*), which is rich in thymol, and of oregano (*O. vulgare*), which is rich in carvacrol, whereas the effect of other thyme chemotypes poorer in phenolic components was inferior. Pina-Vaz *et al.* [76], after testing the essential oils of *T. vulgaris*, *T. zygis*, and *T. mastichina* against seven *Candida* spp. strains, concluded that *T. vulgaris* and *T. zygis* oils, with high carvacrol and thymol content, respectively, were more potent inhibitors than *T. mastichina* oil in which the main component was 1,8-cineol. Another study reported that the oregano essential oil with carvacrol inhibited the growth of *C. albicans* both in vitro and in vivo; similar results were achieved by the two phenolic compounds (carvacrol and eugenol) of the oregano essential oil tested in vitro and in vivo against clinical strains of C. *albicans*, and the *O. virens* essential oil, rich in carvacrol, against *Candida* spp. strains [77]. Similar antifungal effect was observed for *T. poulegioides*, with high thymol and carvacrol concentrations, against *Candida* spp., *Aspergillus* spp., and dermatophyte species [78]. When Tampieri *et al.* [75] examined 16 essential oils against a clinical strain of *C. albicans*, *O. vulgare* demonstrated the greatest inhibitory effect. Thyme essential oil was one of the most potent antifungals out of 12 oils tested against *Aspergillus flavus*, *Aspergillus parasiticus*, *Aspergillus ochraceus*, and *Fusarium moniliforme* [79]. In another study, oregano and thyme oils displayed significant antifungal activity against clinical strains of *C. albicans*, *C. parapsilosis*, *C. tropicalis*, and *C. glabrata* [80] (Table 3).

In summary, the basil essential oil's antibacterial activity is attributed to its high content in linalool and estragole, whereas the antimicrobial spectrum is restricted to specific bacteria (*Staphylococcus* spp., *Enterococcus* spp., *E. coli*, *P. aeruginosa*, *A. baumannii*, *A. hydrophila*, *B. cereus*, *Bacillus subtilis*, *Enterobacter* spp., *Listeria* spp., *Proteus* spp., *Salmonella* spp., *Serratia marcescens*, and *Y. enterocolitica)* and fungi *(Candida* spp., *Rhodotorula* spp., and *Saccharomyces cerevisae)*. The oregano oil antimicrobial effect is accredited to carvacrol

Table 3. Antifungal activity of basil, oregano, and thyme essential oils.

Common name	Botanical name	Chemotype	Activity	Ref.
Basil oil	*O. basilicum*	Estragole	*Aspergillus* spp., *F. moniliforme*	[79]
	O. basilicum	Estragole	*Candida* spp.	[72]
	O. basilicum	Estragole	*Candida* spp.	[75]
Oregano oil	*O. vulgare*	Carvacrol	*C. albicans*	[74, 75]
	O. virens	Carvacrol	*Candida* spp.	[77]
Thyme oil	*T. vulgaris*	Thymol	*C. albicans*	[74]
	N.D*	Thymol, *p*-cymene	*Eurotium* spp., *Aspergillus* spp., *Penicillium* spp.	[26]
	T. vulgaris	Carvacrol	*Candida* spp.	[76]
	T. zygis	Thymol	*Candida* spp.	[76]
	T. mastichina	1,8-Cineol	*Candida* spp.	[76]
	T. poulegioides	Carvacrol, thymol	*Candida* spp., *Aspergillus* spp., dermatophytes	[78]
	T. vulgaris	Carvacrol	*C. albicans*	[75]
	T. vulgaris	Thymol, *p*-cymene	*Aspergillus* spp., *F. moniliforme*	[79]
	T. vulgaris	Thymol, *p*-cymene	*Candida* spp.	[80]

*N.D = no data.

and thymol, and its antimicrobial spectrum is broad, including bacteria (methicillin-resistant *S. aureus*, *Listeria innocua*, *L. monocytogenes*, *A. baumannii*, *K. pneumoniae*, *Citrobacter freundii*, *S. enteritidis*, *S. typhimurium*, *E. coli*, *E. coli* O157:H7, *P. vulgaris*, *P. aeruginosa*, *P. fluorescens*, *Y. enterocolitica*, *Bacillus subtilis*, *B. cereus*, *Serratia liquefaciens*, *Lactobacillus carvatus*, and *Lactobacillus sakes)*, fungi (*Aspergillus* spp. and *Candida* spp.), and parasites (*Blastocystis hominis*, *Entamoeba hartmanni*, and *Endolimax nana)*. The thyme oil antimicrobial effect is also attributed to carvacrol and thymol, and its antimicrobial spectrum is wide, including bacteria (*Aeromonas* spp., *B. cereus*, *B. subtilis*, *E. faecalis*, *L. monocytogenes*, methicillin-resistant *S. aureus*, *S. epidermidis*, *S. enteritidis*, *S.* Typhimurium, *Helicobacter pylori*, *E. coli*, *E. coli* O157:H7, *Y. enterocolitica*, *K. pneumoniae*, *Shigella* spp., *Campylobacter jejuni*, and *P. aeruginosa)* and fungi (*C. albicans C. tropicalis*, *C. glabrata*, *C. krusei*, *C. parapsilosis*, *S. cerevisiae*, dermatophytes, *Fusarium* spp., and *Aspergillus* spp.).

The essential oils, particularly those rich in phenolics, have the potential to alter both the permeability and the function of the cell membrane proteins by penetrating into the phospholipids layer of the bacterial cell wall, binding to proteins and blocking their normal functions. Because of their lipophilic nature, essential oils and their compounds can influence the percentage of unsaturated fatty acids and their structure. However, because of the variety of molecules present in plant extracts, their antimicrobial activity cannot be accredited to a single mechanism but to a number of diverse mechanisms at various sites of the bacterial cell outer and inner components, affecting the functions of cell membrane, cytoplasm, enzymes, proteins, fatty acids, ions, and metabolites. A detailed examination of all the factors potentially influencing the antimicrobial activity of the essential oils should provide the necessary knowledge to unlock nature's hidden apothecary, but it is rather difficult to implement as evidenced by the existing relevant literature. Therefore, considering the current urgent need for new antimicrobials, it is imperative for the plant essential oils and their constituents to be further investigated with regard to their potential as antimicrobial agents.

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