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Chemistry and bioactivities of essential oils of some *Ocimum* species: an overview

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ABSTRACT

Essential oils of different species of the genus *Ocimum* are natural flavouring materials of commercial importance. The data given in current literature are pertaining to the chemical composition of essential oils of different *Ocimum* species *viz*., *Ocimum basilicum* Linn. (alt. *Ocimum basilicum* var. *minimum*, *Ocimum basilicum* var. *purpurience*), *Ocimum campechianum* Mill., *Ocimum canum* Sims. (*Ocimum americanum*), *Ocimum citriodorum*, *Ocimum gratissimum* Linn., *Ocimum kilimandscharicum* Linn., *Ocimum micranthum* Willd., *Ocimum sanctum* Linn., (alt. *Ocimum tenuiflorum* Linn.), *Ocimum selloi* Benth., *Ocimum trichodon*, *Ocimum utricifolium* from different geographical regions. A considerable difference in chemical composition of a particular species is found, which may be due to their occurrence in different eco–climatic zones and changes in edaphic factors. Attention is also focused on the biological properties of *Ocimum* oils which are related to their various interesting applications as antimicrobial, antioxidant, repellent, insecticidal, larvicidal, nematicidal and therapeutic (anti–inflammatory, antinociceptive, antipyretic, antiulcer, analgesic, anthelmintic, anticarcinogenic, skin permeation enhancer, immunomodulatory, cardio–protective, antilipidemic) agents.

1. Introduction

Worldwide demand of essential oils has increased during the past few years. Essential oils are reported in aromatic plants which are distributed in Mediterranean and tropical countries across the world where they are esteemed as an imperative component of the native medicine systems. Almost all plant organs (flowers, buds, stems, leaves, fruits, seeds and roots) of aromatic plants contain essential oils. These are accumulated in secretary cells, cavities, channels, and epidermic cells[1]. Lamiaceae (syn. Labiatae) herb family includes one of the richest essential oil bearing plant family, consists of more than 252 genera and 7 000 species in the vicinity of plant kingdom[2]. Lamiaceae family is known for the wealth of species with medicinal properties, which have been used since early times and many of these species are common in Mediterranean region. Many species of Lamiaceae have long history of uses in culinary spices and folk medicine. For example, oregano, rosemary, sage and thyme are typical seasonings in the Mediterranean region, and especially oregano is consumed in larger quantities all around the world as part of pizza seasoning mix[3]. Although there have been toxic components described for some Lamiaceae plants, the importance of many family members to the culinary and essential oil industries has been commercially explored for more than 75 years[4–6]. Essential oils recovered from the Lamiaceae species have been used against different diseases like intestinal disorder and bronchitis[7].

The genus *Ocimum*, comprising of more than 150 species grows widely and is distributed throughout temperate regions of the world[6,8,9]. *Ocimum basilicum* (*O. basilicum*), *Ocimum gratissimum* (*O. gratissimum*) and *Ocimum sanctum* (*O. sanctum*), commonly known as holy basil, clove basil (wild basil/East India basil) and sweet basil, respectively, are frequently cultivated in several countries of East Asia, Europe, America and Australia for the production of essential oils[10,11]. *Ocimum americanum* (*O. americanum*) formerly known as *Ocimum canum* (*O. canum*), includes wild species in India, but is cultivated

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in Indonesia for its essential oil for commercial purposes. *Ocimum kilimandscharicum* (*O. kilimandscharicum*), a variety species of *O. basilicum*, commonly called African blue basil is known for its camphor like scent of its essential oil. Similarly, *Ocimum minimum* and *Ocimum citriodorum* also include variety species of *O. basilicum* popular in Indonesia, Mexico and Africa for their naturally occurring essential oils as in perfumery and cosmetic applications. Likewise, *Ocimum tenuiflorum* (*O. tenuiflorum*) includes variety species of *O. sanctum*. Traditionally, these *Ocimum* species have been extensively utilized in food and perfumery industries[12]. The aerial parts of the plants are considered as antispasmodic, stomachic and carminative in native medicine[13].

A high degree of polymorphism in the genus *Ocimum* determines a large number of subspecies, different varieties and forms producing essential oils with varying chemical composition offering variable level of medicinal potential[14]. Essential oils extracted from *Ocimum* plants have been reported to possess interesting biological properties. These volatile oils have been applied in perfumery, to inhibit growth of microorganisms, in food preservation and in aromatherapy. The potential uses of *O. basilicum*, *O. canum* *O. gratissimum* and *O. sanctum* essential oils, particularly as antioxidant and antimicrobial agents have also been explored[15-18]. Recently, Mondal *et al*. reviewed the antimicrobial, adaptogenic, antidiabetic, hepato-protective, anti-inflammatory, anti-carcinogenic, radioprotective, immunomodulatory, neuro-protective, cardio-protective and mosquito repellent properties of *O. sanctum*[19]. In order to investigate the structural activity relationship, it is necessary to know the chemical differentiation among volatiles of various *Ocimum* species. Keeping this in view we have reviewed here the chemistry of various samples of *Ocimum* oils from different geographical regions. Further, the objective of our ongoing investigation is to establish biological evaluation of oils as potential source for beneficial uses.

2. Chemical investigation on essential oils

Researches on chemical composition of most of the essential oils were undertaken by various researchers using GC and GC-MS techniques. The other techniques used are Kovat's index from packed capillary column, retention time data from GC, HPLC, GC-MS, capillary GC, HRGG-FID, HRGG-MS and IR, C13, NMR. The constituents were identified by calculation of their retention indices under temperature programmed condition for *n*-alkanes (C8-C20). Identification of individual component was assigned by retention time comparison with authentic components and oil of known composition and by mass spectra with those obtained from Wiley/NIST/Pfleger library spectra as well as with literature data.

3. Chemical composition

Essential oils are very complex natural mixtures which contain about 20-60 components at quite different concentrations. They are characterized by two or three major components at fairly high concentration (20%-70%) as compared to other components present in trace amount. Essential oils are complex mixtures of natural organic compounds which are predominantly composed of terpenic hydrocarbons (myrecene, pinene, terpinene, limonene, p-cymene, α- and β- phellandrene) and terpenoids (oxygen containing hydrocarbons) like acyclic monoterpene alcohols (geraniol, linalool), monocyclic alcohols (menthol, 4-carvomenthol, terpineol, carveol, borneol), aliphatic aldehydes (citral, citronellal, perillaldehyde), aromatic phenols (carvacrol, thymol, safrol, eugenol), bicyclic alcohol (verbenol), monocyclic ketones (menthone, pulegone, carvone), bicyclic monoterpenic ketones (thujone, verbenone, fenchone), acids (citronellic acid, cinnamic acid) and esters (linalyl acetate)[20]. Mono- and sesquiterpenoidal essential oil constituents are formed by the condensation of isopentenyl pyrophosphate units. Diterpenes usually do not occur in essential oils but are sometimes encountered as by-products.

Lawrence classified the basil oils into three large groups' European type, exotic or reunion type and African type according to their chemical composition and geographical origin[21]. He established four essential oil chemotypes (methyl chavicol, linalool, methyl eugenol and methyl cinnamate) and also numerous subtypes of oils extracted from *O. basilicum*[22]. According to the biosynthetic origin of major compounds, he classified them as chemotypes with single or dual biosynthetic pathways. From time to time, other chemotypes *viz*., eugenol-rich and thymol-rich in *O. gratissimum*[23], sesquiterpenes-rich in *O. canum* and *O. sanctum* and terpinene-4-ol-rich[22,24] have also been reported from different places. The *Ocimum* species which are reviewed here for their essential oil chemistry, have been collected from the different countries and regions of the world such as Bangladesh, Brazil, Cameroon, Egypt, Europe, Guinea, India, Iran, Italy, Mali, Nigeria, Pakistan, Rwanda, Thailand, Togo, Turkey, Um Ruaba and Yaounde. Literature survey revealed that chemical constituents and their respective percentage of several *Ocimum* species varied depending upon the origins and cultivars (Table 1).

It can be described from Table 1 that the major constituents which have been isolated from different *Ocimum* oils include 1,8-cineol, linalool, pinene, eugenol, camphor, methyl chavicol, ocimene, terpinene, limonene *etc*. Table 1 also demonstrates that within the *Ocimum* species, there is a clear variation in their composition in terms of type of constituents and their composition. The chemical structures of these compounds are depicted in Figure 1.

4. Biological properties of *Ocimum* oils

Currently, the interests in natural products are focused on sources of alternative, more natural and environmentally friendly antimicrobials, pesticidals and therapeutic activities. The possibility of utilizing volatile oils is now being investigated. Generally the action of volatile oils is the result of the combined effect of both their active and inactive compounds. The inactive compounds might influence resorption, rate of reactions and bioavailability of the active compounds. Several active components might have a synergistic effect. Biological activity of an essential oil is related to its chemical composition. The relation between composition and bioactivity of the essence from the aromatic plants may be attributable both to their major components (alcoholic, phenolic, terpenic or ketonic compounds) and the minor ones present in the oil. It may act together synergistically or antagonistically to contribute to some activity of the tested oil. Experiments on biological activities of essential oils from different *Ocimum* species have been established by numerous researchers. In the present review, we have described the some important bio-properties of different essential oils of *Ocimum* species from different parts of the world.

Table 1

Investigation on chemical composition of essential oils of different *Ocimum* species.

Plant species	Major constituents (%)	Investigator	Place
O. basilicum L.	Methyl chavicol (70.00), Linalool (25.00), Eugenol (5.00)	Mondawi *et al*.[118]	Um Ruaba
O. gratissimum L. 387E	Thymol (35.40), p-Cymene (18.30), Eugenol (10.70)	Ntezuriubanza *et al*.[119]	Southern Western Rwanda
O. gratissimum 345C	Thymol (46.60), γ-Terpinene (22.40)		
O. basilicum	Linalool (45.70), Eugenol (13.40), Methyl eugenol (9.57), Fenchyl alcohol (3.64)	Akgul[120]	Turkey
O. canum Sims. 337C	Linalool (82.30)		
O. gratissimum 345C	Thymol (46.00-7.00)		
O. gratissimum 387E	Thymol (35.40), Eugenol (10.70)		
Ocimum trichodon 213C	Eugenol (74.70)		
Ocimum utricifolium 243C	Trans-Methylisoeugenol (49.70), Trans-β-Ocimene (13.50), Cis-β-ocimene (12.60)		
Ocimum utricifolium 298E	Methyleugenol (73.60)	Janseen *et al*.[26]	Rwanda
Ocimum utricifolium 364A	Trans-Methylisoeugenol (35.60), Cis-β-Ocimene (29.20)		
Ocimum utricifolium 375I	Eugenol (39.40), Cis-β-ocimene (41.00)		
Ocimum utricifolium 378I	Eugenol (37.60), Cis-β-ocimene (39.00)		
Ocimum utricifolium 392G	Methyleugenol (86.60)		
Ocimum utricifolium 401C	Eugenol (71.00)		
Ocimum utricifolium 402C	Eugenol (71.00)		
O. basilicum	Methyl chavicol (87.30), Linalool (5.40), Methyl eugenol (1.50), β-Caryophyllene (2.40), α-Pinene (1.00), β-Pinene (0.80), Limonene (0.50), Camphene (0.20)	Khatri *et al*.[121]	Pakistan
O. basilicum	Linalool, Methyl chavicol, Eugenol	Marotti *et al*.[122]	Italy
O. basilicum	Limonene (10.40), Linalool (50.80)	Zallo *et al*.[28]	Western provinces of Cameroon
O. canum	1,8-Cineole (78.30), β-Pinene (5.80)		
O. gratissimum	p-Cymene (7.00), γ-Terpinene (20.00), Thymol (46.20)		
O. basilicum	Linalool, Methyl eugenol	Chalchat *et al*.[123]	Mali
O. basilicum	Linalool (69.00), Eugenol (10.00), (E)-α-Bergamotene (3.00), Thymol (2.00)	Keita *et al*.[124]	Guinea
O. americanum L. citral type	Geranial (37.70), Neral (27.90)	Mondello *et al*.[125]	Bangladesh
O. americanum L. camphor type	Camphor (38.60), Limonene (10.60)		
O. basilicum var. *purpurascens*	Linalool (29.70), Geranial (27.40), Geranyl acetate (13.80)		
O. sanctum L. green	Eugenol (41.70), Limonene (3.80), E. Caryophyllene (24.40)		
O. sanctum purple	Eugenol (77.50), E-Caryophyllene (10.70)		
O. basilicum	1,8-Cineole (11.00), Linalool (42.50), Estragole (52.20)		
O. basilicum var. *minimum*	Linalool (16.00), Estragole (52.20), 1,8-Cineole (7.40)	Silva *et al*.[126]	North Eastern Brazil
O. basilicum var. *purpurascensus*	Linalool (39.30), α-Muurolol (11.00)		
O. basilicum	Methyl eugenol (78.02), α-Cubebene (6.17), Nerol (0.83), ε-Muurolene (0.74)	Ozcan and Chalchat[127]	Turkey
Ocimum minimum	Geranyl acetate (69.48), Terpinen-4-ol (2.35), Octan-3-yl-acetate (0.72)		

Table 1, continued

Investigation on chemical composition of essential oils of different *Ocimum* species.

Plant species	Major constituents (%)	Investigator	Place
O. gratissimum L.	Eugenol (54.00), 1,8-Cineole (21.60)	Silva *et al.*[10]	Brazil
O. micranthum Willd.	Eugenol (64.80), (E)-β-caryophyllene (14.30), Bicyclogermacrene (8.10)		
Ocimum selloi Benth.	Anethole (64.60), Linalool (20.60)		
O. gratissimum	β-Phellandrene (21.10), Limonene (11.40), γ-Terpinene (21.90), Thymol (11.20)	Tchoumbougnang *et al.*[80]	Yaounde
O. basilicum	Linalool (10.00), Methyl chavicol (60.30), Methyl cinnamate (6.30)	Kasali *et al.*[128]	Nigeria
O. basilicum	Linalool (44.18), 1,8-Cineole (13.65), Eugenol (8.59)	Ismail[107]	Egypt
O. basilicum cv. purple	Methyl chavicol (52.40), Linalool (20.10), Epi-α-cadinol (5.90), Trans-α-bergamotene (5.20)	Sajjadi[13]	Isfahan, Iran
O. basilicum cv. green	Methyl chavicol (40.50), Geranial (27.60), Neral (18.50), Caryophyllene oxide (5.40)		
O. sanctum Shyama	Methyl eugenol (67.80), E-Caryophyllene (17.10)	Awasthi and Dixit [129]	Northern India
O. sanctum Rama	Eugenol (46.20), E-Caryophyllene (27.60), β-Elemene (16.30)		
O. basilicum	β-Ocimene (2.27), Methyl chavicol (92.48)	Bunrathep *et al.*[55]	Pathumthani (Thailand)
O. canum	Linalool (5.65), Neral (34.01), Geranial (37.89), β-Caryophyllene (6.79)		
O. gratissimum	Z-β-ocimene (48.28), β-Caryophyllene (3.06), γ-Muurolene (9.32), α-Farnasene (4.33), Eugenol (25.02)		
O. sanctum	β-Caryophyllene (35.20), Methyl eugenol (53.67)		
O. basilicum	1,8-Cineole (4.00), Linalool (28.60), Estragole (21.70), (E)-Methyl Cinnamate (14.30)	Politeo *et al.*[17]	Austria
Ocimum campechianum Mill.	Eugenol (32.20-60.60), Methyl eugenol (60.60-69.500), 1,8-Cineole (0.90-19.70), Elemicin (0.20-65.90)	Zoghbi *et al.*[130]	North Brazil
O. gratissimum (5 samples)	Thymol (13.10-36.20), γ-Terpinene (0.20-28.10), 1,8-Cineole (0.00-25.20), p-Cymene (4.40-19.90)		
O. basilicum	Linalool (53.00), Methyl chavicol (29.00)	Zheljazkov *et al.*[11]	European basils
O. basilicum	Estragole (85.50), Linalool (1.71)	Koba *et al.*[43]	Lome (Togo)
O. basilicum	Methyl chevicol (70.04), Linalyl acetate (22.54) (13.56), Camphene (7.32)	Anand *et al.*[47]	Uttarakhand, India
O. kilimandscharicum	Camphor (56.07), DL-Limonene		
O. gratissimum	Eugenol (53.89), Cis-ocimene (23.97), Germacrene-D (10.36)		
O. gratissimum	Eugenol (63.70), (Z)-β-ocimene (19.60), Germacrene-D (7.30)	Verma *et al.*[48]	Sub-tropical region of northern India
O. kilimandscharicum	Camphor (63.40), Limonene (7.90), Camphene (5.80), γ-Terpinene (4.70)		
O. basilicum var. purpurascens	Methyl cinnamate (59.95), Linalool (16.40), tau-Cadinal (4.37)	Mohhiuddin *et al.*[131]	Bangladesh
O. basilicum	Methyl chavicol (62.00), Linalool (24.00)	Sastry *et al.*[132]	Deccan Region, India
O. gratissimum	Eugenol (74.80), Limonene 1,8-Cineole (10.80)		
O. tenuiflorum	Eugenol (84.00), β-Caryophyllene (6.90)		

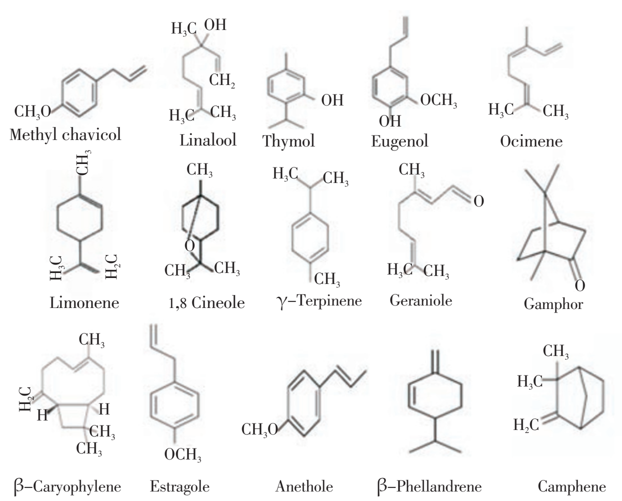

Figure 1. Chemical structure of some foremost compounds isolated from essential oils of *Ocimum* species.

4.1. Antimicrobial activity

The indiscriminate use of antimicrobial agents has resulted in the emergence of a number of drug-resistant bacteria and fungi. To overcome the increasing resistance of pathogenic microbes, more effective antimicrobial agents with novel mode of action must be developed. Essential oils derived from several *Ocimum* species have been reported to be active against several Gram-positive and Gram-negative bacteria as well as against yeasts and fungi due to their terpenic constituents. Recently, essential oils and extracts of certain plants have been shown to have antimicrobial effects[25] as well as imparting flavour to foods[1]. Janssen *et al.* investigated the antimicrobial potential of four *Ocimum* species *viz.*, *O. canum*, *O. gratissimum*, *Ocimum trichodon* and *O. urticifolium* grown in Rwanda against *Escherichia coli* (*E. coli*), *Bacillus subtilis* (*B. subtilis*), *Staphylococcus* aureus (*S. aureus*) and *Trichophyton mentagrophytes* var. *interdigitale*[26]. They found that *O. canum* was the most effective amongst the studied oils. Essential oil extracted from the leaves of *O. sanctum* has been found to inhibit *in vitro* growth of *E. coli, B. anthracis* and *Pseudomonas aeruginosa* (*P. aeruginosa*) which showed its antibacterial activity[27].

As an example of antimycotic activity, the oil of *O. gratissimum* leaves was fungicidal at 78 mg/L for *Microsporum gypseum* and *Trichophyton rubrum*, but a concentration of 312 mg/L was required to inhibit growth of *Candida albicans* (*C. albicans*) and *Cryptococcus neoformans*[28]. Further, Basilico and Basilico reported the antifungal activity of *O. basilicum* oil against *Aspergillus ochraceus* and found that oil was effective at 500 mg/L[29]. At 500 μg/L, *O. canum* oil exhibited 100% mycelial inhibition against *Penicillium italicum*, post-harvest rotting fungus of *Citrus* fruits[30]. Moreira *et al*. worked on antimicrobial activity of *O. basilicum* on survival and growth of different strains of *E. coli* O157:H7[31]. The strains of *E. coli* exhibited similar susceptibilities to the action of the essential oil assayed with the minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) values were 1.9 mL/100mL and 2.0 mL/100 mL, respectively. Mbata and Saikia investigated the antibacterial effect of *O. gratissimum* oil against *Listeria monocytogenes* serotype and reported that at 20-250 μg/mL, the essential oil progressively inhibited the bacterial growth[32]. Similar antimicrobial activity is reported in essential oils isolated from Amazonian basil, *O. gratissimum* and *Ocimum micranthum* (*O. micranthum*)[33,34]. Weseler *et al*. found that MIC value of *O. basilicum* against *Helicobacter pylori* was of 286.7 μg/mL while MBC value increased upto 573.4 μg/mL[35]. Wannissorn *et al*. by using disc diffusion assay, evaluated the antimicrobial activity of *O. basilicum*, *O. basilicum* var. citratum, *O. gratissimum*, *O. tenuiflorum* essential oils from Thailand against zoonotic enteropathogens including *Salmonella* spp., *E. coli* O157, *Campylobacter jejunii* and *Clostridium perferingens* which are important for broiler export[36]. The zone of inhibition ranges of 9-80 mm with *O. basilicum* var. citratum was the most potent. The antifungal activity of eugenol isolated from *O. gratissimum* reported against *Alternaria* and *Penicillium chrysogenum*[37].

Bozin *et al*. reported the antibacterial activity of *O. basilicum* against 13 human pathogenic bacteria and find that the MIC ranges of 8-30 μL/mL[15]. Atanda *et al*. investigated the ability of sweet basil (*O. basilicum*) in the growth control of aflatoxigenic fungus *Aspergillus parasiticus*[38]. Lee *et al*. did the work on inhibitory effect of *O. basilicum* oil and its main constituent eugenol and linalool on *Microsporum gypseum* (guinea pig infection) at MIC of 0.01%-0.03%[39]. Similarly, *O. basilicum* inhibited the growth of *S. enteritidis* at MIC=20.0-80.0 μg/mL[40], *O. forskolei* Benth. oil of *B. subtilis* and *S. aureus* by diffusion test were at MIC 32 μg/mL and 128 μg/mL, respectively, and *O. sanctum* of *Alternaria alternata*, *Aspergillus* species, *Penicillium* species, *Fusarium nivale* were at MIC 0.3 μL/mL[41,42]. The *in vitro* microbiological experiments of Koba *et al*. revealed that only the methyl eugenol and methyl eugenol/t-anethole chemotypes were active against tested fungi and bacteria[43]. Their MIC against fungi ranged from 80-150 μL/L and from 200-500 μL/L respectively. Likewise, on tested bacteria, the MIC varied from 200-400 μL/L and from 250-500 μL/L respectively. In this work, there is no doubt that the antifungal activity of *O. basilicum* chemotype methyleugenol against tested fungi is a predictable consequence of its high content in methyleugenol known as one of the phenolic volatile molecules endowed with antimicrobial properties[44]. Pandey *et al*. did work on the antimicrobial activity of *O. sanctum* against seven bacteria (*Bacillus pumilus, B. subtilis, S. aureus, E. coli, Klebsiella pneumoniae, P. aeruginosa* and *Salmonella typhi*), two filamentous fungi (*Aspergillus niger* and *Aspergillus flavus*) and a yeast (*C. albicans*)[45]. The oil inhibited 100% microbial growth at 700 mg/L for bacteria and 1 300 mg/L for fungi. Recently, Singh *et al*. investigated that essential oil of *O. canum* strongly inhibited the mycobial growth of seven post-harvest pathogenic fungal species (*Aspergillus flavus, Aspergillus nidulans, Aspergillus niger, Aspergillus ochraceus, Mucor* sp., *Penicillium italicum, Penicillium oxalicum* and *Rhizopus arrhizus*) and found that oil was toxic at 500 mg/L against all the fungi[46]. Anand *et al*. look for the antimicrobial activity of essential oils of three *Ocimum* species *viz*., *O. basilicum*, *O. kilimandscharicum* and *O. gratissimum* against Gram-positive (*S. aureus, Enterococcus faecalis*) and Gram-negative (*E. coli, P. aeruginosa*) bacteria as well as yeast *C. albicans*[47]. Report revealed that *O. gratissimum* oil was the most effective with MIC values ranging from 1.5-12.5 mg/mL. Verma *et al*. evaluated the antibacterial activity of *O. gratissimum* and *O. kilimandscharicum* against *S. aureus*, *Streptococcus mutans*, *Enterococcus faecalis* and found that *O. gratissimum* oil was more toxic against all tested bacterial strains and showed a zone of inhibition ranging from 8-16 mm[48]. Pandey *et al*. investigated that *O. sanctum* oil was found to be toxic against two plant pathogenic bacteria *Erwinia herbicola* and *Pseudomonas putida* by exhibiting complete inhibition of their microbial growth[49]. Oil exhibited the MIC 2.0 μL/mL for *Erwinia herbicola* and 1.0 μL/mL for *Pseudomonas putida*, but was bactericidal at higher doses of 8 and 4 μL/mL respectively.

4.2. Antioxidant activity

Antioxidants are substances that inhibit the oxidation of our cells from toxins such as free radicals. The toxins can be from the natural digestion and metabolism of foods, alcohol, nicotine from cigarette smoke, environmental factors, OTC drugs such as acetaminophen, (Tylenol®) prescription drugs, preservatives, *etc*. Reactive oxygen species (ROS) including singlet oxygen ($^1O_2$), superoxide ion (O^{2-}), hydroxyl ion (OH-), and hydrogen peroxide (H_2O_2) are highly reactive and toxic molecules generated in cells during normal metabolism. However, in response to a variety of factors including tobacco smoke, pollutants, ionizing radiations, alcohol, synthetic pesticides, and solvent, their production increases. ROS can cause oxidative damage to proteins, lipids, enzymes, and DNA, and they have also been linked to pathogenesis of oxidative diseases. Living cells possess an excellent scavenging mechanism to avoid excess ROS induced cellular injury, however, with ageing and under influence of external stresses, these mechanisms become inefficient, and dietary supplementation of synthetic antioxidants is required[50]. In this context, aromatic plants, particularly their essential oils, are being evaluated for antioxidant activity. *Ocimum* plants contain large amounts of antioxidants other than vitamin C, vitamin E, flavonoids and carotenoids. The presence of many pharmacologically active compounds in *Ocimum* species provides them protection against free radical induced oxidative damage of cellular components. The antioxidant capacity of basil essential oils has been studied several times[51-54]. Bunarathep *et al*. reported the comparative antioxidant activity of essential oils of four *Ocimum* species (*O. basilicum*, *O. canum*, *O. gratissimum* and *O. sanctum*) by DPPH bioassay and found that *O. gratissimum* was the most antioxidative followed by *O. sanctum*, *O. canum* and *O. basilicum* with EC_{50} values 30.20, 767.82, 8 343.19 and 47 057.45 μg/mL respectively[55]. Politeo *et al*. pointed out the antioxidant capacity of free volatile aglycons from basil (*O. basilicum*) by two different methods which were 2,2-diphenyl-1-picrylhydrazyl radical scavenging method (DPPH) and ferric reducing/antioxidant power assay (FRAP)[17]. DPPH method shows that free volatile aglycones possess good antioxidant properties comparable with that of the essential oil and well-known antioxidant butylated hydroxytoluene, but less than pure eugenol. The results obtained by FRAP method showed that these compounds are somewhat less effective antioxidants than essential oil and butylated hydroxytoluene. From time to time, potential uses of *O. sanctum*, *O. gratissimum* and *O. basilicum* essential oils as antioxidant agent have been explored[15,16,18]. Trevisan *et al*. evaluated the antioxidant capacity of essential oils obtained by steam hydrodistillation from five species of the genus *Ocimum*, namely *O. basilicum* var. *purpurascens*, *O. basilicum*, *O. gratissimum*, *O. micranthum* and *O. tenuiflorum* (syn. *O. sanctum*), using a high-performance liquid chromatography-based hypoxanthine/xanthine oxidase and the DPPH assays[56]. In the hypoxanthine/xanthine oxidase assay, strong antioxidant capacity was evident in all the oils, but the greater was shown by that obtained from *O. tenuiflorum* (syn. *O. sanctum*) (IC_{50}=0.46 μL/mL) compared to *O. basilicum* var. *purpurascens* (IC_{50}=1.84 μL/mL). In the recent research, *O. sanctum* and Omani basil oils were also found to possess significant antioxidant action[57,58].

4.3. Repellent, insecticidal, larvicidal and nematicidal activities

Plant based fumigants have long been touted as attractive alternatives to synthetic fumigants for arthropods management because botanicals reputedly pose little threat to the environment or to human health. Genus *Ocimum* is known for pesticidal properties due to diverse group of compounds in its essential oil. Basil oil contains bioactive constituents that are insecticidal and repellent[59-62]. Esther *et al*. observed that oil extracted from the leaves of tropical shrub, *O. suave* cause mortality in all stages of the tick *Rhipicephalus appendiculatus*[63]. A 10% solution was found to kill all immature and more than 70% of adults feeding on rabbits. The toxicity of the result in this study may be due to the toxic effects of the compounds eugenol, mono and sesquiterpenoids found in the plant extract[64]. Sosan *et al*. studied on larvicidal activity of *O. gratissimum* on larvae of *Aedes aegypti* L. (*Ae. aegypti*) and found that oil exhibited 100% mortality at 300 mg/L concentration of 24 h exposure[65]. However, a related species *O. canum* growing in Zimbabwe was reported to exhibit repellency against adults of *Ae. aegypti*[66]. Aslan *et al*. tested essential oil from *O. basilicum* for their toxicity against the nymphs and adults of *Tetranychus urticae* (Acari: Tetranychidae) and adults of *Bemisia tabaci* (Aleyrodidae)[67]. Cavalcanti *et al*. determined the larvicidal activity of essential oils from Brazilian plants *O. americanum* and *O. gratissimum* against *Ae. aegypti*[68]. The results showed that *O. americanum* and *O. gratissimum* have LC_{50} of 67 and 60 mg/L respectively. Ilondu *et al*. observed that *O. suave* (wild basil) caused mortality of adult *Rhyzopertha dominica* in grain cereals at the 2-8 g plant materials per 50 g cereals (rice, maize and sorghum)[69]. This protects the cereals after 90 d post treatment. Olonisakin *et al*. reported the insecticidal activity of *O. shave* against *Callosobruchus maculatus* with LC_{50} values of 0.66 mg/10 g seed[70]. Lopez *et al*. found that estragole is example of toxic fumigant compound in the basil essential oil (*O. basilicum*) that is active against insect pests[71]. Bakr *et al*. evaluated the insecticidal effect of volatile oil from basil (*O. basilicum*) against two museum insect pests black carpet beetle (*Attagenus fasciatus*, a pest in the museums where it attacks) and cigarette beetle (*Lasioderma serricorne*, a pest of stored tobacco), LC_{50} values of oil against larvae and adults of the black carpet beetle were 1.787 86 and 2.056 47 mL/80 cm^3 as well as 1.660 9 mL/80 cm^3 and 2.014 59 mL/80 cm^3 for the larvae and adults of cigarette beetle, respectively[72]. Manzoor *et al*. reported the *O. sanctum* oil as toxicant and repellent agent against termite, *Heterotermes indicola*[73]. Similarly, Basil oil (*O. basilicum*) and its major constituent's trans-anethole, estragole, linalool were insecticidal to adult fruit flies of *Ceratitis capitata* (*C. capitata*), *Bactrocera dorsalis* (*B. dorsalis*), and *Bactrocera cucurbitae* (*B. cucurbitae*)[74]. The toxic action of basil oil in *C. capitata* occurred significantly faster than that of in *B. cucurbitae*, but slightly faster than that of in *B. dorsalis*. Estragole acted faster in *B. dorsalis* than that of in *C. capitata* and *B. cucurbitae*. Linalool action was faster in *B. dorsalis* and *C. capitata* than that of in *B. cucurbitae*. Trans-anethole action was similar to all the three species. Methyl eugenol acted faster in *C. capitata* and *B. cucurbitae* than that of in *B. dorsalis*. When linalool was mixed with cuelure (attractant to *B. cucurbitae* male), its potency to the three species decreased as the concentration of cuelure increased. Oil of *O. suave* (wild basil) was used under ambient conditions with the aim of evaluating the toxicity of the plant oil on adult housefly-*Musca domestica*[75]. The oil applied at 0.05, 0.10, 0.15 and 0.20 mL/L caused significant mortality of the housefly. The LC_{50} was 0.09 mL/50 mL of water, and the LT_{50} was 4.40 h. This result shows that *O. suave* leaf oil could be used as an alternative to synthetic insecticides for the control of *M. domestica*. More recently, Pandey and Tripathi reported that the dose of 5 and 10 μL *O. sanctum* oil was responsible for absolute repellent and insecticidal activities against pulse beetles *Cryptocarya chinensis* and *Callosobruchus maculatus* respectively[76]. Rajamma *et al*. examined the comparative larvicidal activity of different species of *Ocimum* (*O. sanctum*, *O. basilicum* and *O. gratissimum*) against larvae of *Culex quinquefasciatus* in terms of LD_{50} value on late third or early fourth instar larvae for a period of 24 h[77]. A comparison of LD_{50} value has shown that *O. basilicum* oil is more active than the other two species. The LD_{50} value of *O. basilicum* and *O. sanctum* oils were 39.31 and 40.02 μL/L on the laboratory reared larvae and 129.53 and 139.49 μL/L on field collected larvae. Laboratory reared larvae were more sensitive than field collected larvae.

Bioassay tests were conducted to find out the nematicidal activity of *O. basilicum* oil against *Meloidogyne inconita*[78]. The oil was highly toxic at 250 mg/L. Holetz *et al*. studied on effect of essential oil of *O. gratissimum* on the trypanosomatid *Herpetomonas samuelpessoai*[79]. They observed that at from 20-250 μg/mL, the essential oil progressively inhibited the protozoan growth. The IC_{50} in defined and complex media, at 28 °C were 100 and 91 μg/mL, respectively. Tchoumbougnang *et al*. investigated the antimalarial activity of *O. gratissimum* essential oil on mice infected with *Plasmodium berghei*[80]. The oil showed maximum 77.5% activity at 500 mg/kg of mouse per day. Oil also showed significant suppression of parasitaemia (55%-77.8%) at oral dose ranges of 200-500 mg/kg per day. Santoro *et al*. worked out on *O. basilicum* oil and it active constituent eugenol, linalool and observed that they were strong inhibitor of *Trypanosoma cruzy* which causes epimastigotes, trypomastigotes with LC_{50} values ranges of 99.5-57.5 lg/mL[81].

4.4. Therapeutic properties of Ocimum oils

A variety of curative properties have been recognized to *Ocimum* species. The medicinal plants are rich in secondary metabolites (which are potential sources of drugs) and essential oils of therapeutic importance. The important advantages claimed for therapeutic uses of medicinal plants in various ailments are their safety besides being economical, effective and easy available. Several studies have shown that steam distilled essential oils extracted from fresh leaves of *Ocimum* species have therapeutic importance.

4.4.1. Anti-inflammatory, antinociceptive, antipyretic, antiulcer, analgesic and anthelmintic properties

Essential oil (200 mg/kg body weight) of fresh leaves and fixed oil (0.1 mL/kg, body weight) of seeds (fixed oil) of *Ocimum* species have proved as anti-inflammatory agent on experimental animal's hind paw edema induced by carrageenan, serotonin, histamine and prostaglandin-E-2, significantly reduce the edema when compared with the saline treated control[82]. The oil of *O. sanctum* was found to possess significant anti-inflammatory activity against carrageenan and different other mediator-induced paw edema in rats[83]. This result supports the dual inhibition of arachidonate metabolism and indicated by its activity in inflammation models that are intensive to selective cyclooxygenase inhibitors. The mechanism of action of the anti-inflammatory effects of Tulsi could be the cyclo-oxygenase and lipooxygenase pathways[83,84]. In earlier work, oil of *O. sanctum* was found to inhibit the inflammation induced by carrageenan[85]. The oil also possesses significant antipyretic, analgesic and antiarthritis activity without any noticeable toxicity[86]. Sahouo *et al*. reported inhibitory effect produced by chemical constituents of *O. gratissimum* essential oil as anti-inflammatory and analgesic drugs, *in vitro*, on soybean lipoxygenase L-1 and cyclooxygenase function of prostaglandin H synthase (PGHS), the two enzymes involved in the production of mediators of inflammation[87]. *O. gratissimum* inhibited the two enzymes, cyclooxygenase function of PGHS and lipoxygenase L-1, with an IC_{50} values of 125 and 144 μg/mL respectively. The proteins implicated in production of mediators of inflammation, proposed in literature, were PGHS and lipoxygenase-5LO. Their natural substrate is arachidonic acid. Indeed, it is well established that PGHS catalyzed biotransformation of arachidonic acid into prostaglandins, thromboxanes and prostacyclins which are mediators of inflammation, hormonal modulation and platelet aggregation. Lipoxygenase 5LO catalyzed biotransformation of arachidonic acid into fatty acid hydroperoxides, lipoxines, and leukotrienes, compounds implicated in allergy and suffering. Lipoxygenase L-1 was a model of lipoxygenase 5LO and its natural substrate was linoleic acid[88]. Singh *et al*. showed that *O. sanctum* oil produced hypotensive effect in anaesthetized dog, which seems to be due to its peripheral vasodilatory action. The oil increased blood-clotting time and percentage increases were comparable to aspirin and could be due to inhibition of platelet aggregation[89]. The oil also showed inhibition towards cytochromatic enzyme responsible for hepatic metabolism of pentobarbitone. Both eugenol and *O. gratissimum* oil presented anthelmintic activity against *Haemonchus contortus*, the main nematode of ovines and caprines in Northeastern Brazil[90].

The essential oil of *O. micranthum* was studied for a possible analgesic effect on the acetic acid induced writhing and formalin test in mice and antioedema activities on the carrageenan and dextran induced paw edema in rats. The essential oil demonstrated antinociceptive effects, and pretreatment with naloxone did not reverse the antinociception, indicating that the opioid system is not involved. On the other hand, pretreatment with L-arginine reversed the antinociception, suggesting involvement of the nitric oxide system. The essential oil did not present an antioedematogenic effect in the carrageenan and dextran models[91]. Rabelo *et al*. found that *O. gratissimum* oil produced a dose-dependent inhibition of acetic acid-induced writhing, causing up to a ~60% inhibition at the highest dose (300 mg/kg) used during their experiment antinociceptive effects of *O. gratissimum* essential oil in mice[92]. The therapeutic use of *O. sanctum* in treatment of gastric ulcer has been attributed to antiulcerogenic action of eugenol and essential oil extracted from Tulsi leaves[93,94].

4.4.2. Anti-cancerous property

Estragole, a constituent of *O. basilicum* essential oil, has shown carcinogenic properties in rat and mouse[95,96]. Prakash and Gupta investigated the chemoprotective activity of *O. sanctum* oil against subcutaneously injected 20-methylcholanthrene induced fibrosarcoma tumors in the thigh region of Swiss albino mice and found that supplementation of maximal tolerated dose (100 μL/kg body weight) of the oil significantly reduced 20-methylcholanthrene induced tumar incidence and tumor volume[97]. Earlier they reported the antiproliferative activity of the *O. sanctum* oil against HeLa cells in culture[98]. Manosroi *et al*. have shown an inhibition of the proliferation of murine leukemia and human mouth epidermal carcinoma cell lines by essential oils of *O. sanctum*, *O. basilicum* and *O. americanum*[62].

4.4.3. As skin permeation enhancers

The delivery of drugs via skin routes has been extensively studied. Dermal and transdermal drug delivery is often limited by poor pfermeability of the stratum corneum (SC) to drugs, which precludes their crossing the skin at therapeutic rates. The barrier properties of the SC can be reduced by the use of natural products. Essential oils are receiving considerable interest as enhancers to improve drug permeation. Essential oil of sweet basil (*O. basilicum*) was evaluated as skin permeation enhancer to promote the precutaneous absorption of drugs and reported it as noble enhancers[99].

4.4.4. Cardiovascular and anti-lipidemic actions of Ocimum oils

Both *O. gratissimum* oil and eugenol decrease the blood pressure in conscious DOCA-salt hypertensive rats exhibiting its cardiovascular effects[100]. In earlier research, Lahlou *et al*. found that intravenous treatment of normotensive rats with *O. gratissimum* oil and its main constituent eugenol dose dependently decreased mean aortic pressure[101]. Eugenol was also reported to induce vasorelaxant effects on rat and rabbit thoracic aorta as well as on rat mesenteric vascular bed[102-104].

Essential oil from *O. sanctum* leaves has been shown to have a potential for lipid-lowering action. The anti-hyperlipidaemic ability of the essential oil extracted from *O. sanctum* leaves in rats fed with high cholesterol diet was investigated[105]. In conclusion, the researchers found that there was no significant differences in body weight gain, food intake, and heart weight in all groups of rats. Authors observed that phenylpropanoid compounds, the main composition of *O. sanctum* essential oil is responsible for the lipid lowering effect in high cholesterol rats[105]. In another finding by treating with *O. sanctum* oil to rats fed with a high cholesterol diet, it was found that essential oil suppressed the high serum lipid profile and atherogenic index as well as serum lactate dehydrogenase and creatine kinase MB subunit without significant effect on high serum levels of aspartate aminotransferase, alanine aminotransferase and alkaline phosphatase in rats fed with high cholesterol diet[57]. Oil was also found to decrease the high level of thiobarbituric acid reactive substances, glutathione peroxidase and superoxide dismutase without impacting catalase in the cardiac tissue while in the liver, it decreased high level of thiobarbituric acid reactive substances without significantly effecting glutathione peroxidase, superoxide dismutase and impacting catalase. Authors concluded that essential oil of *O. sanctum* has lipid-lowering and antioxidative effects that protect the heart against hypercholesterolemia.

4.4.5. Immunomodulatory and CNS activity of Ocimum oils

In current competitive life, stress is a very common problem for human beings. Assembly of more free-radicals due to stress leads to activity adverse effects on various vital organs and tissues of the human body. *Ocimum* essential oil has gained special attention due to its biological properties, however, little is known about its immunomodulatory effects. The immunomodulatory potential of *O. sanctum* oil on some immunological parameters in stressed and non-stressed animal was carried out[106]. They concluded that by penetrating the oil it exert immunomodulatory effect by modulating GABAergic activity and influence both humoral and cell mediated immunological parameters in native non-stressed as well as stressed animals[106]. In this context, some CNS activities *viz*., sedative, hypnotic, anticonvulsant, local anesthetic of *O. basilicum* essential oil were also investigated by Ismail[107]. When tested in mice, *O. basilicum* oil had no effect on motor activity up to a dose of 1.2 mL/kg at 90 mm post-administration. Pentabarbitone sleeping time tested in mice was significantly increased in mice by all doses of essential oil higher than 0.2 mL/kg. Intraperitoneal of oil significantly increased in a dose dependent manner, the latency of convolution and percent of animal exhibiting clonic seizures. He found ED_{50} values of oil were 0.61, 0.43 and 1.27 mL/kg against convulsion induced by pentylenetetrazole, picrotoxin and strychnine, respectively. He noted that the observed anticonvulsant and hypnotic activities of oil could be related to the presence of variety of terpenic constituents in it. It has been reported that terpenes have a protective effect against pentylenetetrazole and picrotoxin-induced convulsions[108,109]. Modulation of glutamergic and GABAergic transmission are mechanisms indicated for anticonvulsant action on monoterpenes[110]. Linalool, the most abundant constituent of *Ocimum* oil, has anticonvulsant activity against pentylenetetrazole-induced convulsion and also through inhibition of glutamergic transmission as well as through suppression of voltage-gated current[111-113]. On the other hand, other main constituent of 1,8-cineole exerts anticonvulsant activity, potentiates phenobarbitone sleeping time, and has an inhibitory effect on locomotory activity[114]. Eugenol, the other representative constituent, also exerts anticonvulsant property through potentiating binding of GABA to its receptor and by increasing the affinity of these receptors to bind GABA[115]. Additionally, eugenol has anesthetic, sedative, and muscle relaxant effects[116].

In research of Oliveira *et al.*, CNS depressant and anticonvulsant effects of *O. basilicum* (access "Maria Bonita") leaf essential oil in different experimental models were investigated[117]. *O. basilicum* essential oil, at all doses, showed depressant CNS activity as revealed in the general pharmacological screening; decrease of spontaneous activity, ataxia, and sedation. Additionally, all doses of *O. basilicum* essential oil induced a significant increase of sleeping time ($P<0.05$) and decrease in the latency to sleep ($P<0.01$). *O. basilicum* essential oil also increased the latency for development of convulsions in pentylenetetrazol and picrotoxin tests ($P<0.05$). For pentylenetetrazol, the effect of *O. basilicum* essential oil was reversed by flumazenil. *O. basilicum* essential oil did not interfere with the convulsions induced by strychnine ($P>0.05$). Their data suggests that *O. basilicum* essential oil possesses CNS depressant and anticonvulsant properties which could be mediated by an interaction with central GABAergic receptors.

5. Conclusions

There are many herbal plants in the world among which *Ocimum* (Tulsi) is considered to be the ruler of herbs due to its great medicinal ethics. Various medicinal properties of Tulsi are well documented in the Hindu mythology. Considering the health beneficial effects of Tulsi, our ancestors in India insisted to plant a Tulsi sapling in everyone's house. The composed literature revealed that essential oils of collected *Ocimum* species from different geographical origins existed variety of chemical constituents, and the researchers found vide and varied application in traditional healthcare system. The review of past studies which has been discussed in this chapter showed that essential oils obtained from *Ocimum* plants have gained much appreciation among food scientists and researchers because of their multifold biological activities. The reviewed results aimed at attracting the attention of scientists and researchers looking for new drugs from natural products as well as those investigating the pharmaceutical diversity of essential oils. The data reported in the present study provide a basis for reviving the old art of "essential oil therapy" based on our modern scientific knowledge of their mode of action, supported by safety issues. Probably, such natural components might prove to be potentially beneficial but comparatively less toxic. Eventually, plants belonging to *Ocimum* genus could contribute a lot to solve certain economy and health problems. Thus, essential oils and their constituents of *Ocimum* species can hopefully be considered in the future for more clinical evaluations and applications, and as possible adjuvants to current medications.

Conflict of interest statement

We declare that we have no conflict of interest.

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