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Review Research Paper

Phytochemical Diversity and Antimicrobial Efficacy of *Origanum vulgare* L. Essential Oil: A Review

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ABSTRACT

The Lamiaceae family is known for its rich diversity and valuable compositions of essential oils. *Origanum vulgare* L.is recognized for their strong aromatic qualities and therapeutic uses.These oils are rich in bioactive molecules such as thymol and carvacrol. Constitutes like linalool, γ-terpinene, and sabinene hydrate contribute as important part in the essential oil and contribute to many health benefits. Due to its aromatic and medicinal properties, oregano is used widely in also in the pharmaceutical, cosmetic, and wellness industries. A wide range of diversity in the essential oil composition of the *Origanum vulgare* L. has been reported. Caryophyllene oxide, sabinene, caryophyllene oxide–(E)-β-caryophyllene, (E) β-caryophyllene, carvacrol, and thymol–carvacrol were the chemotypes discovered from many countries.The essential oil of *Origanum vulgare* L. has exhibited strong antimicrobial activity, making it a promising natural alternative to synthetic agents. This study supports the identification of active constituents across various chemotypes and emphasizes the potential of natural remedies as safer alternatives to synthetic treatments.

1. Introduction

The Lamiaceae family, common across many parts of the world, is defined by distinctive botanical characteristics such as square-shaped stems, opposite leaf arrangement in a decussate pattern, and two-lipped tubular flowers [1]. A large number of species in this family are known for their fragrance and have historically been important in both folk remedies and modern healthcare [2].*Origanum* genus belongs to family Lamiaceae includes a diverse range of herbaceous, shrubby, and perennial species renowned for their strong aromatic qualities and therapeutic uses[3]. The name "oregano" is derived from the Greek terms "oreos" meaning mountain and "ganos" meaning delight or beauty, symbolizing "joy of the mountain" [4]. These plants naturally grow in warm, hilly regions. *Origanum vulgare* L., commonly known as oregano or wild marjoram, is the most widely recognized and commercially important species.Origanum vulgare L., also known as Vantulsi or Badri tulsi. Oregano (*Origanum vulgare* L.) has one of the broadest natural distributions among its genus, extending from the Mediterranean basin through much of Europe and into Central Asia. Its native habitat spans Southern, Central, and Eastern Europe.

The species is also indigenous to parts of North Africa, including Algeria, Tunisia, and Morocco [5]. In Asia, it ranges widely from the Middle Eastern countries of Iran and Iraq to the Indian subcontinent, including India, Pakistan, and Nepal, and stretches further into regions like Tibet, China, and Siberia. The natural range of oregano extends to island areas such as the Azores, Balearic Islands, and Canary Islands [6]. The plant is well known for its strong essential oils, which stored in small glandular hairs on the leaves and flowers. These oils are rich in bioactive molecules such as thymol and carvacrol play a key role in fragrance and flavor in Oregano, on the other hand provides health benefits like antibacterial, antioxidant, and anti-inflammatory effects. Constitutes like linalool, γ-terpinene, and sabinene hydrate contribute as important part in the essential oil and contribute to many health benefits [7]. Due to its aromatic and medicinal properties, oregano is used widely in also in the pharmaceutical, cosmetic, and wellness industries. This study aims to analyze the

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chemical composition of *Origanum vulgare* L. essential oil (OVO), evaluate the variation in essential oil composition across various countries, and assess their antimicrobial activities.

2. Methodology

This review selected papers in the PubMed, and Google Scholar databases that comprised the last 15 to 20 years publications. The descriptors chosen to find the selection of studies were "Chemosystematics *Origanum vugare* L.", Chemical composition of Origanum vulgare L. "Antibacterial activity", "Antifungal activity", "Antiviral activity" and Anti parasitic activity of *Origanum vulgare* L.

3. Clasification of *Origanum Vulgare* L.

Kingdom:Plantae
Phylum :Streptophyta
Class:Equisetopsida
Subclass:Magnoliidae
Order :Lamiales
Family :*Lamiaceae*
Genus :*Origanum*
Species :*Origanum vulgare*

4. Essential Oil Composition of *Origanum Vulgare* L. Its Chemosystematics

Raal, A. *et al*., (2024) studied a total of 17 samples of *O. vulgare* aerial parts from Estonia, Turkey, Scotland, Moldova, and Italy and reported six chemotypes of *O. vulgare* rich in (1) caryophyllene oxide; (2) sabinene; (3) caryophyllene oxide–(E)-β-caryophyllene; (4) (E) β-caryophyllene; (5) carvacrol, and (6) thymol–carvacrol[8].Giuseppe De Mastro*et al.* (2017) reported two main groups and three subgroups from the 25 wild populations of *Origanum vulgare* L. samples, growing wild in different locations of Calabria Region (Southern Italy). The first group consisted of acyclic (linalool/linalyl acetate) chemotypes with a predominant presence of linalyl acetate; the second was characterized by chemotypes rich in cymyl-compounds, mainly carvacrol, thymol and γ-terpinene [9]. Three chemotypes the first, primarily containing carvacrol/thymol; the second, with thymol/alpha-terpineol; the third, characterized by linalyl acetate and linalool were identified from the essential oils obtained from inflorescences of three *Origanum vulgare*L.ssp. hirtum (Link) Ietswaart samples, growing wild in different locations in Campania (Southern Italy)[10].Essential oil composition of502 individual of European *O. vulgare* were identified. The monoterpene mainly consisted of sabinene, myrcene, *p*-cymene, 1,8-cineole, *β*-ocimene, *γ*-terpinene, sabinene hydrate, linalool, *α*-terpineol, carvacrol methyl ether, linalyl acetate, thymol and carvacrol. Sesquiterpenes often present in higher amounts were*β*-caryophyllene, germacrene D, germacrene D-4-ol, spathulenol, caryophyllene oxide and oplopanone.Overall,three different main monoterpene chemotypes were defined (1)cymyl-compounds (2)sabinyl-compounds and (3) acyclic linalool/linalyl acetate The cymyl- and the acyclic pathway were usually active in plants from the Mediterranean climate whereas an active sabinyl-pathway was a characteristic of plants from the Continental climate [11].Morshedloo, M.R.*et al.* (2018) reported four chemotypes chemotype I (carvacrol), chemotype II ((Z)-alpha-bisabolene), chemotype III (linalyl acetate), chemotype IV (caryophyllene oxide/germacrene D/(E)-beta-caryophyllene) among seven populations of Iranian oregano [12].Carvacrol, one of the major compounds in the essential oil of *Origanum vulgare* L., has been reported in many countries[13-19]. Shweta Goyal*et al.*, 2021 and M. Vazirian*et al.*, 2015, reported thymol as a major component in the oil composition of *Origanum vulgare*L. [20-21].Mohammad Reza Morshedloo*et al*. 2018, classified the four main chemotypes: *i.e.*, chemotype I (carvacrol), chemotype II ((*Z*)-α-bisabolene), chemotype III (linalyl acetate), chemotype IV (caryophyllene oxide/germacrene D/(*E*)-*β*-caryophyllene) from Iranian oregano[22].The oxygenated sesquiterpene caryophylleneoxide (7.4–49.9%) was predominant in all the essential oil samples. Other major constituents were sesquiterpene hydrocarbon-germacrene D (8.4–22.5%) and (E)-caryophyllene (8.5–10.8%), monoterpene hydrocarbon-sabinene (1.6–7.7%), and oxygen containing monoterpenes-terpinen-4-ol (1.5–7.0%)[23]. Călin Jianu.*et al.* 2023, identified main compounds gamma-terpinene(22.96%), para-cymene (14.72%), ger-macrene (11.64%), beta-trans-ocimene (9.81%), and cis-beta-ocimene (7.65%) in*Origanum vulgare* var. aureum L. essential oil[22].γ -muurolene one of the chemotype of *O.vulgare* L. has been reported from Uttarakhand India in 2000[25]. Carvacrol (37.5%), thymol (22.7%) and p-cymene (7.6%) were detected as main compounds of *O. acutidens*; carvacrol (30.8%), thymol (26.8%) and γ-terpinene (12.1%) were detected as the major constituents of *O. vulgare* subsp. Gracile from Turkey[26]. Germacrene D (17.01%); β-caryophyllene (13.05%); carvacrol (11.65%); sabinene (9.78%); trans- ocimene (9.38%); cis -ocimene (6.03%), and γ-elemene (4.10%) were reported *O.vulgare* ssp. vulgare oil from Moldova[26]. Brigitte Lukas*et al.*, 2008, identified three chemotypes 274 individual plants belonging to 13 populations of *Origanum vulgare* L. (Lamiaceae) from Corsica i.e., a 'cymyl' type, with either carvacrol (0.6–65.5%) or thymol (0.0–49.5%) as the main compound, 'sabinyl' type with sabinene (7.8–20.2%) and cis-sabinene hydrate (0.7–24.8%) as main compounds, 'mixed' type combining compounds of the 'cymyl' and the 'sabinyl' pathway. The 'mixed' type was rich in cis-sabinene hydrate (0.0–52.4%) and γ-terpinene (0.6–35.4%) [27]. para-cymene (25.615%), thymol (23.129%), carvacrol (20.321%) were determined main components of *O. vulgare* L. ssp. glandulosum (Desf.) Ietswaart from Algeria [28].Vijay K. Kaul*et al.* 1996 reported linalool (23.8%), myrcene (18.0%), β-caryophyllene (9.06%), germacrene-D (7.4%) and terpinen-4-ol (4.4%) were found as the major compounds from north India [29].Maria M. Carmo*et al*. 1989 reported two chemotype linalool (36.85%). And thymol (31.86%) from *Origanum vulgare* growing wild in Portugal[30].

5. Antibacterial effect of *Origanum Vulgare* L.

The antimicrobial effect of *Origanum Vulgare* L. essential oils (OVO) vapors against pathogens and spoilage bacteria was assessed which showed that it could be used for the microbial decontamination of food-contact surfaces in some controlled parameters[31].A good antibacterial activity of OVO has been reported against MDR bacteria as well as with *Escherichia coli, Klebsiella pneumoniae, Streptococcus pneumonia, Staphylococcus aureus, Enterococcus faecalis, Staphylococcus aureus, Staphylococcus epidermidis, Enterococcus faecalis, Streptococcus mutans, Enterobacter aerogenes, and Pseudomonas aeruginosa*[32-35]. Essential oil of *Origanum vulgare* could be used as a natural antimicrobial against *S. aureus* and *E. coli* infections because it showed a strong antimicrobial activity with a minimum inhibitory concentration (MIC) of 1.90 mg/mL for *S. aureus* and 0.49 mg/mL for *E. coli* after 18 h incubation [36]. Accordingto BirolÖzkalp*et al.*oregano oil possessed strong antimicrobial activity compared with the antibiotic. Gram-positive bacteria were more sensitive to the antimicrobial agent in spice than Gram-negative ones[37]. A study showed the antimicrobial effect ofOVOagainst *Escherichia coli*, *Staphylococcus aureus*, and filamentous fungi in ripening Minas cheese. OVO at 0.02% (v/v) successfully eliminated all tested pathogens and fungi without affecting pH or moisture, highlighting its potential as a natural preservative in cheese production [38].Omkulthom Al kamaly*et al.* investigated antimicrobial efficacy against many microbial proteins, including tyrosyl-tRNA synthetase (TyrRS), DNA gyrase, and dihydrofolate reductase (DHFR) using molecular docking which indicated that OVO can be used as a nutraceutical to treat infectious diseases [39].Antimicrobial activity in vitro of the essential oil of oregano was evaluated by Nora Mahfouf2017, suggested that it may be a useful alternative to antibiotics for the control of the infections caused by Acinetobacter spp. [40]. According to Nedzad Prazina et al., *Bacillus subtilis*, *Staphylococcus aureus*, and *Staphylococcus saprophyticus* showed the highest sensitivity to oregano oil. In comparison to the antibiotic ampicillin, oregano oil exhibited superior antimicrobial effectiveness[41].

6. Antifungal effect of *Origanum Vulgare* L.

Oregano essential oil was tested against*Aspergillus niger, Penicillium claviforme, Saccharomyces cerevisiae, Candida albicans 8673, Candida glabrata 72*showed **significant antifungal activity.** The activity was **concentration-dependent**, **higher concentrations** led to stronger antifungal effects. In this study Oregano extract exhibits both **fungistatic**and **fungicidal** effects [42]. Bhat V*et.al*, 2018, reported that *Origanum vulgare* essential oil(OVO) is highly effective against oral *Candida* isolates from denture wearers. Essential oil demonstrated greater antifungal potency than fluconazole, may be due to the presence of carvacrol-like compounds [43]. In one of the studies OVO was treated against human fungal pathogen *Malassezia furfur, Trichophyton rubrum and Trichosporonbeigelii.* At a **1/50,000 dilution**, it caused a **95% reduction**in metabolically active fungal cells **within 6 hours** of exposure [44].

Nanoemulsions encapsulated OVO was tested against *Cladosporium* sp., Fusarium sp.,*Penicillium* sp. to evaluate the antifungal activity which showed that**nanoencapsulated oregano essential oil hasantifungal potential** against common cheese-contaminating fungi**especially if storage conditions are controlled [45]**.

YunZhao*et al.* 2021, reported that *Botrytis cinerea* in vitro mycelial growth and spore germination were strongly inhibited by the OVO and two of its main components, thymol and carvacrol. It is **nontoxic** and **environmentally friendly**, and can be used as **natural fungicide** for **postharvest protection** of fruits like tomatoes against gray mold [46].*At a concentration of 0.25 mg/ml, OVO completely inhibited the growth ofCandida albicans. Its in vitro efficacy was comparable to standard antifungal drugs, nystatin and amphotericin B. No toxicity was observed in the animal model, making it a promising candidate for natural antifungal therapy[47].*Asmaa Alhussein Mohamed *et al.*2025, studies the efficiency of mixture of essential oil of oregano, moringa, and cinnamon and individually to inhibited fungal growth on historic wall paintings. They reported that oregano oil showing the strongest individual activity and minimal pigment impact [48]. OVO can be used as a natural alternative to conventional antifungal treatments, supporting safer and more sustainable options for improving animal health against *Aspergillus niger*, *Aspergillus fumigatus*, and *Talaromycesmarneffeietc.* [49]. OVO showed strong antifungal potential for the *Malassezia furfur*, a yeast causes human skin infections [50].Doaallah O *et al.*2024, studiedthat OVO **promising natural antifungal** that is effective against vulvovaginal candidiasis, the **most common fungal infection in women**, with increasing cases of **azole resistance and recurrence [51].**Priscila Dias da Silva Vaz et al. 2022, studied Origanum Vulgare extracts for anthracnose control in common beans and found that extracts show **strong antifungal activity** and **safety for plant use**, offering **a promising, eco-friendly alternative** for sustainable anthracnose management in beans[52].

7. Antiviral effect of *Origanum vulgare* L.

Daiane Einhardt Blank et al. 2019 evaluated the antiviral activity of aqueous and ethanolic extracts of *Origanum vulgare* (oregano) against veterinary viruses, and assess their cytotoxicity, results showed that both aqueous and ethanolic extracts had antiviral activity against Canine distemper virus (CDV) while ethanolic extract had stronger antiviral effect against Equine arteritis virus(EAV) [53].**Extracts** of *Origanum vulgare showed***antiviral and virucidal activity**against **BoHV-1 which is a significant pathogen in cattle production [54].**Huidan Deng *et al.*2024,for the first time to found out that oregano essential oil has anti-PVR effect in vivo and in vitro. It may be due to presence of the carvacrol as a major component in the oil composition [55].Oregano oil-loaded nanogel effectively protects cells from Betacoronavirus 1 infection. It reduces viral replication and cytopathic effects and shows enhanced solubility and delivery of oregano oil [56].**Essential oils and hydrosols** of Origanum vulgare L. has been studied which showed***O.vulgare* haspromising**

antiphytoviral agents [57]. Cintia Hiromi Okino *et al.*2024 reported that*OVO* has **strong antiviral potential against avian coronavirus,** especially at higher concentrations [58].

8. Antiparasitic effect of *Origanum vulgare* L.

Oregano essential oil is antiparasitic. It is highly effective against *T. gondii* in vitro with low toxicity to host cells. The mechanism involves oxidative stress, mitochondrial dysfunction, and necrosis [59]. OVO demonstrates good antiparasitic activity against *Leishmania amazonensis*, both through direct parasite killing and favorable immune modulation, indicating its suitability for formulation into oral or topical therapies [60].OVO showed promising **anthelmintic activity** against gastrointestinal nematodes (GINs) in sheep, which are parasitic wormswhich makes this oil safe**and effective natural alternative to synthetic anthelmintic drugs** in veterinary practice[61].

9. Conclusion

Origanum vulgare L. demonstrates significantphytochemical diversity, as a result of genetic, environmental, and geographical factors. This diversity gives rise to characteristic chemotypes, each distinct by varying concentrations of key bioactive compounds such as carvacrol, thymol, p-cymene, and γ-terpinene. These variations significantly impact the antimicrobial efficacy of the essential oils derived from different *O.vulgare*L. chemotypes.Many studies have showed effectiveness against a wide range of microbial pathogensof *O. vulgare*L. essential oils against a range of pathogenic bacteria and fungi, suggesting to their effectiveness as naturally derived antimicrobial agents. Among the chemotypes, those rich in carvacrol and thymol tend to show the most potent antimicrobial effects.Future research should focus on developing cultivation strategies, chemotype identification methods, and technological approaches to improve and maintain the antimicrobial effectiveness of *O. vulgare* essential oils.

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