Modulating Geraniol Rich Essential Oils Biosynthesis in Palmarosa (Cymbopogon Martinii) Via Plant Growth Regulators: Mechanisms and Applications

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Abstract— *This review explores the modulation of geraniol-rich essential oil biosynthesis in palmarosa (Cymbopogon martinii) using plant growth regulators (PGRs), specifically brassinosteroids (BR) and salicylic acid (SA). Palmarosa oil, valued in perfumery, cosmetics, and pharmaceuticals for its geraniol content, is in increasing global demand. This article examines the mechanisms by which BR and SA influence plant growth, primary metabolism (photosynthesis and enzyme activity), and secondary metabolite pathways, ultimately enhancing the yield and quality of essential oils. Understanding these PGR effects is crucial for developing strategies to boost production of this economically important oil to meet rising market needs sustainably. The research highlights significant potential for agricultural application.*

Keywords— Plant growth regulators, Essential Oils, Citral, Geraniol

I. Introduction: Brassinosteroid And Salycylic Acid

Brassinosteroids are a new group of plant hormones with significant growth promoting activity. The ability of certain pollen extracts to promote growth led to the discovery of this group of substances in plants. Collective efforts initiated by scientist at various agricultural research station of USDA resulted in isolation of an active factor from the pollen grains of rape plant (*Brassica napus*) which was named as brassinolide. Brassinosteroid are considered as plant hormones with pleiotropic effects as they regulate wide array of developmental processes such as growth, seed germination, rhizogenesis, flowering, senescence, abscission and maturation. Brassinosteroids also confer resistance to plants against various abiotic stresses [1].

A large numbers of allelochemicals are present in several members of the crucifereae family. Brassinolide is a natural plant hormones found in pollens of rapeseed plant (*Brassica napus* L.) that promotes growth, proliferate the cereals and fruit yields while induces resistance in plants against drought and cold weather. First time, Brassinolide was isolated and detected from the rape seed (*Brassica napus* L.) plant pollen (Grove *et al*., 1979). Wide variety of plants contains interrelated compounds, called brassinosteroids. The most significant charisma of brassica water extract is known as brassinolide, which is a natural hormone [2]. In the presence of a potentially growth-limiting cell wall, they are helpful in keeping and maintaining processes such as plant growth, including photo morphogenesis and cell expansion. Brassinosteriods are responsible for increasing resistance against heavy metals, temperature, salinity or water stresses and biotic stresses [3]. Additionally, increase in crop yield up to 20–60 % is also attained by genetic manipulation of BRs and it is indication that more exploration on brassinosteroids can improve productivity [4]. Brassinolide is conventional plant hormone which acts as growth promoters and yield enhancer in fruit and grain crops [5], [6], [7], despite the fact it inculcate the resistant factors to cold weather and drought resistence in the plants [8], [9]. Extensive varieties of plants are accompanied with brassinosteroids compound. It is vital for better growth of all plants; sometimes plants become dwarfs if they cannot comprise the ability to synthesize their own brassinolide [10], [11]. Actually, plant will grow better in the presence of brassinolide and if its availability is more to the plants then growth rate will be higher. Brassinolide provides the opportunity to the plants to grow faster because it increases the rate of photosynthesis [12] and its absence influence the growth and development of plant. It was also proved that when plant faces different kinds of biotic and abiotic stresses, then BRs play important role [13]. Brassinolide enhances the growth and development of the plants and ultimately the yield if it is applied at early stages of plant growth [14].

With a high concentration of PGRs on plant could end with drastic or toxic events. Such was a recent case in China with a growth accelerator by the name of Forchlorfenuron. It was applied to watermelons in heavy concentration late in the flowering stage on top of a wet season, causing the fruit to split or as the farmers put it, to “explode” [15]. It should be noted that those farmers were new to growing watermelons and the seasoned farmers did not have any issues, having known not to apply a heavy concentration, or that spraying unevenly could result in larger flower sets on only half of the plant. Phytotoxicity and slow growth could be a result of applying more than the recommended applications. But, much like anything, it seems when used in moderation they will do exactly what they are intended to do. Just remember more is not always better, and chances are you're already using it in the form of your propagation gels and liquids to your nutrient's additives, and one would not realize it.

Salicylic acid (SA) is an endogenous plant growth regulator of phenolic nature which enhances plant resistance to pathogens and other stresses [16]. In addition to provide resistance to plant diseases; SA also has been found to induce tolerance to than some abiotic stresses such as drought [17], heat [18], salinity [19], chilling [20], heavy metal [21], [22] and UV radiation [23]. Moreover, SA plays a role in the regulation of some physiological processes such as seed germination, fruit yield, glycolysis, flowering in thermogenic plants, nutrient uptake and transport, photosynthetic rate, stomatal conductance and transpiration [24], [25].

The word salicylic acid (salicylates) was coined by Raffaele Piria in 1838, from the latin word *salix* , *willow tree*, from the bark of which he obtained the active principle i.e. Salicylic Acid. Salicylates are a class of compounds having activity similar to Salicylic acid (2-hydroxybenzoic acid) which is a plant phenolic acid compound.

Green leaves and reproductive regions are the main sites of Salicylic acid biosynthesis. However, the highest level of salicylic acid was reported in the inflorescence of thermogenic plants infected by necrotizing pathogens. Salicylic acid reduces eighteen biosynthesis and enhances a number of physiological process, including defense mechanism against abiotic and biotic stress, membrane permeability, photosynthesis, seed germination, specific changes in leaf anatomy and chloroplast structure, synthesis of auxin and cytokinin and transpiration rate [26], [27], [28].

There are numerous reports in the literature concerning the effects of growth regulators on growth and development of various aromatic plants. Most of these growth substances have exhibited influences by modifying the growth characters. Brassinosteroids are steroidal plant hormones actively involved in various physiological processes and are essential for plant growth and development. BRs have pleiotropic effects and can induce a broad spectrum of cellular responses including stem elongation, pollen tube growth, leaf bending and epinasty, root inhibition, induction of ethylene biosynthesis, proton pump activation, xylem differentiation and regulation of gene expression [6], [10], [11].

Biosynthesis of terpenoids is dependent on primary metabolism, e.g. photosynthesis and oxidative pathways for carbon and energy supply. Therefore, in this study, effect of plant growth regulators on primary metabolic parameters like nitrate reductase (NR) activity, chlorophyll content and protein content was also determined.

II. Mechanism Of Action Of Plant Growth Regulators

There are two general classes of hormones found in animal system-steroid and peptides both of which also occur in plant system. This steroid class forms a hormone receptor complex in the cytoplasm, which is then transported into nucleus where mRNA is synthesized, resulting in a given response. The peptide class binds to a receptor at a plasma membrane forming hormone receptor complex, which causes the synthesis of secondary messenger for a given response. Each receptor is specific to one hormone [29], [30], [31], [32].

III. Mechanism Essential Oil Biosynthesis In Cymbopogon Species

In response to the clinical shortcomings of small-molecule inhibitors, nanomedicine has introduced a suite of sophisticated strategies designed to fundamentally circumvent ABC transporter-mediated efflux. By encapsulating therapeutic agents within a nanoscale carrier, the drug's interaction with efflux pumps at the cell membrane can be minimized or altogether avoided. Nanoparticles primarily enter cells via endocytic pathways, a mechanism that bypasses the membrane-localized pumps. Once internalized, the nanocarrier releases its high-concentration payload directly into the cytoplasm, effectively overwhelming any remaining efflux capacity and ensuring the drug reaches its intracellular target. This section will explore the key multifunctional nanocarrier designs that leverage this principle, including the co-delivery of inhibitors, gene-silencing approaches, and stimuli-responsive systems.

The essential oil of *Cymbopogons*, the aromatic grasses are mainly made up of terpenoids and have a varied combination of monoterpenes in their essential oils [33], [34], [35]. It is well established that terpenoids are synthesized from 5-C units of isopentyl pyrophosphate (IPP) and its isomer dimethyl allyl pyrophosphate (DMAPP) [36], [37]. These monomeric building blocks are biosynthetic equivalent of Ruzicka's classical isoprene unit [38].

Specific prenyl transferases (prenyl pyrophosphate synthase) couple desired number of IPP units to DMAPP onwards leading to homologous series (C_{10} mono-terpenoids; C_{15} sesquiterpenoids, etc.) of phenyl pyrophosphatases. The monoterpenes are predominantly the product of secondary metabolisms of plants [39]. Modern methods of separation and structure determination and the advent of radioisotope and ^{14}C labelled techniques have led to very rapid advances in the knowledge of the routes of biosynthesis of monoterpenes and their recombinant production in other microbes [40]. The biosynthesis of terpenoids/essential oils takes place through the mevalonate isoprenoid pathway. The mevalonate pathway of terpene biosynthesis in plant is outlined in (Fig. 1).

Besides the ubiquitous, mevalonate pathway, there are now reports of non-mevalonate pathway referred to as Rohmer pathway or 1- deoxy-D-xylulose-5-phosphate (DOXP) pathway [41]. According to this scheme, DOXP pathway starts with DOXP synthase catalyzed formation of 1- deoxy-D-xylulose-3-phosphate (DOXP) from glyceraldehydes-3-P and pyruvate (condensation via TPP dependent decarboxylation pyruvate derived acetyl aldehyde-TPP). DOXP is subsequently transformed into 2-C-methyl-D-erythrotol-4-phosphate by an intramolecular C-C skeleton rearrangement involving DOXP reducto-keto-isomerase in a mechanism similar to ketol acid reductoisomerase (KAKI) operational in the biosynthesis of valine, leucine and isoleucine. The two enzymes catalyze a C-C skeleton rearrangement followed by a NADPH- dependent reduction step. 2-C-methyl-D-erythritol-4-phosphate ultimately gets metabolically transposed to IPP (Fig.1).

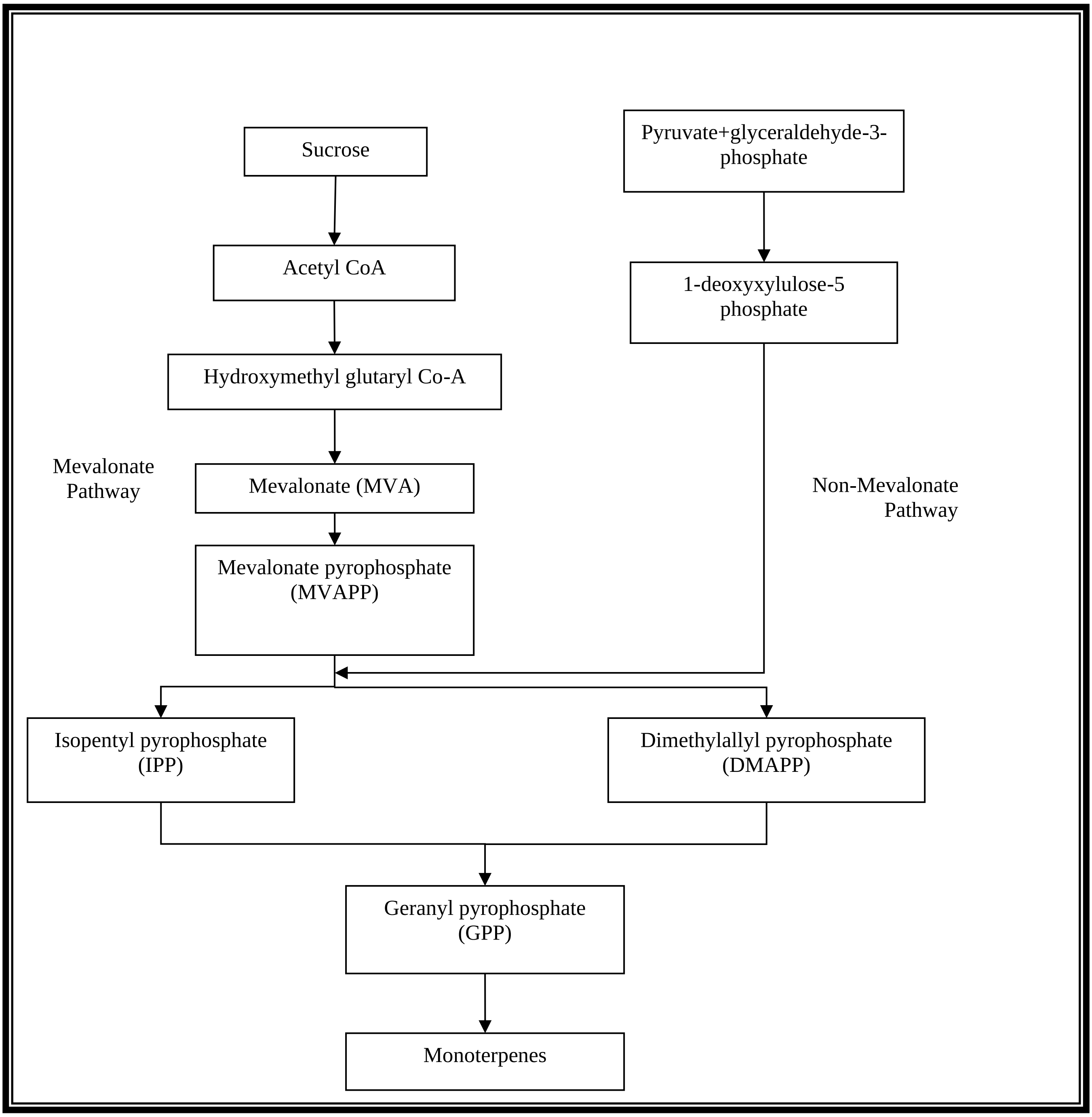

Fig. 1. *General Scheme of Monoterpene biosynthesis*

Mevalonate (MVA) is formed from glycolitically generated acetyl CoA. Subsequently, hydroxymethyl gluataryl CoA (HMG CoA) synthetase catalyses the formation of HMG CoA. A soluble enzyme HMG CoA reductase catalyses the reductive deacylation of HMG CoA into mevalonate (MVA). Successive enzymatic phosphorylation and decarboxylation of MVA yield isopentenyl pyrophosphate (IPP), the basic 5 carbon containing isoprenoid unit. The IPP is isomerised to dimethylallyl pyrophosphate (DMAPP). The IPP and DMAPP then produce geranyl pyrophosphate (GPP), a C_{10} compound under the catalytic action of GPP synthetase. The C_{10} compound which arises from mevalonate is the precursor of monoterpenes.

In *Cymbopogon* species the principal interest is the biosynthetic steps whereby the monoterpenes diverge from other terpenoid compounds and specifically the conversion of geranyl pyrophosphate to the acyclic monoterpenes, citral, geranial, citronellol, citronellal, neral, etc**.** (Fig.2). Geraniol undoubtedly arises *in-vitro* by hydrolysis of the corresponding pyrophosphates [42]. Use of ^{14}C and ^{3}H labelled precursors reveal that leaf blades of *Cymbopogon* *flexuosus* converted Geraniol into citral trans, whereas nerol lost the hydrogen while being converted into citral cis. Secondly, the citral trans is converted into citral cis and vice-versa. There is no separate route for the biosynthesis of two aldehyde isomers [43].

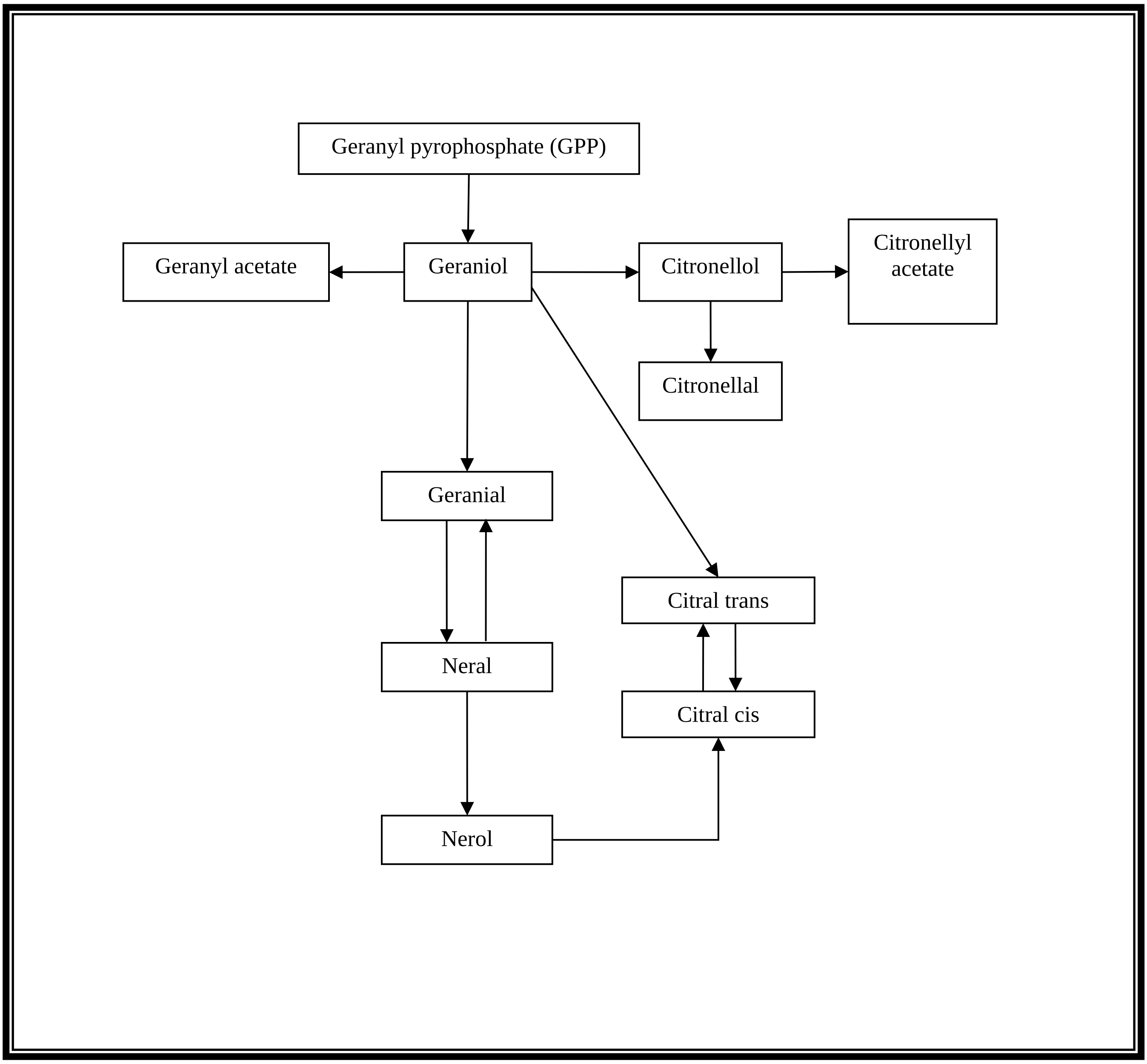

Fig. 2. *Metabolic Interconversion of Monoterpenes in Cymbopogon sp.*

Enzymes catalyse oxidation of geraniol into citral. It also oxidises nerol but at slower rates. The enzyme was found to be in the cytosol which also contains alcohol dehydrogenase activity [44]. *Cymbopogon* cultivars differing in amount of citral and geraniol in their essential oils were screened for geraniol dehydrogenase activity to discern the feasibility of its serving as biochemical marker for oil yield and quality. The enzyme activity had a positive and significant association with citral to geraniol. The results are suggestive of a strong relationship between the enzyme activity and essential oil quality in *Cymbopogon* cultivars [45].

Many evidence including the diurnal and seasonal fluctuation in monoterpene content and the time course of the incorporation of labelled precursors into monoterpenes indicate that monoterpenes are in a state of metabolic flux [46]. The oil content of leaves of *Cymbopogon winterianus* decreased with maturity and exhibited seasonal and diurnal changes [47]. Maximum accumulation of citral occurred during the day when temperature was highest [48]. The percentage of oil is maximum during October and November months [49]. The oil obtained from the harvests in the month of September showed marked rise in the aldehyde content (maximum 45%) over other months of the year [50]. In *Cymbopogon khasianus*, the increase in the feeding time of the labelled precursor 2-^{14}C-acetate resulted in the decrease in the radioactivity of citral with a corresponding increase in hydrocarbons and/or unidentified products [51]. This supports the suggestion that monoterpenes do undergo turnover in plant.

IV. PHYSIOLOGY OF ESSENTIAL OIL PRODUCTION

One of the most important characteristics of oil accumulation is its dependence on the developmental stage of the plant as well as its concerned organ, tissue and cells. The origin of the leaves from primordial, their expansion to full maturity and finally loss through senescence is particularly important in aromatic grasses in which the leaves from the source of this commercially valuable oil. A close coordination between leaf ontogeny and oil accumulation and biogenesis has been demonstrated in many aromatic plants. Net essential oil production is associated with early growth period in *C. flexuosus* [34]. Maximum oil content (1.18%) in the leaves of C. martini has the end of blooming white flowers and inflorescence possesses much higher oil as compared to leaves [52].

Ontogeny also effects the oil composition, but only rarely, to a very substantial extent *e.g.* in *C. martinii* geraniol increases from 65% to 81% till flowering stage and has been demonstrated to be formed at the expense of geranyl acetate [53]. However, *C. flexuosus* does not exhibit much pronounced effects in its composition. Its main constituent citral attains highest value at the leaf age of 20 days and remains almost constant thereafter [54]. Even during the later stages of leaf growth and development, a substantial increase in the *in-vitro* activity of geraniol dehydrogenase involved in citral generation has also been reported. The enzyme level has been shown to be well correlated with citral geraniol ratio not only with difference in species but also with the developmental stages [55].

The flowering tops of *C. martinii* contained more oil than other parts [56]. The oil content remain maximum for 1 week to 10 days after initiation of flowering. The *C. martinii* foliage oil has the highest percentage of geraniol. The geraniol content in the oil increased from 64.8% at vegetative state to 81.4% at the flowering stage [57]. The maximum oil content in *C. martinii* is found at flowering initiation, but the oil yield was highest at the flower open stage and early seed formation stage when the plant biomass was highest. Oil quality depends on the harvesting time. Maximum oil (1.18%) in the leaves towards the end of blooming, and highest oil content in the flower at the flowering time [57]. During leaf ontogeny the amount of citronellal, geraniol and citronellol in the essential oil increased with leaf expansion whereas the amount of geranyl acetate and citronellyl acetate decreased. As the leaves matured, a significant decrease in the essential oil, citronellal and geraniol, content was observed [58]. Thus, in general leaf ontogeny strongly influences the expression of essential oil metabolism and this type of integration of the oil production with the preset developmental program of the tissue is particularly interesting.

V. SITE OF OIL PRODUCTION

Plant volatile oils are synthesized, stored and released to the environment by a variety of epidermis or mesophyll structures, whose morphology tends to be the characteristic of the taxonomic group. These structures on leaves, roots, stems, floral part and fruits include oil cells, secretory glands, glandular hairs or trichomes which synthesize and accumulate large quantities of these compounds [59]. These epidermal appendages (glandular trichomes, glandular hairs, resin ducts, etc.) occur in different plant parts from flowers to roots with special attributes individually. The studies concerning the site of terpenoid biosynthesis in particular, have been elaborately discussed in literature [60], [61], [62], [63]. Micro hairs containing oil have been found on axial epidermis of the leaf lamina of citronella (*Cymbopogon winterianus*) but could not be located on the adaxial face [64]. In *Mentha arvensis*t rich oil glands were present on both the leaf surfaces. The location of oil holding hair is restricted to the interveinal region. An intriguing correlation between one of the anatomical characters and chemical composition of essential oil of citronella has also been projected [47]. Using specific water soluble stains, it has ben recently found that specific oil cells, present in parenchymal tissues, are the sites of citral accumulation in lemongrass (*Cymbopogon citratus*) and lemongrass leaf surface does not contain glandular trichomes, such as those present in many other aromatic plants [65].

Primary metabolic processes like photosynthesis, respiration, etc. influence growth and development of the plant as well as biogenesis of secondary plant products. This is because the initial precursors for essential oil or other secondary products are provided by the primary metabolic processes. Thus, essential oil metabolism is by and large controlled by the balance between photosynthesis and utilization of photosynthate for growth and differentiation [66]. The ultimate partitioning of the photosynthetically fixed carbon is an important component of physiological mechanism of essential oil production. Therefore, photosynthetic characteristics and performance of the tissue, among other factors, are at the centre stage in making carbon 'shareable or separable for the anabolism of the oil components.

In peppermint leaf discs, photosynthetic electron transport when inhibited by DCMU and Paraquat resulted into depression in the oil mono-terpenoids suggesting that photosynthetic NADPH production may be at atleast partially cater to the transformation of monoterpene ketones to alcohols [67]. In *Mentha piperita*, the production and utilization of photosynthates controls oil production. Role of mobilization of photosynthetically generated transient starch has also been found to be very substantial in Cymbopogon species [68].

VI. EFFECT OF PGRS ON GROWTH, BIOCHEMICAL AND QUALITY AND QUANTITY ATTRIBUTES

The oil of *Cymbopogon martini* (Palmarosa) is one of the most important essential oil-bearing herbaceous species of the Poaceae family because of its high geraniol content. The oil of *Cymbopogon martini* is used as base for fine perfumery and is valued because of its geraniol content.

Brassinolide enhance the aromatic oil yield and content, introducing slight increase in the content of geraniol and marginal decrease in citronellol, linalool isomethanone content. The effect of brassinolide on essential oil yield might have been associated through the impact on growth and metabolism also might have trigged the intrinsic genetic potentiality of plants to produce more essential oil, higher levels of carbohydrates and their possible diversion to secondary metabolism might be contributed to increased level of essential oil yield in geranium plants [2].

Twenty eight homobrassinolide application on plant increases the carbon dioxide fixation in *Brassica juncea* the total chorophyll content [69], [70]. Application of brassinosteroid induced changes in nucleic acid content in *Chlorella vulgaris* [71] and similarly a higher contents of RNA was found in *Arachis hypogaea* when treated with brassinosteroids hormone [72].

Enhanced vegetative growth of *Arabidopsis thaliana* has been observed under influence of brassinolide treatement as compared to control plant [73]. Similarly enhancement of root growth in Arabidopsis has been obtained due to application of 24-brassinolide [74]. The treatment of rice plantlets with a 5 ppm solution of brassinolide caused an increase of fresh weight and in dry weight of seeds per plant in the Taebaik cultivar [75]. It was also reported to increase plant growth speed, root size, and root and stem dry weight, to reduce the toxicity of 2,4-D and butachlor to the plantlets and to increase the percentage of ripe grains when cultivated at low temperature.

Brassinosteroids are capable of enhancing plant defense systems against environmental stresses such as water, salt, heat and cold, stress etc [76], [77], [78].

Exogenous application of BR may influence a range of different processes of growth and development in Arabidopsis. Exogenous application of 28 homobrassinolide substantially improved the growth of savory plants as well as essential oil yield and content [79].

SA plays role in the regulation of some physiological processes such as seed germination, fruit yield, glycolysis, flowering in thermogenic plants, nutrient uptake and transport, photosynthetic rate, stomatal conductance and transpiration**.** Salicylic acid (SA) is an endogenous plant growth regulator of phenolic nature which enhances plant resistance to pathogens and other stresses [27]. In addition to provide resistance to plant diseases; SA also has been found to induce tolerance to than some abiotic stresses such as drought, heat, salinity, chilling, heavy metals and UV radiation [20], [23]. SA has a role in controlling gene expression that most of the genes regulated by SA are defense related genes and many of them participate in plant responses to biotic and abiotic stresses [80]. Therefore, SA may change secondary metabolites and its pathway by effects on plastid, chlorophyll level and tolerate condition stress. The SA like stress manipulated quality and quantity of essential oil of *Salvia macrosiphon*. The yield of essential oil increased. The useful components such as linalool were increased. Salicylic acid application resulted in a significant increase in total soluble carbohydrate content in leaves of tomato and sunflower, thus maintaining the carbohydrate pool in the chloroplasts at a high level [81], [82].

The promotive effect of salicylic acid could be attributed to its bioregulator effects on physiological and biochemical processes in plants such as ion uptake, cell elongation, cell division, cell differentiation, sink/source regulation, enzymatic activities, protein synthesis and photosynthetic activity as well as increase the antioxidant capacity of plants [83]. Salicylic acid takes part in the regulation of many physiological processes in corn and soyabean such as stomatal closure, nutrient uptake, chlorophyll synthesis, protein synthesis, inhibition of ethylene biosynthesis, transpiration and photosynthesis [84], [85].

Positive effect on growth, yield and chemical constituents of onion by salicylic acid foliar application [86]. A positive effect on growth and development of *Artimisia annua* along with yield of artemisinin by the foliar application of salicylic acid (0.25, 0.50 and1.0mM) the enzyme activities viz. NR and CA were significantly increased by the gradual increase in the applied levels of SA, with 1.00 mM proving the best foliar application [87]. The increase in the uptake of various nutrients, including NO_3, and the resultant activation of NR, is well established under normal growth conditions. Nevertheless, the beneficial interaction of SA with the NR inhibitors might result in the increased activity of NR in SA-treated plants. Alternatively, the increased activity of NR can be attributed to the fact that SA stabilizes the plasma membrane, hence preventing damage, as evidenced by the SA-increased membrane stability index in wheat [88]. This membrane stabilization could have facilitated the increased uptake of nutrients including the nitrate (NR activity inducer), thereby, increasing the NR activity in the leaves.

Primary metabolic processes such as photosynthesis, respiration and synthesis of amino acid influence the growth and development of plants as well as the biogenesis of secondary products like essential oils. This is because the initial precursors for secondary plant products like essential oils are provided by the primary metabolic processes. Efforts have been made to study the influence of plant growth regulators on primary metabolic processes in aromatic plants and their bearing on the secondary products.

It has been confirmed that brassinolide controls and regulates various physiological processes in plants including cell differentiation, cell elongation, pollen tube development, swelling of cells, differentiation of vascular bundles, reassembling of nucleic acid to form proteins and acceleration of enzymatic as well as photosynthetic activities.

Application of GA_3 on seeds of *Phyllanthus emblica* increased the leaf and stems protein content, whereas it was not found to be effective in enhancing the peroxidase specific activity in leaves, stem and roots; and GA_3 was helpful in increasing the total chlorophyll content of the leaves [89]. Effect of PGR on photosynthesis has been studied in Mentha in relation to triacontanol. GA_3 and IAA application on *Hyoscyamus muticus* increased the *in-vitro* NR activity in the leaves. However, GA_3 was more effective than IAA [90], [91].

The effect of triacontanol and chloromequat chloride on plant hormones (GA_3 like substances and ABA) and artemisinin in *Artemisia annua*. Tria application enhanced the GA like activity, but ABA levels decreased, while chloromequat increased ABA but reduced GA-like substances. Both tria and chloromequat chloride also increased the artemisinin level [92], [93].

Attempts have been made to improve the oil Content and yield of aromatic plants by application of plant growth regulators. Earlier studies exhibited that auxins and GA_3 could not produce any influence on the oil content in *C. flexuosus* and *C. winterianus* [94], [95]. However, a significant increase in the oil content of *C. khasiancis*, whereas in *C. citratus*, chloromequat increased the volatile oil and citral content [96]. Both IAA and GA_3 enhanced the oil content in *C. jwarancusa* while IBA decreased the oil yield but increased piperitone content. IAA and GA application increased oil yield and citral content of *C. citrates*.

Influence of various growth regulators has been studied on the formation of essential oil in other aromatic plants. Chloromequat and GA_3 are reported to effectively increase the oil yield and the quality of oil in *Ocimum sanctum* [97] and in *O. basilicum* [98]. An enhancement in the contents of eugenol, menthyl eugenol and caryphyllene contents of the oil in *O. sanctum* by GA_3 and maleic hydrazide has been reported [99]. Considerable augmentation in volatile oil yield per plant, oil content and proportion of citronellal and geraniol in the oil by IAA, alar and chloromequat application in *Pelargonium graveolens* [100]. "Ethereal" treatment caused a steady rise in the oil content in *Jasminum grandiflorum*, but it was not effective on other species of *Jasrninum* [101].

In flowers of *Rosa damascene* however, the oil content was decreased due to "Ethereal" treatment [102]. Cytokinin such as kinetin, 6-BAP and diphenylamide have also been found beneficial in augmenting the essential oil content of *M. piperita* without affecting the oil composition [103]. GA increased the menthol, neomenthol and isomenthone content in both *Mentha piperita* and *M. crispa*. Similary, significant increase in the oil content of *M. arvensis* by chloromequat chloride while ethephon (2 chloroethyl phosphonic acid) at 0.06% concentration had no significant effect on the oil Content. Among the two oil components studied, only menthone content was significantly increased by 0.06% ethephon. In *Rosa damascena*, ethereal decreased the oil content significantly while kinetin increased the oil yield significantly. Kinetin application also increased citronellol and geranyl acetate level in the oil. Application of CEPA increased the oil yield the significant increase being at 0.02% in *Rosa damascena* [104].

VII. Conclusion

This review emphasizes the importance of PGRs on regulation of essential oil biosynthesis and their applications in various fields like perfumery, cosmetics, and pharmaceutical industries. The global market size of essential oil was 10.3 billion in 2021 and is expected to reach a value of USD 18.25 billion by 2028. So, in order to fulfill the requirement of essential oil for upcoming years. In the present article, the authors reviewed the effect of BR and SA on essential oils yield of Palmarosa plants. The present review demonstrates clearly that the Brassinolide and salicylic acid show significant effect on growth and development of plant and essential oil yield and content.

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