

Review Article

Comprehensive Overview of Eugenol: Focusing on Sources, Structure, Pharmacological Activities, Mechanisms of Action, Safety Profile, and Applications

Ahmad Umar Faruq , Ibrahim Mohammed Ibrahim* 

Biotechnology Advanced Research Centre of Sheda Science and Technology Complex (SHESTCO), Abuja, Nigeria

Abstract

Eugenol is a natural occurring phenylpropanoid that is primarily derived from clove oil. It's known to have a broad spectrum of pharmacological effects such as, antioxidant, anti-inflammatory, antimicrobial, analgesic, neuroprotective, and anticancer activities. Its therapeutic action are mediated through various molecular mechanisms, such as the inhibition of pro-inflammatory enzymes, regulation of oxidative stress, induction of apoptosis, and prevention of tumor metastasis. However, despite its promised clinical benefits as a bioactive compound, its clinical potential faces limitation due to the poor aqueous solubility, bioavailability and dose dependent toxicity. Nevertheless, recent advancements in the field of drug delivery systems particularly Micro/Nano-formulations through encapsulation techniques offer potential solutions to these limitations. This review aims to present a comprehensive overview of eugenol, aiming on its natural sources, chemical structure, pharmacological properties, and mechanisms of action, safety considerations, current applications, recent advancements and future perspectives for eugenol as multifunctional bioactive compound potential.

Keywords

Antioxidant, Anti-Inflammatory, Antimicrobial, Drug Delivery, Eugenol and Toxicity

1. Introduction

Natural products have long served as crucial sources of therapeutic agents, with a wide array of plant-derived bioactive compounds forming the foundation of modern drug discovery and development. Among these, phenolic compounds have drawn significant attention due to their broad pharmacological activities and generally low toxicity [1, 2]. One such compound is eugenol, an allylbenzene derivative predominantly found in clove oil (*Syzygium aromaticum*) and present in other aromatic plants such as *Ocimum gratissimum* (African basil), *Cinnamomum* species (cinnamon), and *Laurus*

nobilis (bay leaf) [3].

Eugenol (4-allyl-2-methoxyphenol) is known for its distinctive spicy aroma and has a long history of use in traditional medicine, particularly for relieving toothaches, digestive disorders, and respiratory issues [4]. In contemporary pharmacology, eugenol has been widely studied for its diverse biological activities, including antioxidant, anti-inflammatory, antimicrobial, analgesic, and anticancer effects [5]. These multifaceted actions are largely attributed to its phenolic structure, which enables it to interact with various cellular

*Corresponding author: ibrahimyamagi@gmail.com (Ibrahim Mohammed Ibrahim)

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targets, modulate oxidative stress, and influence inflammatory signaling pathways.

Beyond its medicinal value, eugenol is also extensively used in the food, cosmetic, pharmaceutical, and agricultural industries as a flavoring agent, preservative, pesticide, and active component in dental care products [6, 7]. However, despite its broad utility, several limitations including low aqueous solubility, volatility, and dose-dependent toxicity have restricted its clinical and industrial applications. These challenges underscore the need for improved formulation strategies and a clearer understanding of its safety profile [8]. This review aims to present a comprehensive overview of eugenol, focusing on its natural sources, chemical structure, pharmacological properties, mechanisms of action, safety considerations, current applications, recent advancements and also highlights its future perspectives for optimizing eugenol's potential as a multifunctional bioactive compound.

2. Natural Sources of Eugenol

Eugenol is a naturally occurring phenolic compound and a key secondary metabolite found in the essential oils of various aromatic plants. It contributes significantly to both the aroma and medicinal properties of these plants. The primary natural source of eugenol is the clove plant (*Syzygium aromaticum*), particularly in its dried flower buds and essential oil. Depending on factors such as harvest time, extraction technique, and geographic origin, clove essential oil can contain between 70% - 90% eugenol [5, 6]. In addition to cloves, eugenol is also present in substantial amounts in several other plant species, including:

Basil (*Ocimum* spp.): Species such as *Ocimum gratissimum* (African basil) and *Ocimum sanctum* (holy basil) are rich in eugenol and are commonly used in traditional African and Asian medicine. Eugenol is a principal component of their essential oils [9].

Cinnamon (*Cinnamomum* spp.): Both *Cinnamomum zeylanicum* (Ceylon cinnamon) and *C. cassia* contain eugenol, particularly in the bark and leaf oils. However, cinnamaldehyde remains the dominant compound in the bark [10].

Bay Leaf (*Laurus nobilis*): Commonly used for culinary and medicinal purposes, bay leaf essential oil contains moderate levels of eugenol alongside other volatiles such as cineole and myrcene [11].

Nutmeg (*Myristica fragrans*): The volatile oil from nutmeg seeds contains small amounts of eugenol, though at significantly lower concentrations than those found in clove or basil

[12].

Pimenta Species: *Pimenta dioica* (allspice) and *Pimenta racemosa* (bay rum tree) are additional sources, particularly in Caribbean herbal medicine and essential oil formulations [5]. These plant species are not only significant from a pharmacological standpoint but also have economic importance in the culinary, cosmetic, and agricultural sectors due to the versatility of eugenol-rich oils. The variation in eugenol content among species and even among different parts of the same plant (buds, leaves, bark) highlights the necessity for standardized extraction methods and quality control in the production of eugenol-based products [7].

3. Chemical Structure and Physicochemical Properties of Eugenol

Eugenol is a naturally occurring phenylpropanoid with a molecular formula of $C_{10}H_{12}O_2$ and a molecular weight of 164.20 g/mol. Structurally, Eugenol has a benzene ring substituted with three distinct functional groups namely hydroxyl group (-OH), a methoxy group (-OCH₃), and an allyl side chain (-CH₂CH=CH₂). The structural conformations play a crucial role in its bioactivities wide-range. The hydroxyl group positioned at the ortho position comparative to the methoxy group contributes significantly to its antioxidant properties, while the allyl chain enhances its lipophilicity and membrane permeability, aiding its biological efficacy [5].

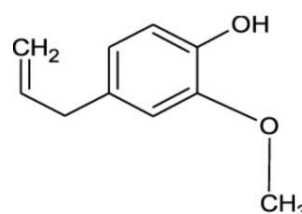


Figure 1. Structure of Eugenol [5].

Eugenol is characterized as a pale yellow, oily liquid with a pleasant clove-like aroma with a boiling point of 254 °C approximately, a melting point of -7.5 °C, and a density of 1.06 g/cm³ at 25 °C. Eugenol is slightly water soluble but readily dissolves in organic solvents such as ethanol, ether, and chloroform. These physicochemical attributes make eugenol suitable for a wide range of pharmaceuticals, cosmetics, and food products formulations [5].

Table 1. Physicochemical Properties.

Property	Value/Description
Molecular formula	$C_{10}H_{12}O_2$

Property	Value/Description
Molecular weight	164.20 g/mol
Appearance	Pale yellow to colourless liquid
Odor	Spicy, clove-like aroma
Boiling point	~254 °C
Melting point	-7.5 °C
Density	1.06 g/cm ³ at 25 °C
Solubility in water	Slightly soluble (~2.46 g/L at 25 °C)
Solubility in organic solvents	Soluble in ethanol, diethyl ether, chloroform, and oils
Log P (octanol-water)	~2.27 (moderate lipophilicity)
pKa (phenolic OH group)	~10.2

Due to its moderate lipophilicity, eugenol exhibits good permeability across lipid membranes, contributing to its rapid absorption and wide distribution in biological systems. However, its low water solubility and volatility can limit its bioavailability and stability in aqueous-based formulations, which has prompted interest in nanoencapsulation and emulsification techniques to improve its delivery and efficacy [8, 13].

The structural simplicity of eugenol also allows for various chemical modifications aimed at enhancing its pharmacokinetic properties or reducing potential cytotoxic effects. These include the synthesis of eugenol derivatives such as esters, ethers, and metal complexes, which are under investigation for enhanced antimicrobial, anticancer, and anti-inflammatory activities [4, 14].

4. Eugenol Biological Activities

4.1. Antioxidant Properties

Eugenol has antioxidant potential due to its ability to neutralize free radicals and protect cells against oxidative damage. Its phenolic hydroxyl group donates hydrogen atoms to stabilize reactive oxygen species (ROS), thereby breaking the chain reactions associated with lipid peroxidation and cellular damage [15]. Studies have shown that eugenol demonstrates significant radical scavenging activity in assays such as 2, 2-diphenyl-1-picrylhydrazyl (DPPH), 2, 2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), and Ferric Reducing Antioxidant Power (FRAP), which often outstand the synthetic antioxidants like butylated hydroxytoluene (BHT). Also, eugenol helps safeguard the cell membranes by averting the membrane lipids peroxidation, limiting its application in disease prevention and health promotion [5].

4.2. Anti-Inflammatory Properties

Eugenol exhibits strong anti-inflammatory effects through multiple mechanisms. It effectively suppresses the production of pro-inflammatory mediators, such as cytokines like Tumor Necrosis Factor Alpha (TNF- α), Inter-leukemia 1 beta (IL-1 β), and Inter-leukemia 6 (IL-6) [16]. Furthermore, eugenol down regulates the expression of cyclooxygenase-2 (COX-2) and inducible nitric oxide synthase (iNOS), reducing the levels of prostaglandins and nitric oxide that typically fuel inflammation.

Mechanistically, eugenol interferes with key intracellular signaling pathways, particularly nuclear factor-kappa B (NF- κ B) and mitogen-activated protein kinase (MAPK), both play essential roles in the transcriptional regulation of genes inflammatory. In vivo studies, including carrageenan-induced paw edema and acetic acid-induced writhing models in mice, have demonstrated its effectiveness in reducing inflammation and pain [17]. These properties recommend it's potential as a natural anti-inflammatory agent with less side effects compared to conventional drugs.

4.3. Antimicrobial Properties

4.3.1. Antibacterial Activity

Eugenol exhibits broad-spectrum of antibacterial activity against both Gram-positive and Gram-negative bacteria. The mechanism of action involves disorderly cell membrane of bacterial, resulting to the increased in permeability and out-flow of intracellular fluids. This often follow by inhibition of critical enzymatic pathways required for survival and replication of bacterial [18]. Its efficacy has been particularly remarkable against resistant strains such as *Staphylococcus aureus* and *Escherichia coli*.

4.3.2. Antifungal Activity

Eugenol also has strong antifungal activity by targeting the membrane and cell wall of pathogenic fungi such as *Aspergillus niger* and *Candida albicans*. It inhibits biosynthesis of ergosterol, an important component of fungal membranes, leading to conceded viability of a cell and growth inhibition.

4.3.3. Antiviral Activity

Although less widely researched, eugenol has revealed promised antiviral agent. Research result shown that eugenol can inhibit viral entry and replication in infections caused by Herpes Simplex Virus (HSV) and Influenza A virus [19]. This shown another breaks through for further examination into its potential as antiviral broad-spectrum compound.

4.4. Analgesic and Anesthetic Properties

For long now, Eugenol has been used for its analgesic and local anesthetic properties, particularly in dentistry. The mechanisms involved blocking the sodium channels voltage-gated, resulting in the inhibition of the propagation of nerve impulses that convey pain sensations [20]. The local anesthetics like lidocaine mode of action is similar to that of analgesic. These effects have been backed up by in-vivo studies, demonstrating the reduction of pains chemically induced nociception, such as acetic acid-induced writhing and formalin-induced paw licking [16].

Applications and Limitations

As a result of eugenol efficacy and safety profile, eugenol is commonly used in dental preparations and topical analgesics while excessive or prolonged use may cause adverse side reactions, like cytotoxicity, mucosal irritation, and allergic responses in sensitive individuals. Therefore, dosage formulation and management plans are vital to exploit its therapeutic benefits while reducing the risks [5].

4.5. Anticancer Properties

Eugenol has gained considerable attention as a natural anticancer agent due to its ability to trigger apoptosis, cell proliferation inhibition, and metastasis suppress in various cancer types. These effects are generally mediated through modulation of oxidative stress, cell cycle disruption, and both intrinsic and extrinsic apoptotic pathways activation [21, 22].

4.5.1. Mechanisms of Action

Eugenol fights cancer through several mechanisms:

Induction of Apoptosis: Eugenol activates enzymes like caspase, particularly caspases-3 and -9 and potential mitochondrial membrane disrupts, leading to programmed cell death.

Cell Cycle Arrest: Eugenol also down regulates cyclins and cyclin-dependent kinases (CDKs), halting cell cycle progression at either the phase G0/G1 or G2/M phase [23].

Inhibition of Metastasis and Angiogenesis: eugenol suppresses matrix metalloproteinase (MMP-2 and MMP-9) and vascular endothelial growth factor (VEGF), thus delaying tumor spread and formation of new blood vessel [22].

Oxidative Stress Modulation: eugenol also shows antioxidant protection in normal cells while promoting reactive oxygen species (ROS) generation in cancer cells to induce cytotoxicity, [22].

4.5.2. Synergistic Effects with Chemotherapeutic Agents

Eugenol has been studied to boost the efficacy of standard chemotherapeutics such as cisplatin, doxorubicin, and 5-fluorouracil. By reducing drug resistance and enhancing apoptosis, it also shows a complementary therapy in cancer treatment [24].

4.6. Anti-Inflammatory and Antioxidant Properties

Eugenol exhibits robust anti-inflammatory and antioxidant activities, making it a valuable compound for managing chronic inflammation and oxidative stress-related conditions. These effects are largely due to its phenolic structure, which enables free radical scavenging and modulation of inflammatory pathways [15, 6].

4.6.1. Anti-Inflammatory Mechanisms

Eugenol reduces inflammation through several biochemical actions:

Enzyme Inhibition: Suppresses COX-2, LOX, and iNOS enzymes, thereby limiting the production of inflammatory mediators like prostaglandins, leukotrienes, and nitric oxide [16].

Suppression of Cytokine: pro-inflammatory cytokines like TNF- α , IL-1 β , and IL-6 levels decreases [20].

NF- κ B Pathway Downregulation: Inhibitions of the NF- κ B signaling pathways, the major transcriptional regulator of inflammatory genes [14].

4.6.2. Antioxidant Activity

Antioxidant activity of Eugenol come from its ability to freely give hydrogen atoms to neutralized reactive oxygen species (ROS) such as hydroxyl radicals and hydrogen peroxide [15]. It has demonstrated strong antioxidant activity assays like DPPH, ABTS, and FRAP. Moreover, eugenol protects biomolecules such as lipids, proteins, and DNA from oxidative damage by preventing lipid peroxidation [25].

4.6.3. Biomedical Implications

Eugenol has being discovered for managing oxidative stress diseases, like cardiovascular disorders, arthritis, neurodegenerative conditions, and metabolic syndrome [5]. It also has adjunct potential in anti-inflammatory therapies,

especially when combined with other phytochemicals or pharmaceuticals.

4.6.4. Antimicrobial Properties

Eugenol has wide antimicrobial activity spectrum, targeting bacteria, fungi, and viruses effectively. Eugenol lipophilic phenolic structure permits it to disrupt microbial membranes, interfere with metabolic processes, and inhibit essential enzymes [7, 4].

4.6.5. Antibacterial Activity

Eugenol is effective against a wide range of bacterial pathogens, both Gram-positive and Gram-negative species:

Disruption of Membrane: membrane permeability Increases, leading to seepage of cellular contents [26].

Intracellular Interference: DNA and proteins Binds to intracellular membranes, resulting to the inhibition of replication and protein synthesis [7].

Anti-biofilm Activity: quorum sensing and biofilm formation in resistant strains like *Pseudomonas aeruginosa* and *Staphylococcus aureus* Inhibitions [27]. Eugenol MIC Reported values range between 0.02-0.5 mg/mL against *E. coli*, *Salmonella typhi*, *Listeria monocytogenes*, and *Bacillus cereus* [4].

4.6.6. Antifungal Activity

Eugenol is particularly effective against fungal pathogens such as *Candida*, *Aspergillus*, and *Cryptococcus*:

Membrane Targeting: Interactions with ergosterol, disrupt the fungal membrane veracity [28].

Morphological Inhibition: Blocks hyphae and germ tube formation factors in fungal virulence [29].

Gene Suppression Expression: Reduces production of virulence enzymes like secreted aspartyl proteases. Additionally, eugenol enhances the efficacy of antifungals like fluconazole in resistant infections [30].

4.6.7. Antiviral Activity

Although, the antiviral activity is less studied extensively, eugenol has shown a promising antiviral activity, particularly against enveloped viruses:

Disruption of Envelope: Destroys viral envelopes or blocks viral entry into host cells.

Replication Inhibition: Suppresses replication of viral, as observed in the studies with herpes simplex virus (HSV) and influenza virus [19]. These findings backed its potential as a multi-target antimicrobial agent.

4.7. Neuroprotective and Analgesic Activities

Eugenol also demonstrates significant neuroprotective and analgesic properties, highlighting its potential in treating neurological disorders and managing pain. These effects are mediated through antioxidant mechanisms, ion channel

modulation, and inhibition of neuro-inflammation.

4.7.1. Neuroprotective Effects

Eugenol safeguards neurons from oxidative and excitotoxic injury by:

Neutralizing ROS: Reduces oxidative stress and lipid peroxidation, preserving neuronal function and viability [31].

Inhibiting Glutamate Toxicity: Protects against glutamate-induced neurodegeneration, an important factor in Alzheimer's and Parkinson's disease [32].

Modulating Neurotransmission: GABAergic enhances activity while suppressing excitatory signals [5]. In vivo studies report an improvements in memory and cognitive performance following eugenol treatment in aged or chemically challenged animals [33].

4.7.2. Analgesic Effects

Traditionally used for dental pain, eugenol's analgesic activity is well established:

Ion Channel Blockade: Inhibits sodium channels voltage-gated and TRPV1 receptors, dampening nerve signal transmission [20].

Anti-inflammatory Action: Reduces production of pain-inducing mediators such as prostaglandins and nitric oxide [16].

Synergistic Pain Relief: Enhances the effectiveness of opioids and NSAIDs without significantly increasing toxicity [15]. In vivo studies has confirm eugenol's ability to relieve thermal, chemical, and mechanical pain.

4.8. Anticancer Activities

Eugenol, a natural compound found in clove and other aromatic plants, has drawn increasing attention for its ability to fight cancer. Studies have shown that it acts on cancer cells in several powerful ways by triggering cell death, halting their growth, and even stopping them from spreading.

4.8.1. Inducing Cancer Cell Death (Apoptosis)

One of the most important ways eugenol works is by initiating apoptosis, the programmed death of cancer cells through:

Activating key death pathways inside cells, including changes in mitochondrial function and the release of molecules like cytochrome c that kick-start the death process [6].

Increasing oxidative stress in cancer cells by generating reactive oxygen species (ROS), which cause damage selectively to these abnormal cells [34].

Balancing cell survival and death proteins, reducing the levels of anti-death (Bcl-2) proteins while boosting pro-death (Bax) signals [35].

4.8.2. Blocking Cancer Cell Growth (Cell Cycle Arrest)

Eugenol also stops cancer cells from multiplying by interfering with their cell cycle, the process by which cells grow and divide. It primarily arrests cells at the G0/G1 and G2/M phases by:

Disrupting the activity of cyclins and CDKs, the proteins that drive the cell cycle forward [36].

Activating the tumor suppressor p53, a key guardian of the genome that helps pause cell division to allow repair or trigger death if damage is too great [37].

4.8.3. Preventing Cancer Spread (Anti-Metastatic Effects)

Cancer's ability to spread makes it especially dangerous.

Eugenol helps to reduce this risk by:

Inhibiting enzymes like MMP-2 and MMP-9, which break down the extracellular matrix and allow cancer to invade new tissues [38].

Blocking epithelial-to-mesenchymal transition (EMT), a process that gives cancer cells the mobility they need to spread throughout the body [39].

4.8.4. Synergistic Effects

Eugenol has also shown promise when used in combination with chemotherapy drugs like cisplatin and 5-fluorouracil. It can:

Make cancer cells more responsive to treatment, even those that have developed resistance [6].

Lower the amount of chemotherapy needed, which could help reduce side effects [34].

Table 2. Summarized the biological activities and corresponding mechanisms of Eugenol.

Biological Activity	Mechanism of Action
Anticancer	Induces apoptosis via caspase-3 activation; modulates p53, Bax/Bcl-2 expression; arrests cell cycle (G0/G1 or G2/M phases); inhibits angiogenesis
Antioxidant	Scavenges free radicals (e.g., DPPH, superoxide); donates hydrogen atoms; upregulates antioxidant enzymes (e.g., SOD, CAT, GPx)
Anti-inflammatory	Inhibits COX-2 and LOX enzymes; suppresses NF-κB signaling; reduces pro-inflammatory cytokines (e.g., TNF-α, IL-1β, IL-6)
Antimicrobial	Disrupts microbial cell membranes; causes leakage of cellular contents; inhibits enzymes involved in cell wall synthesis
Antifungal	Damages fungal cell membranes; inhibits ergosterol biosynthesis; disrupts mitochondrial functions
Antiviral	Interferes with viral envelope integrity; inhibits viral replication enzymes
Neuroprotective	Reduces neuroinflammation and oxidative stress; inhibits AChE; improves mitochondrial function and synaptic plasticity
Hepatoprotective	Reduces lipid peroxidation; enhances glutathione levels; stabilizes liver enzymes (ALT, AST)
Cardioprotective	Inhibits lipid peroxidation; improves lipid profile; suppresses inflammatory markers in cardiac tissue
Antidiabetic	Enhances insulin sensitivity; inhibits α-glucosidase and α-amylase enzymes; modulates glucose transport and metabolism
Anesthetic	Acts on peripheral nerve endings; blocks ion channels (Na ⁺ /K ⁺) and prevents nerve conduction
Analgesic	Inhibits voltage-gated sodium channels and TRPV1 receptors; modulates prostaglandin synthesis

4.9. Safety and Toxicity Profile

The eugenol is generally consider safe and widely used in foods, cosmetics, and dental care products at low concentrations, the effects may vary depending on the dosage, method of using, and formulation.

4.9.1. Toxicity Studies

Short-term exposure: Eugenol is generally tolerated in

animals, with relatively high LD₅₀ values (1,000-3,000 mg/kg), therefore it is required in large doses to be lethal [40].

Long-term use: Prolonged or high-dose exposure may cause harm to the liver or kidneys, as eugenol increased liver enzymes and tissue changes [41]. This feature is importance for accurate dosing.

Allergic reactions: Eugenol can cause skin sensitivity and allergic contact dermatitis, especially with undiluted use or repeated exposure [42]. It may also irritate mucous membranes.

4.9.2. Cancer Risk and Genetic Safety

Research on whether eugenol can damage DNA or cause mutations has shown mixed results. Where some lab tests results suggested weak mutagenic activity at high concentrations, studies in living organisms generally show no cancer-causing potential [43]. Eugenol is not classified as a carcinogen by regulatory authorities.

4.9.3. Metabolizing of Eugenol

Once eugenol is ingested or absorbed, is quickly processed by the liver, where it's conjugated with glucuronic acid or sulfate and then excreted in urine [44]. When it is breakdown to products, there typically become less harmful than the in whole compound form.

4.9.4. Regulatory and Legal Approval

Regulatory agencies like the European Food Safety Authority (EFSA) and U.S. Food Development Agencies, allow the use of eugenol in flavorings and dental products within defined limits [45]. However, involving eugenol in medicinal products applications requires thorough safety assessments.

5. Conclusion and Future Perspectives

Eugenol is a naturally occurring compound with a wide range of health benefits. From fighting inflammation and infections to protecting the nervous system and even combating cancer, it works through multiple biological pathways making it a strong candidate for therapeutic use. However, despite its potential, there are several challenges Eugenol faces, such as low water solubility, rapid metabolism, and narrow margin between effective and toxic doses have limited its clinical usage. To overcome these barriers, researchers are exploring different advanced delivery systems like microcapsules, nanoparticles, and Nano-emulsions to improve stability, absorption, and targeted action.

Future research should focus on the human based toxicological studies for better understanding of the safety dosage limits, running clinical trials to validate its effectiveness across different diseases, Developing smarter formulations that deliver eugenol where it's needed, while minimizing side effects and Exploring combinations of eugenol with other natural products or drugs for enhanced effects. Given its natural origin, affordability, and wide biological actions ranges, eugenol has the potential to play a key role in future pharmaceutical, nutraceutical, and cosmetic innovations. With the right research and development, it could solved the medical leaps from traditional uses to modern medical applications.

Abbreviations

ABTS 2, 2'-azino-bis
(3-ethylbenzothiazoline-6-sulfonic acid)

ATP	Adenosine Triphosphate
BHT	Butylated Hydroxytoluene
CAT	Catalase
CDKs	Cyclin-Dependent Kinases
COX-2	Cyclooxygenase-2
DNA	Deoxyribonucleic Acid
DPPH	2, 2-diphenyl-1-picrylhydrazyl
EFSA	European Food Safety Authority
EMT	Epithelial-Mesenchymal Transition
FDA	Food and Drug Administration (U.S.)
FRAP	Ferric Reducing Antioxidant Power
GABA	Gamma-Aminobutyric Acid
GPx	Glutathione Peroxidase
GRAS	Generally Recognized as Safe
HSV	Herpes Simplex Virus
IC ₅₀	Half-Maximal Inhibitory Concentration
IL-1 β	Interleukin-1 beta
IL-6	Interleukin-6
iNOS	Inducible Nitric Oxide Synthase
LD ₅₀	Lethal Dose (for 50% of test organisms)
LOX	Lipoxygenase
LPS	Lipopolysaccharide
MAPK	Mitogen-Activated Protein Kinase
MIC	Minimum Inhibitory Concentration
MMP-2 /	Matrix Metalloproteinase-2 / -9
MMP-9	
MMPs	Matrix Metalloproteinases
MPO	Myeloperoxidase
NF- κ B	Nuclear Factor-kappa B
NO	Nitric Oxide
NSAIDs	Non-Steroidal Anti-Inflammatory Drugs
pKa	Acid Dissociation Constant
ROS	Reactive Oxygen Species
SOD	Superoxide Dismutase
TNF- α	Tumor Necrosis Factor-alpha
TRPV1	Transient Receptor Potential Vanilloid 1
VEGF	Vascular Endothelial Growth Factor
ZOE	Zinc Oxide-Eugenol

Author Contributions

Ahmad Umar Faruq: Resources, Writing – review & editing
Ibrahim Mohammed Ibrahim: Supervision, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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