International Journal of Chemical and Biochemical Sciences
(ISSN 2226-9614)

Journal Home page: www.iscientific.org/Journal.html

Risks Associated with Adulterated Essential Oils

Asma Shakeel, Ayesha Mushtaq, Reeda Shakeel*

Department of Chemistry, University of Agriculture Faisalabad, Pakistan

Abstract

Essential oils are natural products that are utilised extensively in a variety of industries around the world and have assimilated into daily life. Essential oils are in higher demand, which has led to instances of adulteration. Therefore, authentication is a crucial issue for both customers and chemical corporations. The chemical makeup of commercial essential oils, their uses, their botanical origin, allergic contact dermatitis and contact allergies caused by these essential oils are some of the topics covered in this article. EOs are frequently being used in the food businesses. The adulteration of essential oils is a common practice in the industry, whereby synthetic or low-quality oils to increase profits. Adulterated oils may not have the same chemical compounds as pure essential oils, which are responsible for their healing properties. They may also contain chemicals that are harmful to the body, leading to long-term health problems. Vegetable oils (VOs) must be taken into account among the potential adulterants due to their qualities and affordability. This in-depth analysis covers known contaminated essential oils and the dangers they pose.

Keywords: Essential Oils, adulteration, authentication issues, chemical composition, allergens

Full length article **Corresponding Author*, e-mail: hirar043@gmail.com

1. Introduction

Essential oils are natural, volatile, complex compounds having powerful aroma. These oily liquids are secondary metabolites produced by several aromatic plants and are stored in secretory cells in their buds, flowers, leaves, stems, twigs, seeds, fruits, roots, wood, or bark. EOs are produced from aromatic plants, which are primarily found in temperate regions like the Mediterranean, as well as in tropical regions [1-2]. Due to rising essential oil demand, there have been instances of adulteration.

Adulteration is the act of contaminating or polluting a substance by adding an inferior element or substance, with the intention of reducing its value or quality, particularly for purposes of sale. This can involve replacing more valuable components with cheaper or inert ones [3-4]. There have been studies on about 17,500 aromatic plants. However, there are barely 300 commercial essential oils in use, and their bulk worth was estimated to be $1 billion in 2013. The majority of the raw materials used to make commercial essential oils come from cultivated sources [5].

Additionally, a lot of the raw materials aren't extracted or distilled right where they were cultivated or gathered. Aromatic plant populations in the wild can be homogeneous or diverse. The quantitative composition and essential oil output of different population members can vary. However, there are more complex variances in oil composition in commercial oils than what was just mentioned [6].

To boost revenues or satisfy a specific ISO criterion, essential oils are frequently adulterated by the addition of synthetic and natural substances, both related to and unrelated to the composition of the oil [7]. In light of this, the economic incentive is the root cause of adulteration. About 60,000 publications about food adulteration are available on PubMed [8-9].There have been numerous reports of natural remedies being contaminated with synthetic medications. The research conducted by Huang et al. in 1997, demonstrating the patterns of adulteration in Chinese medicine, discovered that 24% of 2,609 samples contained at least one sort of adulterant [10-11].

Essential oils (EOs) adulteration is a major issue in today's worldwide markets, and non-institutional people or businesses are the ones that commit this illegal and immoral act by adding lower-quality, less expensive ingredients to high-value EOs. This dishonest strategy not only poses a health risk to people who purchase contaminated goods but also poses substantial economic risks to governments [12-13].

2. Commonly used instruments for adulteration detection and their limitations

Adulteration in essential oils can be found using a variety of analytical tools [6]. Standard gas chromatography with flame ionization detection (GC-FID) and gas chromatography-mass spectrometry (GC-MS) [14], Natural isotope fractionation NMR at specific locations (SNIF-NMR) [15], mass spectrometry using gas chromatography and isotope ratios (GC-IRMS) [16], chiral GC-MS and components ratio quantification (enantioselective) are famous techniques for the detection of adulteration [17].

The isotopic ratio measurement method, known as GC-IRMS, is frequently used to establish the validity of an

essential oil's place of origin. However, this method has some drawbacks. The first drawback is that the addition of 14C-labeled molecules can change the 14C activity of essential oil. Second, GC-IRMS cannot detect synthesized chemicals based on natural precursors. As a result, GC-IRMS is not a 100 percent trustworthy source for authenticating essential oils [18]. As it only applies to chiral molecules and the enantiomeric ratio of chiral substances changes from origin to origin, enantioselective or chiral GC-MS also has special limits [19]. It is not possible to detect adulteration in essential oils using only a GCMS compound library search; you must explain why some molecules emerged while others did not. Since essential oils also contain sesquiterpenes and diterpenes, SNIF-NMR cannot be used to identify the origin of tiny molecules (such as monoterpenes) using the deuterium ratio. This technique also needs pure separated chemicals [6-20].

Essential oil adulteration may also be indicated by minor components and their quantities to main components. Every adulterant, whether artificial or natural, contains some sort of impurity or marker. A more reliable method of spotting adulteration in essential oils is to identify the distinctive characteristics of each adulterant [21] [22]. The number of studies on biomarkers or synthetic markers that have been published is currently insufficient to provide tools for adulteration detection. Additionally, Marco Valussi notes in his book that using traditional analytical methods, adulteration of up to 5–10% is undetected [23-24].

3. The Authentication Problem

Several things might cause essential oils to be adulterated. Falsification is sometimes characterized by the use of less expensive synthetic materials or volatiles derived from other natural sources [25], veggie oils to make you heavier. Another method of adulteration is the partial or complete replacement of the original plant with another plants [26], or the inclusion of items that are not volatile. All of these adulteration techniques have the potential to reduce quality, and by introducing one or more synthetic components, they may also compromise safety or fall short of the natural grade. As a result, the problem of verification is crucial for consumer's safety [27]. To prevent being identified by common analytical methods, adulterants are often supplied in low amounts (5-8%) [28-29].

3.1. Common methods of adulterations of essential oils

Standardization of essential oils and control techniques are intended to verify that essential oils meet monographs or other quality requirements, even though non-compliance does not necessarily result in adulteration. As an illustration, aging, processing or storing can cause chiral compounds to racemize or terpenoids to polymerize, which can cause the optical activity values to deviate from specification without being adulterated [30-31]. Adding non-volatile components, synthetic or natural substances or less expensive essential oils are a few examples of known adulterations. These adulteration techniques may reduce the oil's quality and have detrimental impacts on customers [32].

3.1.1. Addition of other products: oil and solvents

Due to their high volumes and turnover, essential oils are occasionally diluted by increasing the non-volatile component to decrease the cost; including mineral or vegetable oils due to their affordable price, their simple accessibility, being nearly as dense as essential oils, and similar to the oily texture of essential oils [33], [34], [32]. The outcome of this type of adulteration is dilution, which decreases the essential oil's aroma. This kind of adulteration just results in dilution, which reduces the aroma of the essential oil [35-36]. In research on kerosene, coconut oil, or lemongrass oil was found to be adulterants [37-38]. Sandalwood oil mixed with polyethylene glycol is an additional illustration of this type of adulteration [37-39]. Triacetin, triethyl citrate, benzyl alcohol, ethyl alcohol, and, for aromatherapy, plant oils like almond oil, are additional solvents that could be employed [40-41].

3.1.2. Addition of specific compounds: synthetic and natural

Essential oil standardization refers to values with low or high limitations for the number of particular components. Commercially available essential oils must adhere to these requirements [42-43]. As a result, instances of adding a compound natural, artificial, or both—can be identified. Natural chemicals are created directly from natural sources through enzymatic, microbiological, or physical processes [44], [28]. Those specific types of adulteration might be committed for a variety of reasons. One reason is to raise the compound composition quality of the essential oil. The purpose of this type of adulteration is to boost the utility of essential oils and to satisfy consumer demand [45-46], [26], [47].

For instance, the Iris oil with 8% iron costs 6200 euros per kilogram, while the cost rises to 9750 euros per kg at 10% iron and even reaches 101,000 euros per kg for pure iron. A good incentive for the adulterating oil of iris is the price differential, especially given that a blend of synthetic - iron and –iron isomers only costs about 25 €/ml. Linaool, linalyl acetate and vetiver oil are added to Bergamot and Lavender oils to improve olfactory essence of these oils [25-32]. Sometimes essential oils are utilized for their therapeutic effects [48-49]. Therefore, they are modified by adding substitute oils that have the appropriate bioactive component(s), such as chamomile oil, which is utilized for its -bisabolol content that could be changed with artificial bisabolol [25-50].

3.1.3. Addition of another essential oil

Olfactory and/or financial considerations may be the driving forces behind the inclusion of another essential oil. To achieve this, a lesser-quality essential oil with comparable olfactory notes may be added [46-51]. This is especially true when the cost of the two oils differs significantly. Adding sweet orange essential oil (the least expensive citrus oil), to citrus essential oils results in adulteration. Another common example is a lavender essential oil, which may cost up to 130 euros per kg and can be combined with essential oils from other Lavendula species that cost about 20 euros per kg [25-52]. A low-yielding, highly prized essential oil called lemon-balm essential oil, with pronounced therapeutic potential, could be combined with inexpensive citronella oil [53-54].

Adulteration can be done by combining several essential oils derived from the extraction of various portions of the same plant. To lessen the number of allergens like

cinnamaldehyde, cinnamon bark essential oil can be diluted with leaf cinnamon essential oil. While decreasing the allergenic effect, this sort of scam can also boost volume and profit [55-56]. Another well-known adulteration involving all citrus oils is the inclusion of orange essential oil [57] [25].

4. Motivating Factors for Adulteration

4.1. High Acceptance

Due to the high level of consumer acceptability of adulterated essential oils and their constituents, interest in them is rising. There are about 3000 different essential oils, 300 of which have significant commercial value, particularly for the medicine, food, sanitary, cosmetic, and perfume industries [58].

4.2. Low Price

The desire to purchase cheap oils is one of the main motivators. Since some oils must be produced using expensive raw materials, a lot of effort, and significant capital, they will undoubtedly have a price margin. If the buyer wants to get anything for a bargain, the provider will undoubtedly have to adulterate in order to stay in business.

4.3. Dishonest Profit

The essential oil business is growing quickly, bringing in billions of dollars annually, but sadly, this has led to adulteration for unfair gains.

4.4. Aroma

Adulteration is also performed to enhance the aroma of essential oils. To create a genuine scent, several synthetic fragrances are applied in very small amounts. Many essential oils are utilised to enhance the aroma, for instance, galaxolide, ethyl vanillin, cyclamen aldehyde, etc.

5. Risks associated with Adulterated Essential Oils

5.1. Lavender oil

Lavender (*Lavandula angustifolia*) plant is the source of lavender essential oil. Lavender oil is regarded as having carminative, ataraxy, antianxiety, antiseptic, antimycotic, aphrodisiac, hypnotic, anesthetic, and other beneficial qualities in traditional herbal medicine [59]. The chemical composition of lavender essential oil is as follows (Table 1);

5.1.1. The Allergens in Lavender Oil

Research on allergies associated with lavender oil is lacking. In numerous case studies, the patients with lavender oil allergy have shown +ve patch test for linalool (a component of lavender oil) and is the major allergen in lavender oil. Caryophyllene is another lavender oil component that can occasionally induce allergic responses [60].

5.1.2. Dermatitis from Allergic Contact

Oil of fresh lavender probably has very little allergenic potential. Linalool, the main component of lavender oil, and linalyl acetate lack natural protection against oxidation, and when exposed to air, powerful contact allergens, including hydroperoxides of linalool are created [61]. In the past, Japanese women's pigmented cosmetic dermatitis was frequently triggered by lavender oil [62]. There have been a few isolated reports of lavender oil photo contact allergies [63].

5.1.3. Reports of Lavender Oil Sensitivity

After using lavender oil in cosmetics, medications, and other products [60] 24 instances of contact hypersensitivity in Belgium were found in the reports of lavender oil sensitivity to topical medicine formulations [64]. In 2 instances, an allergy to lavender oil resulted in topical antihistamines causing allergic contact dermatitis [60] [65].

`A patient who was allergic to lavender oil and two additional goods (jasmine absolute and rosewood oil), which are released into the air as an aerosol by aromatherapy lamps, also experienced airborne contact dermatitis. Linalool, an essential component of all three oils, also caused the patient to respond negatively. Lavender oil have been linked to allergic contact dermatitis in five aromatherapists [66-67]. There have been three instances of allergic contact dermatitis among massage therapists, physiotherapists, and reflexologists due to occupational allergies to lavender oil [68]. Having occupational hand contact dermatitis, a hairdresser acquired a contact allergy to a workplace shampoo that contained lavender oil [69].

5.2. Peppermint oil

The flowering aerial parts and leaves of the peppermint plants are used to make peppermint oil, also known as peppermint essential oil. In Europe, Mentha piperita oil is known by the INCI name, whereas in the US, M. piperita (peppermint) oil is known by the INCI name. Europe as a whole, except the Scandinavian countries, Canada, and the US, has adopted peppermint as a native plant, including the Azores, Australia, New Zealand, and Siberia. The herb Mentha piperita is frequently employed in medicine. It is known by the specific name "piperita" because it possesses a strong, peppery, poignant smell. Peppermint is frequently used to relieve or cure gastrointestinal symptoms such as nausea, vomiting, indigestion, bloating, and abdominal discomfort [70-71].

There are several medicinal uses for peppermint essential oil. It is one of the most principal oils used externally to treat muscular spasms, discomfort, neuralgia, headaches, and toothaches because of its vasoconstrictive and cooling qualities. Additionally, it is frequently taken orally to treat intestinal problems, nausea, and upset stomach. Additionally, popular uses for peppermint and its oil include perfumes, other cosmetic items, the tobacco industry, chewing gum, cough drops, sweets, alcoholic beverages, toothpaste, and mouthwash [72].

5.2.1. Chemical Composition of Commercial Peppermint Oils

Gas chromatography/mass spectrometry (GC/MS) analysis of 157 samples of peppermint essential oil from various nations was performed between 1998 and 2013 by one of us (E.S.). The following 10 compounds were found to have the highest possible concentrations [60].

5.2.2. Chemotypes

Menthol, menthone, and/or related compounds, such as iso-menthone, predominate in nearly all peppermint oils. However, up to 60% linalool or up to 72% linalyl

acetate been identified in significant proportions containing menthol or menthone in small or absent amounts in some studies [73]. It is currently unknown whether this is a particular chemotype or an error (incorrect identification of a plant), such as the fact that the plant under investigation was Menthacitrata rather than M. piperita (bergamot mint, which is reported to be abundant in linalyl acetate and linalool), even though their smells should be very different. We tend to think that this is a botanic misidentification.

5.2.2. Allergens present in the Peppermint Oil

As the major element in commercial oils with doses of 23% to 48% is likely menthol, which interacts in 13 patients with peppermint oil. 5 Other potential allergens that may be present in amounts greater than 5% and have demonstrated interactions with peppermint oil include >-pinene, limonene, caryophyllene, piperine, and pulegone [60].

5.2.3. Contact Allergy/Allergic Contact Dermatitis

Peppermint oil in toothpaste has been linked to stomatitis and cheilitis. It has been noted that contact allergies to peppermint oil in candies, a mouthwash, and a disinfectant spray employed in dentistry can cause swelling of the tongue, lips, and gingival mucosa. Those with allergies to Myroxylon pereirae and propolis [74] .

5.2.4. Cases of Pepermint Oil Contact Dermatitis

Occupational allergy reports leading to contact dermatitis and allergies to peppermint oil, reports on contact dermatitis from other cosmetics, reports of peppermint oil contact dermatitis in other items, and more. Toothpaste containing peppermint oil has been linked to stomatitis and cheilitis [75]. Due to a contact allergy to peppermint oil included in dental antiseptic spray, mouthwash, and sweets, swelling of the tongue, lips, and gingival mucosa has been noticed [76]. Patients with lichenoid mucosal reactions (n = 2), recurrent oral ulcers (n = 2), and burning mouth syndrome (n = 2) were found in six cases of allergic reactions to peppermint oil; patients responded to menthol as well. Although the root reasons for the peppermint oil reactions were not found, they were thought to be important [77].Due to peppermint oil in a lip balm, four individuals experienced allergic contact dermatitis of the lips (allergic contact cheilitis) and the perioral area [60]; A skin care product containing peppermint oil exposed one patient to it. [78]. One in depilatory products, and another [79]. Peppermint oil has been linked to occupational allergic contact dermatitis in two aroma therapists and food handlers [60].

5.3. Ylang-ylang oil

Ylang-ylang tree produces the essential oil known as ylang-ylang oil. Its INCI designations are Cananga odorata flower oil in the EU and the US. Not to be mistaken ylang-ylang oil is cananga oil, which is produced from the macrophylla form of C. odorata (Lam.). These oils are frequently used improperly as synonyms and were formerly believed to be identical. Especially in early scientific publications, there is a chance that the oils of ylang-ylang and cananga have been combined. For the creation of expensive scents, the first fractions are the most valuable [60].

Its blossoms are incredibly fragrant and bloom all year long Malaysia and Indonesia are Canada's original countries, although it has since become a part of northern Australia, Thailand, and Vietnam [60]. Oil of ylang-ylang is utilized in numerous cosmetic products, including soaps, lotions, and detergents, in addition to exquisite (floral) perfumes. Additionally, the oil can be used to flavor baked items, ice cream, candy, and chewing gum. According to claims, ylang-ylang oil can be used in aromatherapy to treat depression, respiratory issues, and hypertension in addition to being utilized as an aphrodisiac. The oil is used in folk medicine as a sedative and antidepressant, as well as a cure for a variety of diseases as skin disorders, insect bites and high blood pressure as well as other ailments [60].

5.3.1. Chemical Composition of Commercial Ylang-Ylang Oils

Between 1998 and 2013, GC/MS was used to examine 127 samples having different grades of ylang-ylang essential oil. The following 12 compounds (concentration ranges indicated) had the highest possible concentrations [60].

5.3.2. The Allergens in Ylang-Ylang Oil

Nothing has happened enough research done on the potential allergens in ylang-ylang oil. Caryophyllene and linalool might have been the allergen [66]. In earlier Japanese research [80] [81] Patients with ylang-ylang oil contact allergies frequently demonstrated core activity to benzyl salicylate both to geraniol, which can be found in such oils in quantities as high as 2.0% and which is present in ylang-ylang oil products in amounts as high as 4.7% [60].

5.3.3. Contact Allergy/Allergic Contact Dermatitis

In Japan, cosmetic dermatitis with pigmentation brought on by ylang-ylang oil was once a widely used sensitizer. The eradication of dihydro isoeugenol, this oil's primary sensitizer, in the 1990s is thought to be the cause of the decrease in the frequency of allergies to this oil [82].

Yet incidences of ylang-ylang oil-related pigmented cosmetic dermatitis are still being documented nowadays [83]. Coreactivity with carangoid occurs frequently, likely because of similarities in their compositions [84]. Additionally, ylang-ylang oil has been linked to numerous instances of favorable patch test results, typically in people who had previously reacted negatively compared to other perfumes and essential oils.

5.3.4. Reports of Allergic Contact by Ylang-Ylang Oil

Case studies or reports of allergic contact dermatitis brought on by ylang-ylang oil of which occupational exposure to the oil was the cause in 11 cases: 8 in masseurs/aroma therapists [84] [85]), 2 more people work in the cosmetics sector [86] [87] and one in a beauty parlour [88]. Ylang-ylang oil in topical pharmacological formulations sensitized two individuals, [60] and the perfume in an eye ointment caused allergic contact dermatitis in one individual. She reacted to 11 different substances, including ylang-ylang oil in the perfume after being patch tested with all 94 of its ingredients [89].

Table 1. Chemical composition of lavender essential oil [60].

Compound	Concentration
Terpinen-4-ol	0.07-5.9%
(Z)-A-ocimene	0.3-7.3%
Linalool	26.0-44.8%
Linalyl acetate	26.1-43.3%
A-Cyropyllene	1.8-5.9%
Lavandula acetate	0.4-6.3%
(E)-A-ocimene	0.7%

Table 2. Chemical Composition of Commercial Peppermint Oils

Compound	Concentration
Menthol	23.0-47.9%
Menthone	10.6-38.5%
Limonene	0.3-18.5%
Iso menthone	2.2-10.6%
1,8-cineole	0.3-9.9%
Alpha-pinene	0.06-9.7%
Menthyl acetate	0.5-7.7%

Table 3. Chemical Composition of Commercial Ylang-Ylang Oils

Compound	Concentration
Geracrene D	11.7-26.4%
A-carophyllene	3.6-18.8%
Benzyl acetat	0.3-16.95
Benzyl benzoate	2.7-14.0%
Linalool	0.1-13.5%
Geranyl acetat	0.8-11.8%
p-cresyl methyl ether	3.5-11.4%
Methyl benzoate	0.8-6.05

Table 4. Concentration ranges

Compound	**Concentration**
Geranial	41.8-46.3%
Neral	30.3-33.3%
Geraniol	3.0-7.9%
Limonene	0.4-5.0%
Geranyl acetate	1.0-4.3%
A-caryophyllene	0.4-3.0%
Citronellal	0.2-1.9%

Table 5. Chemical composition of commercial TTOs

Compound	**Concentration**
p-cymene	0.3-19.45
Cis-sabinene	19.4%
1,8-cineole	0.5-18.3%
Terpinene	2.3-11.7%

Table 6. Chemical Composition of Commercial Australian Sandalwood Oils

Component	**New Caledonian Oils**	**Australian Oils**	**East Indian Oils**
(Z)-trans->-Bergamotol	5.0-8.6	1.0-8.9	4.5-8.6
Beta-Bisabol	0.6-2.9	---	---
A-Bisabolo	0.2-1.1	0.4-1.2	---
(E,E)-Farneso	0.9-1.7	1.4-18.4	---
(Z)-Lanceol	5.0-15.2	0.8-10.8	---
(E)-Nucifero	0.6-2.6	3.9-9.1	0.3-2.9
(E)-Nucifero	---	0.6-10.7	---
(Z)-alpha-santalol	38.6-46.6	17.0-42.9	43.4-53.3
(Z)-beta-Santalol	0.2-0.9	0.2-1.3	0.5-2.0
(Z)-beta-santalol	13.2-19.2	6.4-17.7	15.6-23.6
epi-beta-Santalol	2.2-4.4	2.0-3.7	3.2-6.6

Table 7. Chemical Composition of Commercial Jasmine Absolutes

Component	CAS	Concentration range	
		Jasminum Grandiflorum Absolute	Jasminum Sambac Absolute
Benzyl acetate	140-11-4	9.5%-32.9% (1)	10.5%-21.0% (2)
Bezyl benzoate	120-51-4	7.5%-25.6% (2)	0.5%-1.9%
(E)-Phytol	150-86-7	4.1%-16.9% (3)	0.08%-0.3% (phytol)
(Z)-Phytol	5492-30-8	0.2%-13.3% (4)	0.08%-0.3% (phytol)
Isophytol	505-32-8	0.4%-11.3% (5)	---
Phytyl acetate	10236-16-5	1.4%-11.0% (6)	---
Geranyllinalool	77368-82-2	1.1.%-10.2% (7)	0.8%4.4%
Linalool	78-70-6	0.06%-8.1% (10)	11.5%-34.2% (1)
Squalene 2,3-oxide	7200-26-2	0.8%-3.3%	---
Methyl benzoate	93-58-3	0.8%-2.3%	0.2%-0.7%
(E,E)-alpha-Farnesene	502-61-4	0.2%-3.7%	10.6%-17.1% (3)
(Z)-3-Hexenyl benzoate	25152-85-6	1.7%-5.3%	3.9%-14.9% (4)
1 H-Indole	120-72-9	---	0.9%-12.2% (5)
Methyl linolenate	301-00-60	---	0.4%-8.6%(6)
[1(10)E,5E]-Germacradien_4alpha-ol	207221-31-6	0.5%-3.7%	0.9%-7.6% (7)
Methyl anthranilate	134-20-3	---	0.5%-7.6% (8)
Benzyl alcohol	100-51-6		1.2%-6.3% (9)
Tricosene	56924-46-0		0.2%-5.4% (10)

5.4. Lemongrass oil

The *Cymbopogon* family has two species of lemongrass that are used to make the two main lemongrass oils; East Indian lemongrass oil is made from Cymbopogon flexuosus and West Indian lemongrass oil is made from Cymbopogon citratus. In addition to being farmed in most tropical nations including South America, Africa, and Indochina. Lemongrass is an indigenous plant to Indonesia and India. Oriental cuisine makes use of fresh bulbous stems and leaves because of their distinctive lemon flavor. The herb is used as a remedy for the flu, fever, stomachaches, headaches, diarrhea, and several other illnesses. It is also regarded as a diuretic, tonic, antibacterial, and stimulant.

Numerous applications in the fragrance, cosmetics, and medicinal industries exist for the volatile essential oil extracted from the leaves of lemongrass in addition to flavoring curries, beverages, herbal teas and wines, herbal teas. It can be found in insecticides, detergents, polishes, and waxes. Citral is usually extracted from lemongrass oil. As lemongrass oil contains biological properties that include anticancer, antibacterial, antifungal, and mosquito-repelling actions, according to certain sources. The usage of the oil is thought to be beneficial for a variety of medical ailments, including scabies, athlete's foot more sweating, flatulence, acne and muscle aches. There is the use of lemongrass oil in aromatherapy to enhance muscular tone, skin, and blood flow [60].

5.4.1. Chemical Composition of Commercial Lemongrass Oils

As 32 samples of essential lemongrass oils manufactured in China, Java, Guinea, and Haiti were examined using GC/MS between 1999 and 2013 [60].

5.4.2. Allergens in Lemongrass Oil

There hasn't been enough research done on the sensitizers in lemongrass oil. However, citral, which is made up of neral and geranial, the two main components of lemongrass oil, demonstrated a 51% response rate in a sizable group of people with dermatitis thought to be

brought on by scent exposure and reacting to lemongrass oil [90].

5.4.3. Contact Allergy/Allergic Contact Dermatitis

Strongly irritating and potentially sensitizing, undiluted lemongrass oil [91].

5.4.4. Cases of Lemongrass Oil-Related Allergic Contact Dermatitis

Reports of lemongrass oil-related allergic contact dermatitis are primarily the result of occupational exposure

5.5. Tea Tree Oil

The tea tree leaf oil from *M. alternifolia* is used to make the volatile oil known as tea tree oil. In the EU and the US tea tree leaf oil from M. alternifolia is designated by INCI, respectively. TTO is frequently used undiluted and is seen by many to be a beneficial treatment for a variety of skin disorders. Several biological activities, including analgesic, insecticidal, antibacterial, fungicide, non-steroidal anti-inflammatory drugs, antineoplastic, and acaricide activity, have been linked to tea tree oil, which is made by steam distilling the leaves and terminal branchlets [95] [96] [97] [98] [99].

Many people believe it to be a remedy for several skin issues, like dandruff, warts, herpes simplex, and other skin infections as well as acne and eczema [100] likewise nail fungi [101]. It is promoted as a "natural" topical antibacterial and anti-inflammatory agent, and its antimicrobial activities are extensively proven [102]. TTO was approved for the treatment of mild oral mucosal inflammation, Little boils, superficial cuts, bug bites, athlete's foot cases with itching and irritation, and small boils. The ingredient can be found in a variety of forms, such as pure oil, creams, wart paint, [103], topical treatments for acne [104] [105] and household products including cleaners, detergents, and fabric softeners [102] [106] [107]. Additionally, a variety of cosmetic items employ the oil [102] [102] and diseases of the skin, respiratory system (including asthma, bronchitis, sinusitis, TB, and whooping cough), and genitourinary system are treated with aromatherapy (genital pruritus, vaginitis, and cystitis), fever, and infectious conditions like colds, the flu, and chickenpox [108].

5.5.1. Chemical composition of commercial TTOs

Between 1998 and 2013, 97 samples of Chinese, Vietnamese, and Australian tea tree essential oil (n = 1) underwent gas chromatography/mass spectrometry examination [109].Only one sample from China had a relatively high terpinolene concentration of 45.7%; the average value of terpinolene across 3.1% of all oils. The ten compounds with the highest maximum concentrations,

5.5.2. The allergens in TTO

There has been extensive research done on TTO. Studies on both humans and animals have shown that it can sensitize. New TTO is a poor [110] [111] to a modicum [111] [112] [113] [114] However, oxidation increases the sensitizer's potency [110]. Skin sensitivity may rise along with irritability. Oil ages because it is stored in bottles that have been opened at least once. Peroxides, endoperoxides, and epoxides, which are normally present in very minute concentrations and modify the constituents, are produced as a result of terpinen-4-ol and -terpinene oxidation [115]. to aromatherapists and other practitioners of professional massage who use essential oils [85] [92]. Four men underwent patch tests since there were no samples of the oil itself, pine wood was contaminated with lemongrass oil and all of them responded negatively to pinewood that wasn't. This was due to the thirty men working on the boat having eight cases of dermatitis, which was brought on by the oil that had leaked [93]. Due to citral in lip balm, one patient experienced allergy-induced cheilitis and responded favorably to lemongrass oil in a patch test [94].

These substances have powerful sensitizing effects [116] [110] [117] Knight and Hausen evaluated allergic individuals with various oil components in 1994 to find the sensitizers in TTO [111].

Patch tests for limonene were positive for seven allergic people [111]. Since then, researchers from Germany have examined numerous people with TTO allergies using a single ingredient, a small number of chemicals, or a variety of its components to determine the principal sensitizers.

Ascaridone, terpinolene, and –terpinene (and its oxidation products), limonene, 1,2,4-trihydroxymenthane, and -phellandrene are the three sensitizers that seem to react in TTO the most frequently [117]. Other substances that may contribute to TTO allergies include myrcene, aromadendrene, D-carvone, L-carvone, terpinen-4-ol, viridiflorene, and, sporadically (5%), sabinene, 1, 8-cineole, and p-cymene. However, they are more infrequently (16%) present in the environment. The components of TTO, -pinene, -terpinene, and -terpineol, although they haven't been classified as sensitizers yet. Except -for pinene, it should be highlighted that only a limited percentage of individuals who were allergic to TTO had their levels of these chemicals evaluated. Most sensitizers detected in commercial TTOs were found to be present in low amounts or not at all; for some (such as ascaridole, which is synthesized in). This can be accounted for by the freshness of the oil samples since TTO oxidizes and 1,2,4-trihydroxymenthane is formed throughout the aging process [118].

5.5.3. Clinical picture of allergic contact dermatitis caused by TTO

Pure oil use, usually for therapeutic purposes, is the primary cause of contact dermatitis due to allergies in a greater number of sensitization cases. This causes localized allergies by skin touch at the application site, which is frequently weeping and blistering [119]. It may spread widely or remain contained, occasionally [66]. The product being utilized determines the clinical profile of TTO reactions in cosmetics.

Due to reduced allergen concentrations in cosmetic products and application to undamaged skin, dermatitis is typically not as severe. Examples include shampoo, soap, and cream-induced periorbital/eyelid dermatitis [120-121] Skin irritation in the beard region brought on by shaving oil [120], Face dermatitis brought on by face cream [122] and hand lotion-induced dermatitis of the face and hands [122]. Contact allergy to TTO in toothpaste has led to stomatitis [123]. Numerous cases of allergic contact dermatitis brought on by workplace exposure have been reported, such as in aroma therapists a beautician or beauty therapists [66] [124-125] [126] alternative therapists [125] [92] a pedicurist

[126]. For the most part, the affected areas were the hands and/or forearms [125] [92] [124] [126].

Dermatitis is due to an allergic encounter that resembles folliculitis barbae [120], contact dermatitis that resembles erythema multiform [127] and after oral administration, systemic contact dermatitis [128] has been recorded infrequently. There have been reports of allergic contact dermatitis spread through the air due to inhaling TTO aqueous solution [129]. This could be anticipated when using aromatherapy lamps. Contact allergy brought on by using only pure oil on a penetrating wound caused linear IgA illness in one patient [130]. Women made up nearly all patients with TTO-induced dermatitis from contact allergies.

5.5.4. Cases relative to Allergies caused by TTO

Details are available in numerous reports and series of cases with allergies by skin touch brought on by TTO. There have been reports of 90 allergic patients at least. About two-thirds of the cases in which the allergen-causing items were identified involved pure TTO used therapeutically treating a variety of skin conditions, including mycosis, lump, herpes, scab, suntan, and acne of any origin. Additionally, some cases were brought on by TTO-containing topical medicinal preparations.

TTO was responsible for occupational dermatitis from allergic contact in six patients, including two aroma therapists, a complementary therapist, two pedicurists, and a beautician. As a result, the use of undiluted oil or products with high concentrations, which are typically applied to injured skin, is to blame in about three-quarters of all cases. Only 25% of all cases of tea tree allergic contact dermatitis are brought on by cosmetics [122] [131].

Products with low TTO concentrations don't seem to regularly cause contact allergies or allergic responses. All 27 cases of contact dermatitis brought on by TTO-containing items that the Swedish Medicinal Products Agency received had a TTO content of 2% or more. However, those who have already developed a sensitivity to TTO may develop eyelid dermatitis from using shampoos that include it [121].

5.6. Sandalwood oil

Three types of sandalwood oil exist: Santalum album L. wood was used to create the East Indian sandalwood oil, Wood from Santalum spicatum (R. Br.) was used to create the Australian sandalwood oil, and Santalum austrocaledonicum Vieill wood was used to create the New Caledonian sandalwood oil. Since S. album is prohibited from being exported by Indian law, the East Indian variety of sandalwood oil hasn't been available on the market since 2008. The International Union for the Conservation of Nature has designated sandalwood as an endangered species [132].

An Australian sandalwood species yields an essential oil known as the essential oil of Australian sandalwood. West Australia is its natural habitat. Santalum spicatum is mostly used to make essential oil, though it is also used to make furniture. Australian sandalwood oil is produced through the distillation of the roots, stem wood, and stump wood. This oil serves both medicinal and cosmetic functions and is used to make products like soap, powder, and lotions [133]. In aromatherapy, sandalwood oils are frequently employed.

5.6.1. Chemical Composition of Commercial Australian Sandalwood Oils

Gas chromatography/mass spectrometry (GC/MS) analysis of 23 commercial Australian sandalwood essential oil samples was performed between 1998 and 2013. The main components are listed as follows, with comparisons to other sandalwood oils: [60].

5.6.2. The Allergens in Sandalwood Oils

There hasn't been enough research done on allergies to sandalwood oils. One patient's allergy to sandalwood oil may have been caused by santol.

5.6.3. Contact Allergy/Allergic Contact Dermatitis

More than 30 papers have documented incidences of contact reactions and allergic dermatitis to sandalwood oil (rarely citing the botanical source). Sandalwood oil-induced pigmented cosmetic dermatitis The 1960s and 1970s saw a lot of Japanese ladies with this condition [62].

Since sandalwood has long been a component of photo patch test trays, there have also been several reports of photo contact allergies to the substance. However, the significance of such responses was nearly never clear [60] .

5.6.4. Reports

A patch test on a patient who was sensitive to sandalwood oil and assumed to be allergic to insence revealed the essence of incense with 8% santol content the primary component in sandalwood oil. In a research by the North American Contact Dermatitis Group, conducted in the US from 1977 to 1983, sandalwood oil was found to be the allergen in a cosmetic (photo) allergy that occurred in 3 out of 399 instances [134].

5.7. Jasmine absolute

The jasmine flower's volatile compounds are highly prized in the cosmetic and fragrance industries. Conventional steam distillation, which is how the majority of essential oils are made, is typically thought to be unsuitable for processing these flowers because it causes the heat deterioration of many of the chemicals they contain. To extract the aromatic compounds, supercritical fluids like CO2 or the typical solvent hexane are utilized.

Jasmine absolute, a product used in the fragrance industry, is made by first extracting the ethyl alcohol from the flower and then vacuum distilling the resulting solution to concentrate it [60]. The primary sources of Any Jasminum species' blooms that can be used to make jasmine absolutes are Jasmine grandiflorum L. and Jasminum sambac (L.). India mostly uses the Jasminum sambac flowers it harvests for garlands, jewelry, and ceremonial offerings. To get absolute values, just about 5% is used [60].

It is an occasional naturalized species in the tropics and thrives in Africa, France, Italy, France and India. Its leaves and petals are extensively used in India as a herbal Ayurvedic medication for ailments such as loose teeth, otorrhea, ear pain, ulcers, sores, corns, ulcerative stomatitis, leprosy, and skin disorders. Both the perfume industry and aromatherapy make extensive use of jasmine absolute [60].

5.7.1. Chemical Composition of Commercial Jasmine Absolutes

Between 2001 and 2013, the used GC/MS to examine 41 commercial Jasminum grandiflorum absolute samples. The top 10 compounds by maximum concentrations (concentration ranges given) are displayed;

5.7.2. The Allergens in Jasmine Absolute

Jasmine absolute's allergens have not been properly investigated. In two case studies, eugenol and linalool [135-136]. Allergens may have been found in jasmine absolute. A patch test on 183 people suspected of having cosmetic dermatitis revealed that 44 (24.0%) of them responded well to jasmine in an early Japanese study (test

material and concentration ununknown) [80]. Commercial jasmine absolutes may include the chemical benzyl salicylate, however the highest amounts so far only sometimes exceeded 0.6% [60].

5.7.3. Contact Allergy/Allergic Contact Dermatitis

Due to contact dermatitis to jasmine, in the 1960s and 1970s, many women in Japan acquired colored cosmetic dermatitis [62].

5.7.4. Reports

Research and reports on people who have had severe contact allergies to jasmine. An aroma therapist who developed occupational contact dermatitis after reacting to the Egyptian fragrance line's jasmine absolute was thought to have been harmed by a contact allergy to several different essential oils [137]. Jasmine oil and two additional essential oils used in aromatherapy lamps have been linked to one instance of airborne contact dermatitis, the patient also had an adverse reaction to linalool, a key component of both the oils and the pure jasmine [135].

Undiluted essential oil mixture called lovage oil, that included jasmine absolute, caused allergic contact dermatitis in one case [136]. In one instance, an allergic cosmetic dermatitis was brought on by a face lotion containing J. officinale [138]. According to a NACDG investigation conducted in the US between 1977 and 1983 when the underlying allergen for 399 occurrences of allergic reaction to cosmetic photos was identified, jasmine absolute was to fault [134].

6. Conclusion

Adulteration is a topic that is gaining more attention, especially when it comes to essential oils. Despite this, there are just a few hundred articles that discuss this significant problem with implications for the economy and a challenge for analytical chemists. Due to their high price, growing popularity, and in some cases, Their lack, in contrast to the rising need, essential oils are occasionally falsified. The findings discussed in this article are meant to draw researchers' attention to adulteration and encourage them to look into the dangers of using adulterated essential oils.

Essential oils are typically considered to be safe, but because they are diverse combinations of chemicals, which include several that are well-known skin sensitizers and allergens, they must be disclosed on the labels of cosmetics, particularly for customers with skin conditions that have existed in the past, such as sensitive, allergic skin who may choose to before utilizing items containing them, have a patch test. The scientific research that is now available suggests that the adulteration of essential oils and related constituents may have a significant allergy risk. The focus of this review is on the adverse reactions and allergic contact dermatitis brought on by tainted essential oils.

References

[1] B. Bozin, N. Mimica-Dukic, N. Simin, G. Anackov. (2006). Characterization of the volatile composition of essential oils of some Lamiaceae spices and the antimicrobial and antioxidant activities of the entire oils. Journal of agricultural and food chemistry. 54(5): 1822-1828.

[2] M.A. Hanif, T.M. Ansari, J.N. Al-Sabahi. (2017). A Comparative Study on Hemp (Cannabis sativa) Essential Oil Extraction Using Traditional and Advanced Techniques. Guang pu xue yu Guang pu fen xi= Guang pu. 37(1): 306-311.

[3] E. Knowles. (2014). Merriam-Webster Unabridged (Unabridged. Merriam-Webster. com). Dictionaries: Journal of the Dictionary Society of North America. 35(35): 334-339.

[4] A. Akram, A. Younis, G. Akhtar, K. Ameer, A. Farooq, M. Hanif, M. Saeed, K. Lim. (2017). Comparative efficacy of various essential oil extraction techniques on oil yield and quality of Jasminum sambac L. Sci. Int. 5(3): 84-95.

[5] L.C. Spears, M. Lawrence. (2002). Focus on leadership: Servant-leadership for the twenty-first century. John Wiley & Sons: pp.

[6] B. Lawrence. (2002). Commercial essential oils: Truths and consequences. SPECIAL PUBLICATION-ROYAL SOCIETY OF CHEMISTRY. 277: 57-83.

[7] M.A. Hanif, H. Nawaz, S. Naz, R. Mukhtar, N. Rashid, I.A. Bhatti, M. Saleem. (2017). Raman spectroscopy for the characterization of different fractions of hemp essential oil extracted at 130 C using steam distillation method. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 182: 168-174.

[8] K. Everstine, J. Spink, S. Kennedy. (2013). Economically motivated adulteration (EMA) of food: common characteristics of EMA incidents. Journal of food protection. 76(4): 723-735.

[9] R. Rehman, M.A. Hanif, M. Zahid, R.W.K. Qadri. (2019). Reporting effective extraction methodology and chemical characterization of bioactive components of under explored Platycladus orientalis (L.) Franco from semi-arid climate. Natural product research. 33(9): 1237-1242.

[10] W.F. Huang, K.C. Wen, M.L. Hsiao. (1997). Adulteration by synthetic therapeutic substances of traditional Chinese medicines in Taiwan. The Journal of Clinical Pharmacology. 37(4): 344-350.

[11] S. Naz, M.A. Hanif, H.N. Bhatti, T.M. Ansari. (2017). Impact of supercritical fluid extraction and traditional distillation on the isolation of aromatic compounds from Cannabis indica and Cannabis sativa. Journal of Essential Oil Bearing Plants. 20(1): 175-184.

[12] İ. Tarhan, M.R. Bakır, O. Kalkan, M. Yöntem, H. Kara. (2022). Rapid determination of adulteration of clove essential oil with benzyl alcohol and ethyl acetate: Towards quality control analysis by FTIR with chemometrics. Vibrational Spectroscopy. 118: 103339.

[13] M.A. Ayub, M.A. Hanif, R.A. Sarfraz, M. Shahid. (2018). Biological activity of Boswellia serrata Roxb. oleo gum resin essential oil: effects of extraction by supercritical carbon dioxide and traditional methods. International Journal of Food Properties. 21(1): 808-820.

[14] P.J. Marriott, R. Shellie, C. Cornwell. (2001). Gas chromatographic technologies for the analysis of essential oils. Journal of chromatography A. 936(1-2): 1-22.

[15] V. Monchois, M. Remaud-Simeon, R. Russell, P. Monsan, R.-M. Willemot. (1997). Characterization of Leuconostoc mesenteroides NRRL B-512F dextransucrase (DSRS) and identification of amino-acid residues playing a key role in enzyme activity. Applied microbiology and biotechnology. 48: 465-472.

[16] L. Schipilliti, P. Dugo, I. Bonaccorsi, L. Mondello. (2012). Authenticity control on lemon essential oils employing gas chromatography–combustion-isotope ratio mass spectrometry (GC–C-IRMS). Food Chemistry. 131(4): 1523-1530.

[17] C.-K. Shu, B.M. Lawrence, Reasons for the variation in composition of some commercial essential oils. In ACS Publications: 1997.

[18] R.A. Culp, J.E. Noakes. (1990). Identification of isotopically manipulated cinnamic aldehyde and benzaldehyde. Journal of agricultural and food chemistry. 38(5): 1249-1255.

[19] M.A. Hanif, H. Nawaz, M.A. Ayub, N. Tabassum, N. Kanwal, N. Rashid, M. Saleem, M. Ahmad. (2017). Evaluation of the effects of Zinc on the chemical composition and biological activity of basil essential oil by using Raman spectroscopy. Industrial crops and products. 96: 91-101.

[20] M.A. Hanif, H.N. Bhatti, M.S. Jamil, R.S. Anjum, A. Jamil, M.M. Khan. (2010). Antibacterial and antifungal activities of essential oils extracted from medicinal plants using CO2 supercritical fluid extraction technology. Asian journal of chemistry. 22(10): 7787.

[21] K.A. Krock, N. Ragunathan, C.L. Wilkins. (1994). Multidimensional gas chromatography coupled with infrared and mass spectrometry for analysis of eucalyptus essential oils. Analytical Chemistry. 66(4): 425-430.

[22] A.C. Aprotosoaie, M. Hăncianu, I.I. Costache, A. Miron. (2014). Linalool: a review on a key odorant molecule with valuable biological properties. Flavour and fragrance journal. 29(4): 193-219.

[23] H. Nawaz, M.A. Hanif, M.A. Ayub, F. Ishtiaq, N. Kanwal, N. Rashid, M. Saleem, M. Ahmad. (2017). Raman spectroscopy for the evaluation of the effects of different concentrations of Copper on the chemical composition and biological activity of basil essential oil. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 185: 130-138.

[24] R. Nadeem, S. Mumtaz, M. Hanif, I. Shahzadi, M. Jilani. (2016). BIOCHEMICAL CHARACTERISATION OF OLEORESIN OF Eucalyptus citriodora. Oxidation Communications. 39.

[25] W.A. König, D.H. Hochmuth. (2004). Enantioselective gas chromatography in flavor and fragrance analysis: strategies for the identification of known and unknown plant volatiles. Journal of chromatographic science. 42(8): 423-439.

[26] L. Salgueiro, A. Martins, H. Correia. (2010). Raw materials: the importance of quality and safety. A review. Flavour and fragrance journal. 25(5): 253-271.

[27] A. Mosandl. (2004). Authenticity assessment: a permanent challenge in food flavor and essential oil analysis. Journal of chromatographic science. 42(8): 440-449.

[28] F. Pellati, G. Orlandini, K.A. van Leeuwen, G. Anesin, D. Bertelli, M. Paolini, S. Benvenuti, F. Camin. (2013). Gas chromatography combined with mass spectrometry, flame ionization detection and elemental analyzer/isotope ratio mass spectrometry for characterizing and detecting the authenticity of commercial essential oils of Rosa damascena Mill. Rapid Communications in Mass Spectrometry. 27(5): 591-602.

[29] A.I. Hussain, S.A.S. Chatha, G.M. Kamal, M.A. Ali, M.A. Hanif, M.I. Lazhari. (2017). Chemical composition and biological activities of essential oil and extracts from Ocimum sanctum. International Journal of Food Properties. 20(7): 1569-1581.

[30] A. Mosandl. (1995). Enantioselective capillary gas chromatography and stable isotope ratio mass spectrometry in the authenticity control of flavors and essential oils. Food Reviews International. 11(4): 597-664.

[31] N. Kanwal, M.A. Hanif, M.M. Khan, T.M. Ansari, Khalil-ur-Rehman. (2016). Effect of micronutrients on vegetative growth and essential oil contents of Ocimum sanctum. Journal of Essential Oil Bearing Plants. 19(4): 980-988.

[32] D. McHale, Adulteration of citrus oils. In *Citrus*, CRC Press: 2002; pp 510-531.

[33] K.H.C. Baser, G. Buchbauer. (2009). Handbook of essential oils: science, technology, and applications. CRC press: pp.

[34] C. Cordella, I. Moussa, A.-C. Martel, N. Sbirrazzuoli, L. Lizzani-Cuvelier. (2002). Recent developments in food characterization and adulteration detection: Technique-oriented perspectives. Journal of agricultural and food chemistry. 50(7): 1751-1764.

[35] B.P. Skaria. (2007). Aromatic plants. New India Publishing: pp.

[36] B. Ijaz, M. Hanif, Z. Mushtaq, M. Khan, I. Bhatti, M. Jilani. (2017). Isolation of bioactive fractions from Ocimum sanctum essential oil. Oxidation Communications. 40(1-I): 158-167.

[37] M. John, T. Paul, P. Jaiswal. (1991). Detection of adulteration of (by) polyethylene glycols in oil of sandalwood. Indian perfumier. 35(4): 186-187.

[38] I. Ahmad, M.A. Hanif, R. Nadeem, M.S. Jamil, M.S. Zafar. (2008). Nutritive evaluation of medicinal plants being used as condiments in South Asian Region. Journal of the Chemical Society of Pakistan. 30(3): 400-405.

[39] S. Naz, M. Hanif, H. Bhatti, M. Shahid. (2016). PARTITION, FRACTIONATION, ANTIOXIDANT POTENTIAL AND PHENOLICS PROFILING OF Cannabis sativa GROWING IN PAKISTAN. Oxidation Communications. 39.

[40] M. Lis-Balchin. (2002). Geranium and Pelargonium: the genera Geranium and Pelargonium. Taylor & Francis: pp.

[41] M.K. Naseem, M.B. Chattha, A. Younis, H. Sardar, M.A. Hanif, G. Akhtar. (2017). Supercritical fluid extraction technology for essential oil extraction of Murraya exotica. International Journal of Biosciences. 10(4): 151-159.

[42] T.K.T. Do, F. Hadji-Minaglou, S. Antoniotti, X. Fernandez. (2015). Authenticity of essential oils. TrAC Trends in Analytical Chemistry. 66: 146-157.

[43] M. AYUB, M. HANIF, R. SARFRAZ, M. SHAHID. (2017). EFFECTS OF EXTRACTION TEMPERATURES ON ESSENTIAL OIL YIELD, ANTIOXIDANT AND ANTIBACTERIAL ACTIVITY OF Boswellia serrata Roxb. OLEOGUM RESIN. Oxidation Communications. 40(3).

[44] P. Martinaux, R. Laher, C. Marin, V. Michelet. (2022). Transition Metal-Catalyzed Rearrangement and Cycloisomerization Reactions Toward Hedonic Materials. Israel Journal of Chemistry. e202200047.

[45] N.T. Thao, A. Satake, Enantiomeric and stable isotope analysis. In *Citrus Essential Oils: Flavor and Fragrance*, John Wiley & Sons, Inc. Hoboken: 2010; pp 165-200.

[46] T.-T. Nhu-Trang, H. Casabianca, M.-F. Grenier-Loustalot. (2006). Authenticity control of essential oils containing citronellal and citral by chiral and stable-isotope gas-chromatographic analysis. Analytical and bioanalytical chemistry. 386(7-8): 2141-2152.

[47] E. Brenna, C. Fuganti, S. Ronzani, S. Serra. (2001). Enzyme-Mediated Syntheses of the Enantiomers of γ-Irones. Helvetica chimica acta. 84(12): 3650-3666.

[48] M. Lis-Balchin, S.G. Deans, E. Eaglesham. (1998). Relationship between bioactivity and chemical composition of commercial essential oils. Flavour and fragrance journal. 13(2): 98-104.

[49] R. Rehman, M.A. Hanif, Z. Mushtaq, A.M. Al-Sadi. (2016). Biosynthesis of essential oils in aromatic plants: A review. Food Reviews International. 32(2): 117-160.

[50] H. Schulz, R. Quilitzsch, H. Krüger. (2003). Rapid evaluation and quantitative analysis of thyme, origano and chamomile essential oils by ATR-IR and NIR spectroscopy. Journal of Molecular Structure. 661: 299-306.

[51] T.-T. Nhu-Trang, H. Casabianca, M.-F. Grenier-Loustalot. (2006). Deuterium/hydrogen ratio analysis of thymol, carvacrol, γ-terpinene and p-cymene in thyme, savory and oregano essential oils by gas chromatography–pyrolysis–isotope ratio mass spectrometry. Journal of chromatography A. 1132(1-2): 219-227.

[52] R. Rehman, M.A. Hanif, Z. Mushtaq, B. Mochona, X. Qi. (2016). Biosynthetic factories of essential oils: the aromatic plants. Nat. Prod. Chem. Res. 4(4): 1000227.

[53] G. Acosta, S. Arce, L.D. Martínez, J. Llabot, M.R. Gomez. (2012). Monitoring of phenolic compounds for the quality control of melissa officinalis products by capillary electrophoresis. Phytochemical Analysis. 23(2): 177-183.

[54] A. Sajid, R.A. Sarfraz, M.A. Hanif, M. Shahid. (2016). Evaluation of chemical composition and biological activities of Citrus pseudolimon and Citrus grandis peel essential oils. Journal of the Chemical Society of Pakistan. 38(2): 266-266.

[55] G.O. Sozzi, K. Peter, K.N. Babu, M. Divakaran, Capers and caperberries. In *Handbook of herbs and spices*, Elsevier: 2012; pp 193-224.

[56] M. Saleem, H.N. Bhatti, M.I. Jilani, M.A. Hanif. (2015). Bioanalytical evaluation of Cinnamomum zeylanicum essential oil. Natural product research. 29(19): 1857-1859.

[57] P.Q. Tranchida, D. Sciarrone, P. Dugo, L. Mondello. (2012). Heart-cutting multidimensional gas chromatography: a review of recent evolution, applications, and future prospects. Analytica chimica acta. 716: 66-75.

[58] M.M. Khan, M. Iqbal, M.A. Hanif, M.S. Mahmood, S.A. Naqvi, M. Shahid, M.J. Jaskani. (2012). Antioxidant and antipathogenic activities of citrus peel oils. Journal of Essential Oil Bearing Plants. 15(6): 972-979.

[59] K. Nimet, H. Baydar. (2013). Determination of lavender and lavandin cultivars (Lavandula sp.) containing high quality essential oil in Isparta, Turkey. Turkish Journal of Field Crops. 18(1): 58-65.

[60] A.C. de Groot, E. Schmidt. (2016). Essential oils, part III: chemical composition. Dermatitis. 27(4): 161-169.

[61] L. Hagvall, M. Sköld, J. Bråred-Christensson, A. Börje, A.T. Karlberg. (2008). Lavender oil lacks natural protection against autoxidation, forming strong contact allergens on air exposure. Contact dermatitis. 59(3): 143-150.

[62] H. Nakayama, S. Matsuo, K. Hayakawa, K. Takhashi, T. Shigematsu, S. Ota. (1984). Pigmented cosmetic dermatitis. International journal of dermatology. 23(5): 299-305.

[63] R. Goiriz, Y. Delgado-Jiménez, J. Sánchez-Pérez, A. García-Diez. (2007). Photoallergic contact dermatitis from lavender oil in topical ketoprofen. Contact dermatitis. 57(6): 381-382.

[64] A. Nardelli, E. D'Hooghe, J. Drieghe, M. Dooms, A. Goossens. (2009). Allergic contact dermatitis

from fragrance components in specific topical pharmaceutical products in Belgium. Contact dermatitis. 60(6): 303-313.
[65] G. Zina, G. Bonu. (1969). Phenergan cream (role of base constituents). Contact Dermatitis Newsletter. 6: 117.
[66] B. Dharmagunawardena, A. Takwale, K. Sanders, S. Cannan, A. Rodger, A. Ilchyshyn. (2002). Gas chromatography: an investigative tool in multiple allergies to essential oils. Contact dermatitis. 47(5): 288-292.
[67] A.Y. Al-Maskri, M.A. Hanif, M.Y. Al-Maskari, A.S. Abraham, J.N. Al-sabahi, O. Al-Mantheri. (2011). Essential oil from Ocimum basilicum (Omani Basil): a desert crop. Natural product communications. 6(10): 1934578X1100601020.
[68] A. Trattner. (2008). Grape seed extract/phytotherapies/propolis. Reactions. 1205: 7.
[69] F. Brandao. (1986). Occupational allergy to lavender oil. Contact dermatitis. 15(4): 249-250.
[70] Gopichand, R. Meena, M. Nag, V. Pathania, V. Kaul, B. Singh, R. Singh, P. Ahuja. (2013). Effect of organic manure and plant spacing on biomass and quality of Mentha piperita L. in Himalaya in India. Journal of Essential Oil Research. 25(4): 354-357.
[71] M.A. Hanif, M.Y. Al-Maskari, A. Al-Maskari, A. Al-Shukaili, A.Y. Al-Maskari, J.N. Al-Sabahi. (2011). Essential oil composition, antimicrobial and antioxidant activities of unexplored Omani basil. Journal of Medicinal Plants Research. 5(5): 751-757.
[72] G.P. Kamatou, I. Vermaak, A.M. Viljoen, B.M. Lawrence. (2013). Menthol: a simple monoterpene with remarkable biological properties. Phytochemistry. 96: 15-25.
[73] M. Moldao-Martins, S. Beirao-da-Costa, C. Neves, C. Cavaleiro, L.g. Salgueiro, M.L. Beirao-da-Costa. (2004). Olive oil flavoured by the essential oils of Mentha× piperita and Thymus mastichina L. Food Quality and Preference. 15(5): 447-452.
[74] K.M. Basista, B. Filipek. (2012). Allergy to propolis in Polish beekeepers. Advances in Dermatology and Allergology/Postępy Dermatologii i Alergologii. 29(6): 440-445.
[75] S. Freeman, R. Stephens. (1999). Cheilitis: analysis of 75 cases referred to a contact dermatitis clinic. American Journal of Contact Dermatitis. 10(4): 198-200.
[76] A. Dooms-Goossens, H. Deoreef, C. Holvoet, M. Maertens. (1977). Turpentine-induced hypersensitivity to peppermint oil. Contact dermatitis. 3(6): 304-308.
[77] C. Morton, J. Garioch, P. Todd, P. Lamey, A. Forsyth. (1995). Contact sensitivity to menthol and peppermint in patients with intra-oral symptoms. Contact dermatitis. 32(5): 281-284.
[78] A.C. de Groot. (1987). Contact allergy to cosmetics: causative ingredients. Contact dermatitis. 17(1): 26-34.
[79] A.R. Travassos, L. Claes, L. Boey, J. Drieghe, A. Goossens. (2011). Non-fragrance allergens in specific cosmetic products. Contact dermatitis. 65(5): 276-285.
[80] H. Nakayama, H. Hanaoka, A. Ohshiro. (1974). Allergen controlled system (ACS). Kanehara Shuppan: pp.
[81] J. Mitchell. (1975). Contact hypersensitivity to some perfume materials. Contact dermatitis. 1(4): 196-199.
[82] M. Sucawara, H. Nakayama, S. Watanabe. (1990). Fragrances Contact hypersensitivity to ylang-ylang oil. Contact dermatitis. 23(4): 248-248.
[83] P. Srivastava, A. Bajaj. (2014). Ylang-ylang oil not an uncommon sensitizer in India. Indian Journal of Dermatology. 59(2): 200.
[84] S.E. Cockayne, D.J. Gawkrodger. (1997). Occupational contact dermatitis in an aromatherapist. Contact dermatitis. 37: 306-306.
[85] N. Bleasel, B. Tate, M. Rademaker. (2002). Allergic contact dermatitis following exposure to essential oils. Australasian Journal of Dermatology. 43(3): 211-213.
[86] L. Kenerva, T. Estlander, R. Jolanki. (1995). Occupational allergic contact dermatitis caused by ylang-ylang oil. Contact dermatitis. 33(3): 198-199.
[87] E. Rudzki, P. Rebandel, Z. Grzywa. (1993). Occupational dermatitis from cosmetic creams. Contact dermatitis. 29(4): 210-210.
[88] C. Romaguera, J. Vilaplana. (2000). Occupational contact dermatitis from ylang-ylang oil. Contact dermatitis. 43(4): 251.
[89] W.G. Larsen. (1975). Cosmetic dermatitis due to a perfume. Contact dermatitis. 1(3): 142-145.
[90] W. Uter, E. Schmidt, J. Geier, H. Lessmann, A. Schnuch, P. Frosch. (2010). Contact allergy to essential oils: current patch test results (2000–2008) from the Information Network of Departments of Dermatology (IVDK). Contact dermatitis. 63(5): 277-283.
[91] M. HV. (1946). Lemon grass oil; a primary irritant and sensitizing agent. Archives of Dermatology and Syphilology. 53: 94-98.
[92] J. Newsham, S. Rai, J. Williams In *Two cases of allergic contact dermatitis to neroli oil*, British Journal of Dermatology, 2011; WILEY-BLACKWELL COMMERCE PLACE, 350 MAIN ST, MALDEN 02148, MA USA: 2011; pp 76-76.
[93] H.V. MENDELSOHN. (1944). Dermatitis from lemon grass oil (Cymbopogon citratus or Andropogon citratus). Archives of Dermatology and Syphilology. 50(1): 34-35.
[94] E. Hindle, J. Ashworth, M. Beck. (2007). Chelitis from contact allergy to citral in lip salve. Contact dermatitis. 57(2): 125-126.
[95] C. Gómez-Rincón, E. Langa, P. Murillo, M.S. Valero, C. Berzosa, V. López. (2014). Activity of tea tree (Melaleuca alternifolia) essential oil against L3 larvae of Anisakis simplex. BioMed research international. 2014.
[96] G. Benelli, A. Canale, G. Flamini, P.L. Cioni, F. Demi, L. Ceccarini, M. Macchia, B. Conti. (2013). Biotoxicity of Melaleuca alternifolia (Myrtaceae) essential oil against the Mediterranean fruit fly,

Ceratitis capitata (Diptera: Tephritidae), and its parasitoid Psyttalia concolor (Hymenoptera: Braconidae). Industrial Crops and Products. 50: 596-603.

[97] L.C.A. Barbosa, C.J. Silva, R.R. Teixeira, R.M.S.A. Meira, A.L. Pinheiro. (2013). Chemistry and biological activities of essential oils from Melaleuca L. species. Agriculturae conspectus scientificus. 78(1): 11-23.

[98] C.F. Carson, K.A. Hammer, T.V. Riley. (2006). Melaleuca alternifolia (tea tree) oil: a review of antimicrobial and other medicinal properties. Clinical microbiology reviews. 19(1): 50-62.

[99] A. Calcabrini, A. Stringaro, L. Toccacieli, S. Meschini, M. Marra, M. Colone, G. Arancia, A. Molinari, G. Salvatore, F. Mondello. (2004). Terpinen-4-ol, the main component of Melaleuca alternifolia (tea tree) oil inhibits the in vitro growth of human melanoma cells. Journal of Investigative Dermatology. 122(2): 349-360.

[100] A.C. Satchell, A. Saurajen, C. Bell, R.S. Barnetson. (2002). Treatment of dandruff with 5% tea tree oil shampoo. Journal of the American Academy of Dermatology. 47(6): 852-855.

[101] N. Pazyar, R. Yaghoobi, N. Bagherani, A. Kazerouni. (2013). A review of applications of tea tree oil in dermatology. International journal of dermatology. 52(7): 784-790.

[102] S. Cox, C. Mann, J. Markham. (2001). Interactions between components of the essential oil of Melaleuca alternifolia. Journal of applied microbiology. 91(3): 492-497.

[103] M. Bhushan, M.H. Beck. (1997). Allergic contact dermatitis from tea tree oil in a wart paint. Contact dermatitis. 36(2): 117-118.

[104] S. Enshaieh, A. Jooya, A.H. Siadat, F. Iraji. (2007). The efficacy of 5% topical tea tree oil gel in mild to moderate acne vulgaris: a randomized, double-blind placebo-controlled study. Indian journal of dermatology, venereology and leprology. 73: 22.

[105] K. Hammer. (2015). Treatment of acne with tea tree oil (melaleuca) products: a review of efficacy, tolerability and potential modes of action. International journal of antimicrobial agents. 45(2): 106-110.

[106] G.H. Crawford, J.R. Sciacca, W.D. James. (2004). Tea tree oil: cutaneous effects of the extracted oil of Melaleuca alternifolia. Dermatitis: Contact, Atopic, Occupational, Drug. 15(2): 59-66.

[107] O. Hartford, K.A. Zug. (2005). Tea tree oil. Cutis. 76(3): 178-180.

[108] J. Lawless. (1996). The encyclopedia of essential oils. Element: pp.

[109] D.G. Naik, Essential oils, contact allergy and chemical composition. In Taylor & Francis: 2016.

[110] B.M. Hausen, J. Reichling, M. Harkenthal. (1999). Degradation products of monoterpenes are the sensitizing agents in tea tree oil. American Journal of Contact Dermatitis. 10(2): 68-77.

[111] T.E. Knight, B. Hausen. (1994). Melaleuca oil (tea tree oil) dermatitis. Journal of the American Academy of Dermatology. 30(3): 423-427.

[112] I.A. Southwell, S. Freeman, D. Rubel. (1997). Skin irritancy of tea tree oil. Journal of Essential Oil Research. 9(1): 47-52.

[113] D.M. Rubel, S. Freeman, I.A. Southwell. (1998). Tea tree oil allergy: what is the offending agent? Report of three cases of tea tree oil allergy and review of the literature. Australasian Journal of Dermatology. 39(4): 244-247.

[114] N. Aspres, S. Freeman. (2003). Predictive testing for irritancy and allergenicity of tea tree oil in normal human subjects. Exogenous Dermatology. 2(5): 258-261.

[115] D. Sciarrone, C. Ragonese, C. Carnovale, A. Piperno, P. Dugo, G. Dugo, L. Mondello. (2010). Evaluation of tea tree oil quality and ascaridole: a deep study by means of chiral and multi heart-cuts multidimensional gas chromatography system coupled to mass spectrometry detection. Journal of chromatography A. 1217(41): 6422-6427.

[116] M. Harkenthal, B. Hausen, J. Reichling. (2000). 1, 2, 4-Trihydroxy menthane, a contact allergen from oxidized Australian tea tree oil. Die Pharmazie. 55(2): 153-154.

[117] J. Rudbäck, M.A. Bergström, A. Börje, U. Nilsson, A.-T. Karlberg. (2012). α-Terpinene, an antioxidant in tea tree oil, autoxidizes rapidly to skin allergens on air exposure. Chemical Research in Toxicology. 25(3): 713-721.

[118] M. Pesonen, S. Suomela, O. Kuuliala, M.L. Henriks-Eckerman, K. Aalto-Korte. (2014). Occupational contact dermatitis caused by D-limonene. Contact dermatitis. 71(5): 273-279.

[119] C. Pirker, B. Hausen, W. Uter, U. Hillen, J. Brasch, C. Bayerl, U. Lippert, T. Fuchs, W. Aberer, M. Fartasch. (2003). Sensitization to tea tree oil in Germany and Austria. A multicenter study of the German Contact Dermatitis Group. Journal der Deutschen Dermatologischen Gesellschaft= Journal of the German Society of Dermatology: JDDG. 1(8): 629-634.

[120] W.A. Christoffers, B. Blömeke, P.-J. Coenraads, M.-L.A. Schuttelaar. (2013). Co-sensitization to ascaridole and tea tree oil. Contact dermatitis. 69(3): 187-189.

[121] J.D. Williams, R.L. Nixon, A. Lee. (2007). Recurrent allergic contact dermatitis due to allergen transfer by sunglasses. Contact dermatitis. 57(2): 120-121.

[122] T. Rutherford, R. Nixon, M. Tam, B. Tate. (2007). Allergy to tea tree oil: retrospective review of 41 cases with positive patch tests over 4.5 years. Australasian Journal of Dermatology. 48(2): 83-87.

[123] Y.M. Monthrope, J.C. Shaw. (2004). A 'natural'dermatitis: contact allergy to tea tree oil. Univ Toronto Med J. 82(1): 59-60.

[124] E. Selvaag, J.Ø. Holm, P. Thune. (1995). Allergic contact dermatitis in an aroma therapist with multiple sensitizations to essential oils. Contact dermatitis. 33(5): 354-355.

[125] I. Coutts, S. Shaw, D. Orton. (2002). Patch testing with pure tea tree oil-12 months experience.

BRITISH JOURNAL OF DERMATOLOGY-SUPPLEMENT-. 147: 70-70.

[126] P. Van der Valk, A. De Groot, D. Bruynzeel, P. Coenraads, J. Weijland. (1994). Allergic contact eczema due to'tea tree'oil. Nederlands Tijdschrift voor Geneeskunde. 138(16): 823-825.

[127] M. Khanna, K. Qasem, D. Sasseville. (2000). Allergic contact dermatitis to tea tree oil with erythema multiforme-like id reaction. American Journal of Contact Dermatitis. 11(4): 238-242.

[128] A.C. De Groot, J.W. Weyland. (1992). Systemic contact dermatitis from tea tree oil. Contact dermatitis. 27(4): 279-280.

[129] A.C. de Groot. (1996). Airborne allergic contact dermatitis from tea tree oil. Contact dermatitis. 35(5): 304-305.

[130] C. Perrett, A. Evans, R. Russell-Jones. (2003). Tea tree oil dermatitis associated with linear IgA disease. Clinical and experimental dermatology. 28(2): 167-170.

[131] B.M. Hausen. (2004). Evaluation of the main contact allergens in oxidized tea tree oil. Dermatitis. 15(4): 213-214.

[132] N. Baldovini, C. Delasalle, D. Joulain. (2011). Phytochemistry of the heartwood from fragrant Santalum species: a review. Flavour and fragrance journal. 26(1): 7-26.

[133] J.J. Brophy, C.J. Fookes, E.V. Lassak. (1991). Constituents of Santalum spicatum (R. Br.) A. DC. wood oil. Journal of Essential Oil Research. 3(6): 381-385.

[134] R.M. Adams, H.I. Maibach, W. Clendenning, A. Fisher, W. Jordan, N. Kanof, W. Larsen, J. Mitchell, E. Rudner, W. Schorr. (1985). A five-year study of cosmetic reactions. Journal of the American Academy of Dermatology. 13(6): 1062-1069.

[135] M. Schaller, H. Korting. (1995). Allergie airborne contact dermatitis from essential oils used in aromatherapy. Clinical and experimental dermatology. 20(2): 143-145.

[136] H. Lapeere, B. Boone, E. Verhaeghe, K. Ongenae, J. Lambert. (2013). Contact dermatitis caused by lovage (Levisticum officinalis) essential oil. Contact dermatitis. 69(3): 181-182.

[137] W. Boonchai, P. Iamtharachai, P. Sunthonpalin. (2007). Occupational allergic contact dermatitis from essential oils in aromatherapists. Contact dermatitis. 56(3): 181-182.

[138] K. Penchalaiah, S. Handa, S. BIJAYA LAKSHMI, V. Sharma, B. KUMAR. (2000). Sensitizers commonly causing allergic contact dermatitis from cosmetics. Contact dermatitis. 43(5): 311-313.