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Review Article

A comprehensive review on cultivation, productivity and essential oil quality of rose-scented geranium (*Pelargonium graveolens* L Herit. Ex. Aiton)

Nikil Bhashkar Lothe[1,2] and Rajesh Kumar Verma[1,2]*

1. Crop Production and Protection Division, CSIR-Central Institute of Medicinal and Aromatic Plants (Council of Scientific and Industrial Research) PO- CIMAP, Lucknow 226015, Uttar Pradesh, India.
2. Academy of Scientific and Innovative Research (AcSIR), Ghaziabad 201002, India.

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Corresponding Author
Rajesh Kumar Verma
rajesh.verma@cimap.res.in,
rajeshcimap@rediffmail.com
Tel.: +915222718513
Fax: +915222342666

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Abstract

Rose-scented geranium (*Pelargonium graveolens* L Herit. Ex. Aiton) is an aromatic perennial herb, well adaptable to vivid climatic conditions, regions, and soil-types. Geranium oil is a rich source of citronellol and geraniol, and it is foremost top 20 essential oils globally and used in the perfume, cosmetics, and fragrance industries. Despite the fact that the worldwide production of geranium is about 661.38 tons and its current domestic demand is approximately 200 tons, but India produces only 20 tons. The leftover requirement is met by importing from other countries. This review keenly displays the up-surging demand of geranium in domestic and international markets due to its broad-spectrum applications. Regions-specific studies have been done on this crop related to its cultivation, but there is a cavity of brief knowledge systematically. Therefore, in this review, research work carried out has been compiled related to the information on commercially available varieties/cultivars, proper agronomical practices, chemical constituents, and prophylactic activities of *P. graveolens* essential oil. However, in the research sector, *P. graveolens* prospects will be on an upswing, the demand of the crop burgeoning in the industries, and eventually, farmers also reaping its benefits. Although, its focuses on the package of practices that will help to enhance the production and quality of its essential oil worldwide.

1. Introduction

In the present scenario, the economics of the medicinal and aromatic plants (MAPs) based agriculture sector is not well to meet the exact demand required by the industries due to some factors that affect agricultural growth, likewise climatic change, crop failure, uneven rainfall, and natural calamities. Medicinal and aromatic crops are sustainable and commercially viable crops for the country's economic expansion. The trade sector of aromatic crops upraised rapidly, and the growth of India in the global share market was significantly less. Such an extensive diversification prevailing in different agro-climatic conditions in our country provides adequate access to cultivate and harvest aromatic crops in one or the other parts. Therefore, for the production of high-quality aroma/pharma related raw material, proper implementation of agrotechnology, cultivation, harvesting & processing management, and miscellaneous measure ought to apply.

Rose-scented geranium/geranium (*Pelargonium graveolens* L Herit. Ex. Aiton) plants have the potential to respond according to genotypes/cultivars and environmental conditions for enhancing their growth and production accordingly. According to their growing habitat, geranium is well adaptable to vivid climatic regions and different soils of the world. The ongoing international insistence for geranium oil is around 661.38 US tons, mainly received by foreign countries like China, Egypt, Morocco, Reunion Island, and South Africa [1]. Considering the industrial demand, productivity, quality standards, import-export substitution and promotion, the potentiality of the crop, and profitability of Indian cultivation, it is time for geranium oil production to implement proper cultivation management [2]. In promoting the proper agro-practices of geranium, this review represents comprehensive agronomical measures, production, and quality affected by different climatic conditions. Although in addition, chemical composition, essential oil components, uses, and prophylactic activities have also been illustrated.

P. graveolens is an aromatic perennial herb known as rose-scented geranium. It exhibits a rose-like fragrance and substitutes of rose oil from the geraniaceae family belonging to the genus *Pelargonium* [3]. It is native to South Africa and also grows well in Egypt, India, and China. Meagerly, it is also cultivated in Central Africa, Madagascar, Japan, Central America, Belgium, Reunion Island, Congo, and Europe [3-4]. Its vernacular names are geranium (Hindi, English, Tamil) and Pannirsoppur, Pannir patre (Kannada). Around the end of the 17th century, geranium was first reported from Europe, from where it was eventually exported to the French colonies. The rose scented geranium was first introduced to North Africa in 1847 in Algeria from Grasse (France) and in Egypt by the Frenchmen, Charles Garnier, in 1930. Production in Egypt was not in continuous progress following Nasser's coup d'etat in 1952 but was brought back a few years later under the leadership of Ahmed Fakhry. Afterwards, Algerian geranium (once the world's leading supplier) disappeared from the market, leaving Egypt as the only producer of this geranium type, along with small quantities produced in Morocco. In China, State-owned companies introduced geraniums to Yunnan Province in the 1970s. These were planted around Kunming city in Anning and Chenggong countries back then. The scale was small, and the quantity produced was about 10 tons annually.

In India, it was first introduced by French Christian priests to Yercaud in the Shevroy Hills (near Salem in Tamilnadu) in the early nineteenth century. In 1953, the Cinchona Provincial Government Department introduced crops to the Nilgiris and Anamalai Hills, and the soil and climate of Nilgiris (Udhagamandalam in Tamil Nadu) proved to be relatively more suitable for the cultivation of this crop. By 1975, the geranium area had expanded to 200 hectares in Nilgiris and 32 hectares in the Palani hills. This later increased to about 952 hectares in Nilgiris and 450 hectares in the Palani hills. Now, rose-scented geranium is grown in hills in south India as a perennial crop and as an annual crop in northern areas. Commercial cultivation of geranium is done in Tamil Nadu, Nilgiri Hills, Pulney Hills, Carnatic, Maharashtra, Uttarakhand, and Andhra Pradesh [5]. There is ample evidence that aromatic geraniums are grown and processed into essential oils in different regions of India [6].

Council of Scientific and Industrial Research (CSIR) - Central Institute of Medicinal and Aromatic Plants Lucknow (CIMAP), India, popularly known as CSIR-CIMAP, plays a crucial role in promoting various aromatic and medicinal plants. In the area of aromatic crops, especially crops like rose-scented geranium for essential oils that are in great demand by the aroma industry worldwide are being focussed. CSIR-CIMAP has continuously developed many improved cultivars of rose-scented geranium since last three decades. CSIR- Aroma Mission Phase I and II also played a key role in bringing transformative change through desired interventions to expand areas under rose-scented geranium and enhance essential oil yield and income of the small and marginal farmers of the country as well as role in fulfilling the demands of various aroma and pharmaceutical industries globally.

2. Materials and methods

The current study relies solely on secondary data sources. From the published literature from the last three decades, around 150 experimental research and review papers have been consulted (i.e., 1990-2020). The many databases that are available online were used for this data collection process. Secondary data were obtained by searching scientific electronic search databases, i.e., Elsevier, Google Scholar, PubMed, Web of Science, ACS, Science Direct, Taylor and Francis, Wiley online library, Springer, Frontiers, Scopus, and many other national and international journals database. PubChem and Chem Spider were used to confirm chemical compound structures.

Values or results of the referenced work are noted, if applicable. The references are listed in the articles' order of publication. Work done on cultivation, phytoconstituents, steam/hydro-distillation extraction, supercritical fluid extraction methods for essential oil, ethnobotany, agronomic practices, and various versatile applications of *P. graveolens*, are divided into various sections and subsections accordingly.

3. Results and discussion

3.1. Taxonomy and systematics

Among five genera, the rose-scented geranium has about 700 species; the *Pelargonium* genus consisted of about 280 species under sixteen sections [7]. The *Pelargonium* section (x = 11 chromosomes) includes 26 species, which produce essential oils by steam or hydro-distillation obtained from fresh biomass of herb. Citronellol and geraniol are the prominent components of essential oil which are recognized worldwide as a heptaloid hybrid (2n = 7x = 77) between the species *P. capitatum* and *P. graveolens* that is hexaploid (2n = 6x = 66) × octoploid (2n = 8x = 88), respectively [8] or *P. capitatum* × octaploid *P. radens* H.E. Moore (2n = 8x = 88). Other hybrids of *P. asperum* Ehrh. ex Willd., *P. roseum* Willd., *P. roseum* × *P. denticulatum* Jacq. (2n = 4x = 44) / *P. radens* / *P. scabrum* (L.) L'Herit. ex Ait. (2n = 2x = 22) are also known for aromatic oil and are used/accepted by the aroma industry [9]. In early and modern literature, plants that produce essential oils rich in citronellol and geraniol were mistakenly identified as *P. graveolens* L'Heritier or Aiton (actually a hybrid, known as the geranium species) because of the difference between them the shape and morphologically similar to *P. graveolens* and its hybrids [8-12]. The Systematics of *P. graveolens* are as follows. Kingdom: Plantae; Clade: Tracheophytes; Clade: Angiosperm; Clade: Eudicots; Clade: Rosids; Division: Magnoliophyta; Order: Geraniales; Family: Geraniaceae; Genus: *Pelargonium*; Species: *graveolenes*.

3.2 Morphological characteristics

Rose-scented geranium is a dense, aromatic herb, 60-120 cm in height, 60-100 cm in diameter, with woody cylindrical stems at the base; it appears hairy and green at the young age and turning pale and brown during the senescence period. Short, thick hair single-celled, non-glandular trichomes appear at the base of the epidermal cells and on both surfaces [13]. Simple, alternating, pedicel-shaped stipules, ranging from oval to narrow round shape with 57 primary lobes and 4,080 pinnate lobes with pinnatisect secondary lobes. The segment margins are more or less revolute. The leaves of the plants are deeply carved, smooth in feel, and emit a strong rose fragrance [14]. Bract umbel with a long stalk and short stalk, flower bisexual raceme, inflorescence, hairy sepals, corolla looks light pink to dark pink, with reddish-purple spots, two posterior petals are more significant than the first three. There are about seven to ten stamens and seven anthers. The ovary is hairy, with five carpels and a hairy style that branch into five stigmas. Fig. 1 shows the morphological view of *P. graveolens*.

Figure 1. Morphological view of rose-scented geranium.

([a]A: Leaf, B: Stem, C: Flower, D: Floral diagram, E: Node and internode, F: Field view.)

The Indian genotype is mainly male sterile, but partially or fully fertilized flowers are scrutinized. The flowers bloom around 8 o'clock in the morning. After an hour, the fertile anthers will dehisce. According to reports of Rao [11], seed prevalence in India is low.

The leaves, tender stems, petioles, and flowers have glandular hairs (sebaceous glands); modified epidermal hairs. The sebaceous gland has a basal cell, a multicellular stalk, and a unicellular spherical head having oil-stored in it [13]. The sebaceous glands can be seen with an optical microscope, and variation has been found in size according to different cultivars. Leaves and inflorescence parts contain more essential oils than petioles and pale green stems [15-16].

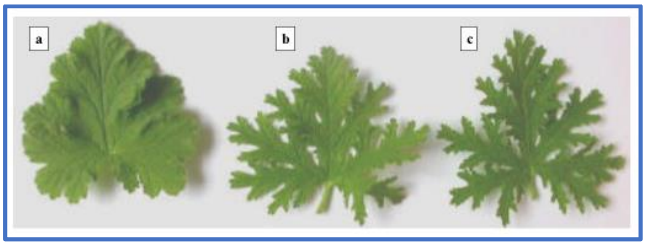

Figure 2. Differentiate between the leaf morphology of different cultivars of *P. graveolens*.
([a](a) Cultivar- Reunion type, (b) Cultivar- Bourbon type, (c) Cultivar-Chinese type)

P. graveolens varieties are exceedingly difficult to distinguish morphologically. Tembe and Deodhar [17] reported that reunion plants show slight differences f rom the two existing cultivars viz., Egyptian and Bourbon, resembling each other. Due to less internode growth, as compared to the thin, heavily dentate leaves that characterize the Bourbon, and Egyptian cultivars, the reunion cultivar has strong habits and thick, less dentate leaves (Fig. 2a-c). As a result of excessive glandular growth, the lamina of the reunion cultivar is eminently pubescent. However, their oils can be distinguished using gas chromatography (GC) based on the appropriate proportion of geraniol and citronellol.

3.3 Global demand and production

Rose-scented geraniums is a highly adaptable crop; however, it negatively impacted by heavy mist, fog, frost, temperatures below 3°C, scorching winds, chronic drought, heavy rains, and water logging. Favorable climatic conditions play a crucial role to maximize the global yield and productivity. According to the global demand and production, Baker and Grant [18] reported that Egypt is the substantial distributor of geranium oil globally, subsequently, China. But currently, China leads in the production world. These two main producers' combined production has reached over 280-350 tons annually. Real bourbon geranium oil is produced on reunion Island (formerly Bourbon), near Madagascar Island [19]. Réunion geranium oil is sourced in France, Egypt overtook Reunion as the dominant supplier in the 1960s, but its market share has declined in recent years compared to China [20]. The production rate of Madagascar is low but has a higher stable price in the world market [18]. Other countries and regions that produce geranium oil include Algeria, Morocco, Spain, France, the United Kingdom, Rwanda, and South Africa [18-19, 21].

According to Tembe and Deodhar [22] report, geranium oil is the foremost top 20 essential oils globally and uses in the perfume, cosmetics, and fragrance industries. The current demand for geranium in India is about 200 tons, of which only 20-30 tons of oil are produced indigenously, and the rest is met by imports from all over the world [22-23] worth US$12.5 million [24]. Due to the increase in the number and preferences of consumers and the increase in essential oil ingredients, it is expected that the essential oil trade will increase in the future [25]. Therefore, there is a need to increase the domestic and global production of geranium oil. The country-wise production rate of rose-scented geranium essential oil is represented in Table 1.

Table 1. Country- wise production rate of essential oil of *P. graveolens*.

S.No.	Name of Countries	Production in tones/year
1	Egypt	200-230
2	China	80-120
3	India	25-30
4	Russia	20
5	Algeria	10-15
6	Madagascar	<10
7	South Africa	5-10
8	Reunion Island	2-6
9	Kenya	<1
10	Morocco	<0.5
11	Congo	<0.5

[a]Source: https://ifeat.org/2015/09/geranium-socio-economic-report/

3.4. Essential oil extraction process

3.4.1 Steam/hydro distillation

The essential oil extraction process was performed for the first time in 1922 at the Chiris factory. After that, researchers have done much work to improve the plant material, agronomical practices, and essential oil extraction process [7]. Geranium oil is extracted from fresh biomass by steam/hydro distillation unit and is widely used in the high-quality perfumes industry (Fig. 3a).

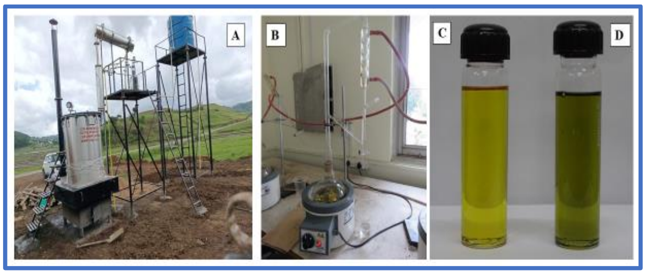

Figure 3. Extraction of essential oil by using hydro/steam distillation unit and Clevenger apparatus. ([a]A: Hydro/steam field distillation unit; B: Clevenger apparatus distillation; C: extracted essential oil from cultivar- 'CIMAP Bio-G-171'; D: extracted essential oil from cultivar- 'CIM-Bharat')

Steam distillation is used as an immiscible liquid to extract and isolate essential oils from the plant herbage material. The harvested plant material should be distilled on the same day it was harvested by hydro/ steam distillation. The distillation unit consists of a tank, condenser, and separator; during the distillation process, the freshly harvested herb is loaded into the tank, but the herb should not be over-pressed in the distilled chamber. After this, the lid is closed tightly, and steam is passed into the tank. The density of geranium oil is around 0.887 g/mL at 25 °C (lit.), and the oil appears yellow to brownish (Fig. 3c-d) and greenish according to different genotypes and environment interactions. For isolation and quality characterization, freshly harvested leaves weighing about 200 grams of rose-scented geranium varieties were subject to hydro-distillation in a Clevenger apparatus for three hours (Fig. 3b). The content (%) is calculated from the volume (ml) of essential oil per 100 g of fresh plant material, while the essential oil is measured directly in the extraction burette. The essential oil samples were dehydrated over anhydrous sodium sulfate (Na_2SO_4) and stored in a cool and dark place for their analyses.

3.4.2 Gas chromatography-mass spectrometry (GC-MS)

The essential oil constituents were quantified using gas chromatography-flame ionisation detection (GC-FID). Essential oil GC analysis was performed on a Nucon gas chromatograph (5765) and a Varian gas chromatograph (CP-3800) equipped with a DB-5 (30 m (0.32 mm; 0.25 m film thickness)-fused silica capillary column and a flame ionisation detector (FID). At 1.0 ml min1, hydrogen is used as a carrier gas. Temperature programming ranges from 60 to 230 °C at three degrees' Celsius minute^{-1}. The temperatures of the injector and detector are generally 220 and 230 °C, respectively. With a split ratio of 1:40, the injection volume is 0.03L neat. The essential oil constituents are identified using gas chromatography-mass spectrometry (GC-MS) on a GC interfaced with a mass spectrometer equipped with an Elite-5 MS-fused silica capillary column (5 percent phenyl polysiloxane, 30 m 0.25 mm internal diameter, film thickness 0.25 m). The column temperature is programmed to range from 60 °C to 240 °C at three °C min^{-1} and to 270 °C at five °C min^{-1} using helium as a carrier gas at a flow rate of 1.0 ml min1. MS conditions are as follows: EI mode at 70 eV, transfer line and source temperatures of 250 °C, injection size 0.03 L neat, split ratio 1:50, mass scan range 40-400 amu. The essential oil constituents are identified using a retention index (determined for homologous series of n-alkanes, C8 - C24), an MS Library search (NIST and WILEY), and a comparison of the MS and retention index data with the literature [26]. The relative amounts of individual components were calculated using a correction factor based on the close peak areas (FID response). Free rhodinol (%) was calculated as the sum of peak area (%) of linalool, geraniol, and citronellol; however, total rhodinol was calculated as the sum of the peak area percentage of linalool, geraniol, citronellol, geranyl formate, and citronellyl formate present in different oils [26].

3.4.3. Supercritical carbon dioxide extraction

Supercritical fluid extraction (SFE), an emerging technology in all industrial sectors, might provide solutions to both problems. In addition to being inexpensive and non-flammable, non-corrosive, and readily available, supercritical carbon dioxide is also environmentally safe [27]. Due to the existence of SFE technology, conventional extraction techniques were able to overcome their shortcomings, particularly with respect to extraction time and temperature. SFE offers a shorter extraction time than conventional extraction, as has been demonstrated by numerous studies based on recent research. According to the research of Binti Idris and associates [28] SFE technique took only 45 minutes to finish tamarind seed extraction. In another investigation of *Leucaena leucocephala* pod oil, the extraction from SFE process took 60 minutes [29]. Therefore, SFE proved to be more efficient than conventional extraction methods in terms of time. The maximum yield under these conditions became 2.53%, which was significantly higher than the normal steam distiller yield of 0.20%. In addition to the steam distillation processes, supercritical extraction processes were also considered for GC–MS analysis. Despite having all major oil components, the supercritical extracted oil lacked a number of minor oil components present in the steam-distilled oil. By varying the extraction time and pressure, the composition of the supercritical oil was changed. SFE may increase geraniol's selectivity based on the GC-MS analysis.

SFE was performed in a laboratory, and geranium oil was extracted using carbon dioxide as a solvent. In a cotton sachet, a 6 g amount of powder geranium leaves was loaded into the extraction vessel and reconstituted with distilled water. A constant flow rate of solvent, solvent temperature, and pressure was maintained throughout the experiment, namely 100 bar, 40°C, and 24 mL/min, respectively. It took 70 minutes to complete the extraction process and 10 minutes were spent collecting oil throughout the time. In order to calculate the yield percentage, we determined the mass of oil extracted from a glass vial and calculated the percent of yield using the following equation [132].

$$Percentage\ yield\ of\ oil\ (\%) = \frac{Mass\ of\ extracted\ oil\ (g)}{Initial\ plant\ biomass\ (g)} \times 100$$

One milligram of extract obtained from *P. radula* oil was dissolved in half a liter of hexane to prepare a solution. Through GC-MS analysis, the organic fractions of extracted and commercialized *P. radula* oil were analyzed. Injection of helium with a flow rate of 1 mL/min, ratio 50:1 injector temperature 250°C and split flow of 50 mL/min; these conditions correspond to a sample injection of 1L, carrier gas helium (99.999% pure) and flow rate 1 mL/min. Initially, the temperature of the oven is set at 60°C for 10 minutes, then increased at 3°C/min to 230°C for 1 minute, and then maintained on the oven for another 2 minutes. Based on mass spectra, the compounds were detected.

3.4.4 Chemical components and phytochemistry

Phytochemicals are primary and secondary metabolites found within plants' leaves, vegetables, and roots that act as defense mechanisms and defend against stresses/illness. Proteins, carbohydrates, chlorophyll, lipids, and customary sugars are primary metabolites created throughout the chemical change and are necessary for plant life, growth, and development [30]. The major biochemical constituents of geranium oil are terpenoids, flavonoids, coumarins, ceramics, and tartaric acid [31]. In addition, Narnoliya and associates [31] detailed that Terpene is assembled by a combination of a five-carbon isoprene unit (CH_2-C (CH_3)-CH-CH_2). The standard equation of terpene is ($C5H_8$)$_n$, where 'n' is the number of isoprene units. Terpenes are classified based on how many units of isoprene are found in them; they can be divided into various categories; the most common are monoterpenes (2 isoprene units, i.e., 10 carbons), sesquiterpenes (3 isoprene units, i.e.,15 carbons), diterpenes (4 isoprene units, i.e., 20 carbons), triterpenes (6 isoprene units, i.e., 30 carbons) and, tetraterpenes (8 isoprene units, i.e., 40 carbons). In essential oil, these terpenes are showing either in their basic shape or in alcoholic, ketonic, aldehyde, and ester shapes, and in some cases as chlorinated or oxygenated subordinates. These terpenes are represented in other structural forms, non-cyclic, monocyclic, and bicyclic structures on the premise of the carbon course of action.

There are more than 200 compounds that have been extracted from rose-scented geranium using gas chromatography (GC) and gas chromatography-mass spectrometry (GC-MS) methods, which are depicted in Table 2.

Table 2. Various types of chemical constituents extracted from rose-scented geranium.

S. No.	Chemical categories	Examples of chemicals
1	Aliphatic hydrocarbons	Butane, isoprene, 1,3-pentadiene, hexane, isooctane, octadecane, nonadecane, nonadecene, eicosane, henicosane, decosane, tricosane, tetracosane, pentacosane
2	Aromatic hydrocarbons	Toluene, p-cymene
3	Terpene hydrocarbons	α-Pinene, β-pinene, α-phellandrene, β-phellandrene, camphene, myrcene, sabinene, limonene, γ-terpinene, terpinolene, cis-β-ocimene, trans-β-ocimene, dehydro-1,8-cineole, 1,4-cineole, p-menthadiene, perillene, piperitone

Table 2. *(continued)*

S. No.	Chemical categories	Examples of chemicals
4	Sesquiterpene hydrocarbons	α-Copaene, α-cadinene, γ-cadinene, δ-cadinene, guaia-6-9-diene, β-bisabolene, α-calcorene, calamenene, β-selinene, α-muurolene, γ-muurolene, α-bourbonene, β bourbonene, 11-norbourbonene, β-caryophyllene, γ-caryophyllene, bicyclo-germacrene, germacrene D, longifolene, β-gurjunene, β-farnesene, (E,E)-α-farnesene, α-cubebene, β-cubebene, β-elemene, β-maaline, α-humulene, viridiflorene, zonzrene, α-ylangene, allo-aromadendrene, selina-4,11-diene, α-guaiene
5	Aliphatic alcohols	Methanol, ethanol, t-butanol, pentanol, 1-penten-3-ol2-propanol, hexanol, 2-methylpropanol, 2-dimethylpropanol, 2-methylbutanol, 2-methyl-3-buten-2-ol,, 3 metylbutanol, 3-methylpentan-1-ol, cis-3-hexenol, trans-2-hexenol, 3-hexen-1-ol, octanol, 1-octen-3-ol, 2-octanol
6	Terpene alcohols	Geraniol, isogeraniol, isopulegol, 7-hydroxy-6,7-dihydrogeraniol, nerol, epi photonerol A, linalool, menthol, isomenthol, neoisomenthol, α-terpineol, citronellol, 7-hydroxydyhydrocitronellol, borneol, isoborneol, terpinen-4-ol
7	Aromatic alcohols	2-Phenylethyl alcohol
8	Sesquiterpene alcohols	10-epi-γ-eudesmol, β-eudesmol, 11-selina-4α-ol, junenol, farnesol, guaiol, spathulenol, T-cadinol, elemol
9	Aliphatic esters	Methyl formate, methyl butyrate, 2-methylbutyl formate, 3-methybutyl formate, 2-methylpropyl formate, 3-methylpentyl formate, ethyl formate, butyl formate, propyl formate, 2-propyl formate, hexyl formate, benzyl tiglate, (Z)-3-hexenyl acetate
10	Aromatic esters	2-Phenylethyl tiglate, 2-phenylethyl propionate, 2-phenylethyl butyrate,

Table 2. *(continued)*

S. No.	Chemical categories	Examples of chemicals
10	Aromatic esters	2-phenylethyl isobutyrate, 2-phenylethyl isovalerate, 2-phenylethyl acetate
11	Terpene esters	(Z)-3-Hexenyl acetate, geranyl formate, geranyl butyrate, geranyl isobutyrate, geranyl 2-methyl butyrate, geranyl tiglate, geranyl acetate, geranyl propionate, geranyl valerate, geranyl 3-methylvalerate, geranyl 4-methylvalerate, geranyl hexanoate, geranyl heptanoate, geranyl nonanoate, geranyl isovalerate, methyl geranate, geranyl 3-methyl pentanoate, geranyl octanoate, citronellyl acetate, citronellyl formate, citronellyl butyrate, Citronellyl tiglate, citronellyl propionate, Citronellyl valerate, citronellyl 4-methylvalerate, citronelly lisovalerate, Citronellyl hexanoate, citronelly lisohexanoate, Citronellyl heptanoate, Citronellyl octanoate, Citronellyl nonanoate, furopelargonic acetate, linalyl acetate, bornyl acetate, neryl acetate, neryl formate
12	Aliphatic ketones	Acetone, 2-butanone, 2-pentanone, 3-methyl-2-butanone, 2-methyl-3-pentanone, 4-methyl-2-pentanone, 2-methylcyclopentanone, 3-methylcyclo-pentanone, 3-metylcyclohexanone, 4-methyl-3-penten-2-one, 2-hexanone, methyl heptenone, 6-methyl-5-hepten-2-one, methyl-3-methylcyclo-pentenyl ketone
13	Terpene ketones	Menthone, isomenthone
14	Sesquiterpene ketones	1,7-Dihydrofurapelargone, furapelargone A, furapelargone B, 7,8-dihydrofurapelargone
15	Aliphatic aldehydes	Benzaldehyde, ethanal, decanal, 2-methylpropanal, 3-methyl-2-butanal, 3-methylbutanal, 2-furfuraldehyde, nonanal, (E)-2-hexenal
16	Terpene aldehydes	Geranial, citronellal, neral, photocitrl A, epi-photocitral A, photocitral B, p-menth-1-en-9-al

Table 2. *(continued)*

S. No.	Chemical categories	Examples of chemicals
17	Terpene oxides	cis-rose oxide, trans-rose oxide, cis-linalool oxide, trans-linalool oxide, anhydrolinalool oxide, bois-de-rose oxide, nerol oxide
18	Sesquiterpene oxides	Caryophyllene oxide
19	Aliphatic acids	Formic acid, propionic acid, acetic acid, caprylic acid
20	Terpene acids	6-oxo-6-,7-dihydrocitronellic acid, geranic acid, citronellic acid
21	Miscellaneous	Dimethyl sulphide, eugenol, methyl eugenol, furan, α-agarofuran, rose furan, epoxy-rose furan, juniper camphor, theaspirans, vetispirans

[a] Source: [31]

The oil chemistry is computed by the GC profile, which is persuaded by several intimate factors. The edaphic factors, plant genetic makeup, plant stage, plant parts, plant age, and plant age leaves; external factors that influenced are location, seasonal or climatic parameters, the presence of weeds, disease; and management practices like planting date, use of growth regulator, crop height, drying or grinding of plant material before distillation, distillation method, oil storage conditions. That is why the composition of these essential oils from different countries varies [32].

With the prevailing details on the chemical composition of *P. graveolens* reported by many researchers' essential oils, presiding volatiles are citronellol, geraniol, and citronellyl formate [33-35]. Geranium cultivars are usually divided into three main sections based on their origins - those from Reunion Island, Egyptian or North African plants, and those from China. Citronellol and geraniol are present in roughly equal proportions in Reunion Island-type cultivars, while isomenthone, citronellyl formate, and 6,9-guaiadiene are the other main components. The prominent components of Egyptian-type oil are citronellol formate, isomenthone, and 10-epi-γ-eudesmol, though they also contain a 1:1 ratio of citronellol and geraniol. Citronellol and citronellol formate have a high concentration in Chinese-type oils, while geraniol is relatively low in content. Quality is graded from Reunion to Egyptian, then Chinese cultivars, and so on [31]. Tembe and Deodhar [17] made a distinction between Reunion (G:C ratio=1) and Bourbon (G:C ratio = 0.5). Egyptian-type oils were suggested to have a G:C ratio of 0.25 [36]. The composition and quality of geranium essential oil produced from different countries and the substantial oil composition difference between Chinese and Egyptian geranium are represented in Table 3.1-3.2, respectively. It is noteworthy reminding that Rhodinol, an essential ingredient in the fragrance industry, is composed mainly of citronellol and geraniol.

Singh and associates [26] recently conducted a study on productivity and essential oil quality of *P. graveolens* cultivars, namely 'CIMAP Bio-G-171', 'CIM-Pawan' and 'Bourbon' and evaluated and compared these cultivars on the basis of two different locations of north India. They found some significant components of the geranium essential oils were citronellol (20.9–39.5%), geraniol (10.9–26.5%), linalool (2.9–14.2%), isomenthone (7.4–9.4%), citronellyl formate (5.5–9.1%) and 10-epi-γ-eudesmol (5.2–9.0%). The essential oil composition of some significant constituents of *P. graveolens* varieties, i.e., 'CIMAP Bio-G-171', 'CIM-Pawan' and 'Bourbon' cultivated under two different locations in North India, are depicted in Table 4.1. Moreover, the variation in essential oil quality parameters among three varieties, i.e., 'Bipuli', 'Hemanti', and 'Kunti' of *P. graveolens* L Herit. Ex. Aiton cultivated in India are depicted in Table 4.2.

Each region's geranium essential oils (GEOs) have a distinct oil composition, with the amount of citronellol to geraniol serving as a crucial sign of the essential oil's quality [38]. Additionally, some allegedly distinct sesquiterpene molecules have been proposed as markers for differentiating the cultivars and provenance of rose-scented geranium, including 10-epi-γ-eudesmol and 6,9-guaiadiene [36]. Additionally, a complex variance in natural plant populations exhibits a wide range of chemical compositions that aren't always associated with the country of origin [39-40]. The phytochemical structures of some commonly found components, like, linalool, citronellol, geraniol, isomenthone, citronellyl formate, and geranyl formate of *P. graveolens* genotypes, are represented in Fig. 4. The value of geranium essential oil lies in its commercialized rhodinol, separated by fractional distillation, and

Table 3.1. Composition of *P. graveolens* essential oil produced in different countries.

Principal Constituent (%)	Country				
	Algerian	Egypt	Morocco	Bourbon	China
Isomenthone	5.3	6.0	5.5	8.3	4.4
Linalool	6.4	9.3	5.1	13.0	3.3
Citronellyl formate	9.0	7.6	7.4	12.8	13.9
Geranyl formate	6.6	3.5	4.1	5.0	3.6
Citronellol	27.3	32.8	18.8	23.6	44.9
Geraniol	25.7	19.5	18.8	20.6	7.7
10-epi-γ-eudesmol	-	5.4	6.5	-	2.2

[a] Source: [37].

Table 3.2. Differences in composition of some prominent constituents of Chinese and Egyptian type geranium essential oils.

Oil components	Chinese type (%)	Egyptian type (%)
Citronellol	32 - 43	25 - 36
Geraniol	5 -12	10 - 18
6,9- guaiadiene	3 - 7	<1= 0.5
10-epi-γ-eudesmol	0 (not detectable)	3- 6.2

[a]Source: https://ifeat.org/2015/09/geranium-socio-economic-report/

mainly includes citronellol, geraniol, and other free alcohols. The chemical components of different essential oils allow the industry to choose the type of their choice to create fragrances that consumers like.

3.5. Versatile applications

3.5.1 Uses in perfumery and cosmetic industries

Rose-scented geranium is one of the best skincare oils because it can open skin pores and cleanse oily skin [41-43, 27]. It possesses a long-lasting note of rose scent fragrance; this is why it is the bestselling product and a substitute for rose. Its essential oil is extensively used in the soaps, perfumery, scents, sprayers, aftershave, and cosmetic industries [44, 34], also used in aromatherapy for body relaxation [40]. The leaves and flowers are used to incorporate with garland due to their pleasant fragrance.

3.5.2. Uses in food industries

Rose-scented geranium oil and its key ingredients are adopted by the food industry when they received FEMA and GRAS (recognized as safe) status in 1965 and are validated by the Food and Drug Administration (FDA) for use in the food industry [45]. *P. graveolens* is used in the food industry due to its antibacterial properties. Numerous studies have shown that phytochemicals/essential oils are effective against bacteria and fungi. This antimicrobial activity has led to the oil being used against food spoilage pathogens. Promising results indicate that it is highly regarded as a preservative in the food industry [46]. Another use of geranium leaves is herbal tea, which is used to treat stress, fight anxiety, relieve tension, improve blood circulation, and treat tonsillitis [27]. In the categories of alcohol, soft drinks, and flavoring agent in food industries, it is also broadly used [3].

3.5.3 Uses in prophylactic activity

Many phytochemical components present in plants have prophylactic properties and can be used to improve and heal human disease [47-48]. This plant's most recent and possibly most relevant use is in the pharmaceutical industry. Studies have shown that geranium has a large number of positive benefits due to its diverse properties. These benefits include antibacterial, antifungal, and antioxidant activity. It is also used to treat dysentery, diarrhea, and colic [3], menorrhagia and menopausal problems [34], hemorrhoids, inflammation, cancer, diabetes, gall bladder problems, gastric ulcers, jaundice, and liver problems [49], pain relief from neuralgia after herpes zoster, infertility, and urinary tract stones [50]. Similarly, Hsouna and Hamdi [51] and Hamidpour and associates [52] observed that *P. graveolens* essential oil has antimicrobial, antifungal, and anti-termite activity. Geranium oil also responds against insomnia, constipation, anxiety, worry, anger, frustration, and emotional upsets. The plant's essential oil improves blood circulation, which helps maintain a healthy immune system and stimulates and cleanses the lymphatic system. This further helps detoxification, overcoming addiction, hemorrhoids, phlebitis, indigestion, and fluid retention [53]. Some researchers reported geranium oils' insecticidal properties and anti-feedant action on insects [54].

Table 4.1. Essential oil composition of prominent constituents of *P. graveolens* varieties/cultivars cultivated under two different locations in north India.

S. no.	Compound	RI[a]	RI[b]	Compound %					
				Lucknow (L_1)			Pantnagar (L_2)		
				V_1	V_2	V_3	V_1	V_2	V_3
1	Linalool	1102	1095	3.5	2.9	5.0	7.5	9.5	14.2
2	Isomenthone	1165	1158	9.4	8.3	7.8	8.6	7.4	8.2
3	Citronellol	1235	1223	35.4	39.5	35.6	23.3	20.9	25.9
4	Geraniol	1259	1249	10.9	12.1	18.3	26.3	26.5	19.7
5	Citronellyl formate	1278	1271	9.1	9.1	8.7	6.9	5.5	7.6
6	Geranyl formate	1304	1298	2.7	2.0	2.4	3.8	3.2	2.5
7	Geranyl acetate	1385	1379	0.9	0.9	0.9	0.9	0.7	0.6
8	Germacrene D	1480	1480	0.8	1.0	1.1	1.5	1.7	1.0
9	10-epi-γ-eudesmol	1619	1622	5.6	5.4	5.2	7.5	9.0	6.6
10	Geranyl tiglate	1701	1696	0.8	1.1	1.1	1.5	1.6	1.1

[a] V_1: 'CIMAP Bio-G-171'; V_2: 'CIM-Pawan'; V_3: Bourbon; RI[a]: retention index determined on DB-5 gas chromatography column; RI[b]: retention index (literature), [b] Source: [26].

Table 4.2. The variation in essential oil quality parameters among three cultivars of *P. graveolens* cultivated in India.

S. No.	Compounds	Compound %		
		Bipuli	Hemanti	Kunti
1	Citronellol	34.5 ± 3.4	50.6 ±1.4	13.0 ± 1.0
2	Geraniol	21.8 ± 3.3	1.2 ± 0.3	43.7 ± 1.4
3	Isomenthone	7.7 ± 0.6	12.4 ± 0.7	10.5 ± 0.7
4	Linalool	4.3 ± 1.6	1.1 ± 0.1	6.6 ± 0.1
5	Cis-rose oxide	0.6 ± 0.3	0.8 ± 0.1	0.1 ± 0.1
6	Trans-rose oxide	0.3 ± 0.1	0.5 ± 0.1	0.1 ± 0.1
7	Menthone	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1
8	Citronellyl formate	7.8 ± 0.3	13.8 ± 0.8	0.6 ± 0.1
8	Geranyl formate	2.1 ± 0.2	0.2 ± 0.1	0.2 ± 0.1
10	10-epi-γ-eudesmol	5.7 ± 0.3	2.4 ± 0.2	4.1 ± 0.1
11	6,9- guaiadiene	0.1 ± 0.1	0.4 ± 0.1	2.0 ± 0.1
12	Decanoic acid	ND	ND	2.8 ± 0.1
13	Isodecanoic	ND	ND	0.6 ± 0.2
14	Phenyl ethyl tiglate	0.8 ± 0.3	0.8 ± 0.2	0.9 ± 0.1

[a] ND = Not detected, [b] Source: [37].

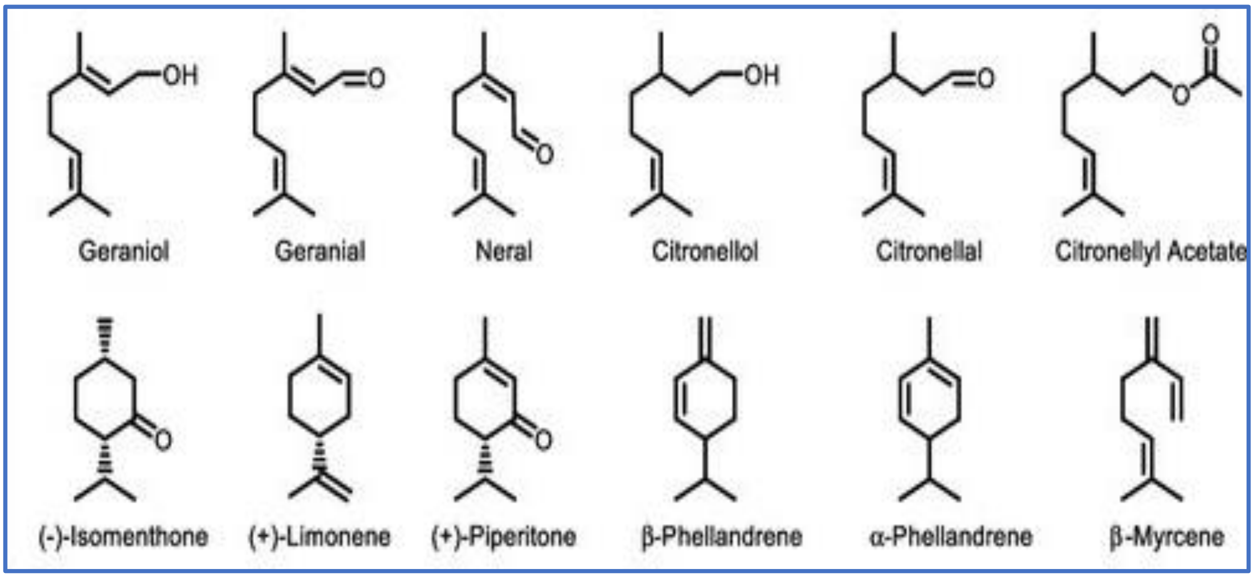

Figure 4. Chemical structures of essential oil commonly found in the oil of *P. graveolens*. ([a] Source: [60].)

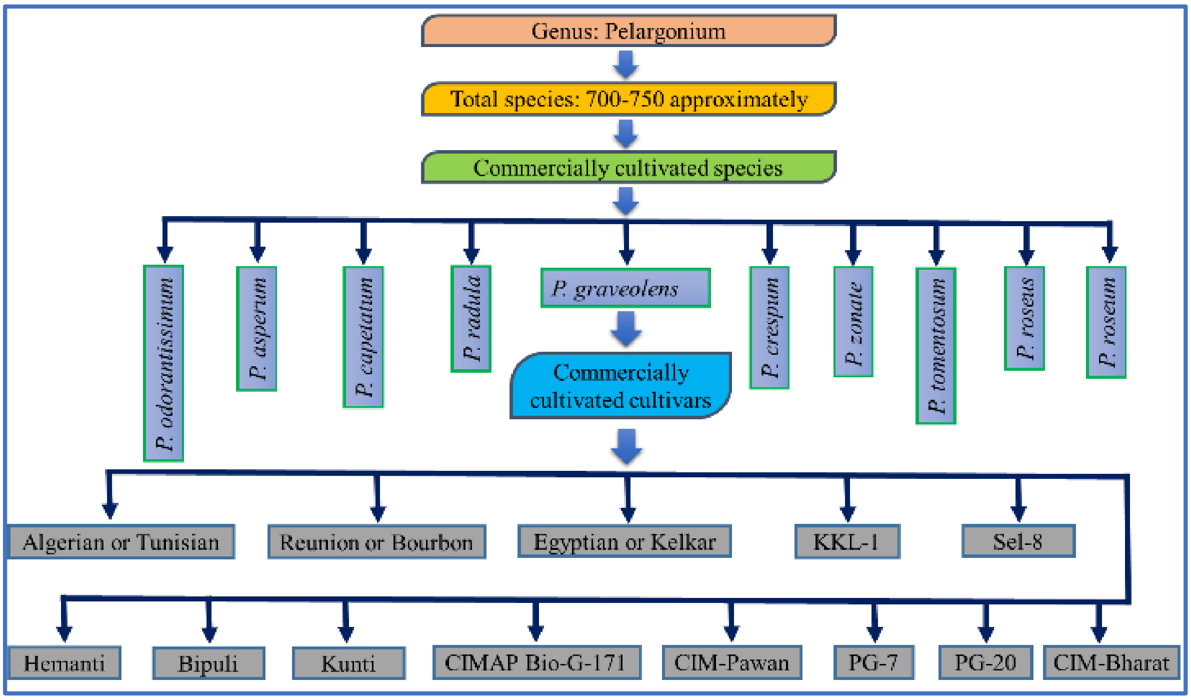

Figure 5. Flow chart of the classification of the commercially cultivated *Pelargonium* species and cultivars/varieties of the geranium worldwide.

3.5.4. Traditional uses

Since herbal medicine is a system of traditional medicine and is considered to be a source of lead compounds, it has become a global concern since its use is considered safe for both humans and the environment. The aerial part of geranium has a long history of its folkloric importance, used as a perfume, medicine, insect repellent, aroma herb for foods and beverages, etc. [55-46]. Some geranium species have been reported to cure throat infections in ancient history [56]. Pohlit and associates [57] also said that the aerial part of geranium is traditionally used in insect and mosquito repellant scents and flavoring agents. Antimicrobial aromatherapy and its use in gastrointestinal tract disorder and skin disease were also noticed by Boukhris and associates [46]; Hsouna and Hamdi [51]. Since ancient times, treatments have been administered with the plant for a wide range of ailments, including nephritis, wounds, fever, cold, sore throat, inflammation, menorrhagia, hemorrhoids, dysentery, cancer, gastrointestinal diseases, high blood sugar, insomnia, heart disease, asthma, nausea, vomiting, fever, and tuberculosis, to name a few [51, 53, 58].

3.6. Agronomical interventions used to enhance growth and yield attributes

The agricultural practices of *P. graveolens* have diversification worldwide due to environmental factors, climatic variation, and different soil types. Therefore, proper agronomical interventions help to enhance the cultivation area and productivity to meet the global up surging demand of industries. Approximately 750 other species are available in the *Pelargonium* [40, 59], but only a few species (*P. odorantissimum*, *P. asperum*, *P. graveolens*, *P. crespum*, *P. radula*, *P. capetatum*, *P. roseus*, *P. tomentosum*, *P. zonate* and *P. roseum*) are cultivated for the production of essential oil [13]. Of these, geranium (*P. graveolens*) is used to extract essential oil from its aerial parts, specially from leaves, buds, and inflorescence by hydro-distillation [3, 34]. The detailed classification of the commercially cultivated *Pelargonium* species and cultivars of the geranium worldwide are depicted in Fig.5. *P. graveolens* cultivars are grown in a wide range of agro-climatic zones throughout India. Algerian or Tunisian cultivars are grown in the North Indian planes of Uttar Pradesh, whereas Reunion or Bourbon cultivars are grown in the hilly regions of Southern India, especially Nilgiris [22]. The *Pelargonium* oil, considered to be of good quality, is known as Bourbon oil and comes from the plant growing on Reunion Island. The complete package of practices of *P. graveolens* has been comprehended in the following section:

3.6.1. Cultivation technology

Rose scented geranium can be grown in tropical, subtropical, temperate, and Mediterranean climatic conditions at an altitude of 120 to 2400 m, sub-medium hills [11, 61-64]. It grows under well-drained sandy, sandy loam, and peat soil; the pH level lies between 5.0-8.5 [65-66]. Temperature ranges from 10°C to 33°C and requires an ample amount of sunlight to produce the best quality of essential oil. The plant is sensitive to cold and cannot tolerate frost. The favorable rainfall for planting geraniums on land should be between 700 mm and 1500 mm per year and distributed evenly throughout the season. In areas with low rainfall, additional irrigation can be used for planting [67-68]. Although the crop can be grown in vivid regions and soils, heavy rain, fog, haze, frost, wind, hot weather, persistent drought, and waterlogging conditions affect the growth and survivability of plants.

P. graveolens can be a rainfed perennial crop in the mountains with well distributed rainfalls and an annual crop in the Northern plains [69-70]. Ram and associates [71-72] evaluated the productivity and quality of various cultivars of *P. graveolens* in the *Tarai* region of Uttarakhand. The rose-scented geranium has wide adaptability to soil environmental conditions; grows in two different areas of India, firstly in highlands cultivated under rainfed conditions and in the plain regions cultivated under proper irrigation.

Table 5. Variation in citronellol and geraniol contents (%) of three genotypes of *P. graveolens* at five different locations in India.

Locations	Algerian		Bourbon		Chinese	
	1	2	1	2	1	2
Nilgiri hills	40.2	6.5	-	-	-	-
Pulney hills	48.9	3.1	23.1	27.5	12.1	39.7
Bangalore	>40.0	<10.0	29.5	17.1	8.7	43.6
Hyderabad	45.8	2.2	21.6	25.5	8.1	26.9
Lucknow	50.8	3.9	25.4	20.2	8.0	34.1

[a] 1: Citronellol; 2: Geraniol, [b] Source: [73].

For the cultivation of crops for large-scale production, the selection of suitable genotypes/cultivars/varieties is essential, considering the diversification of regions and climatic conditions. Varieties/cultivars of *P. graveolens* varied in the chemical composition of essential oils, namely Algerian or Tunisian, Bourbon or Reunion, and Kelkar or Egyptian [11]. Algerian or Tunisian type is distinguished by its slender structure with the dark pink color of the flower. This type is grown in Nilgiris and is not suitable for wet conditions. Oil yield is about 50-60% more than the Reunion type, with a more delicate fragrance. Reunion or Bourbon is sturdier with a light pink flower in appearance, and it is a suitable crop for wet conditions. Here, the oil content is higher during the summer season, and more oil is obtained from the middle and basal portions of the herb. M / S SH Kelkar and Co-Mumbai are India's leading perfumery, flavor, and fragrance companies [74], who launched another variety characterized by the fragrance of its leaves and the essential chemical composition of the oil and is a popular variety among farmers of Maharashtra (India). All these genotypes are called *Pelargonium* species (hybrid 2n = 77) or *Pelargonium graveolens* L'Herit. Former Aiton [11]. A detailed overview of the three genotypes, i.e., Algerian, Bourbon, and Chinese essential oils, is shown in Table 5. The Bourbon type is commercially cultivated for essential oil in India and another cv. Bourbon obtained from leaf-cutting was high in concentration of isometnthone, i.e., 64.4, and 67.6% [75]. The Indian Institute of Horticultural Research (IIHR), Bangalore, discovered and recommended 'Sel-8', a Reunion type, as the highest yielder under Bangalore conditions. Central Institute of Medicinal and Aromatic Plants (CIMAP), Lucknow, released the varieties 'Hemanti', 'Bipuli', and 'Kunti' for cultivation in North Indian plains. But nowadays, these varieties/cultivars are not used for commercial cultivation purposes in place of their recently developed varieties/cultivars viz. 'CIMAP Bio G-171', 'CIM-Pawan', and 'Bourbon' developed by CIMAP, Lucknow, India [26] are used for commercial cultivation in India. CIMAP, Lucknow, India also recently developed a new high-yielding and novel variety/cultivar of a rose-scented geranium viz. 'CIM-Bharat' for commercial cultivation in western and northern parts of India, which is a source of high citronellol: geraniol (C: G) ratio and unique sesquiterpene 6,9-guaiadiene for the use in perfumery and aroma industry. Other than that few known cultivars which are being cultivated worldwide are Algerian or Tunisian, Reunion or Bourbon, KKL-1, Sel-8, PG-7, PG-20, etc. (HORT 282 : Lecture 12 http://eagri.org/eagri50/HORT282/lec12.html. 4/4 Indian plains).

3.6.1.1 Propagation, multiplication, and plantation

At high altitudes, planting time is from May to August [76-77]. Rose-scented geranium is mainly propagated by vegetative methods viz., root cuttings, leaf cuttings, root suckers [78-79], terminal cutting of about 10-20cm in length along with eight nodes are found to be best and got 80% survivability without any treatment for propagation. However, middle and base stem cuttings are used for alternate propagation of buds [11], but the results are not that good for rooting. Therefore, vegetative propagation of stem cuttings was treated with Indole Butyric Acid (IBA) and Indole Acetic Acid (IAA) (as growth regulators) for the early development of roots [80]. However, during the rainy season, from July to September, the crop is affected by waterlogging, high humidity, and high temperature, which together cause the stem to be completely damaged. Affected plants do not retain the green part of the leaves, which is necessary for the reproduction of the crop in the next growing season. Ram and Kumar [81] used to preserve geranium cuttings in AC glasshouse, but this may not be economical for commercial cultivation [82]. Prior to this geranium cultivation in plains was a difficult proposition, as it only grows and survived in hills regions, due to some limitations and lack of improved cultivation practices as saplings propagation, in the rainy season is problematic for a crop to survive, therefore generating cuttings and saplings for next cropping season was also difficult. Therefore, considering these issues, CSIR-CIMAP developed a new low-cost technology to prepare geranium saplings for the next season's cultivation. This technology is farmers friendly and much cheaper. For saving the geranium cuttings, a 50 to 60 square meter semi-protected poly house has to be built before the rainy season to save the saplings for next season. It has been previously reported that roofing or shed materials significantly impact the physiology and performance of crossbred calves [83].

Root cuttings are planted on the plains region in the winter season in October to February, while on hills, we can plant it throughout the year except those months having high rainfall and high humidity, with inter and intra row spacing of 60-90 cm and 30-60 cm, respectively. The primary planting method of genotypes of Bourbon or Reunion type and Algerian or Tunisian type is 50 × 50 cm, while the row spacing of Kelkar or Egyptian type is 60 × 30-60 cm. Kassahun and associates [84] reported that the highest value of fresh leaf yield ha^{-1} and essential oil yield ha^{-1} were recorded at plant population density 1,11,111 plants ha^{-1} (30 × 30 cm) in Ethiopia. For one-hectare, area 30,000-40,000 healthy, 40-45 days old profusely rooted cuttings are required. In the nursery, cuttings are planted in a raised bed of 3 m in length and 1 m in width; cuttings are planted closely at 8-10 cm spacing. Before initiation of roots, partial shade and regular irrigation are required, with proper nutrient supplements. Cuttings can also be upraised in polythene bags to avoid root damage; it assures a high survivability rate in the field, but it's a costly method for the small- marginal farmers. Before transplantation, land should be well pulverized and plowed by a disc harrow, and ridges and furrows should be appropriately made and leveled. Nursery-raised rooted cutting should be carefully dug out and transplanted into the field with the actual spacing required by the cultivar selection. Irrigation must be applied immediately, just after the planting.

3.6.1.2. Irrigations and fertilizers

In the plain region, the geranium crop requires timely irrigation, while it can be grown as a rainfed crop in the hills. Alternate furrow irrigation [85] or irrigation with a ratio of 0.50 to 0.60 irrigation water: cumulative pan evaporation (IW: CPE) ratios are suggested by the researcher's [86-87]. Sprinkler irrigation and drip irrigation, which can save water and fertilizers, can be used and applied with irrigation water [88]. The fertilizers doses needed for the crop use 120-240 kg Nitrogen, 40-60 kg P_2O_5, and 40-60 kg K_2O per hectare/year, respectively. Micronutrients can be sprayed after each harvest [11, 61]. In three successive applications, nitrogen was applied uniformly, one during transplantation and another within 30 to 80 days after transplantation, respectively. The nursery and field were weeded, watered, and hoed uniformly in accordance with proper agronomic procedures. During the first 10-15 days, irrigation is done on alternate days and then once a week for the remainder of the season. The schedule can be changed from 7 to 10 days more or less frequently throughout the winter and summer seasons. Water logging of the plant must be completely avoided, but geranium tolerates short duration of drought. Young and expanded leaves accumulate more N, P, K, Mg, and Fe [89-90] and essential oils, which are positively correlated with the release of essential oils [91].

3.6.1.3. Insects pests and their management

Geraniums are highly tolerant plants and are known for being reliable, but from time to time, some problems may arise, resulting in crop failure if not noticed. Several insect and mite pests that can cause leaf-feeding injury, yellowing, or general disfigurement may attack geranium. Aphids, grasshoppers, ticks, nematodes *Criconemoides, Helicotylenchus, Meloidogyne, Pratylenchus, Scutellonema, Xiphinema* species are controlled with aldicarb, fenamiphos, phorate. Scales, termites, whiteflies, and white worms damage crops, and control measures with the application of insecticides are required [92]. Spoilage wilt (*Fusarium redolent, Rhizoctonia solani,* control by Benomyl or Carbendazim spray), late blight (*Alternaria alternata, Colletotrichum gloeosporioides*, control by chlorothalonil spray), dwarf leaf (Phytoplasma; tetracycline spray) cause extensive plant damage, the mortality rate is as high as 70% [16, 93]. For curation of wilting diseases of the geranium crop, rooted cuttings were dipped with 0.03% Benlate solution at the time of nursery and transplanted the crop in the field. It has been observed by the Council of Scientific and Industrial Research-Central Institute of Medicinal and Aromatic Plants (CSIR-CIMAP), Lucknow, that the co-cultivation of geranium in alliance with marigold (*Tagetes minuta*) enhances the survivability rate of geranium plants in the North during monsoon period. The geranium plant has been reported to the affected by root-knot nematodes, *Meloidogyne incognita*, and *M. hapla*. Incidence of root-knot is reduced by applying of Aldicarb to the soil at the rate of 20 kg ha^{-1}. (HORT 282:: Lecture 12 http://eagri.org/eagri50/HORT282/lec12.html. 4/4 Indian plains).

3.6.1.4. Weed control

Crops are susceptible to weed competition in the early stages of plant growth or before harvest. Regular irrigation, every 5-6 days during the hot and dry summer in the month of February to May [87], applied with a large amount of nitrogen fertilizer, creates ideal conditions for weed growth and competition. In addition, the types of weeds change during the harvest in summer, rainy season, and winter. Previous research reports have claimed that the crop was at high risk of weed competition during the first 90 days after planting; during this critical period, the crop must be weed-free to avoid crop losses and yield [94]. Weed control measures must be taken by application of oxyfluorfen, alachlor, nitrofen, and pendimethalin [95] or manually. Mulching and intercropping with crops also reduced weed growth. Such a long critical time of harvest requires manual weeding three to four times, which significantly increases the cost of geranium oil production.

According to the density and type of weed flora, it has been quantified that oil production has been reduced by up to 65%. There is an inadequacy of knowledge on the use of herbicides to control geranium weeds. Srinivasan and associates [96] evaluated the application of nitrogen at an early stage of the crop in Kodaikanal, India, and 2,4-D, glyphosate, oxadiazon, neburon, or oxysalin in Israel, has been proven effective in weed control. In addition to the use of herbicides, cultivation methods, including manual weeding, plowing, and mulching (wheat straw 5 tons ha^{-1}) have been proven to produce higher amounts of peppermint oil to weed-free crops [97]. Methods like these are commonly used in the cultivation of mint in India, but there is a lack of information about rose-scented geranium.

3.6.1.5. Harvesting management

In the mountains, the crop is harvested during the flowering period, and can be grown for 5 to 10 years, with 2 to 3 harvests per year. Flowering is rare in the plains, harvested 4 to 5 months after transplanting if there is enough biomass composed of delicate stems and plants and young leaves [98]. The crop is grown as a perennial crop for 2 to 3 years or as an annual crop with 2 to 4 harvestings per year [11]. Green leaves and stems are harvested by hand with a sharp sickle on sunny days to avoid excessive pulling [93, 99]. The yields of biomass and essential oil are 20 to 40 tons and 20 to 40 kg per hectare/year, respectively.

The growth attributes and essential oil content are greatly influenced by the harvesting stage. According to Gebremeskel [5], harvesting for 120 days after planting gives a higher essential oil yield, i.e., about 77.10 kg ha^{-1}. Harvesting at different hours also influenced the growth and yield of the geranium crop. Malatova and associates [100] reported that the highest essential oil concentration, 0.22%, was found in geranium when it was harvested in the early afternoon (2:00 PM). Kumar and associates [101] recently conducted a study on three geranium cultivars, Bourbon, CIMAP Bio-G-171, and CIM-Pawan, which were analyzed to determine the essential oil yield and composition at various harvesting times during the day. In a study, it was found that CIMAP Bio-G-171 and CIM-Pawan cultivars of geranium did not exhibit a difference in essential oil yield by harvest time during the day, but the Bourbon cultivar did. To obtain maximum essential oil yield, harvest Bourbon cultivars in the afternoon. (Table 6). In the southern Indian hills, the crop is harvested as soon as the flowers are in the full blooming stage, as the inflorescence part contains more oil content than the other parts of the plants [16]. However, plants grown in the plains of south India either do not bloom or do so sparsely. During this period, harvesting is conducted after 5-6 months following planting, followed by subsequent harvest at 3-4 months intervals for 2-4 years when the leaves become strong and yellow and the plant reaches the necessary biomass [5, 65-66, 77]. Consequently, the average harvest occurs about 3-4 times per year, depending on local conditions and agronomic management practices. For most harvest management techniques prior to the 1990s, the age of the plantation was thought to be the primary factor for achieving a higher oil yield [69, 98]. A morphological indicator of competence was also proposed as a means of determining rose-scented geranium maturity [81].

Table 6. Diurnal variation in essential oil yield in different cultivars of the rose-scented geranium.

Harvesting time	Essential oil yield (%)		
	Bourbon	CIMAP Bio-G-171	CIM-Pawan
6:00 A.M.	0.18	0.30	0.28
10:00 A.M.	0.30	0.35	0.35
2:00 P.M	0.35	0.28	0.35
6:00 P.M.	0.40	0.35	0.35

[a] Source: [101]

Therefore, to promote shoot regeneration for subsequent harvests and to yield higher levels of essential oil, the rose-scented geranium plant should also be harvested at 15 cm above the ground [102]. In contrast, the positioning of the leaf on the shoot is clearly associated with the content and quality of the oil. Among the top leaves, the oil content is more, and in the lower leaves, it declines. The young leaves emit an aroma similar to roses, which contain quality oil [63, 80, 91].

3.6.2. Productivity in different climatic and soil conditions of India

Climatic factors and seasonal variation affect the essential oil content of the crop; Indian researchers indicated that during winters, geraniol concentration reached a peak, which is around 26%. Conversely, to this citronellol and its esters (40-42%) accumulated more readily in the summer months [13]. An earlier study found that the essential oil yield fluctuated throughout the day with a maximum (0.27%) at 12:00 noon [103]. Rose-scented geranium blooms at high altitudes, while the flowers are single and rare [11]. Inflorescence and young leaves contain more oil as compared with other parts of the plant [15]. Arumugam and Kumar [76], Narayana and associates [77] observed that plants produce abundant leaves on clear and sunny days, 3 to 4 harvests per year can be carried out, and plantations survive in the mountains for about eight to ten years. The crop survives for 2 to 3 years in the plains of southern India [77, 11] but is planted annually in the north-central plains of India [104-105]. The biomass is distilled on the same day. The oil is extracted by a batch distillation system with a capacity of 250 to 750 kg, and its working principle is hydro-cum-steam or steam distillation. Oil content ranges from 0.06-0.16%, and distillation runs for 1 to 4 hours.

Table 7. Biomass yield, essential oil yield and gross returns recorded at five Indian locations.

Locations	Biomass yield (t ha^{-1})	Essential oil yield (kg ha^{-1})	Gross returns (USD ha^{-1})
Nilgiri hills	25.0	20.0	1458.3
Pulney hills	46.6	45.7	3332.3
Bangalore	70.8	150.7	10988.5
Hyderabad	96.0	175.1	12767.7
Lucknow	39.2	66.0	4812.5

[a] Gross returns based on oil price (USD 70.00 kg^{-1}), [b] Source: [73]. [c] Current oil price in India (USD 135-161.00 kg^{-1})

The productivity of rose-scented geranium is shown in Table 7, which shows the highest biomass, essential oil yield, and gross returns recorded in the five regions of India. The actual output of the producer is 20 to 40 tons/ha/year of biomass and 20 to 40 kg ha^{-1}/year of essential oil and Rs. 70,000 to 1,40,000 /

hectare / annual gross profit margin [11]. Due to climate change, the production area has gradually decreased in recent decades, and there is competition from other market crops. Therefore, the low oil production of geranium in the same area [106] is also related to India's sensitive harvesting patterns because geranium requires only a mild climate and low humidity where it can grow luxuriantly. According to Singh and associates [26], the yields of fresh leaves and essential oil from the variety 'CIMAP Bio-G-171' were significantly higher (173.64-174.42 q h-1 and 69.93-79.06 l h-1) than those of 'CIM-Pawan' (158.08-160.56 q h-1 and 55.57-64.46 l h-1) and 'Bourbon' (133.34–139.33 q h^{-1} and 44.19–48.38 l h^{-1}).

3.6.3. Application of biostimulants

The application of synthetic fertilizer is a critical factor in geranium production. Unfortunately, chemical fertilizers cause soil degradation and pollution, but the cost is relatively high. In order to achieve sustainable agriculture and improved crops pattern, natural sources of biostimulants have become the focus of attention for sustainable agricultural systems and enhancing productivity [107]. Plant biostimulants contain various biologically active compounds that can improve multiple physiological processes, thereby stimulating plant growth and productivity [108].

Moringa leaf extract (MLE) extracted from *Moringa oleifera* (Lam) is considered one of the most crucial plant biostimulants and can be used as a natural and alternative mineral food source [109]. MLE is known for its beneficial effects due to the presence of cytokinins (such as zeatin), and antioxidants (such as ascorbic acid, amino acids, flavonoids, carotenoids, vitamins A and C, phenolic compounds, and macro and micronutrients). Recently, Ali and associates [110] reported the signs of growth gradually increased with the increase of MLE concentration until MLE 3 (1:20) and then decreased with the rise of MLE 4. Still, there was no significant difference from MLE3. In this regard, there are no significant differences between MLE3 and MLE4. The application of MLE3 (1:20) increased the leaf area and biomass yield of *Pelargonium* in untreated plants by 36.55% and 55.10%, respectively. Cultivation incorporated with arbuscular mycorrhizal fungi (AMF) resulted in higher crop yield, and nutrient uptake is also increased [111-112].

3.6.4. Application of PGPRs

Plants' roots grow faster when biofertilizers are incorporated into the plants' rhizosphere, which is made up of living micro-organisms that can also colonize the interior of plants. In addition, biofertilizers can prevent diseases like rust. *Allorhizobium*, *Azorhizobium*, *Bradyrhizobium*, *Mesorhizobium*, *Rhizobium*, and *Sinorhizobium* have been reported for their ability to act as biofertilizers, as the potent plant growth-promoting bacteria (PGPR) strains. Riahi and associates [113] recently reported that significant positive effect of three PGPRs, namely *Pseudomonas rhizophila* S211, *Halomonas desertis* G11, and *Oceanobacillus iheyensis* E9, on *P. graveolens* growth-related variables, leaf and root biomass, photosynthetic pigments, and secondary metabolites production.

It has been demonstrated that a combination of PGPRs inoculated with AM fungi produces a synergistic effect on essential oil production. According to Prasad and associates [114], quality of the geranium oil is chemically enhanced when it is inoculated with phosphate-solubilizing bacteria (PSB) and AM fungi and when phosphate fertilization is employed. As compared to uninoculated controls, the composition of geranium oil increased for linalool, geranial, 10-epi-γ-eudesmol, and citronellol, and by inoculating with PSB alone or in combination with AM fungi, cis- and trans-rose oxide levels decreased. CIM grow^{R,} a plant growth-promoting rhizobacteria, was found very effective with respect to fresh herb and dry matter yield as well as oil yield of rose-scented geranium, when applied with vermicompost as the carrier at both levels [115]. Mishra and associates [116] reported that the productivity and yield of geranium crops are greatly influenced and increased with PGPR application. Alam and associates [117] suggested that geranium cultivation could benefit greatly from these bioinoculants, and combining *G. mosseae* with *B. subtilis* will be an effective method for improving essential oil yields.

3.6.5. Cultivation as intercrop

The most promising method for utilizing resources is intercropping, which can increase the quantity and quality of crops while suppressing weeds as a result of spatial competition between the component plants [118]. The practice of intercropping was first used by subsistence farmers to meet their needs and maximize their resources utilization [119].

Globally, farmers, researchers, and policymakers have always been looking towards a self-sufficient, more profit-making, energy-efficient, and cost-effective agriculture system for sustainability [120-121]. For sustainability and economic gain purposes of farmers, geranium intercropping with other crops is more suitable, as some researchers already report it. Singh and associates [122] reported that a two-row intercropping of garlic (*Allium sativum* L.) between the two rows of *P. graveolens* (at 60 × 30 cm plant spacing) produced 1860 and 2400 kg ha^{-1}bonus yield of garlic bulb without any significant reduction in geranium essential oil yield. Hence, it is possible to reap the full benefits of geranium essential oil from garlic bulbs without reducing gross profits from garlic bulbs. It resulted in a 59 and 60.5% increase in land-use efficiency 29.3, and 81.3% increase in net return over sole geranium in Lucknow and Purara, respectively. Short-lived beans, black beans (*Vigna mungo*) or cowpeas (*Vigna unguiculata*) [123] or mung beans (*Vigna radiata*) or guar (*Cyamopsis tetragonoloba*) [11] could be important co-crops. In addition, corn mint (*Mentha arvensis*) [124] can be alternated with fragrant rose geranium in the plains. In the mountains, beans (*Phaseolus peopleus*) [77] can be transplanted into crops, forest trees/orchards [102] or alternate planting with short-lived beans [125], vegetables, and aromatic plants [126] or with plants in the corresponding cultivation sequence [16]. Geranium displayed a decrease in growth and yield at the first harvest when compared to soles. Regardless, no differences were observed in the second harvest at the different intercropping systems and sole harvest for the geranium plant. The yields resulting from intercropping exceeded the yields from the geranium. A greater proportion of resources use efficiency and economic benefits, can be achieved in the intercropping system as compared to sole crop. An analysis of the study concluded that geranium-based intercrop offered the best result in terms of yield, productivity as well as most efficient use of resources [127].

Verma and associates [128] found that plant density and intercropping both influenced mint and geranium yield and characteristics in temperate climates, which increased the production potential, resource efficiency, and monetary benefits of intercropping mint and geranium. Despite the reasonable quality of the essential oils of both crops, this intercropping system could benefit geranium growers in temperate regions and provide them with greater profitability while producing high-quality essential oils.

3.7. Response of P. graveolens in polluted soil

In heavy metal contaminated soil, geranium can be cultivated commercially for the production of essential oils. An investigation was carried out by Chand and associates [129] to determine if heavy metal toxicity affects rose-scented geranium plant growth and yield and oil quality and to evaluate the accumulation of metals among plants grown in soil enriched with heavy metals. Pb at 10 and 20 ppm significantly increased citronellol content, and Ni at 20 ppm increased geraniol content. The rest of the essential oil constituents were generally not significantly affected by heavy metals. Investigating the different levels of toxic metals accumulated by geranium versus the minimal impact of heavy metals have on the quality of essential oils was also studied. Geranium plants have good phytoremediation potential properties to remove heavy metals from contaminated soils producing good fresh biomass yield, essential oil yield, and quality of essential oil [130].

3.8. Future potential

A lot of research work has been conducted since the beginning of the 20th century, and attempts are underway to investigate further. For high-yielding cultivars/varieties/genotypes enhancing the productivity of good quality essential oil, various agricultural practices are yet to be optimized. Likewise, the use of short duration high yielding varieties/cultivars and standard cultivation methods/practices, including weed management practices (chemical weed control, manual weeding, ploughing, and mulching), have been proven to produce peppermint oil crops equivalent to weed-free crops [97]. Still, there is no such information are available about rose-scented geranium. The recently developed "CIM-Bharat" high-yielding geranium variety/cultivar by CSIR-CIMAP, Lucknow, is also promising for geranium growers in terms of enhancing essential oil yield, production, and monetary gains for Indian farmers.

Furthermore, supplementing nutrients for commercially grown geranium cultivars can also be studied with different varietal performances; a similar study was evaluated in *Mentha* cultivars [131]. The use of essential oil in the pharmaceutical and food industries also has a broad prospect area for future research purposes. The use of distilled spent of geranium is still unknown. The use of essential oil in the pharmaceutical and food industries also has a broad prospect area for future research purposes. The use of distilled waste (solid, hydrosol &spent waster) of geranium is still unknown.

4. Conclusions

Existing literature, popularity among the growers, and its use in the aroma/pharma industry, *P. graveolens* clearly becomes a crop of worldwide importance. In order to augment the vacuum and insufficient information about this crop, the review here will fill the gaps by providing the necessary stimuli for utilizing it as a potential source of livelihood. This review article provides a critical and comprehensive summary of its historical background, its worldwide production, import and exports, chemical constituents, versatile industrial uses, essential oil extraction methods, and agronomic practices for enhancing the cultivation for better crop growth and yield. Some of the aspects that need the attention of researchers and policy makers include increasing the use efficiencies of agro-inputs like agro-chemicals (fertilizers, PGRs, etc.), irrigation water, development of cost-effective agro technologies for reducing the cost of cultivation, further improvement in distillation technology for better oil recovery, creation of marketing facilities in locations easily accessible to farmers, product development, etc. The government and industries should also promote and encourage farmers to increase their oil production and decrease their reliance on imports. India has the potential to dominate global production and trade of rose-scented geranium oil and related products. This information will create awareness among farmers practicing geranium cultivation in various regions. Hence, the objective of fulfilling the upraised global industrial requirement can be met by improving the cultivation practices in different regions and increasing monetary returns, and reducing imports. In addition, this review will be advantageous to researchers, scholars, and academicians; and will provide better insight for future studies worldwide.

Authors' contributions

N.B.L.: Conceptualization, methodology, writing-original draft, writing-review & editing, visualization and software. R.K.V.: Supervision, validation, resources and writing-review & editing.

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Conflicts of interest

The authors declare that they have no conflict of interest.

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