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Linalool – A Review of a Biologically Active Compound of Commercial Importance

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Since the earliest times fragrant materials have been used in rituals. Today, a lucrative industry has developed to produce and deliver fragrances and aromatic chemicals with various applications in modern society. Linalool, a much sought after compound in the flavor and fragrance industry is a monoterpene alcohol which occurs naturally in many aromatic plants. Linalool and linalool-rich essential oils are known to exhibit various biological activities such as antimicrobial, anti-inflammatory, anticancer, anti-oxidant properties and several *in vivo* studies have confirmed various effects of linalool on the central nervous system. The applications of linalool are not confined to simply adding or enhancing a specific scent to domestic products such as soaps, detergents and shampoos. Linalool also plays an import role in nature as a key compound in the complex pollination biology of various plant species to ensure reproduction and survival. Linalool is also a key compound for the industrial production of a variety of fragrance chemicals such as geraniol, nerol, citral and its derivatives, as well as a lead compound in the synthesis of vitamins A and E. The repellent properties of linalool on various crop-destroying insects has been well documented accentuating the application of this molecule in eco-friendly pest management. This review aims to highlight the various biological properties of linalool and to emphasize the value of linalool and linalool-rich essential oils in phytotherapy.

Keywords: Linalool, essential oils, aromatic plants, biological activities.

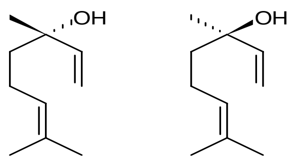
1. Introduction

Fragrance-containing products are part of daily life. The majority of personal-care, household and laundry products on the market contain fragrances. In cosmetic formulations, fragrances are commonly used to give the consumer a feeling of well-being, to mask the odour of other chemical ingredients or to contribute a specific cosmeceutical property (e.g. a soothing effect). It is estimated that approximately 3000 chemical substances (including essential oils and their constituents) are commonly used for this purpose [1].

Many plants produce linalool, with members of the Lamiaceae (mints), Lauraceae (laurels, cinnamon, rosewood) and Rutaceae (citrus), often accumulating linalool in abundance [2]. Linalool is an unsaturated monoterpene alcohol with the specific odour description; “light and refreshing, floral-woody, with a faint citrusy note” [3]. This volatile component is a chemical intermediate in the biosynthesis of vitamin E [2]. Linalool is also the principal component of many essential oils known to exhibit several biological activities such as antibacterial and antiplasmodial effects [4]. In addition, the anti-inflammatory, antihyperalgesic and antinociceptive effects of linalool in different animal models have been established [5-7]. Since its discovery, linalool has been widely studied, yet, most of the research is fragmented and obscured in several broader studies. The purpose of this review is to coherently re-assemble some of the most significant research findings specifically relating to linalool and to highlight its importance in nature, industry and phytotherapy.

2. Chemical aspects

In comparison with other essential oil components linalool has an appreciable solubility in water. Linalool exists in two enantiomeric forms, *S*-(+)- and



(**A**) (**B**)

Figure 1: The structure of linalool: **A** (*S*)-(+)-linalool and **B** (*R*)-(–)-linalool).

R-(−)-linalool (Figure1), which differ in their olfactory and physiological properties [5].

R-(−)-Linalool has a fragrance reminiscent of lavender, whereas *S*-(+)-linalool has more of a petitgrain fragrance [8]. Linalool may be isolated from the essential oils of linalool-biosynthesizing plants. It can be produced industrially by hemi-synthesis from natural pinene or through total chemical synthesis. Isolation of linalool as a single compound from an essential oil mixture can be achieved by using various chromatographic techniques such as column chromatography or through fractional distillation. The partial synthesis of linalool is based either on α- or β-pinene [9]. α-Pinene is hydrogenated to *cis*-pinane and subsequently oxidised to a *cis/trans* mixture of pinane hydroperoxide, which is in turn reduced to the corresponding pinanols and the latter finally pyrolysed to the respective *d*- or *l*-linalools. The total chemical synthesis of linalool is by way of 2-methyl-2-hepten-6-one [2]. It may start from the reaction of acetylene with acetone resulting in 3-methyl-1-butyn-3-ol, which is hydrogenated over a palladium catalyst to 3-methyl-1-buten-3-ol, that is in turn reacted with either diketene or acetic acid ester to the aceto-acetate and the latter thermally reacted to yield 2-methyl-2-hepten-6-one. Alternatively, 3-methyl-1-buten-3-ol is reacted with isopropenyl methyl ether to yield 2-methyl-2-hepten-6-one. In this synthetic pathway, isoprene hydrochloride is reacted with acetone in the presence of either an alkaline agent or an organic base as catalysts to yield 2-methyl-2-hepten-6-one. 2-Methyl-2-hepten-6-one is finally reacted with acetylene to dehydrolinalool, which is partially hydrogenated. The industrial methods for the synthesis of linalool are through the pinene and the dehydrolinalool routes.

3. Linalool production

The industrial estimate for the worldwide production of linalool in 2000 was 12,000 tons. Over half of this is estimated to be produced through synthesis, with the balance obtained from natural plant terpenes [2]. Approximately 95% of synthetic linalool and practically the entire volume extracted from natural sources is used in formulations to contribute a specific fragrance in cosmetics, soaps, perfumes, household cleaners, while only approximately 1% is added to food and beverages for aroma and flavoring [2]. Before the 1950s, nearly all linalool used in perfumery was isolated from essential oils, particularly from rosewood oil [10].

A FAO/WHO Joint Expert Committee on Food Additives [11] estimated the amount of terpene alcohols used in the flavoring of food and beverages in the USA and Europe at approximately 75 tons/annum. The majority of these terpene alcohols consist of linalool and its ester, linalyl acetate.

Traditionally, linalool, has been (and still is) used in the form of natural products such as dried herbs, as a fumigant for the storage of cereals and as a deterrent against pests. However, this specific use cannot be accurately quantified [10].

4. The role of linalool in pollination

Pollination is vital to ensure the existence and continued survival of plants. It is hypothesized that floral heat and scent may have been key components in the breeding systems of early angiosperms [12]. The flowers of many plants attract pollinators by producing volatile aromatic compounds within the various floral organs (e.g. stigma, style, ovary, petals, sepals) or in special glands called osmosphores [13]. Volatile compounds predominate in attracting pollinators at night when visual cues become inadequate [14]. Certain compounds can be detected by insects at a very low concentration, acting as essential components for pollinator attraction in a complex scent or sometimes even as the most informative molecule [15]. Therefore, plant scent in insect interactions cannot usually be reduced to the effect of one major compound.

Linalool is present in the floral fragrance of diverse plant families (e.g. Lamiaceae, Lauraceae, Verbenaceae) and is attractive to a broad spectrum of pollinators (e.g. bee and butterfly), herbivores and parasitoids [16]. An investigation into the pollination of *Satyrium microrrhynchum*, a rare South African orchid revealed that this orchid is pollinated specifically by two insects; a cetoniid beetle (*Atrichelaphinus tigrina*) and a pompilid wasp (*Hemipepsis hilaris*). The two insects have short mouthparts and collect nectar from the perianth hairs. In the orchids, nectar is secreted as droplets on long floral hairs. The fragrance from plants in three different populations, analyzed by gas chromatography coupled to mass spectrometry, confirmed the dominance of linalool [17].

A study was conducted to explore whether or not there are convergent patterns in floral scent composition among plant species that rely (completely or partially) on butterflies for pollination. Floral scent compounds were analyzed from 22 flowering butterfly-pollinated plant species, representing 13 families (originating mainly from temperate North Europe, tropical and temperate America). It was postulated that the benzenoids phenylacetaldehyde and 2-phenylethanol, the monoterpenes linalool and linalool oxide (furanoid) I and II serve as a signal to attract pollinating butterflies, and these compounds may have evolved in conjunction with the sensory capabilities of butterflies as a specific group of pollinators [18].

5. The pharmacological properties of linalool

5.1. Infectious diseases: Despite the progress in understanding the life cycle and control of many pathogens, the majority of diseases affecting millions of people in developing countries are caused by micro-organisms. Although a plethora of papers are available on the anti-infective properties of essential oils, very few studies have explored the activity of individual oil constituents (e.g. linalool). The essential oil of *Bursera aloexylon* which contains high levels of linalool (96%) was shown to be effective against *Rhodococcus equi* (0.60 mg/mL) and *Staphylococcus epidermides* (0.15 mg/mL) [19]. The essential oil of *Croton cajucara* (linalool-rich chemotype) inhibits the growth of *Candida albicans*, *Lactobacillus casei, S. aureus, Streptococcus sobrinus, Porphyromonas gingivalis* and *Streptococcus mutans* cell suspensions. All of these pathogens are associated with oral cavity disease [20]. These results may provide some scientific evidence for the inclusion of linalool as an ingredient in several mouthwash and gargle products claimed to provide symptomatic relief of sore throats, mouth ulcers and tender gums. The effects of linalool on the cell biology of *C. albicans* were further studied by electron microscopy, which showed that linalool induced a reduction in cell size and germination [20].

The antimicrobial activity of linalool against various pathogens using the microtitre plate assay (minimum inhibitory concentration) method [4] indicates that linalool exhibits some degree of activity against *Escherichia coli* (MIC value: 51.9 μM) and *C. albicans* (MIC value: 38.9 μM).

Like most chemotherapeutic agents, linalool exhibits specificity for certain pathogens. Results from an *in vitro* assay (Ames with and without S9 activation) of linalool exposed to *Salmonella thyphimurium* strains (TA92, TA94, TA98, TA100, TA1535 and TA1537) showed that linalool was not capable of inhibiting the growth of this microbe [21-23].

The influence of (*R*)-(−)-linalool on airborne microbes when vaporized with an air washer has been reported. The average reduction in germ count was above 40% [24]. When water devoid of volatile compounds was applied, the colony forming units increased. These results show the positive effect of selected aromatic compounds (including linalool) on the reduction of airborne pathogens.

Various essential oils containing linalool have shown promising activity against *Plasmodium falciparum* [25,26]. However, the antiplasmodial activity of linalool as a single compound exhibited poor activity when tested *in vitro* on *P. falciparum* FCR-3 strain (IC_{50} value: 254.4 μM) using the ^{3}[H]-hypoxanthine incorporation assay [4]. Therefore it may be postulated that linalool probably may act in a synergistic manner with other essential oil components to inhibit the *in vitro* growth of the *P. falciparum* FCR-3 strain.

The *in vitro* leishmanicidal effects of *Croton cajucara* rich in linalool was investigated against *Leishmania amazonensis* [27]. The LD_{50} values for promastigotes were 8.3 ng/mL for the linalool-rich essential oil and 4.3 ng/mL for purified linalool, respectively and the LD_{50} values for amastigotes were 22.0 ng/mL, respectively for the essential oil and 15.5 ng/mL for purified linalool. Morphological changes in *L. amazonensis* promastigotes treated with 15 ng/mL of essential oil were observed by transmission electron microscopy. Leishmanial nuclear and kinetoplast chromatin destruction, followed by cell lysis, was observed within 1 h. Mouse peritoneal macrophages pretreated with 15 ng/mL of essential oil reduced the interaction between these macrophages and *L. amazonensis* by 50% [27].

5.2. Anti-oxidant activity: The anti-oxidant properties of essential oils have been of great interest in recent years. Their possible use as natural additives has emerged from a growing tendency to replace synthetic anti-oxidants with natural compounds [28]. *Cinnamomum osmophloeum* (Lauraceae) oil displayed the ability to scavenge the DPPH radical (IC_{50} value: 29.7 µg/mL) and this activity was correlated to the major compound, linalool (73%) [29]. Although, the anti-oxidant activity of essential oils has mainly been correlated with the presence of the major compounds in some plants (e.g. linalool), van Zyl *et al* [4] demonstrated that linalool as a single component has little anti-oxidant activity (IC_{50} value > 648 µM) against the DPPH radical.

5.3. Anti-inflammatory activity: Inflammation is the normal physiological response which occurs when the body is exposed to infective agents or to physical, or chemical change [30]. Some essential oils are used in aromatherapy for their therapeutic benefits such as their anti-inflammatory, anticancer and antiplasmodial properties. A number of linalool and linalyl acetate-producing species are used in traditional medicine systems to relieve symptoms and cure a variety of ailments, both acute and chronic [5]. Linalool-producing species have been reported to possess good anti-inflammatory activity and exhibit a peripheral analgesic effect [31,32]. These pharmacological activities were attributed to the content of alcohols such as linalool and its corresponding ester (linalyl acetate) [32]. Linalyl acetate is mentioned here as it is considered a pro-drug in the sense that this ester is metabolized to the alcohol. The inhibitory effect of (–) linalool, (±) linalool and linalyl acetate, on carrageenin-induced edema in rats was studied. (–) Linalool at a dose of 25 mg/kg body (wt), did not exhibit any activity 1 h after administration of carrageenin, but after 3 and 5 h, a significant inhibition of oedema (28%, P = 0.008 and 25%, P = 0.0004, respectively) was observed. The administration of higher doses (50 and 75 mg/kg body wt.) resulted in the higher inhibitory effect against oedema, which appeared 1 h after the carrageenin injection (58%, P = 0.008 and 60%, P = 0.006, respectively) [5]. (±)-Linalool at 12.5 mg/kg failed to produce any effect and exhibited a significant anti-oedematous effect (55%, P = 0.03) 1 h after carrageenin administration. At 50 and 75 mg/kg body wt the racemate however failed to produce any obvious effect 1 h after carrageenin induction, but displayed a positive effect after 3 h (51%, P = 0.03 and 38%, P = 0.02) and 5 h (45%, P = 0.01 and 34%, P = 0.04).

5.4. Anticancer activity: Cancer is a worldwide public health concern, with more than 11 million people being diagnosed with the disease every year. It is estimated that by 2020, there will be 16 million new cases annually [33]. Plants and plant products (including essential oils) have a long and established use to prevent or treat symptoms associated with cancer. Studies were conducted on cancer cells derived from eight human organs, using ten related pure compounds from common vegetables and fruits including linalool and flavonoids (e.g. luteolin) [34]. Linalool showed the strongest activity against a broad range of cancer cells, such as carcinoma of the cervix (IC_{50}: 0.37 µg/mL), stomach (IC_{50}: 14.1 µg/mL), skin (IC_{50}: 14.9 µg/mL), lung (IC_{50}: 21.5 µg/mL) and bone (IC_{50}: 21.7 µg/mL). In another study, the effects of linalool on tumor cells were investigated [35]. The results obtained confirmed that linalool inhibited tumor cells (CD_{50} = 82.3, 90.7 and 113.6 µ g/mL for A-549, HeLa e HT-29 cell lines, respectively), while linalool did not exhibit any cytotoxicity against non-tumor cells.

The chemopreventive activity of linalool was also studied using the 7,12-dimethylbenz[a]anthracene (DMBA) induced rat mammary carcinogenesis model. Rats were fed with a diet containing 1% linalool for a period of 20 weeks. A fortnight after the initiation of the dietary regimen, a single dose of 65 mg/kg DMBA in 0.5 mL sesame oil was administered to each rat by gastric intubation. Results showed no significant reduction in the total number of tumors and no significant extension of the tumors when compared to the controls [36,37]. The ability of linalool to inhibit large bowel and duodenal tumor formation using the azoxymethane-induced neoplasia in rats produced no significant decrease in adenocarcinomas of the duodenum [38]. Furthermore, no epidemiological or case reports investigating the association of exposure to linalool and cancer risk in humans have been identified [10].

Linalool has been examined for potential antimutagenic and antitumorigenic activity. It was not effective against the activity of 4-nitroquinoline 1-oxide in *Escherichia coli* strain WP2s at 200 ng/mL [39]. In *Drosophila melanogaster,* linalool had no effect on tumour expression in the melanotic strain, tu bw; +s-tu, but it caused retardation in development [40].

5.5. The effects of linalool on the central nervous system (CNS): The psychopharmacological activity of linalool in mice, showed marked dose-dependent sedative effects on the central nervous system. This includes protection against pentylenetetrazol, picrotoxin and transcorneal electroshock-induced convulsions, hypnotic and hypothermic effects [41-45]. A study was conducted using 40 different extracts including 9 essential oils, to observe their ability to decrease the motility of test animals [46]. Results showed that linalool decreased the motor activity (more than 60%) of 6-8 week old mice after inhalation (1 h).

Several plant species rich in linalool are used as anticonvulsants by practitioners of traditional medicine in the Brazilian Amazon [42]. Thus, it is not surprising that CNS depressant activity was observed with linalool. Various mental disorders have traditionally been treated with plant-derived natural products [47]. Using the Vogel and Geller conflict tests, Umezu *et al* [47] tested linalool which produced significant anticonflict effects in both the Geller and Vogel tests at 400 mg/kg. Thus, although linalool alone could not completely account for the anticonflict effects of lavender oil, it nevertheless could be a major contributor to the observed effects.

Studies have demonstrated that people with Alzheimer's disease have decreased brain levels of acetylcholine. The inhibition of the acetylcholinesterase enzyme favors the accumulation of acetylcholine. Therefore, an increase in the amount of acetylcholine may reduce mental decline in people with Alzheimer's disease and related conditions. The *in vitro* anticholinesterase activity of terpenes including linalool was examined and results indicated that linalool inhibited the acetylcholinesterase enzyme in a dose-dependent manner with 18% inhibition of the enzyme at a concentration of 0.5 mg/mL, while the inhibition by 1,8-cineole, α-pinene and β-pinene was higher than 50% at the same concentration [48].

6. The fumigant and insect repellent properties of linalool

There is growing evidence that many biological pesticides can adversely affect the environment and the identification of safer means of pest management has become crucial. Therefore, the use of safe, low toxicity botanical pesticides is now emerging as one of the prime means to protect crops, their products and the environment from pesticide pollution. Methods used to control insect pests include chemical and biological treatment [49,50]. Essential oils contain a variety of compounds which are known to aid the plants' defense mechanisms against plant enemies [51]. Herbs and their constituents as a source of alternative fumigants have been suggested by many contributors [52,53] and the insecticidal properties of numerous essential oils and some monoterpenes have been extensively studied on various insects [54,55].

Ecologically, insects (e.g. mosquitoes) are important components of the aquatic and terrestrial food chain. With respect to human well-being, mosquitoes pose a potential health risk as they may cause skin allergies, and are vectors of a number of serious diseases, such as malaria, yellow fever, dengue and West Nile Fever [56,57]. Despite prevention and protection measures to curb diseases transferred by mosquitoes, disastrous outbreaks still occur in Africa and the rest of the world often resulting in a humanitarian crisis.

Several aromatic plants are used as natural repellents in many African countries where traditional practices remain the first option of health [58]. In most of the aromatic plants studied, linalool, eugenol, geraniol and terpineol have been identified as contributing positively to the repellent action. Larvicidal assays were conducted to evaluate the LC_{50} and LC_{90} after 24 and 48 h of the essential oils and some of their major constituents against the seaside mosquito *Ochlerotatus caspius*. All tested oils proved to have strong larvicidal activity (LC_{50}: 15–156 ppm), with coriander fruit oil (which is rich in linalool) as one of the most potent oils [59].

An experiment to determine the fumigant toxicities of 10 monoterpenes against the mature mushroom sciarid, *Lycoriella mali* was conducted. The results indicated that the monoterpene linalool (LD_{50} value: 21.15 μg/mL) exhibited the highest toxicity [53]. Oxygenated monoterpenes (e.g. linalool), were also toxic to the rice weevil, *Sitophilus oryzae* [60].

Several monoterpenes (e.g. carvacrol, linalool, eugenol, thymol, cinnamaldehyde, α-pinene, camphor) when tested against *Acanthoscelides obtectus* (bean weevil) showed that linalool (log IC_{50} value: 0.5 mg/L) was the most toxic of all the compounds investigated [61]. Linalool was found to be highly effective and produced 100% mortality of *Rhyzopertha dominica* (lesser grain borer) and 85% mortality on the rice weevil (*Sitophilus oryzae*) after

24 h exposure at a concentration of 0.1 µl/720 mL [62]. Furthermore, studies demonstrated the toxicity of linalool towards *Tribolium castaneum* (rust-red flour beetle) and the saw-toothed grain beetle (*Oryzaephilus surinamensis*) in a dose-dependent manner [63].

Repellent effects of several pure compounds against the false powder post beetle (*Dinoderus bifloveatus*) were investigated and further experiments were carried out to isolate the toxic principles from the combined compounds. Linalool was one of the most toxic compounds to *D. bifloveatus*, resulting in mean mortality values > 50% within 24 h. Increasing the exposure period to 48 h led to higher mortality, particularly for less toxic compounds. The direct contact of linalool was largely responsible for the toxicity of this compound against *D. bifloveatus* [64]. In another study, five monoterpenoids (terpinen-4-ol, 1,8-cineole, linalool, *R*-(+)-limonene and geraniol) were tested in vapour form against different stages of the confused flour beetle, *Tribolium confusum* (eggs, larvae and adults) [65]. Linalool (LC_{50} values ranging between 8.6 and 183.5 mL/L air [65] was among the most toxic to all the stages tested.

7. Percutaneous absorption and penetration enhancement of linalool

Lavender oil was used to measure the transdermal absorption of its main components (linalool: 24.8% and linalyl acetate: 29.6%) in a male subject. Lavender oil (1500 mg) was softly massaged for 10 min into a 376 cm^2 area on the abdomen of a male volunteer and the blood samples were drawn at regular time intervals over a period of 90 min. The results indicated that linalool was absorbed quickly and trace amounts of linalool could be detected in the blood 5 min after the massage had been completed [66]. However, most of the linalool disappears from the blood in 90 min [67]. The concentration of linalool, one of the main constituents of this oil, was found to be about 130 ng/mL of plasma 20 min. after completion of the massage [68].

The effect of linalool as a skin-penetration enhancing agent in excised guinea pig skin was evaluated by assessing the depth to which Rhodamine B (active principle) penetrated the skin in the presence of 50% linalool. After 2 h, Rhodamine B was not detected in the epithelium and hair follicles and the conclusion drawn from the study was that linalool did not enhance skin penetration [69]. However, other studies have demonstrated that linalool could enhance the permeability of a number of drugs through biological tissues like skin or mucus membranes [70-72].

8. Toxicity, irritancy and allergenicity of linalool

In vitro studies have shown that linalool exhibited negligible toxicity against the kidney epithelial cells (Graham cells) (IC_{50} value: 128.5 µM) [4]. An investigation was conducted to assess the general toxicity of linalool in an immuno-toxicity assay [73,74], no toxic effects were recorded when female mice were given 94, 188 or 375 mg/kg of linalool for five days. A combination of linalool and citronellol (1:1) added to the diet of rats showed a slight retardation of growth (only in males) after 90 days and the measurements of haematology, clinical chemistry and urinalysis showed no significant differences between the test and the control groups. The conclusion drawn from the study was that the retardation of the growth in the male mice was biologically insignificant [75].

Linalool was evaluated for skin irritation in humans (approximately 380 male and female volunteers). No irritation was observed with the application of 20% linalool, however, mild irritation was observed with 32% linalool [76,77]. Studies have shown that, undiluted linalool was severely irritating to rabbits and slightly irritating to guinea pigs [40]. Linalool is, at most, a moderate eye irritant and does not cause any eye irritation at 320 ppm to approximately a third of human trial participants [2]. Therefore, linalool should be seen as only mildly irritant to man [2]. Various oral dosages of linalool (0, 250, 500 and 1000 mg/kg/day) were administered to pregnant rats [78]. The results showed no maternal deaths, clinical signs or lesions as a result of linalool intake and it could be concluded that linalool exhibits no developmental toxicant effects in pregnant rats [78].

Studies were carried out in order to determine whether the use of linalool has sensitization effects, using the lymph node assay [79]. The results indicated that linalool was not a protein-reactive compound, suggesting low sensitization potency of linalool [79]. In another sensitization study on guinea pigs [80], linalool of high purity produced no adverse reactions, while linalool that had been oxidized for a long period (10 weeks) sensitized the animals. Based on *in vivo* studies on mousse and rats, linalool presents low acute toxicity, orally and through the skin [2].

Clinical studies have demonstrated that linalool and specifically its oxidation products may be potential allergens [81]. For this reason the European Union legislation requires a labeling obligation for any product containing linalool at certain concentrations.

9. Concluding comments

Due to the abundance of linalool in nature and its occurrence as a major constituent in plants with an established history of use (e.g. lavender), this monoterpene alcohol has been extensively studied. Although it is the tendency to ascribe the biological activity of a complex mixture (such as an essential oil) to the main constituents this should be done with caution, as the role of minor constituents and the possible synergistic interaction between molecules cannot be ignored. Several studies have however confirmed the activity of linalool specifically and future investigations should explore the possible effect of stereochemistry, as linalool exists in two enantiomeric forms. A solid body of evidence has been generated to corroborate the various biological properties of linalool with the *in vitro* and *in vivo* results, with the proof of CNS effects providing most promising potential for treatment of disorders. The repellent properties of linalool together with negligible toxicity and low tendency to bioaccumulation, justifies further research to investigate the feasibility of linalool as a phytobiocide. Despite the positive results obtained in the various assays, the mechanism of action by which linalool (and essential oils in general) exert their specific action remains poorly explored and may prove to be a rewarding challenge to future researchers in this field of study.

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