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UNVEILING THE FUNCTIONAL PROPERTIES OF *Pelargonium graveolens*: INSIGHTS INTO ITS BIOLOGICAL ACTIVITIES

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Abstract

This article aims to present a review of Pelargonium graveolens, or rose-scented geranium, highlighting its diverse medicinal, aromatic, and industrial applications. Thus, P. graveolens is a multifaceted plant with significant medicinal, aromatic, and industrial applications The recent studies highlight its strong antifungal and antibacterial activities, particularly against resistant strains, with key compounds like β-citronellol, geraniol, and linalool contributing to these effects. The essential oil has shown efficacy in formulations for treating vaginal candidiasis and preventing biofilm formation on medical devices, demonstrating potential as a natural adjunct to conventional antifungal therapies. Additionally, P. graveolens exhibits significant antioxidant properties, with hydrosols proving more effective than essential oils in this regard. Its applications extend to pest control, as the oil has acaricidal and insecticidal effects, and it shows promise in treating conditions like diabetes and inflammatory diseases. Moreover, the plant's versatility is evident in its use across cosmetics and food preservation. This review emphasizes the need for further research to fully elucidate the pharmacological potential and to optimize the applications of P. graveolens in medicine, agriculture, and food industry.

Key words: *Pelargonium graveolens, bioactive compounds, pharmacological potential, citronellol, geraniol.*

INTRODUCTION

Pelargonium graveolens, also known as rose-scented geranium, is a versatile plant with significant medicinal, aromatic, and industrial applications. Traditionally used in South Africa, it has been burned and inhaled to treat asthma, while an infusion of its leaves is used for relieving abdominal cramps, diarrhoea, nausea, and insomnia (Meyers et al., 2006). The essential oil of *P. graveolens* is widely recognized in aromatherapy for its relaxing properties, with studies showing it can lower blood pressure, exert sedative effects, and stimulate brain activity (Meyers et al., 2006; Rajesh et al., 2023).

The oil also enhances the antifungal efficacy of ketoconazole and is used in personal aromatherapy blends to alleviate anxiety, often combined with oils like lavender and clary sage (Meyers et al., 2006; Naeini et al., 2011; Hamidpour et al., 2017). However, some rare cases of contact dermatitis and sensitization have been reported (Meyers et al., 2006).

Research has highlighted the oil's antioxidant and antibacterial activities, particularly those extracted during the flowering stage, which demonstrate high efficacy against food spoilage pathogens.

The oil's major compounds include β-citronellol, geraniol, and linalool, which contribute to its medicinal properties. Additionally, the phenological stage of the plant influences the oil yield, composition, and biological activities, suggesting that optimizing the harvesting time can enhance its functional properties for use in pathogen control and food preservation (Boukhris et al., 2015).

In Bosnia, the first detailed phytochemical analysis of *P. graveolens* revealed that its hydrosols possess stronger antioxidant activity than the essential oils, likely due to higher phenolic and flavonoid content. These findings suggest potential applications in antimicrobial and antiviral therapies (Ćavar & Maksimović, 2012).

Moreover, dry extracts of the plant have shown strong antioxidant and cytotoxic effects, indicating possible therapeutic use in treating metabolic diseases such as diabetes and dyslipidaemia (Neagu et al., 2018).

P. graveolens is not only valued for its therapeutic potential but also for its essential oil, which is a key ingredient in perfumes, cosmetics, and the flavour industry (Rajesh et al., 2023; Swanepoel, 2003). In India, efforts to improve agronomic practices, particularly nutrient management, aim to enhance oil yield and quality to reduce the country's dependency on imports (Rajesh et al., 2023; Upadhyay et al., 2022). The plant also shows promise in bioremediation as a phyto-accumulator for heavy metals (Mazeed et al., 2022).

The chemical composition of *P. graveolens* oil varies by region, with studies from Algeria (Boukhatem et al., 2013a) and Egypt (Rajesh et al., 2023; Ibrahim et al., 2021; Abd El-Kareem et al., 2020; Blerot et al., 2016), revealing differences in its primary constituents, which include citronellol, geraniol and linalool. These oils have demonstrated significant antimicrobial efficacy, particularly against Gram-positive bacteria and fungi, suggesting their potential as natural preservatives in the food industry (Ibrahim et al., 2021; Abd El-Kareem et al., 2020). Research also highlights the oil's antidiabetic (Hamidpour et al., 2017, Amel et al., 2022), antifungal (Hamidpour et al., 2017; Gucwa et al., 2018; Abd El-Kareem et al., 2020; Hsouna & Hamdi, 2012; Mahboubi & Valian, 2019; Juárez et al., 2016; Saraswathi et al., 2011; Narnoliya et al., 2019; Ghedira & Goetz, 2015; Gâlea & Hancu, 2014; Amel et al., 2022), and antioxidant properties (Hamidpour et al., 2017; Rahman et al., 2020; Jaradat et al., 2022; Ben Slima et al., 2013; Dimitrova et al, 2015; Saraswathi et al., 2011; Narnoliya et al., 2019; Ghedira & Goetz, 2015; Amel et al., 2022), with studies showing its ability to reduce blood glucose levels in diabetic rats (Hamidpour et al., 2017) and protect against oxidative stress (Rahman et al., 2020; Boukhris et al., 2012; Ben Slima et al., 2013).

Despite these benefits, the oil's toxicity must be carefully monitored to ensure safe therapeutic use (Hamidpour et al., 2017). Further research is necessary to fully understand the pharmacological potential of *P. graveolens* and to optimize its applications in medicine (Hsouna & Hamdi, 2012; Peterson et al., 2006), cosmetics (Swanepoel, 2003; Ghedira & Goetz, 2015; Jeon et al., 2008), and food preservation (Blerot et al., 2016).

ANTIFUNGAL ACTIVITY

The provided studies collectively demonstrate the significant antifungal potential of *P. graveolens* essential oil (PGEO) against various fungal species, with promising applications in both clinical and medical device contexts (Giongo et al., 2016). Thus, *P. graveolens* has demonstrated a large spectrum of antifungal activity, being a versatile option for fungal infections.

• **Vaginal Candidiasis**. A mucoadhesive hydrogel-thickened nanoemulsion containing PGEO was shown to significantly enhance antifungal activity against *Candida* sp., reducing the minimum inhibitory concentration (MIC) by up to 64 times. This formulation not only improves efficacy but also reduces irritant potential, making it a promising treatment for vaginal candidiasis (Dos Santos et al., 2020).

• **Medical Devices**. Nanoemulsions containing geranium oil (GO) were developed to prevent biofilm formation by *Candida* sp. on medical devices. These nanoemulsions (NEG) significantly inhibited biofilm formation, particularly against *C. albicans*, *C. tropicalis*, and *C. glabrata*, suggesting their potential to reduce microbial adhesion and prevent infections in catheterized patients (Giongo et al., 2016).

• **Combination with Antifungals**. The synergistic effects of PGEO with conventional antifungal drugs like Nystatin (Rosato et al., 2009) and Amphotericin B (Essid et al., 2015; Rosato et al., 2008) were explored. While PGEO showed limited synergy with Nystatin, it demonstrated a strong synergistic effect with Amphotericin B, potentially reducing the required dose of the drug and minimizing its side effects.

• **Antifungal spectrum**. In a broader antifungal evaluation, PGEO exhibited both fungistatic and fungicidal activities against *Candida* isolates. It also demonstrated synergy with Amphotericin B, indicating its potential as an adjunct in traditional antifungal therapy (Gucwa et al., 2018).

• **Anti-Pityriasis Versicolor**. PGEO showed significant antifungal activity against *Malassezia* sp., outperforming the conventional drug ketoconazole. The oil's major components, citronellol and geraniol, were identified as key contributors to its effectiveness, suggesting PGEO as a promising natural alternative for treating pityriasis versicolor (Naeini et al., 2011; Hamidpour et al., 2017).

Antifungal potential of *P. graveolens* against *Fusarium proliferatum* and confirms, through in-silico and *in vitro* analyses, its suitability for developing natural antifungal agents (Grine et al., 2023).

Overall, these studies underscore the versatility and efficacy of *P. graveolens* essential oil as a potent antifungal agent with applications ranging from clinical treatments to infection prevention on medical devices.

ANTIBACTERIAL ACTIVITY

Pelargonium graveolens essential oil, rich in compounds like citronellol and geraniol, has shown significant antibacterial activity against various bacterial strains, including antibiotic-resistant pathogens (Elansary et al., 2018; Dumlupinar et al., 2020; Rosato et al., 2007). Its potential applications expand across medical, pharmaceutical, and industrial contexts (Fayoumi et al., 2022; Upadhyay et al., 2022; Okla et al., 2022; M'hamdi et al., 2024).

Antibacterial Efficacy of *P. graveolens* demonstrated high potential in growth inhibition of various bacterial strains.

• **Activity Against** *Helicobacter pylori*. The essential oil demonstrated a minimal inhibitory concentration (MIC) of 15.63 mg/ml against *H. pylori*, a major cause of peptic ulcers. When combined with the antibiotic clarithromycin (CLR), the oil showed a synergistic effect, reducing the effective dose of CLR needed and potentially decreasing the risk of side effects and antibiotic resistance (Ibrahim et al., 2021).

• **Synergistic effects with Standard Antibiotics**. Studies have shown that *P. graveolens* oil enhances the antibacterial activity of standard antibiotics like norfloxacin (Dumlupinar et al., 2020; Rosato et al., 2007; Choi et al., 2007) and erythromycin (Choi et al., 2007). For instance, the combination of the oil with norfloxacin resulted in a significant reduction in the MICs against *B. cereus* and *S. aureus*, including antibiotic-resistant strains of *S. pneumoniae* (Rosato et al., 2007). This synergy can lead to more effective treatments with lower doses of antibiotics, reducing the likelihood of resistance development (Choi et al., 2007).

• **Broad-Spectrum Antibacterial Activity**. The essential oil has demonstrated inhibitory effects against both Gram-positive bacteria, such as *Micrococcus luteus*, *S. aureus, L. monocytogenes* and *E. faecalis*, and Gram-negative bacteria like *P. aeruginosa* and *E. coli* (Wei et al., 2022; Rathore et al., 2023; Dos Santos et al., 2024). Notably, the oil showed comparable efficacy to some commercial antibiotics, particularly in the case of *S. aureus* and *C. albicans*, where complete inhibition of growth was observed (Gâlea & Hancu, 2014).

The applications are correlated with the antibacterial properties of *P. graveolens* oil. It is a promising candidate for developing alternative treatments for infections, particularly those involving antibiotic-resistant bacteria. Its use could be extended to topical formulations for skin infections, oral hygiene products, and as a natural preservative in pharmaceutical preparations (El Aanachi et al., 2020; Swanepoel, 2003).

At the same time, it can be used as cosmetic and personal care products (El Aanachi et al., 2020; Peterson et al., 2006; Ghedira & Goetz, 2015; Szutt et al., 2020; Jeon et al., 2008). The oil's antimicrobial properties, combined with its pleasant fragrance, make it ideal for inclusion in cosmetics, deodorants, and other personal care products, providing both antimicrobial protection and aromatic benefits. The antibacterial potential of *P. graveolens* essential oil is significant, offering a natural and effective alternative or complement to traditional antibiotics (Abd El-Kareem et al., 2020; Choi et al., 2007). Its application spans various contexts, from medicine to food preservation, and its role in combating antibiotic resistance highlights its importance in modern healthcare and food industry (Rajesh et al., 2023; Hamidpour et al., 2017). Further research and development are necessary to optimize formulations and ensure safe and effective use across these applications (El Aanachi et al., 2020; Ibrahim et al., 2021; Jeon et al., 2009).

OTHER PHARMACEUTICAL APPLICATIONS CORRELATED WITH OTHER *Pelargonium graveolens* ACTIVITIES

• **Antiacaricidal Effects**. *P. graveolens* has demonstrated acaricidal properties, notably against cattle ticks (*Rhipicephalus microplus*) (Pazinato et al., 2016) and storage food mites, as *Tyrophagus putrescentiae* (Jeon et al., 2009), *Dermatophagoides farinae* and *D. pteronyssinus* (Jeon et al., 2008). *In vitro* studies revealed that geranium oil, particularly its active compound geraniol, shows effective inhibition of tick oviposition and mite activity (Pazinato et al., 2016). Geraniol, identified as a primary active compound, has an LD_{50} of 1.95 μg/cm³, making it significantly more toxic than benzyl benzoate, which has an LD_{50} of 11.27 μg/cm³ (Jeon et al., 2009). For house dust mites (*D. farinae* and *D. pteronyssinus*), geraniol demonstrated high toxicity with LD_{50} values of 0.26 μg/cm² and 0.28 μg/cm², respectively (Jeon et al., 2008). These results suggest geranium oil could be a valuable alternative to synthetic acaricides for pest control (Jeon et al., 2008; Jeon et al., 2009).

• **Repellent and Insecticidal Activity**. The essential oil of *P. graveolens* exhibits notable repellent and insecticidal effects against adult house flies (*Musca domestica*) and blowflies (*Lucilia cuprina*). At 1% concentration, the oil shows significant repellent activity. In terms of insecticidal effectiveness, the lethal concentration (LC_{50}) is 3.0% for *M. domestica* and 2.5% for *L. cuprina* in direct surface applications. In impregnated paper tests, the LC_{50} values are 5.9% and 3.5%, respectively. The effectiveness is attributed to compounds like citronellol and geraniol, though it is less potent compared to synthetic insecticides like Diazinon (Saraiva et al., 2020).

• **Antidermatophyte Effects**. Geranium essential oil shows strong antidermatophyte activity. In a study performed by Mahboubi & Valian, among tested oils, the E20 sample, high in geraniol and citronellol, exhibited the highest efficacy in inhibiting fungal growth against dermatophytes such as *Microsporum canis* and *Trichophyton rubrum*. Geraniol is identified as a key antifungal compound, underscoring the oil's potential for treating fungal infections (Mahboubi & Valian, 2019).

• **Antileishmanial Activity**. *P. graveolens* essential oil, including its major compounds β-caryophyllene and geraniol, demonstrates significant antileishmanial activity against *Leishmania major* and *Leishmania infantum*. The oil showed IC_{50} values ranging from 0.05 to 0.28 μg/mL for *Leishmania* sp., outperforming the reference drug amphotericin B. The low toxicity against Raw 264.7 macrophage cells and the high selectivity index suggests its potential in developing new antileishmanial drugs (Martins et al., 2017).

• **Anti-inflammatory Effects**. The essential oil of *P. graveolens* exhibits moderate anti-inflammatory effects. In comprehensive studies, the crude extract and ethyl acetate fraction reduced levels of prostanoids like PGE2 and TXB2 at a concentration of 50 μg/mL. The effectiveness is attributed to polar compounds such as flavonoids, including rutin and kaempferol. Geranium oil has shown a significant reduction in edema in carrageenan-induced paw and croton oil-induced ear models, comparable to diclofenac, suggesting its potential for treating inflammatory conditions (Boukhatem et al., 2013b).

• **Antidiabetic and Anti-Alzheimer's Potential**. *Pelargonium graveolens* essential oil shows promise in managing type-2 diabetes and Alzheimer's disease due to its inhibitory effects on α-amylase and acetylcholinesterase. The high antioxidant capacity and hypoglycemic effects further support its use in diabetes management. The plant's extracts also offer potential in Alzheimer's disease treatment by inhibiting acetylcholinesterase (Ali et al., 2020, Fayoumi et al., 2022).

• **Cytotoxicity Against Cancer Cells**. The leaf extract of *P. graveolens* is used to synthesize palladium nanoparticles (PdNPs), which show dose-dependent cytotoxicity against K562 human leukemia cells. This eco-friendly synthesis approach highlights the potential biomedical applications of PdNPs produced using geranium extract (Li et al., 2017). Another study, revealed that *P. graveolens* leaf extract have cytotoxic effects using its gold nanoparticles (AuNPs) on human dermal fibroblasts from neonates (HDFn). The study also confirmed that *P. graveolens* AuNPs displayed slight cytotoxicity (about 20%) at various dosages, with high biocompatibility observed in normal human fibroblasts. This aligns with earlier studies and underscores the increasing interest in nanotechnology-based pharmaceuticals, which have gained FDA approvals for therapeutic use (Asker et al., 2024).

• **Anti-proliferative effects**. The text outlines a study on the biological effects of essential oils, including *P. graveolens* (geranium), on human dermal fibroblasts in a simulated chronic inflammation environment. It highlights the anti-proliferative effects of geranium essential oil but does not provide details on its effects on specific biomarkers (Han et al., 2017)

• **Potential Anesthetic**. Geranium oil demonstrates anesthetic potential in aquaculture, reducing induction time and increasing recovery time in freshwater aquarium fish. The minimum effective concentration for deep anesthesia is 75 $\mu L\ L^{-1}$, suggesting geranium oil's potential as a pleasant-smelling anesthetic for aquatic species (Can et al., 2018).

• **Supplement for Aquaculture**. In aquaculture, *Pelargonium graveolens* essential oil has shown protective effects against pesticide-induced toxicity in common carp (*Cyprinus carpio*). GEO supplementation improved liver and kidney functions, enhanced immune responses, and reduced oxidative stress, indicating its potential as a dietary supplement to mitigate pesticide toxicity in fish (Rahman et al., 2020).

Pelargonium graveolens L. has the ability to remove the antibiotic tetracycline (TC) from soil and the effect of different concentrations on the plant. The researched study investigates the mechanism of antibiotic sequestration in the plant under both soil and hydroponic conditions, as well as the impacts on the plant's biomass, growth, and biochemical content. The research concludes that *P. graveolens* can tolerate tetracycline stress and can be used for the remediation of antibiotic-contaminated areas (Siddiqui et al., 2024).

Overall, *P. graveolens* exhibits a wide range of biological activities and applications, from pest control and antifungal treatment to anti-inflammatory, antidiabetic, and potential anesthetic uses (Can et al., 2018). The plant's active compounds, particularly geraniol and citronellol, are crucial in these therapeutic and practical applications, warranting further research and development (Narnoliya et al., 2019).

CONCLUSIONS

This review highlights that *Pelargonium graveolens*, or rose-scented geranium, exhibits a diverse array of biological activities, including significant antifungal and antibacterial properties, making it a valuable candidate for various therapeutic applications. Its essential oil, rich in compounds like citronellol and geraniol, shows promise in treating infections, enhancing traditional antifungal therapies, and addressing antibiotic resistance, while also being beneficial in areas such as pest control and anti-inflammatory treatments, warranting further investigation into its pharmacological potential.

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