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INSIGHTS INTO ECOLOGICAL AND AGRONOMIC DYNAMICS SHAPING FLORAL ESSENTIAL OIL YIELD AND QUALITY: A REVIEW

V. Siva Teja^{1*}, Anupama T.V.² and Shravani J.¹

¹Department of Floriculture and Landscaping, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur, Kerala – 680656, India

²Fruits Crops Research Station, Kerala Agricultural University, Vellanikkara, Thrissur, Kerala – 680656, India

*Corresponding author E-mail: sivatejaveera777@gmail.com

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ABSTRACT

Floral essential oils derived from plant species have drawn a lot of interest due to their aromatic properties and wide range of applications in cosmetics, perfumery, and pharmaceuticals. The properties of floral essential oil are intrinsically related to the ecological and agronomic conditions under which the flower crops grown. This diverse connections between crop ecology and agronomy, with a focus on how they affect essential oil yield and quality. Crop ecology deals with environmental elements such as soil characteristics, climate, light, humidity, and seasonal fluctuations, which have a substantial impact on biosynthesis of essential oils. Optimal temperature, soil fertility, and moisture levels are critical for enzymatic activity and secondary metabolite production. Similarly, crop agronomic practices, including nutrient management, irrigation, pruning, and the use of plant growth regulators, play a pivotal role in optimizing essential oil yield. The choice of plant varieties, growth media, and harvesting techniques further refines oil quality by ensuring plants are cultivated and harvested at their peak phenological stage. By understanding the ecological requirements of essential oil crops and implementing sound agronomic techniques, growers can optimize the yield and quality of floral essential oil, meeting rising market demands for value-added products but also ensures long-term profitability.

Keywords : Aromatherapy; Essential oil; Secondary metabolites; Volatile compounds

Introduction

Plants have long been known to carry distinctive aromas and flavours in their roots, stems, leaves, flowers, and fruits. These flavour and aroma in a particular part is due to the presence of essential oils, which are volatile compounds stored in special glands within various plant parts. Essential oils (EOs) are low-molecular-weight substances with biological activity, synthesized across diverse plant organs like flowers, buds, leaves, branches, seeds, roots, etc (Bolouri *et al.*, 2022). These aromatic oils play vital roles in plant survival by enhancing plant's immune system, providing protection against pests and predators, and helps in attracting pollinators. The famous Swiss alchemist and physician Paracelsus once referred to distilled herbal oils as “*quintessence*” of the plant, which eventually gave rise to the term “essential oils”(Jahan *et al.*, 2015). Essential oils are stored either

on the plant's exterior structures like glandular brushes (e.g., Asteraceae, Geraniaceae, and Lamiaceae families) and papillae or inside the plant within specialized secretory cells, intercellular spaces, channels, or secretory bags (e.g., Anacardiaceae, Rutaceae, and Myrtaceae families).

Though essential oils can be found in all plant organs, they are distributed in varying concentrations across roots, leaves, flowers, fruits, stem wood, or bark (Butnariu and Sarac, 2018). With over 3,000 known varieties, essential oils have found widespread application in various fields due to their complex chemical compositions and unique functional properties (Sankarikutty and Narayanan, 2003). Commercially, many essential oils are extracted from fragrant flowers such as jasmine, rose, tuberose, marigold, plumeria, champak, magnolia, lavender, and

ylang-ylang, which are renowned for their distinct aromas (Table 1).

Table 1 : Major chemical constituents of essential oils in flower crops

Sl. No.	Crop	Chemical composition
1.	Rose	Citronellol, Geraniol, Nerol, Citronellyl acetate, Eugenol, Nonadecane
2.	Lavender	Linalool, Linalyl acetate, Ethylphenyl acetate
3.	Jasmine	Benzyl acetate, Indole, cis-Jasmone and Methyl jasmonate
4.	Calendula	Calendulin, Triterpendiol ester, Faradiol esters
5.	Tuberose	Methyl benzoate, Methyl anthranilate, Benzyl alcohol, Butyric acid, Geraniol, Eugenol and Farnesol
6.	Geranium	Dimethyl sulphate, Ethyl alcohol, Diacetyl pinayl, Linalool and Terpeneol
7.	Pandanus	Phenyl ethyl methyl ether, Terpinen-4-ol, α -terpineol and p-cymene
8.	Marigold	Limonene, Tagetone, Linalool and Ocimenone

Economic significance and global positioning of floral essential oils

Floral essential oils play an important role in the global market of essential oil industry. In 2025, this market is expected to be around \$800 million and might grow to \$1.4 billion by 2033, with an 7% annual growth rate. Essential oils derived from flowers such as lavender, rose, jasmine, and ylang-ylang are highly valued in areas like perfumery, cosmetics, aromatherapy, and medicine because of their special chemical characteristics and health benefits. One reason for the growth is the increasing consumer interest in natural and organic options, especially in developed places like North America and Europe, which make up nearly 60% of the market (Persistence Market Research, 2023). Additionally, countries in the Asia-Pacific region, such as India and China, are experiencing a growing demand for essential oils as interest in wellness products continues to rise among their populations. In oil producing regions like Bulgaria (rose), France (lavender), and India (jasmine), where cultivation and extraction create employment and generate revenue through exports, by which floral essential oils economically support livelihoods. For instance, because of its high demand in luxury fragrances and labour-intensive production, Bulgarian rose oil, sometimes referred to as "liquid gold," which can fetch up to \$8,000 per kilogramme.

India is a major player in the global market for floral essential oils, because of its abundant biodiversity, ideal agroclimatic conditions, and centuries-old knowledge of growing aromatic plants.

Among the floral essential oils jasmine, rose, and tuberose are highly prized in the fields of perfumery that the nation produces and exports in large quantities. Although India has a much larger potential, its share is only around 10% (Singh *et al.*, 2014). India is one of the leading exporters of floral essential oils having import markets in countries like Europe (France, Germany, UK), North America (USA, Canada), and Asia (Japan, China, South Korea). Leading companies in India's floral essential oil market include Young Living, doTERRA, Plant Therapy, Mountain Rose Herbs, and A.G. Organica, which export organic rose and jasmine oils to nearly 70 nations. Top essential oil manufacturers in India are BMV Fragrances Private Limited, Greater Noida UP; Essential Oil Association of India, Shakarpur, Delhi; Fragrance Palace, Janpat New Delhi; India Essential Oils, Delhi; Indian Aroma Exports, UP (Source: <https://www.pharmaadda.in/top-essentialoil-manufacturers-in-india>)

Uses and biological effects of floral essential oils

Floral essential oils exhibit diverse biological properties (Fig.1), including antibacterial, antifungal, antiviral, anti-inflammatory, antioxidant, anticarcinogenic, carminative, and analgesic activities, due to their major components and the synergistic effects of various active molecules (Raut and Karuppaiyl, 2014; Mohamed and Alotaibi, 2023).

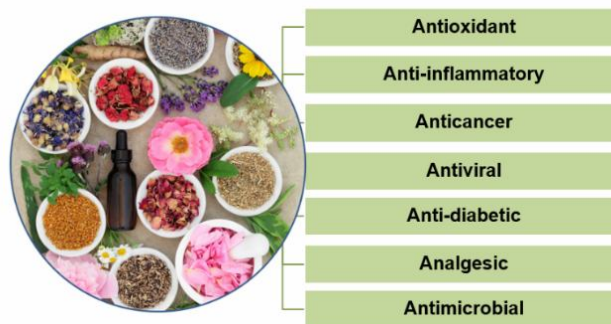


Fig. 1 : Therapeutic properties of floral essential oils.

Aromatically, they emit a subtle natural scent which have healing properties and have been used for protection since ancient times (Halder *et al.*, 2018). These oils find extensive applications in aromatherapy, where they promote relaxation and well-being, as well as in skincare products for their beneficial properties, and in massage therapy to relieve muscle tension. With natural antimicrobial properties, floral essential oils are also used in household cleaning products as eco-friendly alternatives (Chouhan *et al.*, 2017). Their inherent antioxidant and antimicrobial properties make them valuable in the pharmaceutical, food, agricultural, cosmetic, and health industries, where they have long been used for flavouring and as natural food preservatives.

Biochemical pathways of essential oil biosynthesis

The biosynthesis of these fragrant compounds usually begins in the leaves, where they remain until flowering. At this stage, essential oils shift to the flowers, supporting the fertilization process. Post-fertilization, the oils accumulate in fruits and seeds or may even migrate to leaves, bark, and roots (Butnariu

and Sarac, 2018). As plants mature, the composition of their essential oils changes. Young plants primarily contain terpenoid hydrocarbons and simpler molecules, while reproductive organs develop more oxygenated and complex etheric oils. Biosynthesis of essential oil includes two major pathways, such as terpenoid and phenylpropanoid pathways (de Sousa et al., 2023).

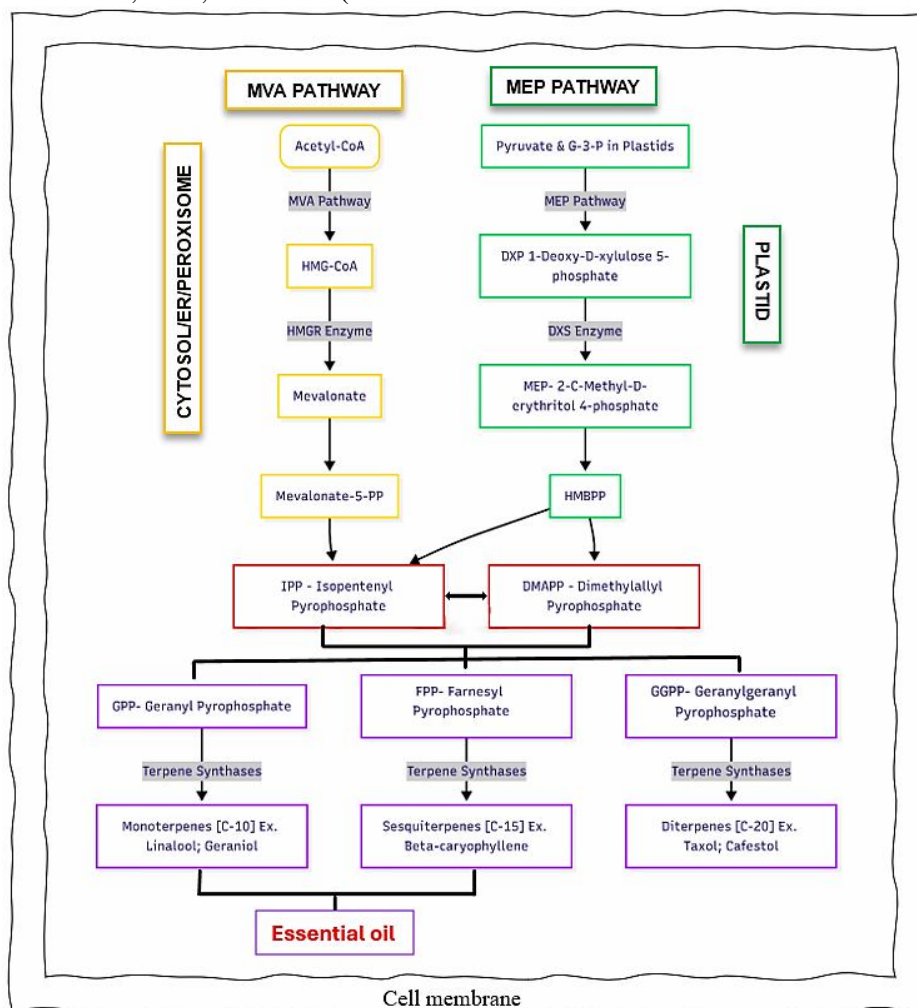


Fig. 2 : Biosynthesis of essential oils.

Terpenoids (including monoterpenes, sesquiterpenes, and diterpenes) and phenylpropanoids make up the majority of essential oils (Fig. 2). Terpenes are hydrocarbon compounds made up of isoprene units; diterpenes ($C_{20}H_{32}$) contain four, sesquiterpenes ($C_{15}H_{24}$) contains three and monoterpenes ($C_{10}H_{16}$) contains two isoprene units respectively. The monoterpenes such as linalool and geraniol are most prevalently found in floral essential oils; for example, these compounds found high in lavender and rose. The sesquiterpene α -bisabolol is found in chamomile (*Matricaria chamomilla*), which is part of a larger group of sesquiterpenes that are less volatile but plays significant role in emitting fragrance (Mrani et al., 2024). Though they are uncommon in

floral essential oils, diterpenes are present in trace amounts in ylang-ylang (*Cananga odorata*) (Tan et al., 2015).

Terpenoid compounds include alcohols, ketones, aldehydes, and esters, as their oxygenated derivatives which enhance the complexity of floral fragrance. Phenylpropanoids, on the other hand, are less common and are aromatic compounds that are derived from phenylpropane (C_6-C_3 structure). Essential oils from flowers like carnations (*Dianthus caryophyllus*), which contain the well-known phenylpropanoid eugenol, which add them sweet or spicy notes. These substances are common in plant families such as the Apiaceae and Lamiaceae (Gladikostic et al., 2023)

The biosynthesis of terpenoids requires two primary and Dimethylallyl precursors named Isopentenyl pyrophosphate (IPP) pyrophosphate (DMAPP). These are produced *via* two pathways: Mevalonate Pathway (MVA) and Non-Mevalonate Pathway (MEP/DOXP). Mevalonate Pathway occurs in cytosol produced from acetyl-CoA by the (sometimes peroxisomes). Mevalonic acid is condensation of three acetyl-CoA molecules and leads to formation of IPP. the chloroplasts. Here Glyceraldehyde Non-Mevalonate Pathway occurs in 3-phosphate and pyruvate react to produce 1-deoxy-D-xylulose 5-phosphate (DOXP) 4-phosphate (MEP), and subsequently IPP and DMAPP (and 2-C-methyl-D-erythritol Yang *et al.*, 2012; Rodriguez-Concepcion *et al.*, 2004 are). Monoterpenes, sesquiterpenes and diterpenes are combined for Geranyl derived from IPP and DMAPP. IPP and DMAPP molecules pyrophosphate (GPP) synthesis, key precursor for monoterpene, and monoterpenes are mainly biosynthesized in chloroplasts by the MEP pathway. GPP subsequently a second IPP to generate farnesyl pyrophosphate (FPP), key condensed with precursor for sesquiterpenes, which are primarily synthesized in the cytosol by MVA pathway. FPP then combines with IPP to make Geranylgeranyl pyrophosphate the precursor of diterpenes, phytol, and carotenoids, usually produced (GGPP), in chloroplasts (Gutensohn *et al.*, 2013). Main volatile sesquiterpenes, which components of essential oils are monoterpenes and determine the fragrance; while diterpenes, usually don't contribute to aroma.

The chemical composition of floral essential oils is highly complex, comprising 5,000-7,000 chemical constituents predominantly made up of mono- and sesquiterpene compounds, along with smaller amounts of phenylpropanoids and rarely diterpenes (Franz and Novak, 2009). Terpenes, key components of EOs, can be linear or cyclic hydrocarbons or their oxygenated derivatives, including oxides, alcohols, aldehydes, ketones, and esters. Monoterpenes (e.g., p-cymene, limonene, sabinene, β -myrcene, γ -terpinene) and sesquiterpenes are synthesized *via* the methylerythritol and mevalonate pathways, respectively, while phenylpropanoids (e.g., cinnamaldehyde, safrole, eugenol) derive from the shikimic acid route (Franz and Novak, 2009). The structure of terpenes is modified by enzymes to produce terpenoids, such as menthol, carvacrol, α -terpineol, geraniol, and thymol, which contribute to the varied chemical properties of EOs (Fig. 3).

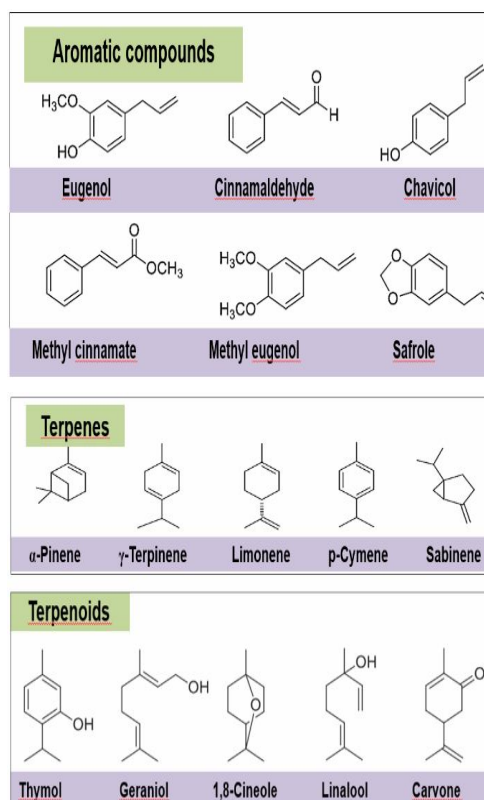


Fig. 3 : Chemical structures of essential oil constituents.

Chemical composition of essential oil

The composition of flower EOs depends significantly on species and environmental factors, and these highly concentrated liquids remain in a fluid state at room temperature due to the presence of oleates, unsaturated fatty acids, which also contribute to their characteristic aromas. Major chemical constituents of the flower crops are shown in Table 1.

Techniques for floral essential oil extraction

The extraction of floral essential oils is a process aimed at capturing the aromatic essence molecules present in flowers, which are highly valued for their fragrance and therapeutic properties. Various extraction methods are employed to isolate these essential oils, each with its own advantages and limitations. The choice of extraction method depends on factors such as the type of flower, the desired quality of the oil, and the availability of equipment (Singh *et al.*, 2014). The most commonly used essential oil extraction methods are Distillation, Enfleurage, Solvent Extraction, and Supercritical fluid extraction.

Distillation: Distillation is a common method for extracting volatile oils from aromatic plants, utilizing hot water vapor to transport and extract essential oils. Water vapour penetrates the plant material, breaking

the olefin coatings and volatilizing the oil, which mixes with the vapor. This mixture condenses into liquid form in a cooling vessel, separating into volatile oil and water in a Florentine vessel, with the lighter oil floating on top. The types of distillation depend on how the plant material is placed in the boiler and include water distillation, water-and-steam distillation, and steam distillation.

Water distillation: Water distillation involves placing the plant material in a round-bottom flask, covering it with water, and connecting a condenser to collect the oil. While it is easy to construct and suitable for field use, it has drawbacks such as slow extraction, odour development from charring, pollution, and high costs. These factors limit its practicality despite of its effectiveness. Damask rose (*Rosa damascena* Mill.) at 1:2 flower-to-water ratio yielded the highest essential oil content (0.051%) with an optimal composition of $41.1 \pm 0.2\%$ citronellol + nerol (Kumar *et al.*, 2018).

Water and steam distillation: Water and steam distillation involves placing the plant material on a grid above water, which is heated to produce steam. This steam extracts the volatile oil from the plant material, and the condensate is separated in an oil separator (Swati *et al.*, 2024). This approach is particularly suited for oils where some components are water-soluble, with steam generated using direct fire or blind steam pipes.

Steam distillation: Steam distillation is a widely used method for extracting essential oils from plants, ideal for use in natural products. In this process, steam is injected into a stainless steel container, or still, containing tightly packed plant material, which releases the aromatic molecules by turning them into vapor. This vapor travels to a condenser where it cools back into a liquid. The liquid collects in a separator, where the essential oil is separated from the water due to differences in density, with lighter oils floating on top and heavier ones, like clove oil, settling at the bottom. The process is conducted at temperatures not exceeding 100°C, using a steam boiler to generate the required steam (Nour *et al.*, 2024). Steam distillation offers several advantages, such as precise steam control, suitability for heat-sensitive oils, no thermal decomposition, and superior oil quality. However, its primary drawback is the high capital cost of equipment.

Enfleurage: Enfleurage is one of the oldest methods of essential oil extraction, involving the use of odourless solid fats such as lard or vegetable fat. This process, though rarely used today, captures the fragrance of flowers by infusing the fat with their aromatic

compounds. In this method, a thin layer of fat is spread on both sides of glass plates within an airtight wooden frame called a "chassis." Freshly harvested flowers are scattered over the fat and left for 24 hours. The withered blossoms are then replaced with fresh ones, and the process is repeated 30–40 times until the fat becomes saturated with the flower's scent. The final fragrant product is known as "enfleurage pomade" (Souiy, 2024). Cold enfleurage involves spreading cooled palm wax in trays, placing flower petals on the wax, and replacing the flowers every 24 hours. The fragrance-infused wax is then extracted with ethanol, leaving behind the absolute after evaporation. In contrast, hot enfleurage uses heated palm oil (60°C) to extract flower scents. Flowers are warmed for 30 minutes, cooled, and then replaced with fresh ones after filtering the oil, which is reheated and reused. The enfleurage process successfully produced flower essential oils, with maximum yields obtained at 5 days of contact time: 0.89% for jasmine, 0.88% for rose, and 0.84% for frangipani. Yield declined beyond this period, indicating that optimal oil recovery depends on controlled contact duration and adsorbent efficiency (Soe'Eib *et al.*, 2016).

Solvent extraction: The solvent extraction method uses food-grade solvents like hexane, ethanol, or methanol to isolate essential oils, particularly from plant materials with low oil yields, delicate aromatics, or resinous properties unsuitable for steam distillation. This method produces finer fragrances than distillation and also extracts non-volatile compounds like waxes and pigments, which may be removed later. The process creates a waxy aromatic substance called "concrete," which releases oil particles when mixed with alcohol. The common solvents for extracting essential oil include hexane, ethanol, and methanol, with ethanol record the highest yield.

Supercritical Fluid Extraction: Supercritical Fluid Extraction (SFE) using CO₂ is an advanced technique for extracting essential oils and other valuable compounds from plant materials. This process utilizes carbon dioxide in its supercritical state-achieved by applying specific pressure and temperature-allowing it to act as a solvent to extract oils without high heat. The CO₂ extraction process operates at temperatures of 95–100°F, compared to 140–212°F in steam distillation, preserving the plant's natural chemical composition. For instance, Demonstration with increasing pressure (36–48 MPa) and adding 5% ethanol as a co-solvent improved the yield and quality of volatile compounds extracted from freeze-dried *Narcissus poeticus* flowers (Baranauskiene and Venskutonis, 2022). Unlike steam distillation, which can denature the plant's

constituents, CO₂ extraction maintains the oil's natural integrity, resulting in a richer and thicker product with a composition closer to the original plant. Additionally, CO₂ extracts often exhibit a fuller aroma and more diverse phytochemical content, making them highly valued in aromatherapy and natural perfumery.

Supercritical CO₂ extraction of lavandin essential oil achieved a yield of 4.768% *via* the SDS (Static-Dynamic Supercritical) method and 4.620% with the SC (Supercritical) method. The SDS method alternates between static and dynamic phases, improving yield and reducing solvent consumption by 81.56% compared to the continuous SC process. Both techniques preserved key components like 1,8-Cineole, linalool, linalyl acetate, and camphor, comprising 80% of the oil (Kamali *et al.*, 2015). Optimal temperature and pressure are critical in supercritical CO₂ extraction, influencing solubility and oil recovery. Hibiscus flower oil yield peaked at 13.11% under 200 bar and 325 K (Alanazi, 2024). Increase in pressure up to 200 bar improved yield but reduced solubility beyond this point. Similarly, temperature enhancement from 300K to 325K boosted solubility, but higher temperature decreased consistency.

Ecological factors influencing essential oil composition

The relationship between where a crop is grown and the essential oil it produces is complex, involving various ecological interactions, farming practices, and environmental conditions (Fig. 4). Understanding this relationship is crucial for optimizing essential oil production and ensuring sustainable agriculture. The chemical makeup of essential oils can differ significantly based on environmental factors like soil type, climate, and altitude (Pal and Singh, 2013). For example, the yield and quality of essential oils are often highest when plants are harvested at specific stages, particularly during flowering, as the concentration of active compounds can change throughout the plant's life cycle.

Crop ecology is a specialized field that focuses on how cultivated plants interact with their environment. It studies how various environmental factors, including soil, climate, water, and living organisms, influence crop growth, development, and productivity. In the context of floral essential oils, crop ecology plays a crucial role in determining the quality and quantity of essential oil produced by flowering plants. The distribution and abundance of floral species, as well as the chemical makeup of their essential oils, are influenced by ecological factors such as topography,

soil type, climate conditions (temperature, relative humidity), light, rainfall patterns.

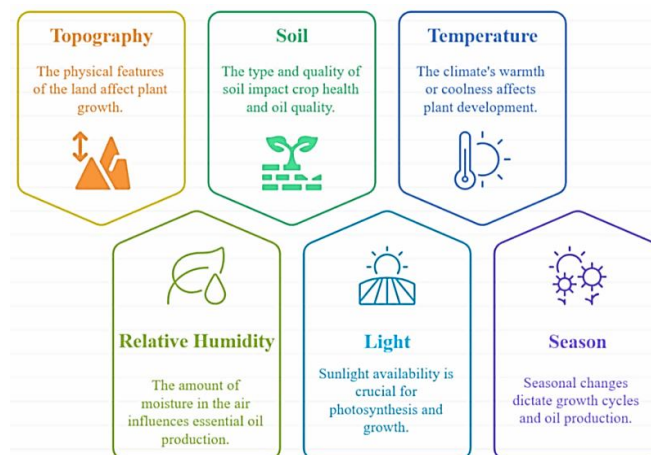


Fig. 4 : Ecological factors influencing essential oil production.

Topography and altitude as determinants of essential oil profiles: Physical features of the land, or topography, significantly affect the production of floral essential oils in several ways. Firstly, the microclimates created by topography, such as differences in elevation and the direction a slope faces, can impact temperature and humidity, thereby affecting plant growth and the creation of aromatic compounds. Secondly, soil characteristics, including texture, pH, and organic matter content, vary with topography, influencing nutrient availability and root development, which in turn affects essential oil production. Thirdly, water availability is influenced by topographic features like the steepness of a slope and soil drainage patterns, which regulate moisture retention and distribution, crucial for plant hydration and the metabolic processes involved in essential oil production. Additionally, sun exposure is modulated by topography, with slopes facing different directions receiving varying levels of sunlight, thereby affecting photosynthesis and the subsequent accumulation of secondary metabolites. Ultimately, how plants adapt to topographic changes, such as altitude-related stress or environmental variations, can impact growth rates and the metabolic pathways involved in essential oil production.

Altitude has been shown to alter the biosynthesis of terpenoids, which are crucial components of essential oil. A study on *Kundmannia anatolica* revealed that essential oil yield increased with altitude, while certain oxygenated monoterpene compounds such as α -Pinene and β -Pinene were more abundant at lower altitudes. Conversely, sesquiterpene constituents were found to be higher at elevated altitudes, indicating a complex relationship between altitude and the types of terpenes produced (Sanli and Karadogan, 2017).

Altitude affects essential oil composition in *Satureja thymbra* L, with higher altitudes (Safsaf, 661msl) enhancing carvacrol concentration which exhibit antibacterial activity, while lower altitudes (Wasita, 156msl) thymol production, enhancing antifungal potency (Khalil *et al.*, 2020). Higher altitudes are associated with increased linalool and reduced 1,8-cineole and camphor in Spike Lavender (*Lavandula latifolia* Medik.), resulting in essential oil with better quality for perfumery and medicinal use (Fernandez-Sestelo and Carrillo, 2020). This variation is attributed to the environmental stress at high altitudes, which boosts secondary metabolite production and bioactivity. Altitude is a key factor in shaping ecosystem conditions, influencing temperature, humidity, wind speed, water availability, and sunlight exposure. These variations impact plant ecophysiology, which in turn affects the chemical composition of essential oils.

Soil properties and their impact on essential oil yield and quality: Physical and chemical characteristics of the soil, especially its ability to hold water and nutrients, significantly affect plant growth and the production of essential oil. Soil with good retention capacity can store moisture and nutrients for a long time, ensuring a continuous supply to the plants. This promotes consistent growth and metabolic activity, leading to a higher yield of essential oil (Bakkali *et al.*, 2008). The availability of nutrients in the soil directly influences plant growth and metabolic processes, including the production of essential oil. Nutrient-rich soil supports plant health and enhances essential oil production by providing the building blocks for aromatic compound synthesis, whereas excessive salinity and poor drainage impair plant growth and reduce essential oil yield (Sarmoum *et al.*, 2019). Salinity can disrupt the water balance within plant cells, leading to stress and reduced metabolic activity, including the synthesis of essential oil.

Soil chemical composition and edaphic factors significantly impact the yield and quality of essential oil in *Rosa damascena*, particularly through the influence on key aroma compounds like citronellol and geraniol. Macronutrients such as phosphorus and potassium correlate positively with these desirable compounds by activating enzymes and pathways critical for terpenoid synthesis (Arvin, 2019). High essential oil yield in *Rosa damascena* correlates with soils rich in gypsum and lime and increased electrical conductivity (EC) level, particularly in sandy, light-textured soils with saline ion-rich irrigation water, while soils with higher phosphorus and potassium but lower EC, lime, and nitrogen favour essential oil

quality by enhancing aroma compounds like geraniol and citronellol (Ghavam, 2021).

Increased salinity and EC pose major constraints to growth, development, and crop quality, but they may stimulate essential oil composition, with higher salinity being linked to increased accumulation of monoterpenes due to stress-induced biosynthesis pathways in plants (Rebey *et al.*, 2017). Soil with higher nutrient content, particularly nitrogen, phosphorus, and potassium, resulted in higher essential oil yield and better quality in *Lavandula latifolia*, characterized by increased 1,8-cineole levels. In contrast, poorer soil conditions were linked to reduced yield and a higher camphor content which make the oil less pleasant or suitable for fragrance-based applications, suggesting that optimal soil management is crucial for maximizing both the quantity and quality of lavender essential oil (Fernandez-Sestelo and Carrillo, 2020). Soil alkalinity and elemental composition significantly impact *Rosa damascena* Mill. essential oil (Shohayeb *et al.*, 2015). Moderately alkaline Hada soils yielded higher citronellol, geraniol, and eugenol compared to slightly alkaline Shafa soils. Elemental differences, with high potassium and sodium in Shafa and selenium, iron, and zinc in Hada, contributed to these variations. Higher salinity in Hada soils was also linked to essential oil yield differences in rose petals. Soil type impacts essential oil yield and quality, with loamy soil enhancing the overall productivity of rosemary, yielding higher essential oil quantity whereas sandy soil improving essential oil quality, especially camphor and α -pinene content (Verma *et al.*, 2020).

Influence of temperature on enzyme activity and essential oil biosynthesis: Temperature changes can significantly affect the production of floral essential oils by influencing enzyme activity. Enzymes are like tiny machines that drive the biochemical reactions in plants, including those responsible for making essential oils. Temperature fluctuations can either speed up or slow down these enzymes. Optimal temperatures generally boost enzyme activity, leading to increased production of essential oil components. However, extreme heat or cold can disrupt the metabolic pathways by damaging enzymes or slowing down reaction rates, ultimately impacting essential oil production. Extreme heat can permanently damage the enzymes, rendering them useless, while extreme cold can reduce their activity by slowing down molecular movement and reaction rates. Therefore, maintaining optimal temperatures is crucial for ensuring efficient enzyme function and optimal essential oil production. Low temperatures enhance both the quality and

quantity of essential oil in *Rosa damascene* (Pal and Singh, 2013).

Low night temperatures of 10-12°C during the flowering stage significantly reduce oil synthesis in *R. damascena*. However, a brief period of low temperatures during the fortnight prior to blooming enhances both the quality and yield of the flowers (Pal and Singh, 2013). Prolonged spring with average temperature of 5-15°C promotes a higher flower count per plant and increases oil content. Additionally, while low night temperature (10-12°C) may inhibit flowering, slightly warmer night temperature (up to 20°C) can stimulate oil production. Higher spring/summer temperatures increase herbage yield and oil content in rose-scented geranium due to enhanced metabolic activity, including photosynthesis and respiration, while cooler autumn/winter temperatures reduce oil yield and decrease geraniol content. This shift reflects geraniol's greater susceptibility to temperature and age, as it metabolizes more readily under colder conditions (Motsa *et al.*, 2006). In higher temperatures reduce essential oil yield and quality due to high-temperature stress effects, including diminished photosynthesis due to reduced leaf area, blocked stomata, lower chlorophyll production, and altered respiratory processes effects on photosynthesis and growth (Ebrahimi *et al.*, 2011).

Role of relative humidity on essential oil profile:

Amount of moisture in the air, or relative humidity, affects the production of floral essential oils by influencing various plant processes and environmental factors. High humidity can decrease the rate at which plants lose water, limiting their uptake of water and nutrients from the soil. This reduced water availability can hinder the production of essential oils, as water is crucial for many of the biochemical reactions involved. Humidity levels also significantly impact essential oil production by potentially encouraging fungal growth and disease, which disrupts plant metabolic processes and directly impacts oil synthesis. Conversely, plants in low-humidity environments often produce higher concentrations of specific essential oil compounds due to stress, resulting in a more potent oil yield. Furthermore, humidity indirectly influences plant growth by affecting energy availability and rainfall patterns. These changes can alter plant metabolism and growth, subsequently impacting essential oil production.

High relative humidity can lead to decreased transpiration rates and reduced water uptake in plants, ultimately affecting essential oil synthesis (Pal and Singh, 2013). Lower humid conditions associated with higher monoterpene production, particularly limonene.

During high humidity months with increased precipitation, the relative concentration of limonene decreased, suggesting that humidity affects the accumulation of volatile compounds in *Pittosporum undulatum* (Lago *et al.*, 2006). In rose-scented geranium, higher relative humidity positively correlated with biomass, oil yield, and concentrations of certain compounds (e.g., alpha-pinene, beta-pinene, linalool). Conversely, humidity reduced the levels of others, like citronellol and rose oxides, highlighting its role in shaping the balance of terpene hydrocarbons and oxygenated terpenes, thereby affecting oil quality and therapeutic properties (Kaul *et al.*, 1999).

Effect of light intensity in regulating essential oil

production: Sunlight is vital for creating fragrant compounds, including essential oils, in plants like *Rosa damascena*. Specific colours of light, like blue and red, stimulate the production of these volatile compounds. Blue light controls processes like stomatal opening and photomorphogenesis, which indirectly influence the production of volatile compounds. Red light is involved in photosynthesis and activates photoreceptors, directly impacting essential oil synthesis through the activation of biochemical pathways (Trivellini *et al.*, 2023). Additionally, essential oil yield increases in open, sunny conditions where plants receive abundant sunlight. This increased exposure boosts photosynthesis, leading to a greater production of carbohydrates and precursors needed for making essential oils.

The essential oil yield of *Rosa damascena* Mill. is significantly higher when the plants grown in open sunny conditions as compared to 25% and 50% shade levels (Thakur *et al.*, 2019). Studies has shown that increased light exposure in damask rose enhance the activity of photosynthetic enzymes, improves stomatal conductance, and optimizes carbohydrate distribution. These factors collectively enhance essential oil production when grown in open, sunny environments (Baroli *et al.*, 2008). The composition of essential oils can also be influenced by varying light qualities. Higher light levels are associated with a greater abundance of oxygenated monoterpenes such as citronellol, trans-geraniol, and linalool. This is because light plays a crucial role in the biosynthetic pathways that produce these volatile compounds, which rely on energy from photosynthesis (Rezai *et al.*, 2018; Kumar *et al.*, 2014). Floral cultivars show varied responses to photoperiod changes; for instance, in essential oil cultivars, extended photoperiods can delay flowering by up to 13 days, thereby impacting biomass yield and essential oil content. Additionally, longer photoperiods may enhance the synthesis of diverse aromatic

compounds, influencing the chemical profile and therapeutic quality of essential oils through changes in secondary metabolite accumulation (Zhang *et al.*, 2021).

Influence of seasonal factors on volatile compound synthesis and yield: Seasonal variation significantly affects the makeup of floral essential oils, as seen in differences between samples collected in winter and summer. Winter oils, produced in colder temperatures, are rich in oxygenated monoterpenes. Summer oils, produced in warmer temperatures, contain more sesquiterpene hydrocarbons. Weather patterns like temperature and humidity have a direct impact on plants secondary metabolism, which alters the synthesis of volatile compounds. The warmth of summer might boost the production of sesquiterpene hydrocarbons, while the coolness of winter might favour oxygenated monoterpene production. Changing seasonal conditions can also affect the availability of resources for secondary metabolite production, like sunlight and soil nutrients.

The season of harvesting resulted significant variation in the yield and chemical composition of essential oil extracted from lavandin flowers, with the highest yield observed in summer (2.0% to 3.8%) (Liao *et al.*, 2021). The essential oil yield of *Thymus serpyllum* peaks in summer, making it the ideal harvesting season. Yields decrease in autumn and winter, while composition varies seasonally, with thymol highest in autumn and precursors like p-cymene and γ -terpinene peaking in winter (Verma *et al.*, 2011). Rosemary (*Rosmarinus officinalis*) essential oil yield and quality are highest during the summer and autumn due to optimal temperature, photoperiod, and flowering stages, which enhance essential oil accumulation. The autumn season yields a 1,8-cineole-rich essential oil, known for its antimicrobial properties, while the rainy season resulted in lower yields and essential oil content due to higher biomass and moisture (Rathore *et al.*, 2022). Seasonal variation, including climatic factors like precipitation and temperature, significantly influences the yield and chemical composition of *Helichrysum italicum* essential oil, with different growth periods affecting both the oil yield and therapeutic properties, particularly enhancing curcumene content during spring and summer (Acimovic *et al.*, 2022). In lemon verbena, essential oil yield and citral content vary seasonally, with peak yield in autumn and high essential oil concentration in early spring growth (Vogel *et al.*, 1999). These seasonal variations allow for targeted harvesting based on desired oil composition and biological activity.

Agronomic practices influencing essential oil profile

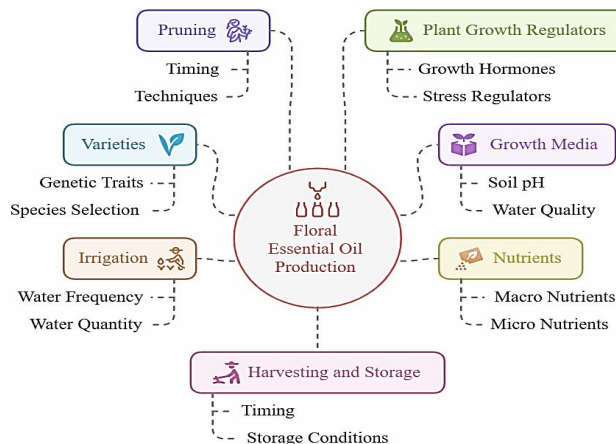


Fig. 5 : Key agricultural factors shaping floral essential oil production.

Crop agronomy, encompassing various farming practices and management techniques (Fig. 5), plays a crucial role in determining the quantity and quality of essential oils extracted from flowers. Maintaining optimal soil fertility and pH levels, along with proper irrigation and nutrient management, ensures that plants receive the necessary nutrients for healthy growth and efficient oil production. Adequate spacing between plants allows for sufficient sunlight penetration and airflow, which are important for photosynthesis and the production of volatile compounds. Effective pest and disease control measures protect plants from damage and stress, preserving oil yield and quality. Additionally, careful timing and methodical harvesting techniques ensure that plants are harvested at the peak of their oil production, maximizing both the quantity and quality of the oil extracted. By implementing sound agricultural practices tailored to specific crop and environmental conditions, growers can enhance floral essential oil production and meet market demands.

Genotypic influence on flower yield and essential oil composition: Cultivation practices that focus on specific genotypes with desirable traits can lead to more consistent yields and higher quality oils. Sahiwal (*Rosa centifolia*) outperformed other cultivars in both flower yield and essential oil quality, with increased levels of key fragrance compounds like citronellol and geraniol, particularly due to its ability to flower throughout the year and adapt well to higher temperatures from May to July (Younis *et al.*, 2009).

Non-recurrent roses bloom once in a year for 2-4 weeks in spring, requiring vernalization shortly after bud break. These roses are ideal for regions with cold winters that naturally meet this need, creating a strong but brief floral display. Recurrent roses, such as

modern cultivars, bloom continuously throughout the growing season outdoors or even year-round in a greenhouse. This trait, largely derived from *Rosa chinensis* and *Rosa wichuraiana*, is linked to a recessive allele at a single genetic locus. Genetic diversity within flower crop varieties results in notable differences in essential oil yield and composition. Flower crops varieties suitable for essential oil extraction was shown in Table 2. A study on *Rosa damascena* clonal selections shows variations in flower yield and essential oil content, with oil content ranging from 0.030% to 0.045% depending on the genotype (Kumar *et al.*, 2023). These differences in flower characteristics may arise from allele segregation at heterozygous loci. Comparable phenotypic variations were previously observed among damask rose germplasm accessions, aiding in the selection of superior accessions for commercially valuable traits (Khaleghi and Khadivi, 2020).

Impact of substrate composition and nutrient management on essential oil production:

Environment in which plants grow, including the soil and any added organic materials, significantly affects the production of floral essential oils through various mechanisms. Rich soil enhanced with organic matter provides vital nutrients for plant growth and the production of essential oils, encouraging strong root development and efficient nutrient absorption. The activity of microorganisms in the growing environment improves soil health and nutrient recycling, further supporting plant vitality and the production of secondary metabolites. Additionally, the pH and availability of ions in the growing environment influence nutrient uptake and the activity of enzymes involved in making essential oils. Proper water retention and drainage ensure adequate hydration and oxygen supply to the roots, optimizing metabolic processes. Ultimately, understanding and managing the composition and characteristics of the growing environment are crucial for maximizing the yield and quality of floral essential oils.

Table 2 : Flower crops varieties suitable for essential oil extraction

Crop	Varieties	Oil content (%)	Reference
<i>Rosa damascena</i>	Jwala	0.044	Kumar <i>et al.</i> , 2014
<i>Rosa damascena</i>	Super jwala	0.051	Kumar <i>et al.</i> , 2014
<i>Rosa damascena</i>	Himroz	0.043	Kumar <i>et al.</i> , 2014
<i>Rosa damascena</i>	Hot himroz	0.045	Kumar <i>et al.</i> , 2014
<i>Rosa damascena</i>	Indica	0.037	Kumar <i>et al.</i> , 2014
<i>Rosa damascena</i>	CSIR-IHBT-RD-04	0.045	Akram <i>et al.</i> , 2017
<i>Rosa bourboniana</i>		0.017	Kumar <i>et al.</i> , 2014
<i>Jasminum sambac</i>	Gundumalli	0.02-0.03	Akram <i>et al.</i> , 2017
<i>Jasminum auriculatum</i>	CO-1 (Mullai)	0.29	Venkatachalam <i>et al.</i> , 2024
<i>Jasminum grandiflorum</i>	CO-1 (Pitchi)	0.31	Bharathi <i>et al.</i> , 2020
<i>Agave amica</i>	Arka Prajwal	0.038	Sirohi <i>et al.</i> , 2017
<i>Agave amica</i>	Arka Suvasini	0.036	Sirohi <i>et al.</i> , 2017
<i>Agave amica</i>	Arka Shringar	0.132	Sirohi <i>et al.</i> , 2017
<i>Agave amica</i>	Arka Niranthara	0.138	Sirohi <i>et al.</i> , 2017
<i>Agave amica</i>	Arka Sugandhi	0.146	Sirohi <i>et al.</i> , 2017
<i>Agave amica</i>	Swarana Rekha	0.115	Sirohi <i>et al.</i> , 2017
<i>Agave amica</i>	Rajat Rekha	0.089	Pocha <i>et al.</i> , 2019
<i>Tagetes patula</i>	Mikrus	0.62	Salachna <i>et al.</i> , 2021
<i>Tagetes patula</i>	Petite Yellow	0.33	Salachna <i>et al.</i> , 2021
<i>Tagetes minuta</i>	Him Gold	0.65	Walia and Kumar, 2021
<i>Tagetes erecta</i>	Discovery Orange	0.43	Das <i>et al.</i> , 2022
<i>Tagetes erecta</i>	Discovery Yellow	0.45	Das <i>et al.</i> , 2022
<i>Lavandula angustifolia</i> Mill	Lydia	3.0	Svydenko <i>et al.</i> , 2022
<i>Lavandula angustifolia</i> Mill	Victoria	3.8	Svydenko <i>et al.</i> , 2022
<i>Lavandula angustifolia</i> Mill	Sinieva Nadiyi	3.25	Svydenko <i>et al.</i> , 2022
<i>Magnolia sirindhorniae</i>	Open flowers	0.50	Ghosh <i>et al.</i> , 2020
<i>Cananga odorata</i>	Cipanas	0.92	Kurniawati <i>et al.</i> , 2024

High-quality growing media provide optimal aeration, proper substrate composition, and nutrient availability, which are vital for plant health and lead to improved biomass production and essential oil yield (Raji *et al.*, 2016). Growing medium amended with peat waste mushroom biomass at 5 per cent by volume significantly enhanced plant biomass, essential oil yield and composition of oil in *Tagetes patula* cvs. 'Mikrus' and 'Petite Yellow' (Salachna *et al.*, 2021). Fine perlite and peat moss mixture (50:50 v/v) with a higher $\text{NO}_3^-/\text{NH}_4^+$ ratio enhances both growth and essential oil yield in *Echinacea purpurea* (Ahmadi *et al.*, 2021). Nitrogen enhances photosynthetic efficiency and supports essential oil production by increasing leaf area and optimizing chlorophyll and enzyme function in photosynthetic carbon metabolism for synthesizing organic compounds like nucleic acids, proteins, and amino acids, essential for the biosynthesis of terpenoid based essential oils (Hosseinpour *et al.*, 2020). Nitrogen producing ATP and NADPH also facilitate the formation of terpenoid units, thereby increasing essential oil content (Sitarek *et al.*, 2017).

Role of essential nutrients in enhancing floral essential oil yield and composition: Essential nutrients play a critical role in the production of floral essential oils, impacting various aspects of plant function and chemistry. These nutrients act as fundamental building blocks for flower development, providing the necessary components for the formation and growth of flower structures that are crucial for oil synthesis. Additionally, micronutrients are vital for enzyme activities involved in making essential oils, ensuring that key metabolic processes function correctly. If there is a shortage or imbalance of micronutrients, enzyme activity and metabolic regulation can be disrupted, affecting both the quantity and quality of oil produced. Moreover, nutrients guide secondary metabolism, directing resources towards essential oil production. Therefore, understanding and optimizing nutrient supply is crucial for maximizing the yield and quality of floral essential oils in cultivation, ensuring optimal plant growth and development.

Micronutrients like Fe and Zn are vital for essential oil biosynthesis as they activate enzymes involved in saccharide metabolism, photosynthesis, and protein synthesis, all of which supply energy and act as building blocks for terpenoid production. Foliar application of iron and zinc has been shown to increase essential oil yield in chamomile (Nasiri *et al.*, 2010). The application of a combination of 120kg nitrogen ha^{-1} and 40kg sulphur ha^{-1} resulted in increased plant biomass and essential oil yield, as well as an improved

secondary metabolite profile with a notable enhancement in essential oil gland density of *Tagetes minuta* in the Western Himalayas (Walia and Kumar, 2021). A higher nitrogen dose enhances vegetative growth and herbage production, thereby boosting essential oil content and yield, while sulphur application improves oil and protein levels by increasing the availability of key nutrients (P, K, Zn) essential for reproductive organ growth and oil gland regulation (Malhi *et al.*, 2007).

Fertilizer application in *Chrysanthemum coronarium* increased flower head yield with minimal impact on essential oil content. However, fertilizers altered the oil's chemical composition: camphor, the main compound, increased by 2.3-5.47% in fertilized plants, along with increased levels of alpha- and beta-pinene (Alvarez-Castellanos and Pascual-Villalobos, 2003). This shift in oil composition is attributed to nutrient-driven changes in plant metabolism, which affect secondary metabolites like essential oils. Applying nitrogen fertilization at 200 kg/ha maximized herb yield and essential oil content (1.16%) in *Tagetes minuta*, while altering the oil's chemical profile by modulating concentrations of key constituents like dihydrotagetone, p-cymene, and limonene. This underscores nitrogen's role in influencing essential oil biosynthesis and specific metabolite accumulation based on dosage (Omidbaigi *et al.*, 2008). The application of N and P with micronutrients increased the growth, yield, and essential oil content of some aromatic plants (Khalid, 2012). The impact of silicon application under water stress on essential oil composition in damask rose (*Rosa damascena* Mill.) and reported that foliar application of silicon at 0.2 and 0.4% under 25% water stress conditions increased essential oil compounds like geraniol, citronellol, eugenol and methyl eugenol (Farahani *et al.*, 2021). Silicon application enhances chlorophyll content, Rubisco activity and net photosynthesis, which are crucial for essential oil synthesis particularly terpenes (Hassan *et al.*, 2024).

Effect of irrigation and water stress on essential oil yield and quality: Proper irrigation practices profoundly influence the production of floral essential oil in flower crops through multiple mechanisms. Sufficient watering facilitates the effective movement of nutrients to plant cells, guaranteeing that the necessary components for creating aromatic compounds are readily available. Furthermore, well-managed irrigation helps control stress levels in plants by keeping them adequately hydrated and reducing stress caused by water deficits or excesses. By maintaining optimal physiological conditions, watering

ensures that plants can devote their resources to making essential oils, rather than struggling with water shortages or excesses. The timing and length of watering periods are essential elements that directly affect how plants absorb water and their metabolic activity, therefore influencing the yield and composition of essential oils. The plant's water needs, which are affected by factors such as its growth phase and environmental conditions, determine the watering requirements for optimal growth and essential oil production. Changes in weather conditions, including temperature and humidity, also affect plant water requirements and how effective watering practices are.

Supplementary irrigation in *Lavandula angustifolia* enhanced plant growth and metabolic activity, leading to higher concentrations of key compounds like caryophyllene oxide, linalool, and β -caryophyllene in the essential oil, indicating improved oil quality and potential therapeutic benefits (Sałata *et al.*, 2020). During initial drought stress, there is an increase in the biosynthesis of secondary metabolites, including terpenes and benzyl isoquinoline alkaloids, which are key components of essential oils (Kleinwachter *et al.*, 2015). The increased concentration of monoterpenes in lavender essential oil under drought stress can be attributed to water scarcity affecting stomatal regulation, reducing photosynthesis and K ion uptake to maintain turgidity and control stomatal function, whereas monoterpene accumulation helps protect cell organelles and maintain ion balance as a defence mechanism (Selmar and Kleinwachter, 2013). However, prolonged drought exposure leads to a reduction in the production of secondary metabolites and essential oils, with up to 35% and 20% decreases in *Chelidonium* and *Thymus*, respectively (Bloem *et al.*, 2014). Water deficit stress, induced by reducing irrigation to 25% of the water requirement, led to a 20% reduction in flower yield. However, it increased the concentration of essential oil by 20% in *Rosa damascena* Miller cv. Kashan Pink (Farahani *et al.*, 2021).

Role of pruning-induced regrowth and hormonal responses in essential oil biosynthesis: Regular pruning is vital for managing bush shape, encouraging branch development, and influencing the amount of essential oils produced by flowers. Yearly pruning helps to maintain the plant's form and improves sunlight and air flow, which are both crucial for plant health and flower growth. The time, amount, and type of pruning directly affect how much essential oil is made, as it stimulates new growth and leads to more flowers. Pruning causes hormone changes, like an increase in cytokinins and auxins, which optimize

nutrient use and direct energy towards flower bud development. Additionally, pruning induces a stress response, which activates defence systems and the production of secondary metabolites, including essential oils, thereby enhancing their quality.

Light to medium top pruning increased flower yield and essential oil content in rose flowers (Erbaş *et al.*, 2022). Light pruning significantly boosted essential oil yield in Rose cv. 'Eiffel Tower' (Hassanein, 2010). Light pruning promoted more new shoots and better flowering, while heavy pruning reduced flower production by removing photosynthetic areas, thereby decreasing the number of flowers produced. In contrast, heavy pruning reduced essential oil yield by limiting flower production. Pruning time influenced fresh flower yield and oil content in *Rosa damascena* Mill. Late pruning (April) resulted in the highest rose oil yield (0.045%), while early pruning (March) produced a lower oil yield (0.030%). The increased oil yield with delayed pruning may be due to additional time for nutrient storage and growth before flowering, leading to enhanced oil production (Erbaş *et al.*, 2022). Pruning in autumn season supported better growth and nutrient storage, while light pruning preserved more buds and foliage, encouraging the development of new shoots.

Partial pruning along with foliar $MgSO_4$ application significantly improved both flower yield and essential oil quality in *Rosa damascena* under rainfed acidic conditions (Pal and Mahajan, 2017). Partial pruning enhanced shoot growth and flower yield due to better shoot initiation, higher bud retention, and improved photosynthate allocation, which supported robust regrowth and flowering (Chesney, 2008). When paired with $MgSO_4$ at 15 g/L, flower yield increased by 38%, likely due to improved chlorophyll content and nutrient uptake under rainfed conditions (Hermans *et al.*, 2010). The enhanced availability of Mg was especially beneficial in acidic, rainfed soils where Mg is often limited by interactions with aluminium, supporting flower and oil yield under these challenging conditions (Cakmak and Marschner, 1992).

Influence of plant growth regulators on essential oil biosynthesis: Plant hormones, or PGRs, are vital for controlling the creation of floral essential oils through a variety of processes. Specifically, PGRs can change root development, which then affects how well the plant absorbs and uses nutrients, both of which are critical for making essential oils. PGRs also manage the switch to flowering, influencing the change from basic growth to reproductive stages, which in turn determines when and how much essential oil is

produced. Moreover, PGRs can directly impact essential oil production by altering the activity of genes in the oil making pathways or by controlling the formation of storage areas, like glandular trichomes, where essential oils are made and stored. Due to high toxicity, essential oils are biosynthesized and stored within specialized structures. Therefore, the presence of these structures is crucial for terpene production. Growth regulators can affect the formation and development of these essential oil biosynthesis and storage structures.

Plant hormones like cytokinin application influence the formation of secretory structures and increase in the density of glandular hairs in the post-secretory stage. Jasmonate application in Norway spruce (*Picea abies*) altered plant anatomy by increasing the number of resin ducts, which was linked to a threefold rise in monoterpene concentrations, including α and β -pinene and limonene (Erbilgin *et al.*, 2006).

The primary effect of cytokinin's, particularly kinetin and diphenyl urea, was to stimulate monoterpene accumulation, with effects on metabolism outweighing those on growth, development, or gland density. Applying 5 mg L⁻¹ of kinetin to *Rosa damascena* increased citronellal and geranyl acetate production by 8% in the first year and by 20% in the second year (Farooqi *et al.*, 1993). Applying benzyl adenine (BA) and naphthalene acetic acid (NAA) at 200 mg/L significantly increased the production of Volatile Organic Compounds (VOCs) in Hybrid Tea and Floribunda roses, particularly enhancing aromatic compounds like cis-muuro-4(141)5-diene, γ -cadinene, prenyl acetate, and γ -murolene (Ibrahim *et al.*, 2019). In *Chrysanthemum cinerariaefolium*, pyrethrin production increased by 31% and 44% with ethrel concentrations of 50 mg L⁻¹ and 100 mg L⁻¹, respectively, suggesting that ethrel may enhance the activity of enzymes involved in the pyrethrin biosynthetic pathway (Haque *et al.*, 2007).

Optimal harvesting and post-harvest practices for essential oil quality: Flower bloom stage is the best time to harvest of flowers for high essential oil due to its peak concentration of aromatic compounds. Harvesting flowers during this time ensure maximum oil yield quality as flowers have fully developed with oil glands and highly fragrant. Proper harvesting of flowers such as handpicking or mechanical techniques, play an important role in preserving the integrity of the flowers and preventing damage to the oil-containing structures. Similarly proper post-harvest handling and storage conditions after picking also has a big impact on the oil's quality. It's important to process the flowers

immediately after harvest to minimize enzymatic degradation and oxidation of volatile compounds in oil. Drying the flowers and keeping them in a cool dark and dry place helps to maintain the stability and potency of the essential oil over time. Additionally, avoiding prolonged exposure to light and air prevents degradation of delicate aromatic molecules.

Effective post-harvest handling is essential for maintaining the quality of floral essential oil. The timing of distillation after harvest significantly impacts the yield and composition of the oils. For instance, immediate distillation of rose petals yields higher quality oil compared to delayed processing, which can lead to degradation of volatile compounds (Swati *et al.*, 2024; Dobрева *et al.*, 2023). The oil content is highest when rose flowers are distilled immediately after harvest, with significant reductions in oil content when distillation is delayed (Baydar and Baydar, 2005). High temperature reduces oil content of flower due to removal of essential oil from the trichomes of petals in rose (Kumar *et al.*, 2013). Roses stored at room temperature before distillation contained higher hydrocarbon levels than those distilled immediately, highlighting the importance of prompt processing for preserving optimal oil quality (Baydar *et al.*, 2008). Managing relative humidity during storage is crucial for preserving essential oil quality, as higher humidity levels enhance oxidative stability. Oils stored at 32% RH, for instance, remained more stable than those stored at 0% RH, underscoring the importance of humidity control in maintaining essential oil integrity in post-harvest handling (Velasco *et al.*, 2009).

Early harvesting stages tend to produce higher levels of camphor, borneol, bornyl acetate, and other key components which are valuable for both the aroma and medicinal properties of the rosemary essential oil (Verma *et al.*, 2020). Harvesting lemon verbena in autumn maximizes yield and quality, while afternoon harvests slightly enhance citral content (Vogel *et al.*, 1999). High-quality rose oil is characterized by a rich concentration of monoterpene alcohols such as citronellol, nerol, geraniol, linalool, phenyl ethyl alcohol, and citral which contribute to its distinctive fresh and floral aroma. Low levels of hydrocarbons like nonadecane, eicosane, and heneicosane are preferred, as these compounds can lead to oil solidification and reduce its quality (Protzen, 2009). Harvesting time and storage conditions played a crucial role in the Phenyl Ethyl Methyl Ether (PEME) per cent, yield and quality of the essential oil of pandanus flowers (Nasim *et al.*, 2017).

Conclusion

Floral essential oils are gaining prominence in the global economy due to their versatile applications and increasing consumer demand for natural products. They are widely used across perfumery, cosmetics, pharmaceuticals, and aromatherapy, owing to their distinct aromatic properties and proven biological activities such as antimicrobial, antioxidant, and mood-enhancing effects. These oils are synthesized through complex biochemical pathways governed by genetic and enzymatic controls, producing a rich variety of chemical compounds that define each oil's quality and function. However, their composition is not static as they are significantly influenced by ecological factors such as climate, altitude, soil characteristics, and seasonal changes, as well as agronomic practices including irrigation, nutrient management, planting density, and harvesting time. Therefore, a comprehensive understanding of these dynamics between crop ecology and agronomic practices is essential to develop integrated management practices that ensure consistent quality, improve productivity, and support the sustainable production of high-value floral essential oils to meet rising global demand. So, ongoing research is vital for developing effective strategies that balance agricultural needs with environmental sustainability.

References

- Acimovic, M., Zeremski T., Sovljanski O., Loncar B., Pezo L., Zheljzkov V.D., Pezo M., Suput D. and Kurunci Z. (2022). Seasonal variations in essential oil composition of immortelle cultivated in Serbia. *Horticulturae*, **8**(12), 1183.
- Ahmadi, F., Samadi A., Sepehr E., Rahimi A. and Shabala S. (2021). Optimizing hydroponic culture media and $\text{NO}_3^-/\text{NH}_4^+$ ratio for improving essential oil compositions of purple coneflower (*Echinacea purpurea* L.). *Sci. Rep.*, **11**, 8009.
- Akram, A., Younis A., Akhtar G., Ameer K., Farooq A., Hanif M., Saeed M. and Lim K. (2017). Comparative efficacy of various essential oil extraction techniques on oil yield and quality of *Jasminum sambac* L. *Sci. Int.*, **5**, 84-95.
- Alanazi, T.Y.A. (2024). Optimizing the supercritical carbon dioxide extraction of hibiscus flower essential oil using response surface analysis. *Eng. Technol. Appl. Sci. Res.*, **14**(2), 13567-13571.
- Alvarez-Castellanos, P.P. and Pascual-Villalobos M.J. (2003). Effect of fertilizer on yield and composition of flowerhead essential oil of *Chrysanthemum coronarium* (Asteraceae) cultivated in Spain. *Ind. Crops Prod.*, **17**, 77-81.
- Arvin, P. (2019). Study of different levels of nitrogen, phosphorus and potassium on physiological and morphological parameters and essential oils in savory plant (*Satureja hortensis* L.). *J. Plant Res. (Iran)*, **32**(2), 260-279.
- Bakkali, F., Averbeck S., Averbeck D. and Idaomar M. (2008). Biological effects of essential oils-A review. *Food Chem. Toxicol.*, **46**(2), 446-475.
- Baranauskienė, R. and Venskutonis P.R. (2022). Supercritical CO_2 extraction of *Narcissus poeticus* L. flowers for the isolation of volatile fragrance compounds. *Molecules*, **27**(2), 353.
- Baroli, I., Price G.D., Badger M.R. and Caemmerer S.V. (2008). The contribution of photosynthesis to the red light response of stomatal conductance. *Plant Physiol.*, **146**(2), 737-747.
- Baydar, H. and Baydar N.G. (2005). The effects of harvest date, fermentation duration and Tween 20 treatment on essential oil content and composition of industrial oil rose (*Rosa damascena* Mill.). *Ind. Crops Prod.*, **21**(2), 251-255.
- Baydar, H., Schulz H., Kruger H., Erbas S. and Kineci S. (2008). Influences of fermentation time, hydro-distillation time and fractions on essential oil composition of damask rose (*Rosa damascena* Mill.). *J. Essent. Oil-Bear. Plants*, **11**(3), 224-232.
- Bharathi, P.R., S.K. and Naga Lakshmi A. (2020). *Jasminum grandiflorum* Linn. - An update review. *Int. J. Pharm. Sci. Res.*, **11**(5), 1994-2010.
- Bloem, E., Haneklaus S., Kleinwachter M., Paulsen J., Schnug E. and Selmar D. (2014). Stress-induced changes of bioactive compounds in *Tropaeolum majus* L. *Ind. Crops Prod.*, **60**, 349-359.
- Bolouri, P., Salami R., Kouhi S., Kordi M., Asgari Lajayer B., Hadian J. and Astatkie T. (2022). Applications of essential oils and plant extracts in different industries. *Molecules*, **27**(24), 8999.
- Butnariu, M. and Sarac I. (2018). Essential oils from plants. *Journal of Biotechnology and Biomedical Science*, **1**(4), 35-43.
- Cakmak, I. and Marschner H. (1992). Magnesium deficiency and high light intensity enhance activities of superoxide dismutase, ascorbate peroxidase, and glutathione reductase in bean leaves. *Plant Physiol.*, **98**(4), 1222-1227.
- Chesney, P. (2008). Nitrogen and fine root length dynamics in a tropical agroforestry system with periodically pruned *Erythrina poeppigiana*. *Agrofor. Syst.*, **72**(2), 149-159.
- Chouhan, S., Sharma K. and Guleria S. (2017). Antimicrobial activity of some essential oils-present status and future perspectives. *Medicines*, **4**(3), 58.
- Das, S., Hossain M., Jahan N. and Uddin M. (2022). Chemical analysis of essential oil extracted from *Tagetes erecta* L. sourced from Bangladesh. *SSRN Electron. J.*, **2022**, 4273535.
- de Sousa, D.P., Damasceno R.O.S., Amorati R., Elshabrawy H.A., de Castro R.D., Bezerra D.P., Nunes V.R.V., Gomes R.C. and Lima T.C. (2023). Essential oils: Chemistry and pharmacological activities. *Biomolecules*, **13**(7), 1144.
- Dobreva, A., Nedeva D. and Mileva M. (2023). Comparative study of the yield and chemical profile of rose oils and hydrosols obtained by industrial plantations of oil-bearing roses in Bulgaria. *Resources*, **12**(7), 83.
- Ebrahimi, A., Moaveni P., Dashtbozorg A.T. and Farahani H.A. (2011). Effects of temperature and varieties on essential oil content and quantity features of chamomile. *J. Agric. Ext. Rural Dev.*, **3**(2), 19-22.

- Erbas, S., Kazaz S. and Baydar H. (2022). Effects of top-pruning time on fresh flower yield, rose oil content and compounds in oil-bearing rose (*Rosa damascena* Mill.). *J. Nat. Appl. Sci.*, **26**(2), 211-215.
- Erbilgin, N., Krokene P., Christiansen E., Zeneli G. and Gershenzon J. (2006). Exogenous application of methyl jasmonate elicits defenses in Norway spruce (*Picea abies*) and reduces host colonization by the bark beetle *Ips typographus*. *Oecologia*, **148**(3), 426-436.
- Farahani, H., Sajedi Ali N., Madani H., Changizi M. and Naeini M.R. (2021). Effect of foliar-applied silicon on flower yield and essential oil composition of damask rose (*Rosa damascena* Miller) under water deficit stress. *Silicon*, **13**, 4463-4472.
- Farooqi, A.H.A., Sharma S., Naqvi A.A. and Khan A. (1993). The effect of kinetin on flower and oil production in *Rosa damascena*. *J. Essent. Oil Res.*, **5**(3), 305-309.
- Fernandez-Sestelo, M. and Carrillo J.M. (2020). Environmental effects on yield and composition of essential oil in wild populations of spike lavender (*Lavandula latifolia* Medik.). *Agriculture*, **10**(12), 626.
- Franz, C. and Novak J. (2009). Sources of essential oil. In: Baser K.H.C. and Buchbauer G. (eds.), *Handbook of Essential Oils: Science, Technology, and Applications*, 1st edn. CRC Press, pp. 991.
- Ghavam, M. (2021). Relationships of irrigation water and soil physical and chemical characteristics with yield, chemical composition and antimicrobial activity of damask rose essential oil. *PLoS ONE*, **16**(4), e0249363.
- Ghosh, D., Choudhary N., Kumari K., Singh J., Tripathi P., Meena A., Luqman S., Yadav A., Chanotiya C., Pandey G. and Kumar N. (2020). Diversity of essential oil-secretory cells and oil composition in flowers and buds of *Magnolia sirindhorniae* and its biological activities. *Chem. Biodivers.*, **18**, e202000750.
- Gladikotic, N., Ikonc B., Teslic N., Zekovic Z., Bozovic D., Putnik P., Bursac Kovacevic D. and Pavlic B. (2023). Essential oils from Apiaceae, Asteraceae, Cupressaceae and Lamiaceae families grown in Serbia: Comparative chemical profiling with in vitro antioxidant activity. *Plants*, **12**(4), 745.
- Gutensohn, M., Nagegowda D.A. and Dudareva N. (2013). Involvement of compartmentalization in monoterpene and sesquiterpene biosynthesis in plants. In: Bach T.J. and Rohmer M. (eds.), *Isoprenoid Synthesis in Plants and Microorganisms: New Concepts and Experimental Approaches*. Springer, New York, pp. 155-169.
- Halder, D., Barik B.B., Dasgupta R.K. and Roy S.D. (2018). Aroma therapy: An art of healing. *Indian Res. J. Pharm. Sci.*, **5**(3), 1540-1558.
- Haque, S., Farooqi A.H.A., Gupta M.M., Sangwan R.S. and Khan A. (2007). Effect of ethrel, chlormequat chloride and paclobutrazol on growth and pyrethrins accumulation in *Chrysanthemum cinerariaefolium* Vis. *Plant Growth Regul.*, **51**(3), 263-269.
- Hassan, K.M., Ajaj R., Abdelhamid A.N., Ebrahim M., Hassan I.F., Hassan F.A.S., Alam-Eldein S.M. and Ali M.A.A. (2024). Silicon: A powerful aid for medicinal and aromatic plants against abiotic and biotic stresses for sustainable agriculture. *Horticulturae*, **10**(8), 806.
- Hassanein, A.M.A. (2010). Improved quality and quantity of winter flowering in rose (*Rosa* spp.) by controlling the timing and type of pruning applied in autumn. *World J. Agric. Sci.*, **6**(3), 260-267.
- Hermans, C., Vuylsteke M., Coppens F., Cristescu S.M., Harren F.J.M., Inze D. and Verbruggen N. (2010). Systems analysis of the responses to long-term magnesium deficiency and restoration in *Arabidopsis thaliana*. *New Phytol.*, **187**(1), 132-144.
- Hosseinpour, M., Ebadi A., Habibi H., Nabizadeh E. and Jahanbakhsh S. (2020). Enhancing enzymatic and nonenzymatic response of *Echinacea purpurea* by exogenous 24-epibrassinolide under drought stress. *Ind. Crops Prod.*, **146**, 112045.
- Ibrahim, M., Agarwal M., Yang J.O., Abdulhussein M., Du X., Hardy G. and Ren Y. (2019). Plant growth regulators improve the production of volatile organic compounds in two rose varieties. *Plants*, **8**(2), 35.
- Jahan, J.S., Chowdhury S.F., Mitu S.A., Shahriar M.S. and Bhuiyan M.A.B.H. (2015). Genomic DNA extraction methods: A comparative case study with gram-negative organisms. *Banat's J. Biotechnol.*, **6**(11), 61-68.
- Kamali, H., Aminimoghadamfarouj N., Golmakani E. and Nematollahi A. (2015). The optimization of essential oils supercritical CO₂ extraction from *Lavandula hybrida* through static-dynamic steps procedure and semi-continuous technique using response surface method. *Pharmacogn. Res.*, **7**(1), 57-65.
- Kaul, P.N., Rajeswara Rao B.R., B.A.K. and S.K. (1999). Effect of weather parameters on yield and quality of the essential oil of rose-scented geranium (*Pelargonium* species). *Agric. Sci. Dig.*, **19**(2), 84-86.
- Khaleghi, A. and Khadivi A. (2020). Morphological characterization of damask rose (*Rosa × damascena* Herrm.) germplasm to select superior accessions. *Genet. Resour. Crop Evol.*, **67**(8), 1981-1997.
- Khalid, K.A. (2012). Effect of NP and foliar spray on growth and chemical compositions of some medicinal Apiaceae plants grown in arid regions in Egypt. *J. Soil Sci. Plant Nutr.*, **12**(3), 617-632.
- Khalil, N., El-Jalel L., Yousif M. and Gonaïd M. (2020). Altitude impact on the chemical profile and biological activities of *Satureja thymbra* L. essential oil. *BMC Complement. Med. Ther.*, **20**(1), 186.
- Kleinwachter, M., Paulsen J., Bloem E., Schnug E. and Selmar D. (2015). Moderate drought and signal transducer induced biosynthesis of relevant secondary metabolites in thyme (*Thymus vulgaris*), greater celandine (*Chelidonium majus*) and parsley (*Petroselinum crispum*). *Ind. Crops Prod.*, **64**(1), 158-166.
- Kumar, A., Gautam R., Singh S., Chauhan R., Kumar M., Kumar D., Kumar A. and Singh S. (2023). Phenotyping floral traits and essential oil profiling revealed considerable variations in clonal selections of damask rose (*Rosa damascena* Mill.). *Sci. Rep.*, **13**, 34972.
- Kumar, R., Sharma S., Ramesh K., Pathania V. and Prasad R. (2014). Irradiance stress and plant spacing effect on growth, biomass and quality of wild marigold (*Tagetes minuta* L.) - An industrial crop in Western Himalaya. *J. Essent. Oil Res.*, **26**(5), 348-358.
- Kumar, R., Sharma S., Sharma S., Sharma M. and Kumar N. (2018). Influence of flower to water ratio and distillation time of damask rose (*Rosa damascena* Mill.) flowers on

- essential oil content and composition in the Western Himalayas. *J. Essent. Oil Res.*, **30(5)**, 353-359.
- Kumar, R., Sharma S., Sood S., Agnihotri V.K. and Singh B. (2013). Effect of diurnal variability and storage conditions on essential oil content and quality of damask rose (*Rosa damascena* Mill.) flowers in North Western Himalayas. *Sci. Hortic.*, **154**, 102-108.
- Kumar, R., Sharma S., Sood S., Agnihotri V.K., Singh V. and Singh B. (2014). Evaluation of several *Rosa damascena* varieties and *Rosa bourboniana* accession for essential oil content and composition in western Himalayas. *J. Essent. Oil Res.*, **26(3)**, 147-152.
- Kurniawati, A., Naimah M. and K. (2024). Dynamics of flower production and flower oil components from two accessions of *Cananga odorata* in dry season. *IOP Conf. Ser. Earth Environ. Sci.*, **1359**, 012082.
- Lago, J.H.G., Favero O.A. and Romoff P. (2006). Microclimatic factors and phenology influences in the chemical composition of the essential oils from *Pittosporum undulatum* Vent. leaves. *J. Braz. Chem. Soc.*, **17(7)**, 1334-1338.
- Liao, Z., Huang Q., Cheng Q., Khan S. and Yu X. (2021). Seasonal variation in chemical compositions of essential oils extracted from lavender flowers in the Yun-Gui Plateau of China. *Molecules*, **26(18)**, 5639.
- Malhi, S.S., Gan Y. and Raney J.P. (2007). Yield, seed quality, and sulfur uptake of *Brassica* oilseed crops in response to sulfur fertilization. *Agron. J.*, **99(2)**, 570-577.
- Mohamed, A.A. and Alotaibi B.M. (2023). Essential oils of some medicinal plants and their biological activities: A mini review. *J. Umm Al-Qura Univ. Appl. Sci.*, **9(1)**, 40-49.
- Motsa, N.M., Soundy P., Steyn J.M., Learmonth R.A., Mojela N. and Teubes C. (2006). Plant shoot age and temperature effects on essential oil yield and oil composition of rose-scented geranium (*Pelargonium* sp.) grown in South Africa. *J. Essent. Oil Res.*, **18**, 106-110.
- Mrani, S.A., Zejli H., Azzouni D., Fadili D., Alanazi M.M., Hassane S.O.S., Sabbahi R., Kabra A., Moussaoui A.E., Hammouti B. and Taleb M. (2024). Chemical composition, antioxidant, antibacterial, and hemolytic properties of ylang-ylang (*Cananga odorata*) essential oil: Potential therapeutic applications in dermatology. *Pharmaceuticals*, **17(10)**, 1376.
- Nasim, N., Behera J.K., Sandeep I.S., Kar B., Ramarao V.V., Srivastava R., Nayak S. and Mohanty S. (2017). Effect of harvesting time and storage on essential oil and PEME content of *Pandanus fascicularis*. *J. Appl. Pharm. Sci.*, **7(10)**, 185-189.
- Nasiri, Y., Zehtab-Salmasi S., Nasrullahzadeh S., Najafi N. and Ghassemi-Golezani K. (2010). Effects of foliar application of micronutrients (Fe and Zn) on flower yield and essential oil of chamomile (*Matricaria chamomilla* L.). *J. Med. Plants Res.*, **4(17)**, 1733-1737.
- Nour, A.H., Modather R.H., Yunus R.M., Elnour A.A.M. and Ismail N.A. (2024). Characterization of bioactive compounds in patchouli oil using microwave-assisted and traditional hydrodistillation methods. *Ind. Crops Prod.*, **208**, 117901.
- Omidbaigi, B., Dadman B. and Fattahi F. (2008). Influence of nitrogen fertilizer on the herb yield, essential oil content and composition of *Tagetes minuta* L. *J. Essent. Oil-Bear. Plants*, **11(1)**; 45-52.
- Pal, P.K. and Mahajan M. (2017). Pruning system and foliar application of MgSO₄ alter yield and secondary metabolite profile of *Rosa damascena* under rainfed acidic conditions. *Front. Plant Sci.*, **8**; 507.
- Pal, P.K. and Singh R.D. (2013). Understanding crop-ecology and agronomy of *Rosa damascena* Mill. for higher productivity. *Aust. J. Crop Sci.*, **7(2)**, 196-205.
- Pocha, P.N.R., Mallikarjun M., Devi G.N. and Kumar M.R. (2019). Assessment of improved variety of tuberose (*Polianthes tuberosa*) Prajwal for yield and economics in western parts of Chittoor district of Andhra Pradesh. *J. Krishi Vigyan*, **8(1)**, 13.
- Protzen, K.D. (2009). Storage and transport of essential oils. In: Baser K.H.C. and Buchbauer G. (eds.), *Handbook of Essential Oils: Science, Technology, and Applications*, 1st edn. CRC Press, pp. 991.
- Raji, R., Hadizadeh N., Aalifar M. and Sadat-Hosseini M. (2016). Effect of different plant media composition on essential oil yield and growth traits of pepper (*Capsicum frutescens* var. *grossum*) seedlings. *J. Essent. Oil-Bear. Plants*, **19(6)**, 1435-1441.
- Rathore, S., Mukhia S., Kapoor S., Bhatt V., Kumar R. and Kumar R. (2022). Seasonal variability in essential oil composition and biological activity of *Rosmarinus officinalis* L. accessions in the Western Himalaya. *Sci. Rep.*, **12(1)**, 7298.
- Raut, J.S. and Karuppaiyil S.M. (2014). A status review on the medicinal properties of essential oils. *Ind. Crops Prod.*, **62**, 250-264.
- Rebey, I.B., Bourgou S., Rahali F.Z., Msaada K., Ksouri R. and Marzouk B. (2017). Relation between salt tolerance and biochemical changes in cumin (*Cuminum cyminum* L.) seeds. *J. Food Drug Anal.*, **25(2)**, 391-402.
- Rezai, S., Etemadi N., Nikbakht A., Yousefi M. and Majidi M.M. (2018). Effect of light intensity on leaf morphology, photosynthetic capacity, and chlorophyll content in sage (*Salvia officinalis* L.). *Hortic. Sci. Technol.*, **36(1)**, 46-57.
- Rodriguez-Concepcion, M., Fores O., Martínez-García J.F., Gonzalez V., Phillips M.A., Ferrer A. and Boronat A. (2004). Distinct light-mediated pathways regulate the biosynthesis and exchange of isoprenoid precursors during *Arabidopsis* seedling development. *Plant Cell*, **16(1)**, 144-156.
- Salachna, P., Lopusiewicz L., Wesolowska A., Meller E. and Piechocki R. (2021). Mushroom waste biomass alters the yield, total phenolic content, antioxidant activity and essential oil composition of *Tagetes patula* L. *Ind. Crops Prod.*, **171**, 113961.
- Salata, A., Buczkowska H. and Nurzynska-Wierdak R. (2020). Yield, essential oil content, and quality performance of *Lavandula angustifolia* leaves, as affected by supplementary irrigation and drying methods. *Agriculture*, **10(12)**, 590.
- Sankarikutty, B. and Narayanan C.S. (2003). Essential oils / Isolation and production. In: Caballero B., Finglas P. and Toldra F. (eds.), *Encyclopedia of Food Sciences and Nutrition*. Elsevier, pp. 2185-2189.
- Sanli, A. and Karadogan T. (2017). Geographical impact on essential oil composition of endemic *Kundmannia anatolica* Hub.-Mor. (Apiaceae). *Afr. J. Tradit. Complement. Altern. Med.*, **14(1)**, 131-137.

- Sarmoum, R., Haid S., Biche M., Djazouli Z., Zebib B. and Merah O. (2019). Effect of salinity and water stress on the essential oil components of rosemary (*Rosmarinus officinalis* L.). *Agronomy*, **9**(5), 214.
- Selmar, D. and Kleinwachter M. (2013). Stress enhances the synthesis of secondary plant products: The impact of stress-related over-reduction on the accumulation of natural products. *Plant Cell Physiol.*, **54**(6), 817-826.
- Shohayeb, M., Arida H., Abdel-Hameed E.S.S. and Bazaid S. (2015). Effects of macro and microelements in soil of rose farms in Taif on essential oil production by *Rosa damascena* Mill. *J. Chem.*, **2015**, 935235.
- Singh, B., Sellam P., Jayoti M. and Puja R. (2014). Floral essential oils: Importance and uses for mankind. *HortFlora Res. Spectr.*, **3**(1), 1-6.
- Sirohi, U., Kumar M., Chauhan P., Kumar R., Chand P. and Chaudhary V. (2017). Morphological variation and genetic distance in tuberose (*Polianthes tuberosa* L.) genotypes for growth, yield and essential oil traits. *Chem. Sci. Rev. Lett.*, **6**(24), 2086-2093.
- Sitarek, P., Rijo P., Garcia C., Skala E., Kalembe D., Białas A.J., Szemraj J., Pytel D., Toma M., Wysokińska H. and Śliwiński T. (2017). Antibacterial, anti-inflammatory, antioxidant, and antiproliferative properties of essential oils from hairy and normal roots of *Leonurus sibiricus* L. and their chemical composition. *Oxid. Med. Cell. Longev.*, **2017**, 7384061.
- Soe'Eib, S., Asri N.P. and NH A.D.S. (2016). Enflourage essential oil from jasmine and rose using cold fat adsorbent. *Widya Teknik*, **15**(1), 58-61.
- Souiy, Z. (2024). Essential oil extraction process. In: Vickelis J. (ed.), *Essential oils - Recent Advances, New Perspectives and Applications*. IntechOpen Ltd., London, United Kingdom, pp. 186.
- Svydenko, L., Hlushchenko L., Vergun O., Gudz N. and Markovska O. (2022). Assessment of the weather conditions influence on the economic and value characteristics of *Lavandula angustifolia* L. in the conditions of Kherson region. *Agroecol. J.*, **2022**, 266413.
- Swati, Basoli M. and Kashyap B. (2024). A review on essential oil extraction from ornamental crops: Method and prospects. *Int. J. Minor Fruits Med. Aromat. Plants*, **10**(1), 23-33.
- Tan, L.T.H., Lee L.H., Yin W.F., Chan C.K., Kadir H.A., Chan K.G. and Goh B.H. (2015). Traditional uses, phytochemistry, and bioactivities of *Cananga odorata* (ylang-ylang). *Evid.-Based Complement. Altern. Med.*, **2015**, 896314.
- Thakur, M., Bhatt V. and Kumar R. (2019). Effect of shade level and mulch type on growth, yield and essential oil composition of damask rose (*Rosa damascena* Mill.) under mid hill conditions of Western Himalayas. *PLoS ONE*, **14**(4), e0214672.
- Trivellini, A., Toscano S., Romano D. and Ferrante A. (2023). The role of blue and red light in the orchestration of secondary metabolites, nutrient transport and plant quality. *Plants*, **12**(10), 2026.
- Velasco, J., Holgado F., Dobarganes C. and Márquez-Ruiz G. (2009). Influence of relative humidity on oxidation of the free and encapsulated oil fractions in freeze-dried microencapsulated oils. *Food Res. Int.*, **42**(10), 1492-1500.
- Venkatachalam, L., Sivakumar G. and Balakrishnan M. (2024). Comparative analysis of essential oil contents in *Jasminum auriculatum* ecotypes Muthu Mullai and CO 1 Mullai. *Med. Plants*, **16**(1), 156-161.
- Verma, R.S., Padalia R.C., Chauhan A., Upadhyay R.K. and Singh V.R. (2020). Productivity and essential oil composition of rosemary (*Rosmarinus officinalis* L.) harvested at different growth stages under the subtropical region of north India. *J. Essent. Oil Res.*, **32**(2), 144-149.
- Verma, R.S., Verma R.K., Chauhan A. and Yadav A.K. (2011). Seasonal variation in essential oil content and composition of thyme (*Thymus serpyllum* L.) cultivated in Uttarakhand Hills. *Indian J. Pharm. Sci.*, **73**(1), 233-235.
- Vogel, H., Silva M.L. and Razmilic I. (1999). Seasonal fluctuation of essential oil content in lemon verbena (*Aloysia triphylla*). *Acta Hort.*, **500**(9), 75-80.
- Walia, S. and Kumar R. (2021). Nitrogen and sulfur fertilization modulates the yield, essential oil and quality traits of wild marigold (*Tagetes minuta* L.) in the Western Himalaya. *Front. Plant Sci.*, **11**, 631154.
- Yang, D., Du X., Liang X., Han R., Liang Z., Liu Y., Liu F. and Zhao J. (2012). Different roles of the mevalonate and methylerythritol phosphate pathways in cell growth and tanshinone production of *Salvia miltiorrhiza* hairy roots. *PLoS ONE*, **7**(11), e46797.
- Younis, A., Riaz A., Khan M.A. and Asif K.A. (2009). Effect of time of growing season and time of day for flower harvest on flower yield and essential oil quality and quantity of four *Rosa* cultivars. *Flor. Orn. Biotechnol.*, **3**(1), 98-103.
- Zhang, M., Anderson S.L., Brym Z.T. and Pearson B.J. (2021). Photoperiodic flowering response of essential oil, grain, and fiber hemp (*Cannabis sativa* L.) cultivars. *Front. Plant Sci.*, **12**, 694153.