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EXPLORING ELICITORS IN FRAGRANCE CHEMISTRY OF FLOWER CROPS: A COMPREHENSIVE REVIEW

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ABSTRACT

Elicitors, a diverse array of compounds, play a pivotal role in modulating and enhancing fragrance profiles in flowers. These compounds have the ability to enhance the synthesis of fragrance compounds in plants, which are accountable for captivating the scents associated with various major and minor flower crops. In the field of fragrance chemistry, elicitors are utilized to stimulate the production of volatile organic compounds (VOCs), the primary constituents of floral scents. It discusses the mechanism by which elicitors function, including their interaction with the plant receptors and subsequent activation of signalling pathways and metabolic processes related to fragrance synthesis. This review delves into the multifaceted landscape of elicitors in fragrance chemistry, elucidating their mechanisms of action, applications, and implications in the flower crops.

***Key words*:** Elicitors, Fragrance chemistry, Benzenoid, Terpenoid, Biosynthesis.

Introduction

In the fascinating world of fragrance chemistry in flower crops, elicitors play a crucial role in enhancing and modulating the production of aromatic compounds (Abbas *et al*., 2022). Elicitors are substances that can stimulate or induce specific biochemical pathways in plants, resulting in the synthesis and release of volatile organic compounds (VOCs) responsible for the characteristic scents of flowers as reported by Aguirre-Becerra *et al*., (2021).

Elicitors are substances (or bio-factors) from the various resources which can trigger the physiological and morphological responses in the targeted living organisms as well as the building up of phytoalexin accumulation (Thakur and Sohal, 2013). The perception of the elicitors is to enhance the synthesis of various signalling compounds mainly jasmonic acid, methyl jasmonate, salicylic acid and the production of other secondary metabolites (Giri and Zaheer 2016, Narayani and Srivastava 2017).

Elicitors are the components which induces the signals to activate the plant defensive mechanism. The enzymes in the plant related defensive mechanism are found to be effective by the activation of elicitors like methyl salicylate, salicylic acid, chitosan, benzothiadiazole, benzoic acid etc (Zehra *et al*., 2021).

Based on their source, nature and molecular structure, elicitors will vary among them. They are classified into exogenous and endogenous elicitors. The exogenous elicitors are the compounds produced by the pathogens, whereas the other, endogenous elicitors are molecules released from the plants in response to the pathogenic attack (Kumari *et al*., 2020). Secondary metabolites, which is responsible for the fragrance chemistry can also be raised from these elicitors, they act as a vital role in the production of commercially available compounds (Handa *et al*., 2019).

Elicitor-based disease management represents a promising and socio-environmentally sustainable strategy. Several chemical activators of plant defence responses, including 2,6-dichloroisonicotinic acid (INA), salicylic acid (SA), 3-aminobutyric acid (BABA), acibenzolar-S-methyl (ASM; benzo [1,2,3] thiadiazole-7-carbothioic acid S-methyl ester, also known as benzothiadiazole or BTH; CGA 245704), and methyl jasmonate (MeJA), have been demonstrated to enhance innate defence mechanisms or induce systemic resistance pathways such as systemic acquired resistance (SAR) and induced systemic resistance (ISR), thereby offering significant potential for integrated disease management (IDM) (Darras, 2012).

Elicitors and its classification

Molecules identified as elicitors, including phytoalexins, stimulate the synthesis of metabolites. Elicitors are substances that modify the quantity and make-up of specific substances in secondary metabolites found in plants (Humbal and Pathak, 2023).

Depending upon their origin, they are classified as biotic and abiotic elicitors. Biotic elicitors are either pathogen (or) host origin that can stimulate defense responses (such as phytoalexin accumulation) in plant tissues and it include Polysaccharides, Fungal, Bacterial and Yeast extract. Abiotic elicitors are of non-biological origin are essential for enabling plants to adapt to and thrive in harsh environments and it include Physical (UV radiation, Salinity, Drought, Osmotic and Thermo stress), Chemical (Heavy metals, Mineral salts) and Hormonal (Auxin, Gibberellic acid, Cytokinin, Ethylene, Abscisic acid, Jasmonate, Brassinosteroids, Salicylic acid and other floral scent volatiles) (Razzaq *et al*., 2025).

Mechanism of Elicitors

In plant biotechnology, elicitation is a highly effective method for initiating the production of new secondary metabolites, improving biomass yield and metabolite accumulation. Elicitors aid in the synthesis of specific secondary metabolites in the plant system. These secondary metabolites in turn control signal transduction pathways, stress tolerance, production of scent volatiles, survival and other developmental processes. The success of elicitation depends on a number of variables, such as the type of elicitor, dosage, length of treatment and culture type (Zheng *et al*., 2023).

Action of Elicitors

Elicitors exert their effects through multiple regulatory mechanisms, including transcriptional control of biosynthetic genes, modulation of enzyme activities, alteration of precursor availability or release, and hormonal signalling. Experimental studies in ornamental crops have demonstrated these distinct modes of action. Integrated molecular profiling and enzyme assays have established direct links between elicitor treatments and pathway-level changes in terpenoid and phenylpropanoid biosynthesis.

- **(i) Transcriptional induction:** In *Rosa damascena*, methyl jasmonate (MeJA) significantly upregulated the expression of key scent-related genes such as Carotenoid Cleavage Dioxygenase 1 (CCD1), Phenylalanine Ammonia-Lyase (PAL), MYB transcription factor 1 (MYB1), and other regulatory genes, indicating that MeJA enhances volatile production through gene-level regulation (Rajabzadeh *et al*., 2024).
- **(ii) Enzyme activity modulation:** In *Agave amica*, treatments with MeJA and the PAL inhibitor 4-amino-4-deoxychorismate lyase (AOPP) modified PAL enzymatic activity and influenced metabolic flux through the phenylpropanoid pathway, resulting in altered benzenoid profiles and extended flower spike longevity (Kanani *et al*., 2017).
- **(iii) Precursor feeding and glycoside hydrolysis:** The supply of glycosylated precursors and sodium acetate enhanced β-glucosidase-mediated hydrolysis of stored conjugates, leading to increased release of aglycone volatiles and immediate enhancement of floral fragrance in cut *Delphinium* (Nazarideljou, 2023).
- **(iv) Hormonal regulation and plant growth regulator effects:** Treatments with benzyl adenine, naphthalene acetic acid (NAA), and gibberellic acid (GA_3) altered volatile organic compound profiles, supporting the role of hormonal regulation in controlling secondary metabolism and terpene biosynthetic pathways in ornamental plants (Niazian and Sabbatini, 2021).
- **(v) Cultivation system interactions:** Elicitor responses are influenced by growth conditions and cultivation systems, which can modify or redirect volatile production, as demonstrated in *Tulipa* species (Kishimoto and Watanabe, 2023).

Floral Scent Biosynthetic Pathways

Floral scents are composed of volatile chemical molecules characterized by low vapour pressure, low polarity, and low molecular weight. The composition of floral fragrances varies widely among plant species and is predominantly derived from terpenoids, phenylpropanoids, benzenoids, and fatty acid derivatives, as reported by Iqbal *et al.*, (2025) and Dudareva *et al.*, (2006). In most cases, floral aroma functions to attract pollinators, thereby facilitating successful plant reproduction; however, in rare instances, pollinators may also derive direct rewards from floral fragrances.

Floral aroma represents one of the most important plant traits, playing a central role in the fertilization of angiosperms by attracting and guiding pollinators (Dudareva *et al*., 2004). In addition to pollination, certain volatile compounds emitted from flowers contribute to plant defense mechanisms by deterring harmful organisms (Caruso *et al*., 2016; Picazo-Aragonés *et al*., 2020).

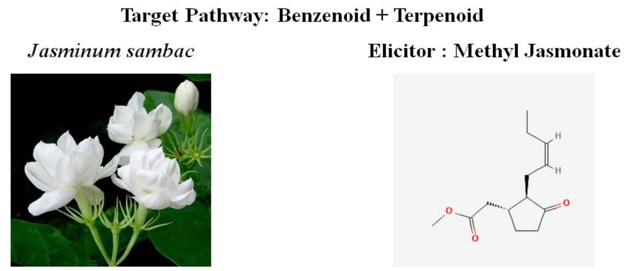
The qualitative and quantitative composition of floral scent emissions varies across the floral life cycle and is also influenced by diurnal rhythms and day-night cycles (Piechulla *et al*., 2003). Generally, floral volatile compounds predominantly belong to either the terpenoid or phenylpropanoid / benzenoid classes (Pichersky *et al*., 2007).

(A) Fragrance chemistry of major flower crops

(1) Jasmine (*Jasminum sambac*; Oleaceae)

(i) Floral scent volatiles: Night-blooming flowers, particularly those belonging to *Jasminum* spp., emit sweet fragrances predominantly composed of benzenoid and terpenoid volatile compounds (Loughrin *et al*., 1991). The floral scent of *Jasminum sambac* (Oleaceae) is primarily derived from the benzenoid and terpenoid biosynthetic pathways, with most volatile production occurring in the petals during the dark phase (Bera *et al*., 2015). In *J. sambac*, the biosynthesis of floral fragrance is a tightly regulated physiological process involving the coordinated activity of multiple enzymes (Ito *et al*., 2002). Approximately 12–17 distinct volatile compounds belonging to the benzenoid and terpenoid classes contribute to the characteristic sweet aroma of *J. sambac* flowers (Younis *et al*., 2011). The major constituents of *J. sambac* floral scent include benzyl acetate, methyl benzoate, methyl salicylate, linalool, ocimene, and farnesene (Bera *et al*., 2016).

(ii) Genes involved in floral scent: Salicylic acid (SA) levels were higher during the floral bud stage within the benzenoid biosynthetic pathway, whereas Methyl Salicylate (MeSA) levels showed a significant increase at the fully bloomed flower stage. Terpene synthase (TPS) genes associated with the terpenoid pathway were more abundantly expressed in floral buds compared to fully opened flowers (Ito *et al*., 2002). Transcriptomic analysis revealed that approximately 202 genes are actively expressed at the bud stage, establishing the metabolic framework for the synthesis of around 203 volatile compounds responsible for floral fragrance at the full-bloom stage (Yu *et al*., 2017).



(2) Tuberose (*Agave amica*; Asparagaceae)

(i) Floral scent volatiles: Flowers of *Agave amica* emit an intense fragrance composed of a complex blend of floral volatiles, primarily including benzenoid compounds such as methyl benzoate and methyl salicylate, and terpenoid compounds such as 1,8-cineole, farnesene, and germacrene D (Rakthaworn *et al*., 2009; Kanani *et al*., 2017). Transcriptomic profiling of *A. amica* flowers using RNA-sequence was performed across four distinct developmental stages.

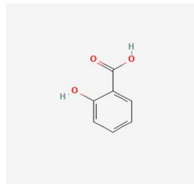
Within the benzenoid biosynthetic pathway, the expression of *Ptelea trifoliata* Isoeugenol/ Methyltransferase (PtIEMT), associated with the production of methyl benzoate and methyl salicylate, showed a progressive increase during flower development.

In the terpenoid pathway, *Ptelea trifoliata* Terpene Synthase 1 (PtTPS1) exhibited significantly elevated expression levels during the flowering stage (Fan *et al*., 2018). This comprehensive analysis generated four Digital Gene Expression (DGE) libraries, revealing gene expression patterns crucial for the regulation and development of floral fragrance during flowering (Hamilton *et al*., 2012).

(ii) Major floral compounds: At the early bud stage, only low concentrations of terpenoid and benzenoid compounds were detected; however, their levels progressively increased during the mid-bud stage. At both the anthesis stage and the fully opened flower stage, benzenoids constituted the predominant class of volatile compounds, while terpenoids were present in comparatively lower proportions. Overall, *Agave amica* exhibited a marked accumulation of benzenoid and terpenoid volatiles from early bud stage to the anthesis stage, followed by a decline in their concentrations from anthesis to the fully opened stage (Fan *et al.*, 2018).

Target Pathway: Benzenoid

Agave amica **Elicitor : Salicylic Acid**



(3) Rose (*Rosa sp.;* Rosaceae)

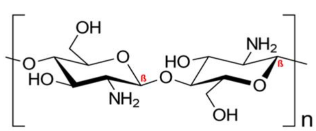
(i) Floral scent volatiles: Only 8 to 20 of the nearly 200 species of *Rosa* spp., including Chinese roses (*R. chinensis, R. multiflora,* and *R. gigantea*) and European roses (*R. moschata, R. gallica,* and *R. canina*), have contributed to the genetic background of modern cultivated roses, as reported by De Vries *et al*., (1995) and Reynders-Aloisi *et al.*, (1995).

Chinese roses predominantly produce alcohols and esters derived from lipids and aromatic compounds, along with substantial levels of sesquiterpenoids. In contrast, the fragrance of European roses is largely composed of monoterpenes (Verma *et al*., 2011). In *Rosa hybrida*, floral scent compounds are mainly synthesized in the petals, and key petal associated scent biosynthesis genes include *RcEGS1, RhPAAS,* and *RcPOMT* (Wang *et al*., 2012).

The two epidermal layers of rose petals exhibit distinct cellular morphologies, and both layers are capable of synthesizing and emitting volatile aromatic compounds (Sun *et al*., 2017). However, not all scent-related metabolites are produced exclusively in petals; for instance, three esters citronellyl acetate, geraniol acetate, and nerol acetate are synthesized in the stamens of *R. rugosa* rather than in the petals (Feng *et al*., 2015).

Target Pathway: Terpenoid + Phenylpropanoid

Rosa hybrida **Elicitor : Chitosan monomer**



(B) Fragrance chemistry of minor flower crops

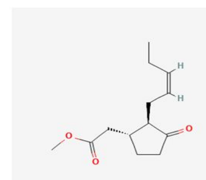
(1) White Champaca (*Magnolia × alba*; Magnoliaceae)

(i) Floral scent volatiles: The floral fragrance of white champaca is predominantly composed of benzenoid and terpenoid volatile compounds. The expression of linalool synthase and (3R)-linalool synthase (LIS) was found to be high during the early developmental stages (Maheswary *et al.*, 2011). Upregulation of (3R)-linalool synthase (LIS) was associated with a strong floral scent and a rapid increase in linalool emission during the later stages of floral development, particularly from half bloom with outer and middle whorls of petals opened; full bloom with all whorls of petals opened; and stamens turned brown with partial petal abscission. (Maheswary *et al*., 2019).

Similarly, cinnamate and cinnamoyl-CoA were consistently associated with strong floral fragrance throughout all developmental stages include very small closed buds with green petals and no fragrance; yellowish swollen buds; greenish-cream elongated buds; fully cream buds with opened bracts; quarter bloom; half bloom; full bloom and senescence stage (Maheswary *et al*., 2019).

Target Pathway: Terpenoid

Magnolia × alba **Elicitor : Chitosan monomer**



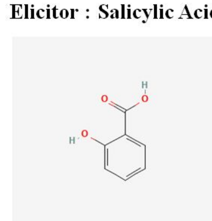
(2) Night Blooming Jasmine (*Nyctanthes arbor-tristis*; Oleaceae)

(i) Floral scent volatiles: *Nyctanthes arbor-tristis* contains a wide range of phytochemical constituents distributed across various plant parts, including flowers, leaves, stems and seeds (Khanapur *et al*., 2014). Phytochemical screening of *N. arbor-tristis* revealed the presence of steroids, terpenes, flavonoids, iridoid glycosides, carbohydrates, and alkaloids.

In the flowers, ethyl acetate extracts showed a high abundance of stigmasterol, while methanolic and ethanolic extracts were rich in crocin and crocetin. Nyctanthic acid was predominantly detected in the leaves. Methanolic seed extracts exhibited a high concentration of arbortristoside C, whereas pelargonic acid and lignoceric acid were found to be more abundant in the stem tissues (Dewi *et al*., 2022).

Target Pathway: Phenylpropanoid

Nyctanthes arbor-tristis **Elicitor : Salicylic Acid**



(3) Ylang-Ylang (*Cananga odorata*; Annonaceae)

(i) Floral scent volatiles: *Cananga odorata* should be harvested at the full bloom stage, as this developmental phase contains the highest concentration of volatile compounds responsible for its characteristic fragrance (Qin *et al*., 2014). Volatile profiling across different floral developmental stages has been effectively performed using headspace solid-phase microextraction coupled with gas chromatography–mass spectrometry (HS-SPME–GC–MS) (Qin *et al*., 2014).

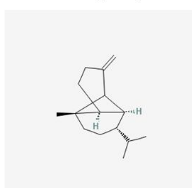
Bioinformatics approaches combined with RNA sequencing have been employed to identify genes involved in the biosynthetic pathways of floral volatiles (Jin *et al*., 2015). The functional characterization of four full-length terpene synthase genes which include *CoTPS1*, *CoTPS2*, *CoTPS3*, and *CoTPS4* was conducted using yellow flower tissues. Among these, *CoTPS2* was identified as a novel multifunctional enzyme that catalyses the biosynthesis of the sesquiterpenes β-ylangene, β-copaene, and β-cubebene (Jin *et al*., 2015).

Furthermore, among the 52 volatile compounds identified, *(E)-cinnamyl acetate, 1,4-dimethylbenzene, benzyl acetate* and *benzyl benzoate* were found to be highly abundant and primarily associated with the phenylpropanoid biosynthetic pathway (Toghueo *et al*., 2018).

Target Pathway: Terpenoid

Cananga odorata

Elicitor : β-copaene



Applications of elicitors in different flower crops

Flower crops	Elicitor Used	Effects	References
Rosa hybrida 	Methyl jasmonate	Delayed flower opening, suppressed petal wilting, prolonged vase life.	Hasanzadeh-Naemi *et al*., (2021)
Gerbera jamesonii 	Salicylic acid	Improved petal water status, increased relative water content, extended vase life.	Hemati *et al*., (2019)
Dendrobium spp 	Chitosan	Increased number and size of flowers, delayed full bloom, extended flower longevity.	Kongklom *et al*., (2018)
Gladiolus grandiflorus 	Salicylic acid	Delayed petal senescence and extended quality of cut spikes.	Sharma *et al*., (2024)
Lilium asiaticum 	Benzoic acid	Modified the growth, extended the quality of flower spikes and induces the stress tolerance.	Ragini (2019)
Alstroemeria peruviana 	Salicylic acid	Extended vase life and improved postharvest quality.	Ershad Langroudi (2020)

Conclusion

Moreover, the elicitors induced fragrance enhancement can have practical implications for various industries. Perfumers and fragrance developers can benefit from the knowledge of elicitors to create captivating scents and improves the longevity of fragrance formulations. Additionally, the horticulture industry can leverage elicitors to breed or cultivate flower varieties with enhanced fragrance, attracting more consumers and increasing market demand.

Statements and Declarations

Authors' contributions

SPM collected and wrote the draft manuscript. MG reviewed and corrected the manuscript, while MG, SB and SS provided valuable suggestions to enhance the manuscript's quality.

Conflict of interest: Authors do not have any conflict of interests to declare.

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