Essential oils: an ecofriendly approach for plant pest and disease management

ABSTRACT

Recently plant essential oils received increasing attention for plant health and food security in the sustainable agriculture context. Essential oils are promising biological sources since they are cost-effective, biodegradable, and safe for human health and the environment. This review covers the essential extraction characteristic, extraction methods, and conservation needed for the scientist's and industries' knowledge. Furthermore, the main biological activities and involvement of essential oils in plant pests and diseases are outlined. Finally, this review concludes the potential commercial application and the future challenges of essential oils as an eco-friendly method in sustainable agriculture.

Keywords: Sustainable agriculture; Plant disease; Bioactive compounds; Essential oils.

1. INTRODUCTION

Essential oils are produced naturally by some plants and possess a large group of molecules known to perform a function in protecting plants against many phytopathogenic fungi [1]. Many of essential oils are known for centuries for their antioxidant, anesthetic and anti-septic properties and many have been reported for use in traditional medicine [2,3]. Essential oils are an important source of biologically active compounds (fungicidal, antibacterial, nematicidal, herbicidal, insecticidal, anti-inflammatory and antioxidant) [2-4].

Essential oils from plants have already found their place in aromatherapy [5], pharmacy, perfumery, cosmetics [6] and food preservation [7]. Their use is linked to their broad spectrum of biological activities or to specific targeting [2]. Despite this, investigations into the search for active principles of essential oils that can be used in the preservation of lignocellulosic products are still very sporadic [8].

An essential oil according to the pharmacopeia is a product of complex composition containing volatile principles contained in plants. According to the French Standardization Association (AFNOR), it designates a product obtained from a raw material of vegetable origin, after separation of the aqueous phase by physical processes: either by steam, by mechanical processes from the epicarp of plants containing citrals, or by distillation [5-8].

Essential oils are volatile, aromatic, oily liquids, concentrated and hydrophobic that come from various parts of plants [9]. Essential oils exist only in plants, they can be stored in all organs of aromatic plants (i) flowers: orange tree, rose, lavender, floral buds, etc. (ii) leaves eucalyptus, mint, thyme, laurel, savory, sage, etc. (iii) fruits: fennel, anise, epicarp of citrus, etc. (iv) stems: lemon grass, etc. (v) rhizomes and roots: ginger, vetiver, iris, etc. (vi) seeds: nutmeg, coriander, etc. (vii) wood and barks: cinnamon, sandalwood, rosewood, etc. [10]. Essential oils are generally terpenoids, responsible for the aroma and flavor associated with herbs, spices and perfumes, also called volatile oils because they spread easily into the air [11].

Thus, the present review focuses on collecting information and results from various studies on the properties of essential oils, and extraction methods, with emphasis on biological activities against phytopathogens, especially fungi. Furthermore, this review outlines the recent advances in future commercial application and the challenges of green pesticides based-essential oils.

2. CHEMICAL COMPOSITION AND PROPRIETIES

The chemical composition of essential oils is complex and results very often from a mixture that can contain from 10 to more than 200 constituents with very diverse chemical structures and chemical functions. The constituents of essential oils can be divided into two classes according to their biosynthetic pathway [11,13]:

(i) terpenoids (the most volatile, with low molecular weight), especially monoterpenes: (C 10) cineol, menthol, which sometimes make up more than 90% of the essential oil, and sesquiterpenes: (C 15) caryophyllene, humulene, although diterpenes (C 20) may also be present, in this group carbohydrates, phenols, alcohols, ethers, aldehydes and ketones, responsible for the antimicrobial activity as well as their perfumes [11,13].

(ii) the group of aromatic compounds represented by the phenylpropanoids is much less frequent, such as safrol, apiol, anisaldehyde eugenol, vanillin and cinnamaldehyde. It also contains organic acids, ketones and volatile coumarins are also found in low concentrations volatile coumarins [11-13].

The Essential oils form a very homogeneous group. Their main characteristics are:

*Liquid at room temperature,

*Volatile and very rarely colored,

*Low density for essential oils with high monoterpene content,

* A refractive index varying essentially with the content of monoterpenes and oxygenated derivatives. A high content of monoterpenes will give a high index; however, a high content of oxygenated derivatives will produce the opposite effect,

*Soluble in alcohols of high alcoholic strength and in most organic solvents but not very soluble in water.

*Highly alterable, sensitive to oxidation and have a tendency to polymerize giving rise to resinous products, it is then advisable to preserve them in the shelter of light and air [11-13].

3. EXTRACTION METHODS OF ESSENTIAL OILS

The extraction of essential oil is necessarily a complex and delicate operation. It aims, in fact, to capture and collect the most volatile, subtle and fragile products and the most fragile that elaborate the plant without altering their quality. To measure the difficulty of the undertaking, it is enough to keep the speed with which the plant is released, disappears, or the speed with which the fragrance of a flower, even of a flower, even the most fragrant, when the petals are crumpled. Once the waxy cuticle of the epidermal pockets is broken, the essence escapes and several odorant molecules are dispersed in the air [14].

Several methods are used for the extraction of essential oils. Traditional methods are the most used in the case of hydrodistillation or enfleurage or by innovative methods such as supercritical CO_2 extraction and microwave-assisted solventless extraction [15].

3.1 Hydrodistillation

This method consists of evaporating the essential oil by heating a mixture of water or other materials such as solvents with the plant, followed by the liquefaction of the vapors in a condenser vapor, this last step can be done without or with the return of water in the flask. The distillation of the plant is carried out either with an immersion of the plant in water or by direct injection of steam by placing the plant material on a perforated grid and not in contact with water [16].

3.2 Enfleurage

It is a complex method; it is no longer used except for flowers. These are spread delicately on greasy plates that will absorb all the perfume. A solvent will then, exhaust the fatty bodies. Once the aroma of the flowers is absorbed, other fresh ones replace the flowers, and this is until saturation of the fatty body. After 24 hours, the fat and essential oil are separated [14].

3.3 Supercritical CO_2 extraction

Supercritical fluid extraction (SFE) using carbon dioxide is a technique that can be used to obtain volatile extracts from plant matrices without any trace of solvent. Carbon dioxide is the most used supercritical fluid, particularly for the extraction of pharmaceutical and food compounds due to its chemical and physical properties and its relatively low critical temperature and pressure values (304 K and 7.38 MPa, respectively) [17]. SFE is a so-called "green" technique that uses little or no organic solvent and has the advantage of being much faster than traditional methods [14].

3.4 Microwave-assisted extraction

Microwave extraction consists in heating the extractant (water or organic solvent) put in contact with the plant under microwave energy which allows homogeneous heating. This new extraction process allows considerable time and energy savings [18].

3.5 Ultrasound extraction

Ultrasound extraction (UE) is a simple and effective method of extraction. The ultrasonic waves damage the cell wall, resulting in the release of the cell contents (including bioactive compounds) and heating of the liquid space. This sequence of events results in increased diffusion of the extracts. The use of UE reduces the consumption of chemicals, the extraction time and the degradation of the targeted components [14].

3.6 Incision extraction

This process is used very rarely. It is sufficient to split the bark of trees to collect the juice, such as the rubber tree [18].

3.7 Extraction by organic solvent

The "classic" solvent extraction technique consists in placing, in an extractor, a volatile solvent and the plant material to be treated. Thanks to successive washings, the solvent will be loaded with aromatic molecules, before being sent to the concentrator to be distilled at atmospheric pressure. The restrictive use of volatile organic solvent extraction is justified by its cost, the safety and toxicity safety and toxicity issues, as well as environmental protection regulations. However, yields are generally higher than with distillation and this technique avoids the hydrolyzing action of steam [14].

3.8 Cold expressions

The technique is reserved for the extraction of volatile essences contained in the pericarp of citrus fruits by tearing them by mechanical treatment. It consists in breaking or dilacerating the walls of the oleiferous bags contained in the mesocarp located just under the peel of the fruit, the epicarp, to collect the contents to collect the content that has not undergone any modification [14].

4. CONDITIONS OF CONSERVATION AND STORAGE OF ESSENTIAL OILS

In order to avoid any degradation that could alter the quality and effectiveness of essential oils, it is advisable to respect some simple rules of conservation and storage described below [3].

The essential oils being of unstable nature and sensitive to the phenomena of oxidation caused by light or heat, they must be kept in a sealed bottle, colored (brown or blue), of small volume, in a cool place (temperature lower than 20°C), protected from air and light. Plastic bottles are not recommended due to their high potential to be attacked by the constituents of essential oils. In order to limit as much as possible, the contact of the essential oils with the oxygen in the air, it is also advised to close well the bottle of essential oils after use [19].

5. MECHANISMS OF ESSENTIAL OILS ACTION

Several plant essential oils showed a broad spectrum of activities against plant pests and diseases. In addition, essential oils are responsible for the aromatic odor propriety of plants, which is important for attracting seed-pollinating insects. Furthermore, they play a defensive role against predators and diseases. This role is related to their antifungal [20], antiviral [21] and antibacterial [22] activity thus ensuring plant protection [2].

5.1 Antifungal activity

Most essential oils include monoterpenes compounds (10 carbon atoms) and sesquiterpenes (15 carbon atoms). Higher terpenes can also be found as minor compounds.

The oils are generally composed of complex mixtures of monoterpenes, biologically related phenols, and sesquiterpenes. Terpenoids are the primary constituents of the essential oils responsible for the aroma and flavor. Examples include 1,8-cineole, the major constituents of oils from rosemary and eucalyptus; eugenol from clove oil; thymol from garden thyme; menthol from various species of mint; carvacrol and linalool from many plant species [23].

The essential oil extracted from *Ocimum gratissimum* showed high thymol content followed by terpinene, p-cymene, carvacrol and linalool [24]. Prakash and Gupta [25] found that eugenol (1-hdroxy-2-methoxy-4-allyl benzene) is the active constituent in *O. sanctum*. Joy et al. [26] revealed that citral constituted 41.82% of the essential oil of *Cymbopogon citratus*. Azadiradione is known to have antifungal activity extracted from *Azadirachta indica* oil [27].

Cinnamaldehyde (major components of essential oil of *Cinnamomum zeylanicum*), eugenol (major components of essential oil of *Syzygium aromaticum*) [28], Citral (major components of essential oil of *Cymbopogon citratus*) and geraniol (major components of essential oil of *Cymbopogon martinii*) are known for their potent antifungal activity [28,29]. Linalool, a major component in the essential oil of *Thymus mastichina*, has antimicrobial activity [30].

The biological assay showed that the fungitoxic of *Thymbra spictata*, *Satureja thymbra*, *Saliva fruticosa*, *Laurus nobilis* and *Origanum minutiflorum* against *Fusarium moniliforme*, *Rhizoctonia solani* and *Phytophthora capsici* due to the phenolic fraction, especially thymol and carvacrol. The antifungal activity of peppermint essential oil is probably due to the presence of menthol and carvone [20,30,31].

Compounds of essential oils represent an eco-friendly and bio-safe alternative to increase agricultural productivity and to maintain the pathogen population under economic injury level [32]. Singh et al. [31] stated that the essential seed oil of *Anethum graveolens* was found to be highly effective for the management of the growth of *Penicillium citrinum*, *F. graminearum* and *Aspergillus niger*. Silva et al. [33] and Bhuyan et al. [34] reported the essential oils of *Allium sativum*, *S. aromaticum*, *Vernonia polysphaera* and *Cinnamomum impressinervium* were active against the mycelial growth and conidial germination of *F. oxysporum* f.sp. *radicis-lycopersici*, *F. moniliforme*, *Colletotrichum gloeosporioides* and *Alternaria alternata*. Naveenkumar et al. [20] investigated the *in vitro* and *in vivo* antifungal activity of three essential oils (at 0.1% concentration) viz., *Cymbopogon citratus*, *Cymbopogon martini* and *Pelargonium graveolens* against *Curvularia lunata*, *Fusarium moniliforme*, *Helminthosporium oryzae* and *Sarocladium oryzae*. Naveenkumar et al. [35,36] had reported the antifungal activity of *Cymbopogan citrates*, *Pelargonium graveolens* and *C. martinii* against *Fusarium oxysporum* f.sp. *niveum* (at 0.02% concentration) under laboratory and greenhouse assays. Matrood and Rhouma [37] identified that *Ocimum sanctum* aqueous plant extracts seemed to be the most effective under laboratory conditions with mycelial inhibition rate above 82%. The same authors pointed out that in greenhouse experiments, the treatment of eggplant leaves with *O. sanctum* and *Justicia adhatoda* aqueous plant extracts generated the highest damage reduction and the strongest activity of catalase and peroxidase, superoxide dismutase, polyphenol-oxidase, total phenolic content and total sugars [37].

5.2 Antiviral activity

Essential oil as well as different molecules found in essential oils may have antiphytoviral activity [21,38-40].

5.3 Anti-bacterial activity

The antibacterial activity of essential oils is mainly a function of their chemical composition; in particular, their major volatile compounds [41]. Due to the variability of the components of essential oils, it is likely that their antimicrobial activity is not attributable to a single mechanism, but to several sites of action at the cellular level [12]. The mode of action of essential oils depends primarily on the type of the characteristics of the active components, in particular their hydrophobic property which allows them to penetrate the phospholipid double layer of the bacterial [12,41]. The membrane of the bacterial cell induce a change in membrane conformation, a chelo-osmotic disturbance and an ion leak (K+): this mechanism was observed with tea tree oil on the bacteria Gram+ and Gram-, and yeast under *in vitro* conditions. Essential oils can also inhibit the synthesis of DNA, RNA, proteins, and polysaccharides. In general, Gram-bacteria are more resistant than Gram+ thanks to the structure of their external membrane. Antibiotic targets are involved in the physiological or metabolic functions of the bacteria [4,12,41,42]. Badawy and Abdelgaleil [43] showed that the essential oil of *Thuja occidentalis* revealed the highest antibacterial activity among the eighteen tested essential oils on *Agrobacterium tumefaciens* and *Erwinia carotovora* var. *carotovora*. The essential oils of *Tagetes minuta* revealed promising antibacterial activities against *Pseudomonas savastanoi* pv. *phaseolicola*, *Xanthomonas axonopodis* pv. *phaseoli*, and *X. axonopodis* pv. *manihotis in vitro* and *in vivo* conditions [44]. Proto et al. [22] found that the essential oil of *Origanum compactum* (at 0.03% v/v) showed resistance induction in tomato plants against *Xanthomonas vesicatoria* infections. The same authors noted that the essential oils of *Origanum compactum* and *Thymus vulgaris* resulted in being the most effective against *Erwinia amylovora* under in laboratory conditions.

5.4 Other activities

Some essential oils are insect repellents or insecticides like those with aldehyde functions such as citronellal contained in lemon Eucalyptus or lemongrass [45]. Bossou et al. [46] found the efficacy of nine plant species (*Cymbopogon citratus*, *C. giganteus*, *C. schoenanthus*, *Cochlospermum planchonii*, *Co. tinctorium*, *Eucalyptus citriodora*, *E. tereticornis*, *Chenopodium ambrosioides* and *Securidaca longepedunculata*) against *A. gambiae* bites. Insecticidal bioassay showed that *Carum carvi*, *Daucus carota* and *Petroselinum crispum* essential oils caused 90% of exposure mortality, while, *Cuminum cyminum* and *Foeniculum vulgare* essential oils had induced 100% of larval mortality [47].

The formation of free radicals is a continuous and evolving process. These molecules play a vital role in cell signaling, vascular tone control, and defense against microorganisms, cell generation and regulation of homeostasis [48]. However, when there is an excess of free radicals, there active oxygen species (ROS) also participate in pathogenesis related to DNA and protein damage causing gene modifications and protein mutations, glucooxidative protein mutations, glucooxidative damage and degradation of cell membrane lipids (*Carochaea*) [41,49]. It has been shown that in vitro essential oils have an antioxidant capacity by converting free radicals into stable products and by inhibiting the degenerative activity of certain skin enzymes [50]. The polyphenolic substances of properties are their ability to best described in all groups of phenolic compounds is their ability to act as an antioxidant. The antioxidant activity of phenols depends on the arrangement of functional groups around the nuclear structure, the configuration, substitution, and the total number of hydroxyl groups that significantly influence the different antioxidant effects of radicals and antioxidant effects of radicals and metal chelation [51,52].

Ruberto and Baratta [53], who studied the antioxidant activity of 98 pure components of the essential oil of *Teucrium marum*, representing the main classes of compounds typical of essential oils, showed that sesquiterpene hydrocarbons exerted a weak antioxidant effect, while monoterpene hydrocarbons showed a significant antioxidant effect, with several variants due to the different functional groups [54]. Teixeira et al. [10] described that the high antioxidant activity of Indian clove essential oil is due to its majority compound eugenol which is a phenylpropanoid, known as a powerful antioxidant.

The antiradical effect of the essential oil could be due to the presence of a high proportion of phenolic compounds. It is reported that phenolic compounds can give a hydrogen atom to free radicals stopping the chain reaction of propagation during the process of oxidation of lipids. The antioxidant gives up a hydrogen radical, which can be an electron transfer of electrons followed, more or less quickly, by a transfer of protons, to give a stabilized radical intermediate [55,56].

An anti-inflammatory effect has been described for many essential oils. The essential oil of the roots of *Carlina acanthifolia* is able to inhibit inflammation induced by carrageenan injection in rats. *Myrciaria tenella* and *Calycorectes sellowianus* oils were able to dramatically decrease the carrageen an induced paw edema. The essential oils of *Cinnamomum osmophloeum* leaf have excellent anti-inflammatory activities and thus have great potential as a source of natural health products [57,58].

The biochemical families with anti-inflammatory and/or analgesic action which constitute the compounds of various essential oils are monoterpenic aldehydes, terpenic esters, sesquiterpenes and monoterpenes, eugenol (aromatic phenol), eucalyptol (terpenic oxide) or 1,8 cineole, terpenic alcohols terpenes (Sesquiterpenols, Monoterpenols), terpene ketones, and phenol methyl- ethers [57-59]. The activity of anti-inflammatory may depend on the composition and the ratio of the compounds of the essential oil [58].

6. APPLICATION, AND COMMERCIALIZATION CHALLENGES

Fungicides are indispensable to worldwide food security and plant health. Due to the legislation towards the harmful effect of synthetic fungicides and the growing concern about sustainable and organic farming systems, the move to green pesticides based on natural products is an excellent alternative for developing new crop protection tools.

essential oils-based pesticides are approved in different studies as efficient to control several plant pests and diseases. However, their application faces different constraints such as theirhigh volatility and low stability, low water solubility, a strong influence on organoleptic properties, and phytotoxic effects. Therefore, the main challenges of the widespread application of essential oils are to determine the mode of action and the appropriate formulation. In fact, the development of appropriate essential oils formulations and methods of incorporation optimizes the effectiveness and minimizes the high volatility for better introduction in-field [9].

Among the essential oils application challenges are their degradation and oxidation caused by their high sensitivity to light radiation, and high temperature [60]. In addition, the phytotoxic effects of essential oils are a limiting factor of their application, since they are a complex mixture of biologically active molecules and they are able to exert broad-spectrum effects on microorganisms at the same time, including some non-target beneficial species [61].

7. CONCLUSIONS

Despite the promising effects of essential oils approved in several scientific reports, authorized commercial essential oils-based pesticide formulations available on the market are very limited.

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