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Bioprospecting the genus *Origanum*: Taxonomy, bioactivity and commercial applications

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Abstract
The genus *Origanum* comprises of aromatic perennial herbs of high culinary, medicinal, and commercial importance. This genus belongs to the order Lamiales and it has over 50 species, the most famous of them being the one named, *Origanum vulgare*. The latter is found throughout the Mediterranean basin, Europe, and neighbouring parts of Asia, and have adaptation to temperate climatic zones worldwide.
Phytochemically, the character of the *Origanum* species is high content of essential oils which are mainly phenolic mono-terpenes like thymol and carvacrol. These volatile compounds have phenolic acids and flavonoids that add to the functional properties. Traditionally the plants have been used as flavouring agents and food preservatives, as well as, a traditional therapeutic agent to treat microbial infections, gastrointestinal disorders, respiratory illness. The international market shares a significant percentage of derivatives of *Origanum* in form of dried herb preparations, essential oils, dietary supplements, and in cosmetic formulations.
The range of pharmacological actions of *O. vulgare* includes anti-oxidant, anti-microbial, and anti-inflammatory actions. In addition, it can be grown using sustainable agronomic methods with its intrinsic pesticidal characteristics, its ability to be an integral component of organic farming systems, and its possible use in the functional food market.

Keywords: *Lamiaceae*, *Origanum*, pharmacological, bioactivity

Introduction
The term "traditional medicine" means complementary or alternative medicine (CAM), which includes herbal and natural remedies. About 60-80% of the world's population uses traditional herbal medicine for healthcare, body care, and nourishment. This creates a strong demand for medicinal plant materials. Aromatic essential oils found in medicinal plants are employed in both traditional medicine and the food, flavour, and fragrance industries.
Since the beginning of human civilization, plants have been used for therapeutic and medicinal purposes. MAPs, or medicinal aromatic plants, are a rich and varied source of both conventional and contemporary medicines. These include both wild plants and plants cultivated on herbal plantations, which are well-known for their traditional culinary and medicinal applications. The presence of essential oils (EOs), volatile compounds with a complicated chemical makeup, is linked to the distinctive scent of MAPs. The Lamiaceae, also known as the mint family, is one of the largest and most distinctive families of flowering plants. It consists of approximately 236 genera and 7173 species distributed over Mediterranean basin and Central Asia.
Among the most well-known members of the Lamiaceae family is the genus *Origanum*, which contains Mediterranean plant species that have long been used as medicines and spices.
Hippocrates (460–370 BC) was the first to use the name *Origanum*, which means "joy of the mountains" and is derived from the combination of two Greek words 'oros' (mountain)and 'ganos' (joy). *Origanum* has a complicated classification and is a member of the Lamiaceae family. It is in use as early as Paleolithic (50 000 -70 000 BCE), and the earliest records of it can be found in Hittite tablets (1600 - 1200 BCE). The *Origanum* species have traditionally been used in Ayurveda as a remedy against a wide range of illnesses.
Origanum genus is classified into ten sections that contain 43 species, six subspecies, three cultivars, and eighteen natural hybrids. Those taxa are shrubs, annuals, and perennials and are mainly found in the Euro-Siberian, Iranian-Siberian and Mediterranean floristic provinces. The species are restricted to the western Mediterranean about three quarters of which are native to Turkey. *Origanum* belongs to the larger family of Lamiaceae, which includes over 236 species. This genus is characterized by a high production of volatile oil constituents and high repository of non-volatile pharmacologically active compounds. The plant is often found in India's temperate Himalaya, ranging from Kashmir to Sikkim at elevations of 1,500 to 3,600 meters.

Taxonomy
Kingdom: Plantae
Division: Magnoliophyta
Class: Magnoliopsida
Subclass: Asteridae
Order: Lamiales
Family: Lamiaceae
Genus: *Origanum*

Botanical description
Genus *Origanum* belongs to the Lamiaceae family is also known as Oregano or Marjoram. Oregano is a versatile aromatic perennial herb which is commonly known as badri tulsi, Van Tulsi, Sathra, Jakhambooti, Basoolghas and Jonk-jari in India. Origanum species are perennial or sub-shrubby herbs with height ranges from 20cm to over 1 meter depending on the species. Stems are quadrangular (4 angled)

upright, branching, hairy or glabrous, and frequently woody at the base. Leaves are simple, petiolate or subsessile and ovate to lanceolate in shape (Bharti *et al*. 2014). Flowers color ranges from white to pink, purple or lavender, usually found in dense terminal or axillary spike-like clusters, zygomorphic, bisexual flowers are sometimes accompanied by vibrant, petal-like bracts. A tubular, five-toothed calyx and a two-lipped corolla, with the lower lip typically having three lobes and the upper lip typically having two, are features of every flower. Stamens are didynamous (two long, two short) and often protrude from the corolla. Inflorescence terminal or axillary, compact to lose spikes or panicles, often forming head-like clusters; bracts often colorful (purple, pink or green) and persistent. The ovary is superior and four-lobed, with a gynobasic style and bifid stigma. The fruits resemble tiny nutlets (Singh *et al*. 2024, Maithani *et al*. 2023) [24, 34].

Geographical Distribution

Geographical distribution of various species of genus *Origanum* have been mentioned in Table 1 and the representative species have been shown in figure 2.

Table 1: Distribution of various species of Genus Origanum

Species	Common Name	Distribution
O. vulgare	Oregano	Mediterranean areas and Northern Africa. Temperate regions of Western Himalayas (J&K, H.P., Uttarakhand).
O. majorana	Sweet marjoram	Native to Southern Turkey and Cyprus, cultivated widely in temperate regions.
O. dictamnus	Dittany of Crete	Endemic of Crete (Greece)
O. syriacum	Syrian oregano	Middle east (Israel, Syria, Lebanon)
O. onites	Turkish oregano	Southeastern Europe, Turkey
O. heracleoticum	Greek oregano	Mediterranean (Greece, Italy)
O. elongatum	Moroccan oregano	Morocco, primarily found in the northeastern regions, including the Rif and Middle Atlas Mountains
O. microphyllum	Cretan marjoram	Cretan
O. laevigatum	Ornamental oregano	Eastern mediterranean region (Cyprus, Syria, Turkey)
O. compactum	Compact Oregano	Morocco, South-West Spain and North Africa
O. dubium	Rigani	Cyprus, Greece and in Southern Turkey
O. sipyleum	Showy pink oregano	Native to Western Anatolia, Turkey
O. floribundum		Recorded in Algerian site
O. acutidens		Central Anatolia region of Turkey

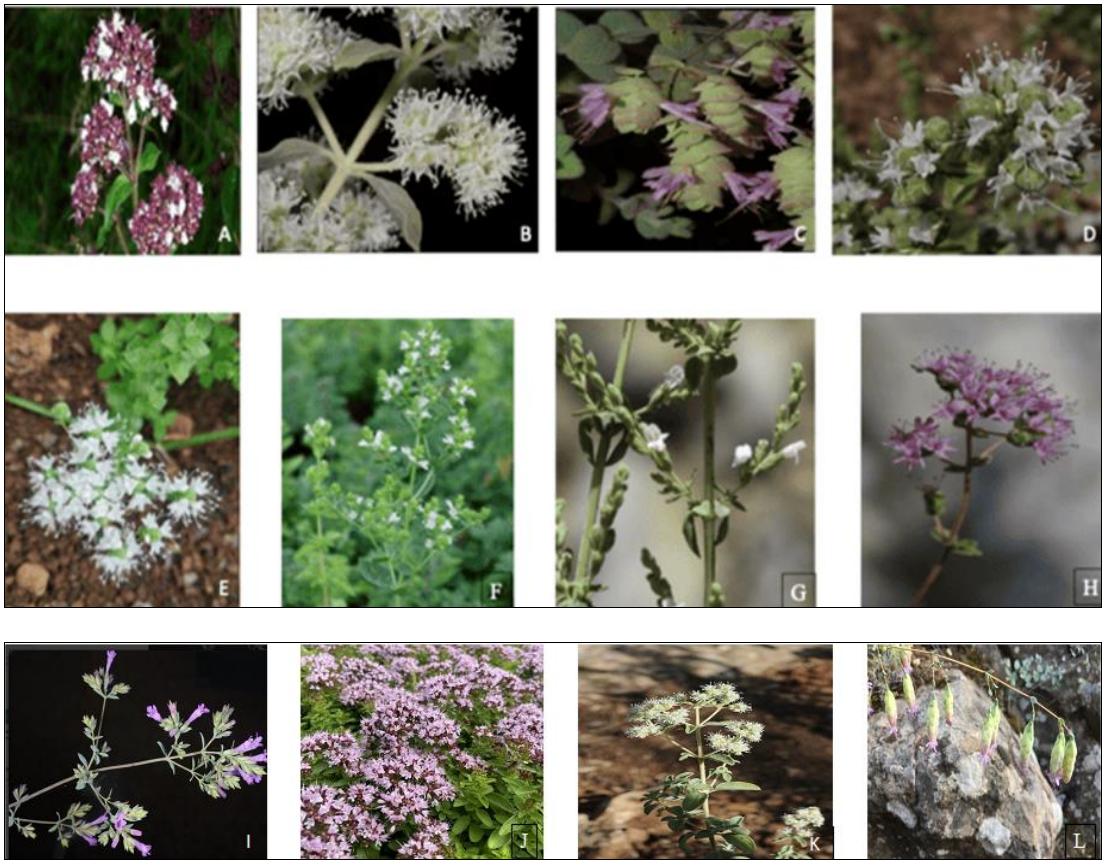

Fig 1: (A) *O. vulgare* (B*) O. majorana* (C) *O. dictamnus* (D) *O. syriacum* (E) *O. onites* (F) *O. heracleoticum* (G) *O. elongatum* (H) *O. microphyllum* (I) *O. laevigatum* (J) *O. compactum* (K) *O. dubium* (L) *O. sipyleum*
(https://powo.science.kew.org; https://antropocene.it/en/2023/01/11/origanum-heracleoticum-2/; https://www.teline.fr/en/photos/lamiaceae/origanum-elongatum; https://flora.nhm-wien.ac.at/Seiten-Arten/Origanum-microphyllum.htm; https://www.kelways.co.uk/origanum-vulgare-compactum-3-litre-pot/p46420;https://www.inaturalist.org/taxa/743245-Origanum-sipyleum;)

Culinary and Ethnomedicinal Uses

Origanum species have been used as spices and in ethnomedicine for thousands of years. Oregano has been used for its antibacterial properties since the time of Hippocrates, approximately in the fifth century BC, to treat infections of the skin, respiratory system, and digestive tract. Dried leaves and blossoms are used as condiments in a variety of culinary dishes around the world (Singh *et al*. 2024) [34].

It is used in traditional medicine to treat irregular menstrual cycles, colic, cough, and toothaches. Additionally, *Origanum* species are utilized as potent disinfectants and flavoring agents in fragrant soaps and perfumes (Force *et al.* 2002, Chishti *et al*. 2013). As a culinary herb, it is used in flavoring food products and alcoholic beverages (Aligiannis *et al*., 2001; Bendahou *et al*., 2008) [1, 2, 5]. In traditional medicine, oregano is used to treat a wide range of conditions, including rheumatoid arthritis, respiratory conditions, stomach aches, analgesics, nutritional disturbances, and urinary tract disorders (as a diuretic and antiseptic). The National Library of Medicine states that oregano products are taken orally to treat psoriasis, allergies, headaches, unpleasant menstrual cramps, and urinary tract infections. Additionally, oregano oil is administered tropically to treat psoriasis, varicose veins, warts, wounds, muscular and joint discomfort, acne, and dandruff (Licina *et al.* 2013; Khaki *et al*. 2013; Veenstra and Johnson 2019) [20, 40].

The Ethnomedicinal uses of various species of Genus *Origanum* have been mentioned in table 2.

Table 2: Ethnomedicinal Uses of various species of Genus Origanum

S. No.	Name of the Plant Species used	Plant part used	Ethnomedicinal uses
1.	*O. vulgare*	Leaves	Antifungal, antibacterial, antioxidant,
2.	*O. majorana*	Dried leaves, flowering tips	Diuretic, antiasthmatic, antiparlytic
3.	*O. dictamnus*	Flower, bracts	Headache, kidney and liver problems, obesity, antimicrobial
4.	*O. syriacum*	Leaves	Antiseptic, relieve stomach and intestinal pain, cough, toothaches, hear problems
5.	*O. onites*	Leaves	Antispasmodic, control tick infestations, antifungal, antibacterial, antimycotic
6.	*O. heracleoticum*	Leaves	Antiseptic, analgesic, respiratory ailments, antioxidant, immune support
7.	*O. elongatum*	Leaves, aerial parts	Anti-inflammatory, cold, cough, antimicrobial, antioxidant, digestive disorders
8.	*O. microphyllum*	Flowers, young stem	Antiseptic, wound healing, general tonic, immune support
9.	*O. laevigatum*	Young stem, flowers	Antimicrobial, bronchial congestion, muscle aches, loss of appetite
10.	*O. compactum*	Leaves, flowers	Antimicrobial, antioxidant, antibacterial
11.	*O. dubium*	Infusion of leaves, flowering stem, flower	Digestive aid, antirheumatic
12.	*O. sipyleum*	Leaves and flowers	Cough, respiratory disorders, gastrointestinal disorders
13.	*O. floribundum*	Leaves	Diarrhoea, digestive disorders
14.	*O. acutidens*	Leaves	Antagonistic activity against food-borne pathogenic bacteria
15.	*O. hypericifolium*	Leaves	Common cold, stomach pain

Phytochemistry

The genus *Origanum* has been considered to have a great large and diverse phytochemical profile that supports its wide range of biological and pharmacological activity. The species of the genus are characterised by the essential oils, as well as a variety of secondary metabolites, such as phenolic monoterpenes, flavonoids, phenolic acids and terpenoids. Among them, carvacrol and thymol are considered to be the most important bioactive components that explain the typical aroma and the strong antimicrobial and antioxidant effect detected in the *Origanum* species. Besides volatile compounds, non-volatile compounds like rosmarinic acid, caffeic acid, and other flavonoids also increase their therapeutic efficacy (Kumar *et al*. 2020) [22].

It is important to note that the phytochemical profile of the *Origanum* species is highly variable which depends on genetic aspects, chemotype, geographical origin, environmental factors as well as extraction procedures. This chemical heterogeneity does not only influence their biological efficacy but also requires strict standardization in order to make them effective when they are used in pharmaceutical, food and cosmetic formulations.

A thorough overview of the phytochemistry of the genus Origanum is, therefore, necessary to be able to match the chemical compounds with the biological effects and take advantage of the Origanum utilization in various industrial fields. The main bioactive constituents present in *Origanum* genus have been mentioned in Table 3 and figure 2.

Table 3: Main bioactive constituents present in Origanum genus

Species	Bioactive constituents
O. vulgare	Carvacrol, Thymol, p-Cymene, ϒ-terpinene, Rosmarinic acid, Salvianolic acid, Lithospermic acid, Apigenin, Quercetin
O. majorana	Sabinene linalyl acetate, cis-sabinene hydrate
O. microphyllum	cis-sabinene hydrate, α-terpinene, ϒ-terpinene and trans-sabinene hydrate
O. dictamnus	Carvacrol, α-terpinene, p-cymene, caryophyllene, carvacrol methyl ether

O. syriacum	Aqueous extract (Carvacrol, Carveol, Thymoquinone), Methanolic extract (Ursolic acid, Vitexin, Isovitexin, Oleanolic acid, Rosmarinic acid, Vicenin) Ethanolic extract (β-carotene, Thymol, Rutin, Ctechinic acid, Catechol, Pyrogallol, Carvacrol).
O. onites	Terpenoids, triterpene acids, phenolic acids, hydroquinones, flavonoids, hydrocarbons, sterols, pigments, fatty acids, tocopherols and inorganic compounds
O. heracleoticum	Carvacrol, p-cimene, ϒ-terpinene, E-caryophyllene.
O. elongatum	Carvacrol, thymol, linalool, and limonene.
O. microphyllum	Carvacrol, terpineol-4, linalool
O. laevigatum	Bicyclogermacrene, germacrene-D and β-caryophyllene.
O. compactum	Carvacrol, p-cymene and ϒ-terpinene
O. dubium	Carvacrol

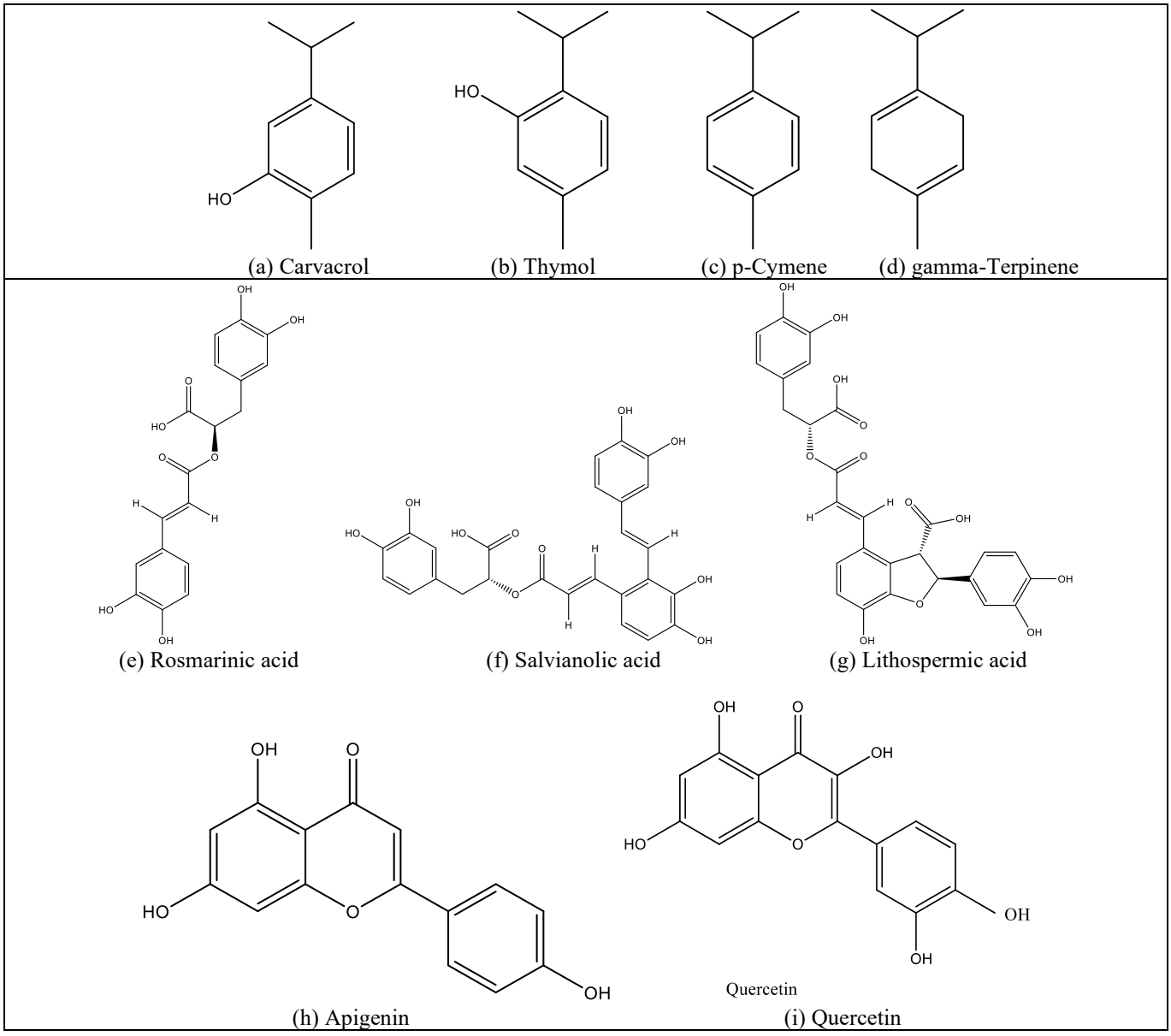

Fig 2: (a-i) Main bioactive constituents present in *O. vulgare*.

Commercial products utraceut in global market

Origanum species, particularly *O. vulgare*, have received a great deal of attention in both traditional and modern systems because to their various pharmacological and aromatic properties.

Bioactive compounds of *Origanum* species have broad applications in pharmaceutical preparations, utraceuticals preparations, cosmetic preparations, and in the food industry. Both international and local (Indian) markets imply a high concentration of commercial goods based on *Origanum* extracts, which also contributes to the high levels of versatility of the product and the increasing popularity of naturally obtained plant-based compounds among consumers. The following section outlines a broad overview of relevant products that use *Origanum* species, particularly the practical use and the economic opportunities that it relates to, have been mentioned in table 4.

Table 4: Commercial products derived from Origanum genus

Species used	Product name	Plant part used	Brand name	
O. vulgare	Deve Herbes Oregano Essential oil	Leaves and Flowering tops	Deve Herbes	
	KUNJ Oregano essential oil	Leaves and tops	KUNJ	
	Natura Vitalis Oregano oil	Leaves and tops	Natura Vitalis	
	Plant therapy Oregano Essential oil	Flowers and leaves	Plant therapy	
	M.K. Exports Essential oil	Leaves	M.K Exports India	
	Vaastavik Premium essential Oil	Shoots and dried leaves	Vaastavik	
	Natural origanum	Leaves and stems	Lorann Oils	

O. majorana	AOS Products Marjoram Oil	Dried and flowering herb	AOS Products Pvt Ltd	
Species used	**Product name**	**Plant part used**	**Brand name**	
O. vulgare	Keya Italian Pizza Oregano	Dried leaves	Keya	
	Snapin oregano seasoning- Italian Herbs Blend		Snapin	
	Chef's art premium Italian seasoning		Chef's art	
	Italian seasoning mix		Catch	
	Oregano pizza seasoning		Domino's	

O. syriacum	Zatar by Tyme foods-with Genuine Hyssop herb		Tyme foods	
	Lebanese Zaatar		The Spice way	

Pharmacological Activities

The genus *Origanum,* contains several aromatic and pharmaceutically significant species that have received a lot of research attention due to their phytochemical diversity and associated biological activities. However, it is the species, *O. vulgare*, that has been the most extensively studied, which can be explained by the abundance of bioactive constituents and the wide range of established pharmacological actions.

Despite the fact that a number of the taxa of the genus *Origanum* have shown therapeutic potential, experimental and clinical studies have mostly focused on the use of a single species, *O. vulgare*, demonstrating antioxidant, antimicrobial, anti-inflammatory, anticancer, and immunomodulatory effects. Based on this, the focus of the review is the pharmacological profile of *O. vulgare* that provides the most detailed and strictly documented knowledge about the therapeutic potential of the genus.

Antioxidant Activity

O. vulgare is a potential functional food and medication due to its abundance of phenolic acids and flavonoids, which have powerful antioxidant action.

These chemicals scavenge free radicals, shielding cells from oxidative stress and the resulting degenerative illnesses. Human diseases are often caused by an overabundance of reactive oxygen species, either from the immune system or external sources The accumulation of free radicals in the body has been considered one of the variables involved in the development of different age-related disorders. Han *et al*. (2017) [16, 17] found that the oils effectively scavenged 2,2-diphenyl-1-picrylhydrazyl (DPPH) radicals, as evidenced by their half maximum inhibitory concentrations (IC_{50}). They also shown protective properties against lipid peroxidation in liposomes and were capable of neutralizing nitrous oxide and hydrogen peroxide (Han and Parker, 2017) [16, 17]. Further testing demonstrated that they have ferric reducing antioxidant power (FRAP) (Marrelli *et al*., 2016) [25] and radical-scavenging activity in UV-induced peroxidation in liposomal membranes (Tuttolomondo *et al*., 2013) [37]. The ethanol extract of the bark exhibited an IC_{50} value of 133.47 µg/mL, categorizing it as a moderate antioxidant. The study also reported a positive correlation ($R^2 = 0.8426$) between extract concentration and antioxidant activity, indicating that higher concentrations enhance free radical scavenging efficiency (Rosmalena *et al*., 2021).

Antibacterial Activity

O. vulgare has been widely studied for its broad-spectrum antibacterial activities, which are mostly because of essential oil components such as carvacrol & thymol. These chemicals have shown strong activity against a wide range of pathogenic microorganisms, including Gram-positive and Gram-negative bacteria, as well as some fungi. In recent years, multiple investigations have demonstrated the efficacy of *O. vulgare* extracts and essential oils against clinically significant microbial strains. The main active ingredient in the ethanolic extract of O. vulgare, which has been demonstrated to have antibacterial activity against isolates of *Lacticasei bacillus, Enterococcus, and Streptococcus* identified in dental plaques from Algerian patients, was thymol, according to GC-MS (Idir *et al*. 2022; Kariminik *et at*. 2019) [18, 19].

The antibacterial properties of essential oils isolated from two *O. vulgare* populations in the Indian Himalayan region were assessed in a study conducted by Singh *et al*. (2012). Significant variances in essential oil composition were found in the study, and these variations were linked to variations in antibacterial effectiveness against pathogens including *Escherichia coli* and *Staphylococcus aureus.* Sharma *et al*. (2014) conducted additional research that concentrated on the antibacterial activity and chemical profile of *O. vulgare* essential oil. Major components such as trans-sabinene hydrate and terpinen-4-ol were found in the study to have strong biostatic and biocidal properties against a variety of bacteria, including *Pseudomonas aeruginosa* and *Bacillus subtilis.* Seasonal, geographic, and geological factors have been shown to significantly alter the essential oil content of *Origanum vulgare* populations in India. Essential oil, which is high in thymol, caryophyllene oxide, β-myrcene, and linalool, had potent antibacterial activity against *S. aureus, A. niger,* and *E. coli* at 600 ppm. These results highlight how regional heterogeneity affects *O. vulgare's* bioactivity (Vinit Prakash *et al.* 2021) [32].

These investigations highlight *Origanum vulgare's* potential in India as a natural antibacterial agent. The disparity in essential oil composition brought about by environmental

and geographic conditions emphasizes how crucial regional research is to comprehending and utilizing the plant's therapeutic potential.

Anti Inflammatory Activity

Anti-inflammatory properties of *O. vulgare* have been intensively researched by a wide range of *in vitro* and *in vivo* studies. Its biologically active constituents, especially phenolic monoterpenes, carvacrol and thymol, display modulatory action on the key inflammatory signal pathways, such as inhibition of pro-inflammatory mediators and cytokines. Over the last few years, there has been a wide range of experimental paradigms that are being used to test its effectiveness, including cell-based assays, and animal inflammatory models. The following table outlines the key investigations, highlighting the type of the study, the models used in experiments, and the most significant findings, thus providing a concise synthesis of the available evidence to support the claim of the anti-inflammatory effect of the *O. vulgare.*

Table 5: Anti-inflammatory activities of *O. vulgare*

Study Type	Model Used	Key Findings	Reference
In vitro	N11 microglia, RAW 264.7 macrophages	Inhibited NO and TNF-α release; IC50 values effective	Gunawardena *et al.* 2014
Biochemical	Soybean lipoxygenase, aldose reductase	Inhibited lipoxygenase more at lower concentrations	Koukoulitsa *et al.* 2006 [21]
In vitro	THP-1 macrophages	Reduced TNF-α, IL-1, IL-6; increased anti-inflammatory cytokines	Ocana-Fuentes *et al*. 2012
In vivo	Transgenic NF-κB luciferase mice	Synergistic suppression of NF-κB with plant combinations	Pezzani *et al*., 2017 [30]
In vivo	Mouse colitis model	Reduced mortality, improved colon health	Bukovska *et al.* 2007
In vivo	Mouse airway model	Reduced TNF-α and lipid peroxidation	Grondona *et al.* 2014 [15]

Anti Fungal Activity

The hydroalcoholic extract and the essential oil of *O. vulgare* have shown a high degree of antifungal activity. Studies have demonstrated activity on both the pathogen Sporothrix brasiliensis with 29 strains of cats and dogs (Waller *et al.,* 2018) [41], and a variety of species of the genus *Candida*. Specifically, *C. tropicalis* was more resistant than *C. glabrata, C. albicans, and C. krusei* (Stringaro *et al.,* 2022).

The essential oil contains phenolic compounds, including carvacrol and thymol, and other compounds such as (Z)-2-farnesene, apioline, methyl eugenol and myristicin, so this essential oil presents a potential ecological friendly fungicide against grey mold in postharvest.

Essential oil of *O. vulgare* has demonstrated strong *in-vitro* antifungal activity against *Pythium insidiosum*, with minimum inhibitory concentrations of 0.05 to 1.75 mg mL -1, but has no effect when applied topically in isolation, but synergistic performance was found when used together with *Mentha pipperita* essential oil and immunotherapy (Fonseca *et al*., 2015). It was observed to have synergistic effects when used together with itraconazole but not terbinafine (Valente *et al.,* 2016) [38].

Role of *O. vulgare* in Sustainable Agriculture and Food Safety

Oregano (*O. vulgare*) is a well-known multipurpose species with a significant scope of application in sustainable agriculture and food systems and has received considerable scholarly attention. It's essential oil, which is mainly made up of bioactive compounds including thymol and carvacrol, possesses strong antibacterial, antifungal, and insecticidal properties and thus can be used as a natural replacement of synthetic agrochemicals in protecting crops (Simirgiotis *et al*., 2020) [33]. Such replacement helps to reduce the environmental effects of traditional pesticides and promotes the use of environmentally sustainable pest management practices. In addition, products derived by means of oregano have been widely researched as natural preservatives in food systems, in which case they are effective inhibiting pathogens in food and hindering food spoilage, thus extending the shelf life of perishable products (Veenstra & Johnson, 2019) [40].

The use of oregano essential oil in the development of edible coating, biodegradable coating as well as active packaging also improves food safety and encourages sustainable packaging. Post-harvest treatment using oregano has been shown to prevent fungal rot, as well as preserve the quality of fruits and vegetables (Badia *et al*., 2020; Pinto *et al.,* 2024) [2, 31]. Also, oregano essential oil has demonstrated itself as a potential phytogenic feed supplement, enhancing the activity of digestive enzymes, gut health, and performance in aquaculture species, thus offering a viable alternative to antibiotic growth promoters (Özel *et al*., 2022) [29].

Despite the variability of chemical composition and the absence of large-scale validation, the emerging evidence shows the possibility of oregano to play a vital role in a sustainable agriculture setting due to its natural antibacterial effect, preservation of foodstuffs, and use in livestock. Altogether, decreasing chemical input, enhancing food safety, and promoting greener production practices, the incorporation of *O.vulgare* into the agricultural and food systems complies with the concept of sustainability.

Conclusion

The genus *Origanum* belonging to family Lamiaceae, has many valuable aromatic and medicinal species which are spread mainly in Asia, Europe, and the Mediterranean region. *O. vulgare* is the most researched of these due to its high importance in industry, cuisine and as a medicine. The variety of biological functions of these plants can be explained by the high concentrations of essential oils and bioactive substances, including carvacrol and thymol, as well as flavonoids and phenolic acids. The widely used *Origanum* species are used as natural preservatives and flavouring agents, in addition to its traditional therapeutic use in gastrointestinal, respiratory, and infectious conditions. The pharmacological properties of *O. ' vulgare* have proven to highlight its phytomedicinal potential by impacting anti-inflammatory, antibacterial and antioxidant effects.

Origanum based products have a large value in the international market whereby the demand of natural products has been increasing. These plants also enhance the sustainability of the agricultural and food systems by offering pest management using environmentally benign methods, food preservation, and growing on marginal soils. However, there are still difficulties, especially the lack of clinical validation, standardization, and a high level of divergence of phytochemical profiles. Collectively, *O. vulgare* is a rich resource that can be used in healthcare, food security, and environmental safety.

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