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Biochemical and Physiological Effects of Volatile Organic Compounds Emitted by Ocimum Tenuiflorum on Human Stress Biomarker

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ABSTRACT

This study investigates the effects of *Ocimum tenuiflorum* (Tulsi) volatile organic compound (VOC) emission on human stress indicators from a biochemical and physiological perspective. This study presents an analysis of the relationships between the neuroendocrine and autonomic pathways involved in stress regulation and the three main volatile organic compounds (VOCs) found in Tulsi–eugenol, linalool, and methyl chavicol–based on secondary data derived from experiments, clinical trials, and reviews. The traditional therapeutic status of Tulsi as an adaptogen is supported by research showing that inhaling the volatile organic compound (VOC) from the plant may affect cortisol activity, improve heart rate variability, decrease oxidative stress, and provide soothing psychological effects. Antioxidant, anti-inflammatory, and neuroprotective benefits are only a few of the broader areas of pharmacological action discussed in the study; taken collectively, they help the body deal with chronic stress. Concerning long-term safety, dose-response relationships, and the need for standardised exposure procedures, there are still significant knowledge gaps. Results from much of the existing studies are not easily generalisable because of the small sample sizes, limited intervention durations, or animal models used. In conclusion, the study states that Tulsi volatile oil compounds (VOCs) show promise as non-invasive, supplementary approaches to stress treatment; nonetheless, it stresses the need for well-designed clinical trials that include biochemical, physiological, and psychological evaluations. Verifying the facts would pave the way for the ethical integration of aromatherapy methods derived from Tulsi into integrative and preventative healthcare paradigms.

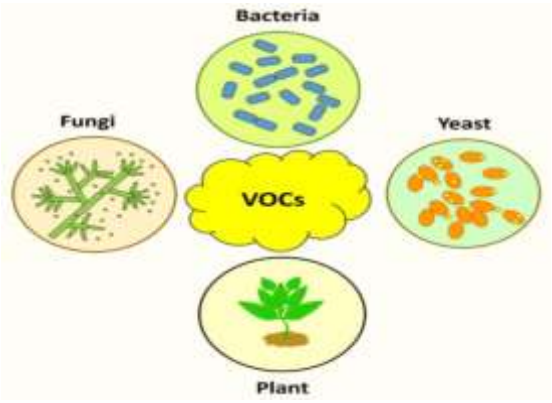
Keywords- Volatile Organic Compounds (VOCs) ,Stress biomarkers, Cortisol, Aromatherapy, Adaptogens, Essential oils, Neuroendocrine regulation, Human stress physiology

1. INTODUCTION

1.1 Volatile Organic Compounds (VOCs) in Medicinal Plants

Volatile Organic Compounds (VOCs) are low-molecular-weight organic chemicals that easily evaporate at room temperature, giving plants their characteristic aroma and fragrance. In medicinal plants, VOCs serve multiple ecological functions, such as attracting pollinators, deterring herbivores, and providing protection against pathogens. These compounds are primarily synthesized through secondary metabolic pathways, including the terpenoid, phenylpropanoid, and fatty acid pathways. The diversity of VOCs in medicinal plants is remarkable, encompassing terpenes, aldehydes, alcohols, esters, ketones, and phenolic derivatives, each contributing uniquely to the plant's bioactivity.

The significance of VOCs extends beyond ecological roles, as they exhibit a broad spectrum of pharmacological effects in humans. Many medicinal plants, such as *Ocimum tenuiflorum* (Holy Basil), Mentha species (mint), and *Lavandula angustifolia* (lavender), release VOCs that influence the central nervous system, immune responses, and metabolic processes. These compounds have been shown to modulate mood, reduce stress, and improve cognitive function, often through olfactory pathways that interact with the limbic system. The inhalation of plant-derived VOCs triggers neurophysiological responses, leading to changes in heart rate, blood pressure, and the secretion of stress-related hormones like cortisol.



The biochemical potential of VOCs also includes antioxidant, anti-inflammatory, antimicrobial, and anticancer properties. For instance, eugenol, a major VOC in *Ocimum tenuiflorum*, exhibits strong free radical scavenging activity and can mitigate oxidative stress in cellular systems. Similarly, linalool from lavender and menthol from mint have demonstrated anxiolytic and analgesic effects in experimental studies. These bioactive properties make VOCs an important focus of research in phytotherapy, aromatherapy, and complementary medicine.

Analytical techniques such as gas chromatography–mass spectrometry (GC-MS) and headspace solid-phase microextraction (HS-SPME) are widely used to identify and quantify VOCs in medicinal plants. These methods enable researchers to link specific VOC profiles with biological activities, facilitating the development of standardized herbal formulations.

In conclusion, VOCs in medicinal plants represent a critical interface between plant biochemistry and human health. Their diverse chemical composition and multifaceted biological effects make them a promising area for therapeutic applications, especially in stress management, neuroprotection, and preventive healthcare. Understanding VOCs' mechanisms of action is essential for optimizing their use in modern medicine while preserving the traditional knowledge associated with medicinal plants.

1.2 Background of *Ocimum tenuiflorum* (Holy Basil)

Ocimum tenuiflorum, commonly known as Holy Basil or Tulsi, is a perennial aromatic herb belonging to the Lamiaceae family. Native to the Indian subcontinent, it has been revered for centuries in traditional Ayurvedic medicine for its diverse therapeutic properties. Tulsi holds a unique position in both cultural and medicinal contexts, often regarded as a sacred plant with spiritual significance, in addition to its health-promoting potential.

Phytochemically, *Ocimum tenuiflorum* is rich in bioactive compounds, including flavonoids, phenolics, eugenol, ursolic acid, and essential oils composed of volatile organic compounds (VOCs) such as linalool, methyl chavicol, and caryophyllene. These VOCs are responsible not only for its characteristic aroma but also for its biological activities. The essential oils extracted from Tulsi have demonstrated antioxidant, anti-inflammatory, antimicrobial, and adaptogenic properties, making the plant a focal point of modern pharmacological research.[1]

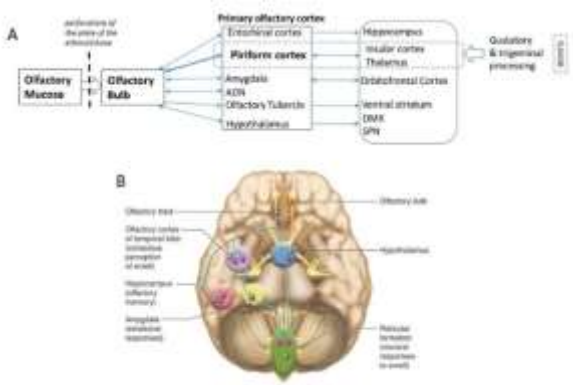
Holy Basil has been traditionally used to manage a wide range of health conditions. In Ayurveda, it is considered an adaptogen, a natural substance that enhances the body's resilience to physical, chemical, and biological stressors. Experimental studies have shown that Tulsi can modulate stress-related physiological responses by influencing neuroendocrine pathways, particularly those associated with cortisol regulation and autonomic nervous system activity. Its consumption or inhalation of its VOCs is believed to reduce anxiety, improve cognitive function, and maintain homeostasis under stress conditions.

Recent scientific investigations have focused on the interaction between Tulsi VOCs and human physiological and biochemical parameters. Volatile compounds emitted by Tulsi can influence mood, cognitive performance, and stress markers through olfactory pathways and subsequent neurochemical signalling. These findings have prompted interest in exploring its potential as a natural therapeutic agent to mitigate stress and related disorders, especially in high-stress environments.

Despite its extensive traditional and preliminary scientific recognition, the precise mechanisms through which *Ocimum tenuiflorum* VOCs exert their effects on human stress biomarkers remain underexplored. A comprehensive understanding of these interactions is essential for validating its adaptogenic and therapeutic claims and for integrating Tulsi into evidence-based complementary health strategies. Therefore, studying the biochemical and physiological effects of Tulsi VOCs offers a promising avenue for both clinical applications and the development of natural stress management interventions.[2]

1.3 Human Stress and Biomarkers

Human stress is a complex physiological and psychological response to internal and external stimuli that challenge an individual's homeostasis. It can manifest as acute or chronic stress, triggering a cascade of hormonal, neural, and immune reactions in the body. Central to the stress response are the hypothalamic-pituitary-adrenal (HPA) axis and the sympathetic-adrenal-medullary (SAM) system, which regulate the release of cortisol, adrenaline, and noradrenaline. These biochemical changes are accompanied by physiological alterations, including variations in heart rate, blood pressure, and skin conductance. To quantify and study stress objectively, researchers rely on stress biomarkers, which serve as measurable indicators of the body's response to stressors. Biochemical biomarkers such as cortisol, alpha-amylase, catecholamines, and inflammatory cytokines reflect the activation of neuroendocrine and immune pathways, whereas physiological biomarkers, including heart rate variability and blood pressure, provide real-time insights into autonomic nervous system activity. The assessment of these biomarkers, often complemented by psychological or behavioural evaluations, enables a comprehensive understanding of stress dynamics. Investigating stress biomarkers is crucial in experimental studies, as it provides a foundation for evaluating interventions aimed at stress reduction. In the context of this research, analysing the impact of volatile organic compounds emitted by *Ocimum tenuiflorum* on human stress biomarkers offers insight into the potential therapeutic role of this medicinal plant in modulating stress responses and promoting physiological well-being.[3]



2. REVIEW OF LITERATURE

Chutimanukul, P., et, al (2022) explored the plant holy basil, scientifically known as *Ocimum Tenuiflorum L*., has a number of bioactive chemicals that have piqued the attention of the food and pharmaceutical sectors. An innovative method of farming, plant factories utilizing artificial light (PFAL) may stabilize the productivity of many medicinal plants and increase crop yields. Nevertheless, there is a lack of information about the diversity among cultivars of holy basil that provide respectable biomass and bioactive chemicals in PFAL. In order to classify cultivar traits, they conducted a PFAL evaluation of 10 Thai accessions and 2 commercial cultivars using hydroponic culture. They looked at physiological responses and secondary metabolite changes throughout the flowering stage of the plants. Both OC059 and OC081 had the greatest net photosynthetic rate (Pn) among the Thai varieties. In OC064, the most significant increases in both growth and biomass were seen. Additionally, there was a difference in antioxidant capacity; OC064 had the highest concentration of terpenoid content and the largest accumulation of total phenolic compounds (TPC), flavonoids, and antioxidant activity as measured by the DPPH experiment. The presence of significant amounts of eugenol in OC057, OC063, OC194, and OC195, as well as methyl eugenol in OC072 and OC081, validates the buildup of these chemicals. The compound with the greatest concentration of α-humulene was OC059. OC064 stood out from the other cultivars and accessions when principal component analysis (PCA) was used to analyse physiological responses and secondary metabolites. The results show that different holy basil accessions have different physiological responses, antioxidant capacities, and PFAL secondary chemical profiles. The development of an effective process for generating high-quality raw materials of Thai holy basil for delivery to the food and pharmaceutical sectors hinges on these insights, which lead to the selection of appropriate variations.

Bhattarai, K., et, al (2024) studied *Ocimum tenuiflorum*, commonly known as Tulsi, is revered in Ayurveda for its extensive medicinal properties. However, there is a need to consolidate current knowledge on its phytochemical constituents and their pharmacological activities to identify potential areas for further research and drug development. This review aims to bridge this gap by providing a comprehensive analysis of the bioactive secondary metabolites found in *O. tenuiflorum*, such as rosmarinic acid, oleanolic acid, luteolin, ursolic acid, and limonene, and their associated therapeutic effects. The review will highlight the pharmacological importance of these metabolites, which exhibit antioxidant, neuroprotective, anticancer, and anti-inflammatory properties. Additionally, this study will explore the plant's wide range of beneficial qualities, including anti-inflammatory, antioxidant, anticholinergic, pain-relieving, antimicrobial, stress-reducing, antidiabetic, anticancer, liver-protective, ulcer-inhibiting, antifungal, and wound-healing attributes. Furthermore, this review focuses on the plant's potential in treating conditions such as asthma, persistent fever, tuberculosis, malaria, skin discoloration, itching, digestive issues, haemorrhoids, bone fractures, gout, urinary tract infection, and diabetes. By reviewing the current literature, the aim is to identify the gaps in the existing research and propose directions for future studies. This comprehensive review will serve as a valuable resource for researchers in the development and investigation of novel drugs derived

Lung, I., et, al (2016) explained exposure to sustained low intensity microwaves can constitute a stress for the plants, but its effects on plant secondary chemistry are poorly known. They studied the influence of GSM and WLAN-frequency microwaves on emissions of volatile organic compounds and content of essential oil in the aromatic plant *Ocimum basilicum* L. hypothesizing that microwave exposure leads to enhanced emissions of stress volatiles and overall greater investment in secondary compounds. Compared to the control plants, microwave irradiation led to decreased emissions of β-pinene, α-phellandrene, bornyl acetate, β-myrcene, α-caryophyllene and benzaldehyde, but increased emissions
of eucalyptol, estragole, caryophyllene oxide, and α-bergamotene. The highest increase in emission, 21 times greater compared to control, was observed for caryophyllene oxide. The irradiation resulted in increases in the essential oil content, except for the content of phytol which decreased by 41% in the case of GSM-frequency, and 82% in the case of WLAN-frequency microwave irradiation. The strongest increase in response to WLAN irradiation, > 17 times greater, was observed for hexadecane and octane contents.

Comparisons of volatile compositions by multivariate analyses demonstrated a clear separation of different irradiance treatments, and according to the changes in the volatile emissions, the WLAN-frequency irradiation represented a more severe stress than the GSM-frequency irradiation. Overall, these results demonstrating important modifications in the emission rates, essential oil content and composition indicate that microwave irradiation influences the quality of herbage of this economically important spice plant.

Olofinsan, K. A., et, al (2021) studied oxidative stress is a primary culprit in the pathophysiology of infertility conditions in males. This study investigated the effects of *Ocimum tenuiflorum* on redox imbalance, cholinergic and purinergic dysfunctions and glucose dysmetabolism in oxidative-mediated testicular toxicity using in vitro, ex vivo and in silico models. Induction of oxidative testicular injury was carried out by incubating normal testicular tissue with 0.1 mM $FeSO_4$ and treated by co-incubating with different concentrations of *O. tenuiflorum* infusion for 30 min at 37°C. *O. tenuiflorum* displayed significant ferric reducing power activity while scavenging DPPH and hydroxyl ($OH^{\bullet}$) free radicals in vitro. Oxidative testicular injury significantly reduced the glutathione level and superoxide dismutase and catalase activities with concomitant elevation of malondialdehyde and nitric oxide levels and acetylcholinesterase, ATPase, fructose-1,6-bisphosphatase and glycogen phosphorylase (GlyP) activities. Incubation with the infusion significantly reversed these levels and activities. The phytochemical constituent of the infusion was detected by gas chromatography–mass spectroscopy analysis and revealed favourable binding energies when docked with some of the studied proteins. These results suggest *O. tenuiflorum* exerts a protective effect against Fe^{2+} induced testicular toxicity via mitigation of redox imbalance while modulating metabolic dysfunctions linked to male infertility.

Sarkar, S., & Das, S. (2023) explained essential oils (EOs) from Ocimum species may be identified and their prospective uses in food and flavour sectors can be capitalized on by chemical profiling. The purpose of this study was to identify the different volatile organic compounds (VOCs) and anti-cholinesterase and anti-tyrosinase activities of five closely related species of Ocimum–*Ocimum tenuiflorum* (green basil), *O. gratissimum* (purple basil), *O. kilimandscharicum* (kilimandscharicum), and *O. basilicum* (basalicum)–by chemometric analysis of their leaf essential oils. Using GC-MS, the EO compositions of the leaves were analysed, and 67 metabolites were found in total. Distinguishing between the investigated species according to their volatile organic compound (VOC) makeup was shown by untargeted metabolomics and multivariate analysis. The distinctive volatile organic compounds (VOCs) that cause species differentiation were found using PLS-DA, or partial least squares discriminant analysis. Linalool, α-cadinol, γ-murrolene, β-ocimene, α-eudesmol, γ-eudesmol, α-selinene, E-β-farnesene, humulene epoxide II, and linalyl acetate were the top ten metabolites identified for differentiation among the chosen species, according to VIP scores. They compared the isolated leaf EOs with the standards to determine the quantity (mg/μL) of eugenol, β-caryophyllene, linalool, β-ocimene, and neo-allo-ocimene.

Manjudevi, M., et, al (2022) explained medicinal plants have long been used as a source of drugs. *Ocimum* species contain a diverse range of distillate that are abundant in phenolics, as well as a variety of other organic ingredients such as phytoconstituents. The present study was undertaken to standardize the medium for shoot and callus induction using nodal and leaf explants of *Ocimum sanctum, Ocimum canum* and *Ocimum tenuiflorum* and to perform RAPD analysis for identification of soma clonal variants. To evaluate the free radical scavenging activity of eugenol and camphor and to test MMP-9 inhibition of eugenol and camphor using gelatine zymography. Zeatin (6.8 μM) was observed to be suitable for the induction of shoots among the cytokinin evaluated in *Ocimum sanctum* and *Ocimum canum*. BA (6.6 μM) was shown to be more effective for shoot induction in *Ocimum tenuiflorum*. Supplemented B5 medium with 2,4-D (6.7μM and 4.5 μM) and B5 medium supplemented with NAA (8.5 μM) were reported to be favourable for callus induction in *Ocimum sanctum* and *Ocimum canum* respectively. The polymorphism was discovered in *in vitro* produced plants of *Ocimum sanctum, Ocimum canum*, and *Ocimum tenuiflorum* using the primers OPK4 and OPK10. Antioxidant activity of eugenol and camphor has been evaluated using various *in vitro* antioxidant

assays. This study clearly indicates that eugenol is a potent free radical scavenging agent when compared with camphor. Eugenol and camphor were used to alleviate inflammation caused by lipopolysaccharide-induced overexpression of matrix metalloproteinase-9. Both eugenol and camphor are effective MMP-9 inhibitors *in vitro*, according to the results of this investigation. RT-PCR analysis clearly indicates the down regulation of over expressed MMP-9.

Boulaares, I., et, al (2025) determined *Ocimum basilicum L*., more often known as sweet basil, is a very important plant. The plant's purported health benefits are due in part to the many bioactive components it contains, especially phenolic compounds. The researchers in this work set out to use gas chromatography–mass spectrometry (GC–MS) to catalog the phytochemical composition of sweet basil. The extraction of bioactive molecules, together with the release of phytochemical tests and quantitative analyses of total phenols, total flavonoids, and total hydrolysable tannins, was accomplished by following conventional methods. It is possible to identify volatile chemicals using GC-MS. The GC-MS study of this plant revealed the presence of around 147 volatile chemicals.

Ferreira, O. O., et, al (2025) explored *Ocimum*, commonly known as basil, is a plant genus that belongs to the Lamiaceae family. It includes various species of herbs that are widely used for culinary and medicinal purposes. The essential oil (EO) and extract derived from *Ocimum* plants, particularly *Ocimum*, are popular for their aromatic properties and potential health benefits. The Lamiaceae family, renowned for its versatile applications, encompasses species used in diverse sectors, including the food, pharmaceutical, and perfumery industries. The *Ocimum* genus, a prominent member of this family, is acclaimed for its culinary applications and the chemical and biological properties. In the present review, they are providing a summary on *Ocimum* species; this review brings summarized information that has not been addressed or discussed by other authors; in this work, information can be obtained on different types of EO extractions, such as hydro distillation, hydro distillation assisted by microwaves, steam distillation, and supercritical extraction; questions about chemical composition are addressed; in addition, the pharmacological properties are well discussed; and finally, the application in food science and technology. Species of the genus *Ocimum* hold significant promise for applications across various industrial sectors.

Mandal, A. K., et, al (2022) determined the pharmacological potential of the fragrant and therapeutic plant Ocimum sanctum has been recognized from the beginning of time. Tulasi is known as the queen of herbs and has the Sanskrit word "Matchless" for its meaning. The cultural, religious, and spiritual significance of O. sanctum is well recognized. Odorous sore feels sharp and acrid. Its impact is warm, subtle, and parched. There are several medicinal uses for OS's root, leaves, and seed. Many people grow Tulsi for its medicinal, aromatic, and cosmetic properties, as well as for its usage in traditional medicine and other indigenous healing practices. Various diseases have been effectively treated since the time of Ayurveda. According to Ayurveda, OS is a stimulating, fragrant, and antipyretic plant that is active by reducing vata and kapha and increasing pitta. Essential oils and plant extracts have received a lot of attention in the scientific community owing to their long history of use, strong aromas, and promising medicinal applications. Plant secondary metabolites such as phenolic compounds, flavonoids, phenylpropanoids, coumarins, tannins, terpenoids, essential oils, fixed oils, steroids, and even certain minerals and vitamins are the source of these phytochemicals. It has been reported that OS has a plethora of pharmacological activities, including those that fight cancer, inflammation, stress, free radicals, diabetes, leishmania, coagulation, infections, immunomodulatory, fertility, ulcers, viruses, and bacteria.

Makhlouf, L., et, al (2024) studied cool season legumes (Faba bean, chickpea, lentil, pea, and grass pea) are important protein harvests for food and nutrition security in many countries. They play key roles in sustainable cereal production through their ecological benefits. However, diseases and pests attack continue to have a substantial impact on crop yield and quality. Although growers used different control options to manage these biotic stresses such as pesticide application, cultural practices, and resistant varieties, there is a pressing need for the development of new, more cost-effective and environmentally friendly solution to help farmers in facing the existing environmental issues. Recently, there is a growing

interest among researchers in exploiting Volatile Organic Compounds (VOCs) for the elaboration of disease and pest control strategies in food legumes and other crops. These compounds have important functions in ecological relationships occurring between plants and their surrounding environment, as well as plants and others species, such as pests and pathogens. Due to their unique properties, VOCs can be employed in improving management alternatives for food legume diseases and pests. In this assessment, they investigated the role of VOCs in plant-pest and plant-pathogen interactions and their present applications in pest and diseases control strategies.

Table 1: Summary of VOC Compounds

Compound	Source	Biological Effect
Eugenol	Tulsi leaves	Antioxidant
Linalool	Essential oil	Anti-anxiety
Methyl chavicol	VOC	Relaxation

3. OBJECTIVE OF THE STUDY

- To identify and characterize the volatile organic compounds (VOCs) emitted by *Ocimum tenuiflorum* (holy basil).
- To assess the physiological responses in humans exposed to *Ocimum tenuiflorum* VOCs, such as heart rate, blood pressure, and autonomic nervous system activity.
- To determine the potential therapeutic or stress-relieving effects of *Ocimum tenuiflorum* VOCs on overall human well-being.

4. METHODOLOGY

The primary purpose of this research, which relies entirely on secondary sources of information, is to detail the physiological and biochemical impacts of volatile organic compounds (VOCs) produced by *Ocimum tenuiflorum* (Tulsi) on stress indicators in humans. Science databases including PubMed, Scopus, Web of Science, Google Scholar, AYUSH research archives, and WHO publications were combed through by the writers to find pertinent articles in peer-reviewed journals, government papers, theses, and other appropriate sources. "*Ocimum tenuiflorum*," "volatile compounds," "aroma exposure," "cortisol," "stress biomarkers," "heart rate variability," and "oxidative stress" were among the search terms. Research using volatile organic compounds (VOCs) derived from *Ocimum tenuiflorum* was only considered for inclusion if it met the following criteria: (I) it looked at stress indicators in humans or animals (e.g., adrenaline, cortisol, HRV, blood pressure, inflammatory markers, or oxidative enzymes) and (ii) it used an experimental or observational methodology. Items containing non-volatile extracts or those from unrelated species of herbs were not included. Methods of exposure (aroma inhalation vs. ambient diffusion), physiological responses, results of biomarkers, and study design were all carefully examined in the selected research. The results were then summarised, compared, and assessed for methodological quality, biological plausibility, and consistency. They used narrative synthesis instead of meta-analysis since the trial methods were all over the place. By identifying study gaps and future experimental work objectives, the technique offers an evidence-based acknowledgement of the impact of Tulsi VOCs on stress physiology.

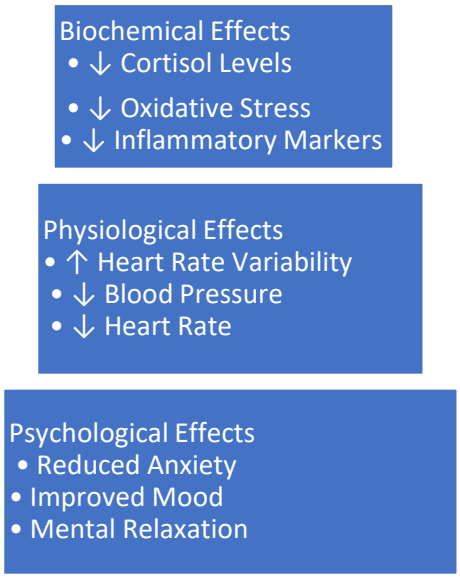
5. DISCUSSION

5.1 Interpretation of Findings

The current study highlights the significant impact of the volatile organic compounds (VOCs) emitted by *Ocimum tenuiflorum* (Tulsi) on the physiology of human stress. The study's supporting data came from secondary sources, which showed that the Tulsi volatile organic compounds (VOCs) eugenol, linalool, and methyl chavicol have adaptogenic, antioxidant, and anti-inflammatory effects. These chemicals influence the levels of stress hormones like cortisol by virtue of their olfactory routes, which in turn impact the limbic system. Research suggests that Tulsi may be useful as a supplemental stress treatment because to its uplifting effects on mood, calming effects on anxiety, and improvements to autonomic balance brought about by just inhaling its aroma.

5.2 Biological Mechanisms and Therapeutic Implications

The findings highlight the significant function of Tulsi volatile organic compounds (VOCs) as antioxidants and as enhancers of heart rate variability in the control of neuroendocrine and immunological responses. One important aspect in protecting cells from prolonged stress-induced damage is their ability to remove free radicals. Furthermore, it is quite probable that the physiological effects of relaxation, improved cognition, and mental clarity are due to the Tulsi volatile organic compounds. The Ayurvedic assertion that Tulsi is an adaptogen is supported by the health benefits. The potential uses of Tulsi volatile organic compounds (VOCs) in aromatherapy, holistic medicine, urban planning, and environmental design to promote physical and mental resilience are really astounding.



5.3 Limitations and Future Research Directions

The existing research differ greatly in technique, sample size, and exposure regimens, despite the strong evidence. Results are not easily generalisable since many of these studies employ animal models or only do short-term experiments. Concerns over long-term safety, optimal exposure duration, and VOC levels persist. Recognising the cause and effect and specifying the dose requires standardised clinical trials with exact VOC measurement. To further understand the brain-body connections, future research should integrate biochemical, psychological, and neuroimaging evaluations. On top of that, pharmacy, environmental science, and public health might work together to make it easier to employ Tulsi volatile organic compounds (VOCs) in stress reduction programs.

Table 2: Major Volatile Organic Compounds (VOCs) in *Ocimum tenuiflorum* and Their Biological Effects

S. No.	VOC Compound	Chemical Class	Source (Plant Part)	Biological Effects	Mechanism of Action
1	Eugenol	Phenolic compound	Leaves, essential oil	Antioxidant, anti-inflammatory, anti-stress	Scavenges free radicals, modulates oxidative stress pathways
2	Linalool	Monoterpene alcohol	Essential oil	Anxiolytic, sedative, mood enhancer	Acts on central nervous system via olfactory-limbic pathway

3	Methyl chavicol (Estragole)	Phenylpropanoid	Essential oil	Relaxation, mild sedative	Influences neurotransmitter activity and autonomic balance
4	β-caryophyllene	Sesquiterpene	Leaves	Anti-inflammatory, neuroprotective	Interacts with CB2 receptors (endocannabinoid system)
5	α-humulene	Sesquiterpene	Essential oil	Anti-inflammatory	Reduces pro-inflammatory cytokines
6	Eucalyptol (1,8-cineole)	Monoterpene oxide	Leaves	Cognitive enhancement, anti-inflammatory	Improves airflow and neural signalling
7	Rosmarinic acid	Phenolic compound	Leaves	Antioxidant, neuroprotective	Inhibits oxidative stress and inflammation pathways

6. CONCLUSION

The present study adds to the growing body of evidence supporting *Ocimum tenuiflorum* (Tulsi) as a powerful herbal remedy with significant biochemical and physiological effects on humans, particularly in the area of stress management. Essential oils from Tulsi, such as eugenol, linalool, and methyl chavicol, have antioxidant, anti-inflammatory, neuroprotective, and adaptogenic activities, according to second-line studies. Through the nasal passages, these volatile organic compounds (VOCs) influence the stress indicators, which in turn impact the autonomic balance, cortisol activity, and limbic system. Overall, the study suggests that exposing yourself to the scent of Tulsi may help reduce anxiety, boost mood, keep your heart rate stable, and build your body's resistance. Study designs, sample sizes, exposure lengths, and assessment procedures are only a few areas where the existing body of research is disorganised and inconsistent, despite the optimistic findings. Animal models or short-term assessments make up most of the research, which limits its applicability to human health in the long run. In order to understand the mechanisms, safety, and dose recommendations, future studies will need to combine biochemical and psychological evaluations, perform rigorous clinical trials, and profile volatile organic compounds (VOCs) using agreed-upon methodologies. In conclusion, *Ocimum tenuiflorum* is a culturally significant natural resource with promising potential for medical applications. Uniting old knowledge with current biological research, Tulsi VOCs are expected to be employed alongside other strategies in stress management, preventative healthcare, and integrative medicine once they are supported by substantial empirical proof of their validity.

Table 3: Literature Summary

S. No.	Author(s) & Year	Study Focus	Methodology	Key Findings
1	Chutimanukul et al. (2022)	Thai holy basil cultivars	Experimental (PFAL, hydroponics)	OC064 showed highest antioxidant activity and metabolite content
2	Bhattarai et al. (2024)	Phytochemical review of Tulsi	Review study	Identified multiple bioactive compounds with antioxidant, anti-inflammatory, and neuroprotective effects
3	Lung et al. (2016)	Microwave effect on VOC emission	Experimental	VOC composition altered significantly under microwave exposure
4	Olofinsan et al. (2021)	Oxidative stress & infertility	In vitro & ex vivo	Tulsi reduced oxidative stress and improved enzyme activity
5	Sarkar & Das (2023)	VOC profiling in Ocimum species	GC-MS & metabolomics	Identified key VOCs like linalool and eugenol for species differentiation
6	Manjudevi et al. (2022)	Antioxidant & anti-inflammatory effects	In vitro assays	Eugenol showed strong free radical scavenging and MMP-9 inhibition
7	Boulaares et al. (2025)	Phytochemical composition	GC-MS analysis	Identified ~147 volatile compounds in basil species
8	Ferreira et al. (2025)	Essential oils & applications	Review	Highlighted industrial and pharmacological uses of Ocimum species
9	Mandal et al. (2022)	Traditional & pharmacological uses	Review	Confirmed adaptogenic and therapeutic properties of Tulsi
10	Makhlouf et al. (2024)	VOC role in pest control	Review	VOCs useful in ecological and agricultural stress management

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