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Exploring the ethnomedicinal, phytochemical, and pharmacological dimensions of *Pelargonium graveolens*: A review

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Abstract
Pelargonium graveolens L 'Hér., commonly known as rose-scented geranium, is an aromatic and medicinal plant widely valued in traditional medicine systems for treating a variety of ailments, including respiratory disorders, gastrointestinal issues, skin conditions, and infections. Its essential oil and extracts are extensively utilized in the pharmaceutical, cosmetic, food, and aromatherapy industries. This review comprehensively explores the ethnomedicinal uses, phytochemical composition, and pharmacological properties of *P. graveolens*, drawing from both traditional practices and contemporary scientific research. Phytochemical analysis has identified a rich diversity of compounds, predominantly monoterpenoids such as citronellol, geraniol, and linalool, alongside flavonoids, phenolic acids, tannins, and fatty acids. These bioactive constituents contribute to the plant's broad spectrum of pharmacological activities, including antioxidant, antimicrobial, anti-inflammatory, antidiabetic, cardioprotective, and anticancer effects. The essential oil has demonstrated significant antimicrobial and antioxidant properties, while experimental studies have indicated potential therapeutic applications in managing diabetes, cardiovascular diseases, and certain cancers. Despite these promising findings, clinical validation and mechanistic studies remain limited, highlighting the need for further research. Future prospects include standardizing cultivation and extraction protocols, developing novel formulations, and expanding applications in nanotechnology and sustainable agriculture. This review underscores the multifaceted therapeutic potential of *P. graveolens* and advocates for its continued exploration as a natural source of bioactive compounds in modern medicine and industry.

Keywords: *Pelargonium graveolens*, essential oil, phytochemistry, pharmacology, ethnomedicine, antioxidant, antimicrobial, antidiabetic, anticancer

Introduction
Due to the promise of medicinal plants as a source of natural molecules that are frequently free of side effects and can be purchased at a lower cost, the general public has become more interested in using them in recent years rather than synthetic medications [1, 2]. Plant secondary metabolites, such as volatile chemicals or essential oils (EOs), phenolic compounds, and flavonoids, are of special interest among the various varieties of these natural substances due to their potential health advantages [3-8].
Due to their numerous applications beyond their traditional use as raw materials in a variety of industries, including pharmaceutical, agronomic, food, health, cosmetic, and perfumery, essential oils and their derivatives from a variety of aromatic plants have been the focus of numerous studies in recent years [9]. Furthermore, a wide range of essential oil yields, chemical compositions, and possible biological properties have been documented by a number of researchers [10-14].
Geographical location, environmental circumstances, cultivars, distillation technique, post-harvest storage, processing and storage conditions, transplanting date, and intercropping were the primary determinants of this diversity [15].
A significant and lucrative aromatic crop in the Geraniaceae family, the genus Geranium, also called rose-scented geranium, is frequently grown for its precious volatile oil. For the manufacture of essential oils, only four of the 25 Pelargonium species—*Pelargonium graveolens, Pelargonium odoratissium, Pelargonium capitatum, and Pelargonium radens*—are utilized [16]. Rose geranium, or *P. graveolens* L'Hér, is a useful herb that belongs to the

Geraniaceae family and contains oil [17]. It is a multibranched, upright shrub. The leaves are cut, spiky, and deeply indented. According to, the flowers are often little and pink. The genus Pelargonium has about 1796 known species that grow naturally in Morocco, Egypt, and South Africa [18].

According to earlier research, *P. graveolens* extract was used to treat gastroenteritis, fever, cough, and diarrhoea [19]. Crucially, *P. graveolens* was employed as a sunscreen and to slow down the aging process of the skin, according to [20]. In order to enhance its use, efficacy, and impact against Sitophilus oryzae L., a nano-emulsion formulation of *P. graveolens* essential oil was recently reported [21] and studied. As far as we are aware, *P. graveolens* oil was only used to make fragrances [22].

P. graveolens leaves were traditionally used as a treatment for sprains and bruises, while the roots were traditionally decocted and infused to cure fever and backache. The leaves herbal tea effectively alleviated nausea and dysentery [23]. *P. graveolens* was recently used as a sunscreen in Northwest Morocco to slow down the aging process of the skin [20].

The fragrant and medicinal qualities of plants and their extracts have been used for ages. Bioactive substances have garnered increasing attention in recent years, with natural chemicals receiving special emphasis. Essential oils (EOs), also known as volatile or odoriferous oils, have attracted a lot of interest because of their antibacterial and antioxidant properties. Global developments and the emergence of numerous diseases linked to contemporary society are major causes of this increased attention [24-29]. They are extremely complex mixes that frequently consist of several hundred to a few hundred distinct components. In addition to woody sections like bark or roots, which contain the glands and ducts that contain the essential oils, these volatile, aromatic, oily liquids are derived from a variety of plant parts, primarily non-woody ones including flowers, leaves, peels, buds, and seeds [25-30]. Numerous businesses use volatile oils extensively. The majority of cosmetic goods contain them as natural preservatives or fragrances. In order to shield foods and food packaging materials against oxidative damage and inflammatory disorders, they are also used as natural additives. Moreover, EOs have supplanted synthetic materials in the fields of nutrition, medicine, and agriculture because of their alleged antiviral, nematicidal, antifungal, and insecticidal properties [25, 27, 30-32].

The aromatic, hairy shrub *P. graveolens* can reach a height of 1.3 m and spread to 1 m. It usually yields little, pink flowers and has delicate, cut leaves. Because of its distinctive characteristics and range of scents, *Pelargonium* species are often used in the biosynthesis of essential oils. They produce a significant amount of EOs, between 0.1% and 0.9% v/w [33]. The oil is typically extracted from the leaves, petals, and stalks [34]. Numerous factors have been found to influence the composition of rose-scented geranium, including the cultivar, the method of distilling the oil, the part of the plant that has been distilled, the material's age, the storage of the essential oils, the plant's growth location and seasonal variations in the surrounding environment (temperature, light intensity), as well as the time of year and harvest [35].

Traditional Chinese medicine acknowledges geranium essential oil for its alleged capacity to help detoxification processes, which in turn promotes bodily balance, and to offer antioxidant protection [36]. Even against more resilient fungus as *Aspergillus* species and Mucor mucedo, *P. graveolens* essential oil showed strong fungicidal action. Furthermore, it demonstrated potent antioxidant action that was dose-dependent [37]. Essential oil (EOPG) of *P. graveolens* (geranium) demonstrated promise in regulating physiological indicators of mind-body harmony. EOPG inhalation dramatically reduces heart rate and blood pressure, suggesting impacts on autonomic control. These cardioprotective effects may be caused by key compounds—linalool, citronellol, and geraniol—that were found in the brain following exposure. This could indicate a mechanism via which EOPG promotes autonomic stability and mind-body balance [38].

The fragrant herb *P. graveolens* which belongs to the *Geraniaceae* family, is indigenous to a few regions of South Africa and is primarily found in the Mediterranean region [39, 40]. PGEO is widely used in the traditional food and aromatherapy sectors, as well as in the pharmaceutical, cosmetic, and flavouring industries worldwide [39, 41, 42].

Because of how well it cleans greasy skin and opens pores, it is one of the greatest oils used in skincare products. Herbal tea made from the leaves is used to treat tonsillitis, increase blood flow, reduce stress, combat anxiety, and relax tension [43]. According to a number of studies, PGEO and its extracts have strong antioxidant activity, antibacterial and antifungal qualities, and can be used to treat a number of diseases, such as diabetes, obesity, and cancer [41]. Thus, the purpose of this work is to investigate the chemical composition, cytotoxicity, COX inhibitory, antiobesity, and antidiabetic qualities of PGEO cultivated in Palestine, which have never been investigated in this manner before.

The medicinal geranium family includes the scented geranium (*Pelargonium graveolens)* (Mainardi *et al*., 2009). Local populations make considerable use of it as a culinary herb, either fresh or dried. Additionally, it is well-known for its pharmacological qualities in treating bronchitis, gastroenteritis, fever, diarrhoea, and other respiratory conditions (Tahan and Yaman, 2013; Taj Karimi *et al*., 2010) [134, 135]. Additionally, the food sector and the synthesis of cosmetics and perfumes both use their essential oils. Additionally, a number of pharmacological characteristics have been shown, including antibacterial, immunostimulant, antioxidant, hypoglycaemic, anti-inflammatory, and inflammatory.

Botanical Description

Description

Pelargonium graveolens is a multibranched, upright, aromatic subshrub that can reach a height of 1.5 m and a spread of 1 m. Because of the glandular hairs, the leaves are velvety, soft to the touch, and deeply indented. The plant's aboveground portions are essentially glandular and hairy. Petioles and leaf blades are separated from the alternately placed leaves. The leaf blade is blunt, heart-shaped, palmately split, and has lobes that are lobed or coarsely serrated.

The natural form has a minty scent. While the shape and aroma of the leaves varies among cultivars, some have a scent reminiscent of rose petals, while others have little to no scent at all. While some leaves, like those of *P. capitatum*, are scarcely lobed, others are extensively incised [44]. The flowers, which peak in the spring, occur from late winter to summer and range in colour from pale pink to nearly white [45].

Fig 1: Different parts of *Pelargonium graveolens*
1: Aerial parts **2:** Fruits and Flowers **3:** Stem and Leaves **4:** Roots

Taxonomy

There are roughly 283 known species in the genus *Pelargonium* [46]. In 1789, William Aiton reported about *P. graveolens* in Hortus Kewensis, citing the National Center for Biotechnology Information (NCBI). In his thorough work published in 2003, Brawner noted that Linnaeus initially placed *P. graveolens* in the genus *Geranium* in 1753. Although the French botanist Charles L'Heritier first identified *pelargoniums* as a distinct genus in 1787, it took many years for the general public to accept this nomenclature, and for a long time, *pelargoniums* were associated with the more general word geraniums [47]. The World Checklist of Selected Plant Families (WCSP-in review) lists *Geranium graveolens* (L'Hér.) Thunb and *Geraniospermum terebintaceum* (Spreng.) Kuntze as synonyms of *Pelargonium graveolens.*

There are multiple local forms of *P. graveolens* that differ morphologically and can be identified by other traits without compromising taxonomic classification [48]. Currently, the genus *Pelargonium* belongs to the global family *Geraniaceae*, Order Geraniales. The following list of scientific names is acceptable: Pelargonium intermedium Kunth is regarded by INaturalist and Tropicos as a synonym of *P. graveolens*, along with *Geranium terebinthinaceum Cav*. *Pelargonium graveolens*, *Pelargonium roseum*, and *Pelargonium species* are the three Latin names that have been used most frequently in research and publications on this plant.

Kingdom: Plantae
Clade: Tracheophytes
Clade: Angiosperms
Clade: Eudicots
Clade: Rosids
Order: Geraniales
Family: Geraniaceae
Genus: *Pelargonium*
Species: *P. graveolens*

Vernacular names

English: Roses cented Geranium, Sweet-scented Geranium
Hindi: Gulabi Pati, Sugandha Patti
Tamil: Roja Marikolunthu
Telugu: Gulabi Pachha
Malayalam: Rosemaram
Kannada: Gulabi Patre
French: Geranium rosat

Botanical aspects

The evergreen shrub *P. graveolens* has woody shoots at the base that soften toward the tips. It is a perennial with a powerful aroma that is managed like an annual [49]. This shrub is common in areas with low humidity and rainfall [50, 51] in a variety of environments, including rocky slopes, grasslands, forests, and streams. Geranium grows naturally on roadside weed, old pastures, rock fissures on top of plains, riverbanks, and limestone woods. [52, 50] Of the ten Pelargonium species known to exist in Algeria, *P. graveolens* is the most extensively distributed [53]

Wet, partially shaded conditions are conducive to perennial development. It is a medium-lived perennial shrub that reaches a height of approximately 4.9 feet (1.5 meters) and a width of 3.3 feet (1 meter). With a robust stem that emerges from the ground, the roots are flexible and brown. The leaves have deeply cut blades and are concentrated to a sparse pubescent, tomentose, or hairy state. From late summer to mid-winter, the plant blooms for about six months, and it continues to bloom nearly nonstop until it dies. Glomerulus seeds guarantee reproduction, and the flowers are white or pinkish with crimson striations [54]. In agro-ecosystems, *P. graveolens* is beneficial for pollination since it produces blooms throughout the year and gives nectar to bees and wasps [55, 56].

Distribution and habit

The Rose Geranium is a plant native to the provinces of the Cape and the northern provinces of South Africa, Zimbabwe and Mozambique.

Its natural habitat is that of mountain areas, in sheltered positions such as gorges and ravines, usually in relatively humid areas.

It is native to Mozambique and Zimbabwe in southern, tropical Africa, and South Africa (Cape Province, Transvaal). *Pelargoniums* have been cultivated in South Africa and Namibia for at least 200 years. The plant is also found in the Canary Islands, Corsica, Costa Rica, Cuba, the Dominican Republic, Haiti, southwestern Mexico, and Puerto Rico, where it has been introduced.

Traditional Uses

In Africa, *p. graveolens* has been used for generations as a medicine. It is mostly used to treat respiratory conditions, wounds, and digestive problems. Reports on its medical application outside of Africa are, however, scarce. Regarding the allusions to traditional medicine, three techniques are used to make various extracts from whole or partial plants: juice, infusion, and decoction. The aerial parts are used to cure skin conditions, while the root decoction, as shown in Table 1, has been used to treat respiratory tract infections and gastrointestinal disorders. Despite this, the relevant pharmacological basis for these indications is often lacking.

According to the Botanical Safety Handbook, *P. graveolens* leaves are a category 1 herb "if handled properly" [57]. No information regarding geranium contraindications is available. Topical geranium oil has been reported to produce contact dermatitis or sensitization (*Pelargonium sp*.) [58-60] and to cause irritation while handling the plant [61-63]. However, other investigations have indicated that the oil is non-irritating and non-allergic [59-60]. However, adverse reaction reports are uncommon [58].

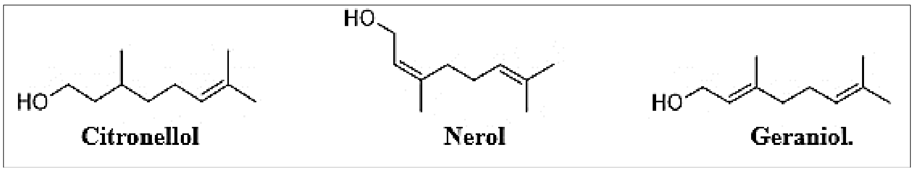
Aside from its medical significance, clear cosmetic values of geranium also have been confirmed. The powdered leaves were reportedly used as a deodorant by African members of African tribes [58]. In the Victorian era, the lemon leaf of geranium became a popular addition to finger bowls, [64-65] and table-top water bowls were used to keep hands clean and refreshed during meals. Geranium oil can be found in a wide range of commercial cosmetics, such as detergents, soaps, lotions, creams and perfumes [66-67].

Table 1: The traditional uses of *P. graveolens*

Traditional use	Part used	Mode of use
Fever	Roots	Decoction (bath)
Internal pain	Leaves	Mixed with two species
Headache	Leaves	Mixed with vinegar and salt
Backache	Roots	Infusion
Stomach cramps and vomiting	Leaves	Infusion
Cough, Carretones, Pencahue.	Flowers	Infusion
Asthma	Unspecified	Burned and inhaled
Tuberculosis	Roots	Decoction
Diarrhoea	Roots	Infusion (enema)
Wounds and boils	Leaves	A paste
Cervical cancer	EO	Applied locally
Night blindness	Leaves	Unspecified

Phytochemical Profile

According to a recent investigation, the essential oil of *P. graveolens* from an Australian source contains more than 50 chemical components. Similar phytochemical profiles were found in analyses of Indian geranium oils, which revealed that citronellol + nerol were the main ingredients (in terms of percentage composition) as well as geraniol [68-71].



Many chemical constituents such as volatile substances, terpenoids, flavonoids, phenolics, coumarins, cinnamic acids and tannins have been isolated from the plant [72-73]. Citronellol (29.90%), trans-geraniol (18.03%), 10-epi-γ-eudesmol (8.27%), isomenthone (5.44%), linalool (5.13%), geranyl acetate (4.52%), γ- Cadinene (2.89%), geranyl butyrate (2.53%), geranyltiglate (2.50%) and gemacrene D (2.05%) were identified as the major constituents of the *P. graveolens* aerial parts essential oil [74]. Phytochemical investigations in 1996 resulted in characterization of the indole alkaloids, elaeocarpidine, and its 20-H isomer epielaeocarpidine in the leaves of geranium [75].

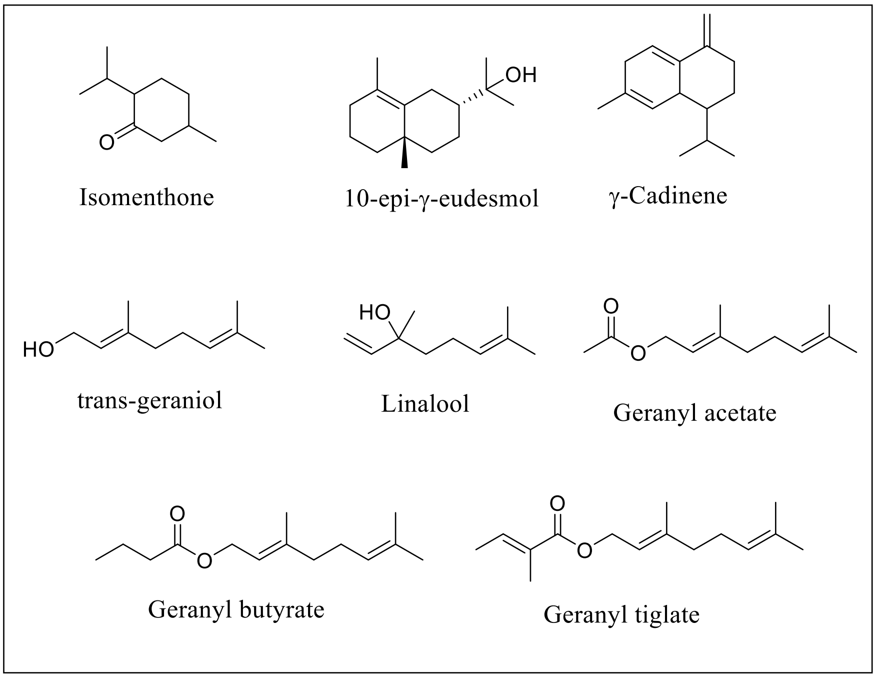


Fig 2: Phytochemical structures of *pelargonium graveolens*

Pelargonium graveolens (rose-scented geranium) is rich in a diverse array of phytochemicals, which are responsible for its medicinal, aromatic, antioxidant, and antimicrobial properties. These phytochemicals can be broadly classified into several categories [76-79].

Table 2: Major Classes of Phytochemicals

Class	Examples
Monoterpenoids	Citronellol, Geraniol, Linalool, Isomenthone
Sesquiterpenes	10-epi-γ-Eudesmol, Germacrene D, Guaiadiene derivatives
Phenolic Compounds	Gallic acid, Caffeic acid, Chlorogenic acid
Flavonoids	Quercetin, Kaempferol, Luteolin
Tannins	Hydrolyzable and condensed tannins
Fatty Acids	Palmitic acid, Linoleic acid, Stearic acid
Vitamins	Ascorbic acid (Vitamin C), Tocopherol (Vitamin E)
Others	Alkaloids, Saponins, Coumarins

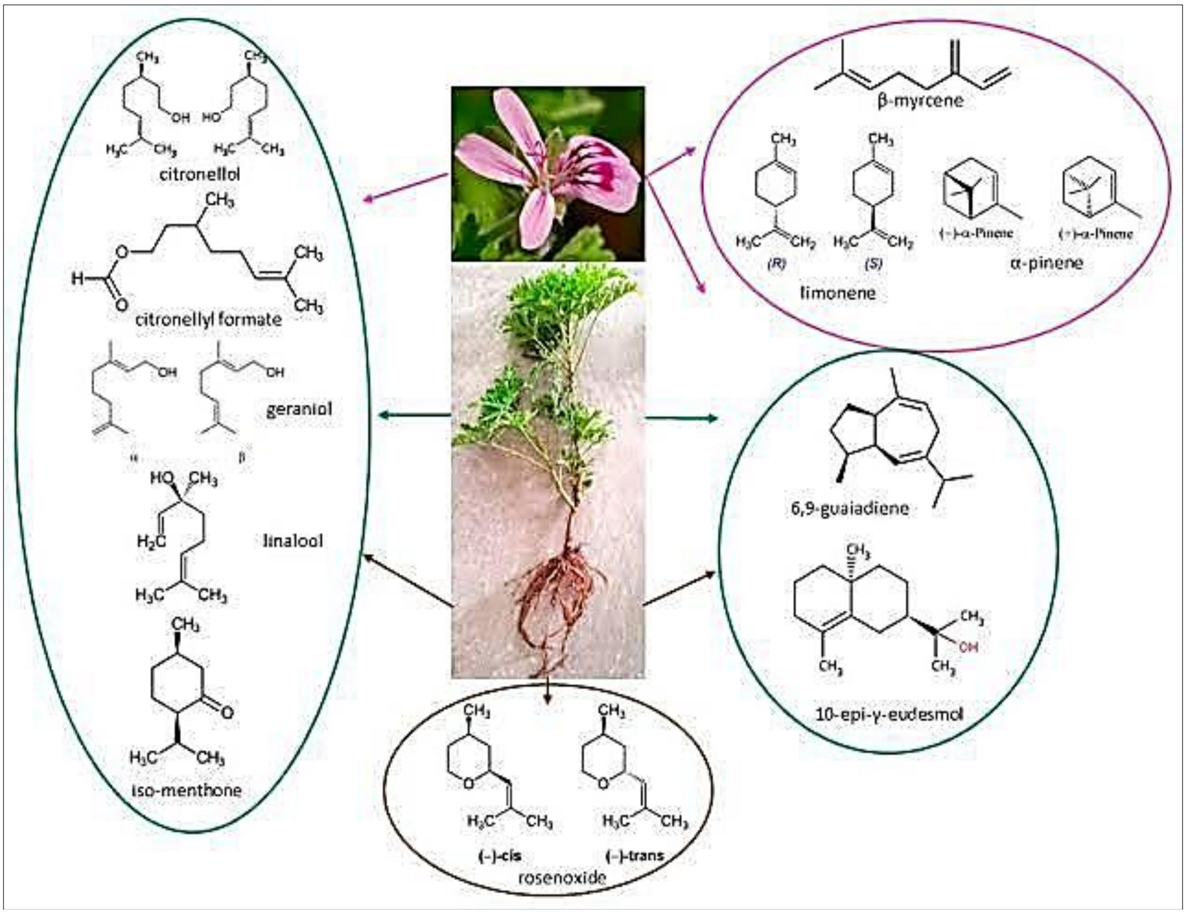


Fig 3: Phytochemical constituents isolated from *Pelargonium graveolens*. The central image represents the plant, while the surrounding structures illustrate key identified compounds including terpenoids, flavonoids, phenolics, and other bioactive constituents. These phytochemicals contribute to the plant's medicinal and pharmacological properties.

Essential oil profile of *pelargonium graveolens* [80-83]

P. graveolens, commonly known as rose-scented geranium, is a medicinal and aromatic plant whose essential oil is widely used in the perfumery, cosmetic, and pharmaceutical industries. The essential oil is primarily obtained by steam distillation of its fresh leaves and aerial parts.

Major Chemical Constituents

The essential oil of *P. graveolens* is complex and rich in monoterpenoids, sesquiterpenes, and aromatic compounds. The primary constituents typically include:

Citronellol
Geraniol
Linalool
Citronellyl formate
Isomenthone
10-epi-γ-Eudesmol
Guaiadiene derivatives
Geranyl formate

The exact composition may vary based on factors such as geographical origin, plant part used, harvest time, and extraction method.

Table 3: Examples of Essential Oil Composition (Approximate% by GC-MS)

Compound	Percentage (%)
Citronellol	25-35%
Geraniol	10-25%
Linalool	5-8%
Isomenthone	4-7%
Citronellyl formate	3-6%
Geranyl formate	1-3%
10-epi-γ-Eudesmol	0.5-2%

Phytochemistry of the *Pelargonium graveolens* Essential oil

About 120 phytochemicals make up the PGEO, and the main ones that give it its smell are citronellol, geraniol, and linalool, along with their esters, which make up over 60% of the total EO [84]. One of the most expensive EOs used in flavouring, cosmetics, and fragrance is PGEO. A colourless oil with a yield of 1.01% was obtained by hydro-distilling air-dried *P. graveolens* leaves; this oil was equivalent to the oil obtained from *P. graveolens* aerial parts that were gathered in Isfahan, Iran [85].

Afifietal, nevertheless. PGEO was extracted from air-dried leaves collected in Amman, Jordan, with a reported yield of 1.5% [86]. The climate of Tulkarem, which is located 15 kilometres east of the Mediterranean, may be the cause of this discrepancy. Winters are damp and cold, whereas summers are lengthy, hot, and extremely humid in Tulkarem [87].

Citronellol (24.44%), citronellylformat (15.63%), γ-eudesmol (8.60%), iso-menthone (7.43%), geranylformate (3.40%), geranyl butanoate (2.69%), germacrene (2.56%), phenylethyltiglate (2.53%), linalool (2.45%), geranyltiglate (2.38%), viridflorene (2.20%), and cis rose oxide (2.04%) made up the majority of the PGEO. Significant levels of citronellyl butanoate, citronellyl tiglate, caryophyllene, geraniol, rhodinol, and citronellyl propanoate were also found.

Pharmacological Activity

Reports on pharmacology *P. graveolens* has been investigated in a number of pharmacological domains, including analgesic, anti-inflammatory, antibacterial, antifungal, antidiarrheal, antiviral, and antioxidant properties, per a review of the literature study.

More emphasis has been paid to PG's antipathogenic microorganism activities, and its antibacterial, antiviral, and antifungal qualities have been well studied and demonstrated. Crucially, oxygenated molecules have been identified as this plant's main active ingredient.

Antiviral effect

According to earlier studies, *P. graveolens* suppresses the coronavirus, influenza virus, respiratory syncytial virus, and H1N1 neuraminidase (NA-1). After 30 minutes of vapor exposure, geranium oil at 0.3% suppressed the influenza type A (H1N1) virus by 95% and by 80% *in vitro*. However, it hasn't been proven to work against the H3N2 influenza virus [88]. SARS-CoV prevention may involve blocking ACE2 or TMPRSS2 receptors due to the distinct enzymatic action and tissue distribution mechanisms of ACE2. As a result, geranium essential oil significantly reduced ACE2 activity without being cytotoxic [89].

Furthermore, research shown that geranium has an inhibiting effect on the Ross River virus infection RRV-T48, with a CC10 of 533 µg. mL^{-1}[90]. Furthermore, by blocking viral entry into A549 cells through particular interactions with viral attachment proteins, Geranium may potentially decrease adenovirus-signalling pathways necessary for virus gene expression [91]. Geranium also worked well against the virus that causes yellow fever [90].

Antifungal effect

When paired with fluconazole, geranium caused 73.28 and 69.51 percent mortality of Candida albicans cells after three hours of incubation, allowing for four to eight times reductions in effective dosages in comparison to MIC values. Geranium alone exhibited a modest inhibitory effect on Candida albicans [92]. The ability of geranium to inhibit mitochondrial function, generate reactive oxygen species (ROS), restrict growth and AFB1 synthesis, and target the cell wall integrity pathway is the basis for its antifungal effect [93].

Cardiovascular system protection effects

The leading cause of death worldwide is cardiovascular illnesses (CVDs), which impact the heart or blood vessels. By 2030, it is anticipated that CVDs will claim the lives of over 23 million people annually [94]. Significant antiatherosclerosis, antihyperlipidemic, antidiabetic, and antihepatic steatototic effects on key CVD risk factors have been demonstrated for geranium. Recent studies have demonstrated the protective effects of polyphenols in geranium against cardiovascular diseases (CVDs), including myocardial ischemia reperfusion injury, heart failure, arrhythmia, and hypertension. [95, 96]. Free radical-induced hepatoprotective action was also demonstrated by geranium [95]. However, more research is necessary to determine the exact mechanism causing the protection, which may call for future studies.

Anti-atherosclerotic effect

Endothelial dysfunction and subendothelial lipoprotein retention are the main causes of atherosclerosis (AS), which is most commonly detected in the subendothelial space (intima) of arteries [97]. Geranium and its main terpenoids, such as linalool and geraniol, have been demonstrated to decrease RAW 264.7 macrophages uptake of Dil-ox-LDL, decrease lipopolysaccharide-induced NFkB activation in RAW-Blue macrophages, [98], and stop chronic inflammatory processes by preventing the formation of foam cells through various mechanisms [99]. Therefore, a treatment approach for atherosclerosis may involve focusing on macrophages, metabolism, and reactions to oxidative stress and inflammation. One crucial stage in the development and progression of AS is the build-up of foam cells in the subendothelial area.

Anti-hyperlipidaemic effect

Elevated blood lipid levels, or hyperlipidaemia, are a well-known risk factor for cardiovascular disorders. Suppressing and increasing lipid ingestion, conversion, and excretion is the primary basic mechanism of hyperlipidaemia resistance [100]. By suppressing the expression of 3 hydroxy-3-methylglutaryl-CoA reductase (HMGCR), a marker of hepatic cholesterol synthesis, linalool may reduce plasma cholesterol levels [101]. Furthermore, without changing the total levels of Ras proteins, geraniol changed cholesterogenesis via decreasing the expression of membrane-related Ras proteins in animals that were heterotransplanted [102]. Through lipid peroxidation and increased catalase and SOD enzymatic activity, geranium may inhibit the oxidation of several kinds of low-density lipoprotein (LDL) [103].

Whole plant extracts frequently exhibit noticeably more hypolipidemic action than single isolated components, as seen by the experimental results above. This bioactivity could be explained by the polyphenols present in the different extracts. The commonly asserted beneficial impact of *P. graveolens* in cardiovascular disease may be supported by this trait [104].

Antidiabetic effects

The current definition of diabetes mellitus (DM) includes changes in the metabolism of fats, proteins, and carbohydrates, along with an increased risk of the repercussions of vascular disease [105]. The studies investigated the potential mechanisms of action and antidiabetic effects of *P. graveolens* [106,107]. The present study unequivocally shows that geranium and its constituents not only have notable hypoglycaemic effects, but also enhance antioxidant defence mechanisms and decrease lipid peroxidation processes [108, 109]. Because it enhances insulin resistance (IR) and glucose metabolism, geranium has anti-diabetic effects and may help prevent oxidative stress-related diabetes.

Oxidation and inflammation have a direct relationship with diabetes. TNF-a, IL-6, iNOS, and COX-2 were among the proinflammatory cytokines that decreased as a result of geranium therapy [110]. Notably, a very significant and potent acute antihyperglycemic trend in rats given starch confirmed the combination inhibitory effect of geranium-based α-amylase and *in vitro* α-glucosidase [107]. More significantly, its extract did not enhance the fasting rats' postprandial glycaemic response to glucose load. All things considered, *P. graveolens* is a noteworthy and promising plant choice for combination medicine therapy of type 2 diabetes and prediabetes. A pathological condition known as insulin resistance (IR) occurs when cells are unable to react to the normal activity of insulin. The risk of type 2 diabetes and pre-diabetes is increased by IR. Geranium at a dose of 65 mg/kg/day was beneficial for 13 days in reducing the symptoms of IR syndrome and improving IR indices such body weight, hyperglycaemia, hyperinsulinemia, and hypercholesterolemia [111].

Anticancer effects

By 2020, 10 million people will have died from cancer, making it the second leading cause of death worldwide. The World Health Organization estimates that one out of every six deaths globally are caused by cancer.

Leukaemia, lung cancer, melanoma, myeloma, cholangiocarcinoma, colon cancer, stomach cancer, bladder cancer, breast cancer, cervical cancer, and leukaemia have all been reported to benefit from geranium. By inhibiting tumour cell development, inducing apoptosis, reducing migration and invasion, and enhancing immune function, geranium and its active ingredients can help prevent cancer.

- **Inducing apoptosis**

By producing ROS, geranium stimulates apoptosis in human colon cancer cell line HT-29, leukaemia cell lines ATL and MT-2, and breast cancer MCF-7 cells. Geranium uses a range of apoptosis-regulating signals to trigger apoptosis. By increasing the levels of apoptosis-related markers p53, caspase-3, mir-21, mir-92a, Bcl-2, and ki-67, geranium prevents MCF-7 gastric cancer cells from producing survivin [112]. Additionally, linalool activated the intrinsic apoptosis pathway in the human glioblastoma U87-MG cell line by increasing the expression of pro-apoptotic proteins (Bax and Bak) and lowering the expression of anti-apoptotic factors (Bcl-2 and Bcl-xl) [113] Increased ROS formation and decreased antioxidant enzyme activity are the causes of linalool's apoptotic and anti-proliferative effects, as shown by *in vitro* and *in vivo* models of S-180 tumour-bearing mice [114].

- **Cell cycle arrest**

By decreasing the number of cells in the S and G2/M stages, geranium stopped the growth of T24 bladder cancer cells [115]. Geranium causes G2/M phase arrest, which stops the growth of colon adenocarcinomas [116]. Another geranium component, linalool, can also cause cell cycle halt in some cancers [117]. used the 3 (4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay to show that linalool at 20, 40, and 80 µM concentrations caused sub-G1 cell cycle arrest, which resulted in DNA damage, in human prostate cancer cells (DU145).

Similarly, a recent study verified that linalool was fatal to human Caucasian prostate cancer cells (PC-3) and DU145 [118]. Additionally, it caused cell cycle arrest at the G2/M transition and moderately cytotoxically suppressed the proliferation of melanoma MV3 cells, which was linked to decreased expression of the CDK6 gene and MMP2 [119].

Antibacterial and antifungal activities

P. graveolens has been found to possess good antibacterial activity against S. aureus, Proteus vulgaris, B. cereus and Staphylococcus epidermidis [120]. *P. graveolens* oil is being used as potent oil on the pathogenic vaginal bacteria such as *Atopobium vaginae*, *Gardnerella vaginalis*, *Bacteroides vulgates*, *Streptococcus agalactiae*, H_2O_2-producing lactobacilli, non H_2O_2 producing lactobacilli, *C. albicans*, *C. glabrata*, *Candida parapsilosis and Candida tropicalis* [120-123] and has been used to extend the shelf life of foods, beverages, pharmaceutical and cosmetic products. The essential oil from the fresh aerial parts of the plant exhibited antimicrobial activity against *B. subtilis*, *S. aureus*, *Enterococcus fecalis*, *C. glabrata*, *C. krusei*, *C. neoformans*, Mycobacterium tuberculosis and Mycobacterium intracellulare. Geranium oil has shown inhibition properties on *S. aureus* and *C. albicans* [124]. Presence of α-pinene (37.4%), β-pinene (16%) and limonene (13.3%) in high concentrations are believed to actively inhibit the growth of microorganisms [125,126]. The profound antimicrobial activity of *P. graveolens* may partly explain their wound-healing properties [127,128]. The extract broad spectrum antimicrobial activity may be caused by the coumarins and phenolic acids [129] and may be potential sources of effective agents for wound infections [130-134].

The leaf essential oil of *P. graveolens* exhibited a broad fungi toxic spectrum against *Aspergillus fumigatus*, *Aspergillus terreus*, *Aspergillus alternata*, *F. oxysporum*, *H.*

oryzaeand T. viride [135] first reported the anti-aflatoxigenic nature of *P. graveolens* oil with complete inhibition of aflatoxin B_1 production even at 0.50 gL^{-1}suggesting the relevance in enhancing shelf-life of commodities by controlling microorganisms and minimizing health hazards by inhibiting aflatoxin B1elaboration in food by use of the essential oil of *P. graveolens.* The oil was found to be highly efficacious, showed better fungi toxicity against *A. flavus* at concentrations lower than the earlier reported oils and synthetic fungicides [136].

The antimycotic investigation revealed that *P. graveolens* extracts showed significant growth inhibition against *Aspergillus flavus, A. niger* and *Penicillium notatum* [135].

Applications

Medicinal Applications

- **Anti-inflammatory:** Used in traditional and modern medicine for treating inflammation-related disorders.
- **Antimicrobial:** ESSENTIAL oils and extracts exhibit antibacterial, antifungal, and antiviral activity.
- **Antioxidant:** Rich in phenolics like geraniol and citronellol, offering free radical scavenging properties.
- **Antidepressant & Anxiolytic:** Aromatherapy with *P. graveolens* essential oil has mood-enhancing effects.
- **Wound healing:** Topical formulations assist in tissue repair and healing.
- **Antidiabetic:** Studies suggest blood glucose-lowering effects.
- **Hepatoprotective:** Protection against liver toxicity in animal models.

Cosmetic & Perfumery

- **Aromatherapy:** Calming and mood-lifting effects via essential oil inhalation.
- **Fragrance industry:** Used in perfumes, soaps, lotions, and personal care products for its rose-like scent.
- **Skin care:** Used in creams and oils for anti-aging, anti-inflammatory, and antiseptic properties.

Food and Beverage Industry

- **Flavouring agent:** Essential oil and extracts used in food products for flavour enhancement.
- **Preservative:** Antioxidant and antimicrobial activity makes it a candidate for natural food preservation.

Agricultural and Veterinary Uses

- **Natural pesticide/repellent:** Essential oil repels mosquitoes and agricultural pests.
- **Animal wound care:** Applied traditionally for treating minor wounds and infections in animals.

Environmental Uses

- **Natural air freshener:** Essential oil is used in diffusers for air purification.
- **Insect repellent:** Itronellol and geraniol-rich oils act as eco-friendly repellents against mosquitoes.

Phytopharmaceutical and Nutraceutical Applications

- Development of herbal formulations, capsules, teas, and tonics for managing lifestyle diseases like diabetes and anxiety.

Modern Research Trends

- **Nanoparticle synthesis:** *P. graveolens* extracts used in green synthesis of silver and zinc oxide nanoparticles with antimicrobial applications.
- **Anti-cancer potential:** Preliminary studies exploring cytotoxic effects on various cancer cell lines.

Conclusion

Pelargonium graveolens L'Hér., commonly known as rose-scented geranium, has demonstrated significant ethnomedicinal importance, supported by its diverse phytochemical composition and broad-spectrum pharmacological properties. The plant is rich in essential oils, phenolic compounds, flavonoids, and other bioactive constituents that contribute to its antioxidant, antimicrobial, anti-inflammatory, antidiabetic, cardioprotective, and anticancer activities. Traditional uses across various cultures have been largely validated by modern pharmacological studies, highlighting its potential in managing several health conditions, including metabolic disorders, infectious diseases, and oxidative stress-related pathologies.

Despite the extensive research on its bioactivity and essential oil profile, gaps remain in fully understanding its pharmacokinetics, clinical efficacy, and safety profiles. Further investigations, including well-designed clinical trials and mechanistic studies, are warranted to establish standardized therapeutic applications and dosage regimens. Additionally, the exploration of *P. graveolens* in novel fields such as nanoparticle synthesis and its role in food preservation and cosmetics emphasizes its versatility as a multipurpose medicinal and aromatic plant.

In summary, *Pelargonium graveolens* holds considerable promise as a natural source of therapeutic agents and functional products. Continued research into its phytopharmacology will likely expand its applications in modern medicine, nutraceuticals, and allied industries.

Future Prospects

Although extensive research has established the phytochemical diversity and pharmacological potential of *Pelargonium graveolens*, several areas remain underexplored and offer promising avenues for future investigation. Clinical studies are urgently needed to validate the therapeutic efficacy, optimal dosing, and long-term safety of its extracts and essential oils in human populations. Additionally, comprehensive mechanistic studies should be conducted to unravel the molecular pathways responsible for its antidiabetic, anticancer, cardioprotective, and antimicrobial effects. Standardization of cultivation, harvesting, and extraction techniques is also crucial to ensure consistency in essential oil yield and chemical composition, which directly impact its therapeutic and industrial applications. The development of advanced formulations, such as nano emulsions, herbal supplements, and topical preparations, can enhance the bioavailability and effectiveness of its active compounds. Moreover, the emerging use of *P. graveolens* in the green synthesis of nanoparticles and as a natural preservative in food and cosmetic products presents innovative prospects for its application in sustainable industries. Interdisciplinary research integrating pharmacology, nanotechnology, food science, and clinical medicine will be essential to fully realize the medicinal and commercial potential of this versatile aromatic plant.

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