Review Article

Terpenoids as Major Constituent of Essential Oil: Their Properties and Applications

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Abstract

Plant and plant-derived natural products have a protracted and huge records in conventional medicinal drug everywhere in the world. The use of plant and plant-derived natural products for medicinal, spiritual and beauty functions have a history dating back to the emergence of humanity. Medicinal vegetation are rich sources of bioactive compounds including phytochemicals and/or bio nutrients, that have proven vital function in stopping persistent illnesses like cancers, diabetes, and coronary heart illnesses. They additionally show interest in biological activity like insecticidal, antiseptic action, therefore beneficial in pharmacy. Terpenoids are the most important components of essential oils, that are broadly used immediately as flavouring agents or for further isolation of flavouring substances. Menthol is one of the most critical flavouring chemical compounds and it is used extensively in pharmaceuticals, toothpastes, chewing gum. The terpenoids also have potential medical applications in treating microbial infections alone or in mixture with other different constituents of essential oils. Volatile terpenoids possess various activities like antimicrobial, pesticidal and antifungal activities, so it is able to additionally enhance the shelf life of stored fruits or reduce pesticide use.

Keywords: Terpenoids, bioactive, essential oil, chronic diseases, menthol, antimicrobial, shelf life

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Introduction

Plants produce a huge numbers of secondary metabolites as bioactive compounds like alkaloids, tannins, flavonoids, sterols and terpenes, etc., which possess vital function in nutrition, body structure and prevention of diseases. Terpenoids are one of the most important classes of bioactive compounds in higher plants, as a result, the foremost challenge is the screening of these compounds withinside the plants. According to world health organization, 80% of the world's population depends on such conventional plant-based systems of medicine to provide them with number one healthcare. The use of bioactive compounds as herbal medicines continues to expand rapidly internationally with many people now resorting to these products for treatment of various health challenges in country wide healthcare settings [1]. Terpenoids are a very diverse group of natural compounds which may be determined in a number of plants. Monoterpenoids are chief components of the essential oils and are recognized for their aromatic/fragrant properties.

Plants can manufacture many different types of secondary metabolites, that have been subsequently exploited by humans for their useful function in a diverse array of applications. Often, plant secondary metabolites can be known as plant natural products or plant herbal products, in which case they illicit effects on different organisms [2]. Although this review demonstrated the speciality of plant terpenes, it is realized that other organisms are capable to synthesize terpenes. For example, the endophytic fungus isolated from St. John's Wort (*Hypericum perforatum*) was recently proven to provide hypericin and emodin, two varieties of terpene lactones. There are three broad categories of plant secondary metabolites as herbal products; terpenes and terpenoids (~25,000 types), alkaloids (~12,000 types), and phenolic compounds (~8,000 types) [3]. It has long been acknowledged that the primary unit of most secondary plant metabolites, including terpenes, consists of isoprene, a simple hydrocarbon molecule. The term terpene generally refers to a hydrocarbon molecule while terpenoid refers to a terpene that has been modified, such as by the addition of oxygen. Hence, isoprenoids are the building blocks of different metabolites which include plant hormones, sterols, carotenoids, rubber, the phytol tail of chlorophyll, and turpentine.

The terpenoids, sometimes known as isoprenoids, are a huge and diverse class of naturally occurring organic chemicals derived from the 5-carbon compound isoprene, and the isoprene polymers known as terpenes. Most are multicyclic structures with oxygen-containing functional groups. About 60% of known herbal products are terpenoids. Although sometimes used interchangeably with "terpenes", terpenoids comprises of additional functional groups, usually O-containing. As a consequence, many terpenoids have suggested pharmacological activities and are therefore interesting for medicine and biotechnology." Terpenes belong to the biggest class of secondary metabolites and basically consist of five carbon isoprene units that are assembled to each other.

Terpenes are simple hydrocarbons, while terpenoids are modified class of terpenes with different functional groups. So, chemical modification of terpenes results in the formation of terpenoids. Terpenoids accommodates the second largest group of herbal compounds which are represented in a majority of essential oils obtained from tissues of certain plants. Natural products have performed a extensive function in human disease therapy and prevention. More than 60% and 75% of the chemotherapeutic drugs for cancer and infectious disease, respectively, are of herbal origin. With more than 23,000 known compounds, terpenoids, also referred to as terpenes, are the largest class of herbal products. Among this group, many interesting compounds are extensively implemented in the industrial sector as flavors, fragrances, and spices, and are also used in perfumery and cosmetics products and food additives. Many terpenes have biological activities and are used for medical purposes. For example, the antimalarial drug Artemisinin and the anticancer drug paclitaxel (TaxolR) are two of a few terpenes with established medical applications. Natural products continue to be one of the most important and crucial sources of lead compounds for the pharmaceutical industry. At the same time, more terpenes have been discovered as efficacious compounds in human disease therapy and prevention. In particular, marine chemists and biologists have recognized many marine terpenes with promising ability for scientific application in medical [4].

There are many distinctive classes of naturally occurring compounds. Terpenoids also form a group of naturally occurring compounds majority of which occur in plants, a few of them have also been obtained from other sources. Terpenoids are volatile substances which give plants and flowers their fragrance. They occur widely in the leaves and fruits of higher plants, conifers, citrus and eucalyptus. The term ‘terpene’ was given to the compounds isolated from terpentine, a volatile liquid isolated from pine trees. The simpler mono and sesquiterpene is chief constituent of the essential oils obtained from sap and tissues of certain plant and trees. The di and tri terpenoids are not steam volatile. They are obtained from plant and tree gums and resins. Tertraterpenoids form a separate group of compounds called ‘Carotenoids’. The term ‘terpene’ was originally employed to describe a mixture of isomeric hydrocarbons of the molecular formula $C_{10}H_{16}$ occurring in the essential oils obtained from sap and tissue of plants, and trees. But there is a tendency to use more general term ‘terpenoids’ which include hydrocarbons and their oxygenated derivatives. However the term terpene is being used in recent times by some authors to represent terpenoids.

By the modern definition: “Terpenoids are the hydrocarbons of plant origin of the general formula $(C_5H_8)n$ as well as their oxygenated, hydrogenated and dehydrogenated derivatives” [5]. Terpenes are the most numerous and structurally diverse plant herbal products. For this reason, a system of nomenclature has been established. The nomenclature of terpene compounds is ostensibly complex, yet can be quickly elucidated upon closer examination. The isoprene unit, which can build upon itself in various ways, is a five-carbon molecule. The single isoprene unit, therefore, represents the most basic class of terpenes, the hemiterpenes. An isoprene unit bonded with a second isoprene is the defining characteristic of terpene, which is also a monoterpene (C_{10}). While sesquiterpenes contain three isoprene units (C_{15}), diterpenes (C_{20}) and triterpenes (C_{30}) contain two and three terpene units, respectively. Tetraterpenes consist of four terpene units and polyterpenes are those terpenes which are containing more than four terpene units (i.e., more than eight isoprene units) [6].

Plant terpenoids are used for their fragrant features and play a vital function in conventional natural remedies. Terpenoids make a contribution to the flavors of cinnamon, cloves, and ginger, the yellow color in sunflowers, and the red color in tomatoes. Well-known terpenoids include citral, menthol, camphor and the curcuminoids found in turmeric and mustard seed [7]. The provitamin beta carotene is a terpene derivative referred to as carotenoid. The steroids and sterols in animals are biologically produced from terpenoid precursors. Sometimes terpenoids are added to proteins, e.g., to decorate their attachment to the cell membrane; this is called isoprenylation [8]. Terpenoids, such as the carotenoids, contribute to the color of many fruits. They additionally make a contribution to most of the flavors in our foods, and are important components of many medicinal recipes. Terpenoids possess a broad range of potent activities, such as anti-microbial, anti-inflammatory, cardio-stimulant, properties. Monoterpenoids are widely studied for their antiviral property. Terpenoids have ability to function as anti-cancer and anti-diabetic reagents. They also show interest in biological activity like insecticidal, antiseptic action, and consequently beneficial in pharmacy [9]. The pharmaceutical properties of aromatic plants are partially attributed to essential oils (EO’s), which can also be visible as an important group of plant secondary metabolites. Although the usage of EO’s has been ordinarily associated with food flavorings, cosmetics, and perfumes because of their aroma,

studies demonstrate the high potential of the use of volatile monoterpene constituents to cure and prevent human diseases [10]. During the recent years, plant EO's have come greater into the point of interest in phytomedicine and aromatherapy; hence their widespread use has raised more interest to scientists in basic research, especially their antimicrobial, antioxidant, and anticancer activities [11]. Many terpenes have biological activities and are used for the treatment of human diseases. The global income of terpene-based pharmaceuticals in 2002 were approximately US $12 billion. Among those pharmaceuticals, the anticancer drug Taxol R and the antimalarial drug Artimesinin are two of the most renowned terpene-based drugs. All terpenoids are synthesized from two five-carbon building blocks. Based on the number of the building blocks, terpenoids are commonly classified as monoterpenes (C_{10}), sesquiterpenes (C_{15}), diterpenes (C_{20}), and sesterterpenes (C_{25}). These terpenoids show a huge variety of biological activities against cancer, malaria, inflammation, and a variety of infectious diseases (viral and bacterial) [12].

Essential oils (EOs) are complicated mixtures of low molecular weight compounds extracted from plants by steam distillation and various solvents. Terpenoids and phenylpropanoids are the primary materials which provide characteristic aroma and biological properties to EOs. Essential oils are prescribed for a variety of health problems by traditional systems of medicine, all around the world. Various pharmaceutical and biological activities like, antibacterial, antifungal, anticancer, antimutagenic, antidiabetic, antiviral, antiinflammatory, and antiprotozoal properties are assigned to them [12]. Essential oils of plant origin are one of the important products of agriculture based industry. They are commonly used as flavouring agents in food products, drinks, perfumaries, pharmaceuticals and cosmetics [13]. Use of plant EOs for perfumery, additives in food/ confectionary as well as for pharmaceuticals and cosmetics is a developing marketplace trend. A rapid increase has been observed in the number of essential oil derived products. The cosmetics industry uses many herbs and spices in the manufacture of skin creams, balms, shampoos, soaps, and perfumes. Essential oils are utilized by soft drink companies and by food companies. Essential oils have been a critical part of the medicinal industry throughout the twentieth century [14]. Their use as aromatherapy products, traditional systems of medicines and in complementary systems of medicines is growing continuously in USA, Europe, Africa and in Asian countries. The important components of this hundreds of million dollar industry are pharmaceuticals, medicinal supplements, and nutraceutical companies [15] and [16]. Historically, specialized terpenoids, collectively with alkaloids and a few of the phenolics, have been referred to as secondary metabolites. Based on their numbers and diversity, terpenes provide capability in an array of commercial and medicinal applications [3].

Examples of Terpenoids

Terpenoids are the major constituents of essential oils. Some of the common essential oils are used as a natural flavour additives in food industry shown in **Table 1**.

Table 1 Showing Examples of Terpenoids as major constituent of which essential oil.

Essential oil	Terpenoid
Lemon oil	Limonene
Clove oil	Eugenol
Peppermint oil	Menthol
Cardamom oil	α −Terpineol
Ginger	Zingiberene
Coriander	Linalool

Classification of Terpenoids

Terpenes are the most numerous and structurally diverse plant herbal products. For this reason, a system of nomenclature has been established. The nomenclature of terpene compounds is ostensibly complex, yet may be quickly elucidated upon closer examination. The isoprene unit, that can construct upon itself in various ways, is a five-carbon molecule. The single isoprene unit, therefore, represents the most basic class of terpenes, the hemiterpenes. An isoprene unit bonded with a second isoprene is the defining function of terpene, which is also a monoterpene (C_{10}). While sesquiterpenes contain three isoprene units (C_{15}), diterpenes (C_{20}) and triterpenes (C_{30}) contain two and three terpene units, respectively. Tetraterpenes consist of four terpene units and polyterpenes are those terpenes containing more than four terpene units (i.e., more than eight isoprene units) [6].

Based on number of isoprene units

Terpenoids are modified terpenes, where methyl_groups have been moved or removed, or oxygen atoms added. Terpenoids are classified according to the number of isoprene units- shown in **Table 2**.

Table 2 showing Classification of terpenoids based on the number of isoprene units

Terpenoids	No. of isoprene units	No. of carbon atoms	Molecular formula	Examples
Hemiterpene or isoprene	1	5	C_5H_8	Isovaleric acid, isoprenol
Monoterpenoids	2	10	$C_{10}H_{16}$	Linalool, menthol
Sesquiterpenoids	3	15	$C_{15}H_{24}$	humulone
Diterpenoids	4	20	$C_{20}H_{32}$	retinol
Sesterterpenoids	5	25	$C_{25}H_{40}$	manoalide
Triterpenoids	6	30	$C_{30}H_{48}$	sterols, squalene
Tetraterpenoids	8	40	$C_{40}H_{64}$	Carotenoids
Polyterpenoids	>8	>40	$(C_5H_8)_n$	Natural rubber

Based on number of rings present in terpenoids

Acyclic Terpenoids: They contain open structure (**Figure 1**).

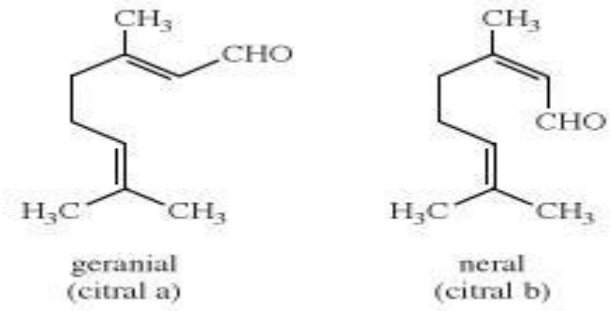

Figure 1 showing structure of acyclic terpenoids

Monocyclic Terpenoids: They contain one ring in the structure (**Figure 2**).

Figure 2 showing structure of monocyclic terpenoids

Bicyclic Terpenoids: They contain two rings in the structure (**Figure 3**).

Figure 3 showing structure of bicyclic terpenoids

Isoprene Rule

Thermal decomposition of terpenoids provide isoprene as one of the product. Otto Wallach mentioned that terpenoids may be constructed up of isoprene unit. Isoprene rule states that the terpenoid molecules are constituted of two or more isoprene unit. Further Ingold suggested that isoprene units are joined in the terpenoid via 'head to tail' fashion. Special isoprene rule states that the terpenoid molecule is built of two or more isoprene units joined in a 'head to tail' fashion.

The fundamental building block of terpenes is the isoprene unit, C_5H_8, i.e. 2-methylbuta-1,3-diene. The single isoprene unit, therefore, represents the most basic class of terpenoids, hemiterpenoids. The larger structures are assembled from several isoprene units, typically through head-to-tail linked isoprene units. The so-called isoprene rule states that all terpenoids are derived from the ordered, head-to-tail joining of isoprene units (**Figure 4**). A head-to-tail fusion is the most common; however, non-head-to-tail condensation of isoprene units also occur. Head-to-head fusions are common among triterpenoids and carotenoids, while some compounds are shaped through head-to-center fusions (e.g., irregular monoterpenoids).

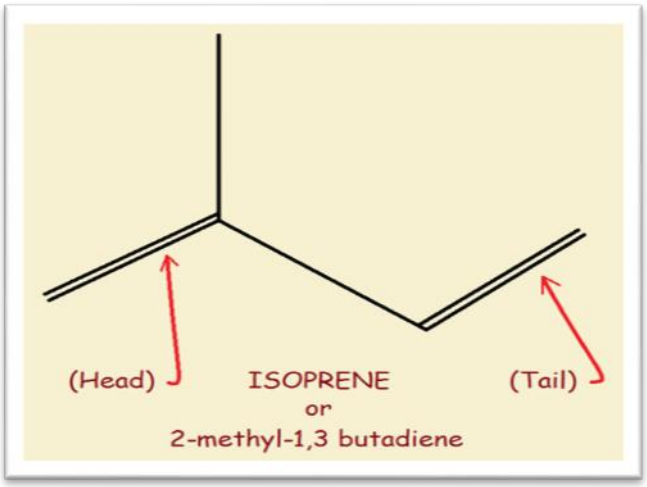

Figure 4 showing joining of isoprene units viz., head and tail method

Generally, there are 3 methods for the joining of isoprene units:
1. Head-Head, 2. Tail-Tail, 3. Head-Tail

According to Isoprene rule, Terpenoids are composed of isoprene units which are joined through head-to-tail linkage. The empirical formula and thermal decomposition of terpenes is shown in **Figure 5**.

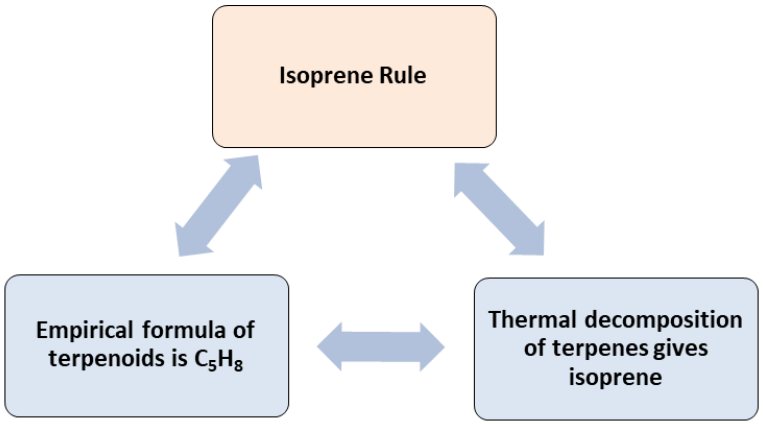

Figure 5 showing Isoprene rule

Isolation of Mono and Sesquiterpenoids

Both mono and sesquiterpenoids have common source i.e., essential oils. Their isolation is carried out in two steps:

i) Isolation of essential oils from plant parts
ii) Separation of Terpenoids from essential oils.

Isolation of essential oils from plant parts

The plants having essential oils normally have the highest concentration at some particular time. Therefore, higher yield of essential oil plant material need to be accumulated at this particular time. e.g. From jasmine at sunset. There are four methods of extractions of oils.

a) Expression method
b) Steam distillation method
c) Extraction by means of volatile solvents
d) Adsorption in purified fats

Steam distillation is most widely used method. In this method macerated plant material is steam distilled to get essential oils into the distillate form these are extracted by using pure organic volatile solvents. If compound decomposes during steam distillation, it may be extracted with ether at 50°C. After extraction solvent is removed under reduced pressure.

Separation of Terpenoids from essential oil

A wide variety of terpenoids are found in essential oil obtained from the extraction. Definite physical and chemical methods may be used for the separation of terpenoids. They are separated with the aid of fractional distillation. The terpenoid hydrocarbons distill over first followed by the oxygenated derivatives. More recently different chromatographic techniques have been used both for isolation and separation of terpenoids.

General Properties of Terpenoids

1. Most of the terpenoids are colorless, aromatic liquids which are lighter than water and volatile with steam. A few of them are solids e.g. camphor. All are soluble inorganic solvent and normally insoluble in water. Most of them are optically active.
2. They are open chain or cyclic unsaturated compounds having one or more double bonds. Consequently, they undergo addition reaction with hydrogen, halogen, acids, etc. A number of addition products have antiseptic properties.
3. They undergo polymerization and dehydrogenation.
4. They are easily oxidized nearly by all the oxidizing agents. On thermal decomposition, most of the terpenoids yields isoprene as one of the product.
5. Terpenoids are unsaturated compounds composed of linked isoprene units.
6. They consist of complicated combination of terpenes or sesquiterpenes, alcohols, aldehydes, ketones, acids and esters.
7. They undergo addition reaction with hydrogen, halogen acids to form addition products.
8. On thermal decomposition, terpenoid gives isoprene as one of the product.

Applications of Terpenoids

1. Terpenoids are the important constituents of essential oils, which can be broadly used directly as flavouring agents or for further isolation of flavouring substances.
2. Menthol is one of the most important flavouring chemical compound and it is used extensively in pharmaceuticals, cosmetics, toothpastes, chewing gum and other toiletries as well as in cigarettes. The foremost supply of (-)-menthol is the oil of *Mentha arvensis* that is frozen to acquire crystals of menthol which can be then separated by centrifugation. Menthol is introduced to confectionaries or beverages not only for its minty odour but also as a cooling and refreshing agent.
3. Menthone has a typical minty, peppermint-like scent while iso-menthone has a musty, sweet, herbaceous, earthy camphoraceous, hay-like scent. Menthone and iso-menthone are constituents of the essential oils of pennyroyal, peppermint, *Pelargonium geraniums*, and others. Menthone can be obtained by distillation of corn mint oil, by oxidation of menthol or by hydrogenation of thymol.
4. Carvone, is the compound liable for the taste of caraway, dill and spearmint, has been used for millennia in food. Carvone is present in two enantiomeric forms: R-(+)-carvone smells like spearmint while S-(-)-carvone smells like caraway. In the past, Rand S- carvones had been extracted and isolated by fractional distillation of caraway oil and spearmint oil, respectively.

5. Limonene, the preferred beginning material for carvone production is mainly used as a precursor of carvone. It is also used as a flavoring agent in foods, beverages and chewing gum. It is found in non-alcoholic beverages (31ppm), ice cream and ices (68ppm), candy (49ppm), baked goods (120ppm), gelatins and puddings (48-400ppm), and chewing gum (2300ppm). Limonene is a chiral molecule, and biological sources produce D-limonene ((+)-limonene). The main industrial source of this compound is orange peel, from which it is extracted using organic solvents.
6. Because of flavourful and aromatic properties, linalool is added to processed food and beverages, perfumes, cosmetics and soaps as well as to household detergents and waxes. The Food and Drug Administration allows the use of numerous natural and synthetic flavourings in beverages, candy, ice cream and baked goods containing various amounts of linalool and its esters. The GRAS list of flavoring ingredients published in 1965 lists linalool and nine of its common esters. Linalool has a chiral center at C3 and therefore two stereoisomers are present: (R)-(-)-linalool and (S)-(+)-linalool. Plants produce both enantiomeric forms. S-linalool is found, for example, as a major constituent of the essential oils of coriander (*Coriandrum sativum* L.) seed and sweet orange (*Citrus sinensis* Osbeck) flowers.
7. α- and β-Ionone are aroma compounds found in a variety of essential oils, including rose oil and are widely used by the flavor industry, hence their importance in foods. β-ionone is also a raw material for the production of retinol. They are the main volatile compounds found in the headspace of raspberry fruits. The α-ionone is sometimes used in conjunction with anethole, liquorice or menthol to flavor sugar confectionery (candy), and both are typically included in raspberry flavoured beverages.
8. Eucalyptol has a pleasant camphor-like smell, highly spiced aroma and taste, and is used in flavorings, fragrances, and cosmetics. Cineole based eucalyptus oil is used as a flavoring at low levels (0.002%) in various products, including baked goods, confectionery, meat products and beverages. Eucalyptol with purity from 99.6 to 99.8 percent can be obtained in large quantities by means of fractional distillation of eucalyptus oil or can be synthetically prepared from α-terpineole.
9. Nootkatone is used for flavoring beverages and is the most essential and expensive aromatic compound of grapefruit. It has been isolated from grapefruit peel and juice.

Pharmaceutical applications of Terpenoids

1. Plant terpenoids are extensively used for their aromatic qualities.
2. They have a great importance in foods and pharmaceutical beverage industries.
3. Therapeutically, they exert wide spectrum of activities such as antiseptic, diuretic, aromatic etc.
4. Also used as insect repellent, insecticides, pesticides.
5. Play an important role in traditional herbal remedies.

Bioactivity of Terpenoids

Some sesquiterpenoids are very toxic/poisonous, but some are antifungals, carminatives, and insecticides. Being complicated combinations of constituents, overall activities of EOs cannot consequently be attributed to their major components. Many aroma components of EOs, such as terpenes and terpenoids, had been proposed to make a contribution in their antioxidant activity; that include *β*-terpene and *β*-terpinolene in *Melaleuca alternifolia*, 1,8-cineole in *Mentha aquatic*, and linalool in black cumin. Less volatile but strongly bitter-tasting or toxic terpenes additionally shield some plant from being eaten by animals. Some terpenes are potent drugs against various illnesses together with coronary heart diseases, malaria, and cancer [17]. Terpenoids are recognized as a very diverse group of natural compounds possessing a broad range of biological activities-

Antimicrobial activity of Terpenoids

Terpenoids have been shown to exhibit a broad spectrum of inhibitory activities against various Gram-positive and Gram-negative pathogenic bacteria. Being lipophilic, they easily permeate through the cellullar wall and cellular membrane. Disruption of membrane integrity and potential, leakage of cellular contents, denaturation of cytoplasmic proteins, and inactivation of cellular enzymes results in bacterial cellular death. Strong antibacterial activity is characteristic for thyme essential oil which also demonstrated activity against methicillin resistant *Staphyloccus aureus* and to several multidrug resistant bacterial strains. Even the vapor of the oil is highly effective against respiratory tract pathogens. The activity is mainly attributed to thymol and carvacrol. Thyme oil is also highly antifungal.

Anticancer activity of Terpenoids

The mechanism of action is based on the prevention of tumour cell proliferation through necrosis. Their anticancer effects are associated with a decrease in inflammation and oxidative stress; however, some of them, like β-caryophyllene, thymol, or eugenol, produce oxidative stress in cancer cells without increasing oxidative stress in normal cells. Terpenoids play an important role in depolarization of the membrane of cancer cells. Terpenoids are also known to demonstrate significant anticancer capabilities in combination with chemotherapy agents. Eugenol is one of the most active and then most studied. Limonene, one of the most widespread monoterpenes, is found mostly in the essential oils of citrus fruits.

Nutraceutical Applications

The terpenoids are the largest class of phytonutrients in green foods, soy plants, and grains. The importance of terpenoids to plants relates to their necessity to fix carbon through photosynthetic reactions using photosensitizing pigments. This dependence on photoreactive chemistry, in addition to the inability of plants to move to avoid irradiation, places a strong reliance on a spectrum of phytochemical protectants on oxidative reactions. Terpenoids, especially carotenoids, have a unique antioxidant activity in their interaction with free radicals. β-Carotene, along with γ-carotene, lycopene, and lutein, seem to offer protection against lung, colorectal, breast, uterine, and prostate cancers. Carotenes are tissue-specific in their protection. Overall protective effects are therefore greater when all carotenes are taken together. Carotenes also enhance immune response and protect skin cells against UV radiation. Phytosterols compete with dietary cholesterol for uptake in the intestines. They have demonstrated the ability to block the uptake of cholesterol (to which they are structurally related) and facilitate its excretion from the body. The value of our nutrition, in terms of nutritional physiology, is not only conditioned by nutrient and calorie contents but adequate meal preparation and presentation. Thus fragrances play an important role to nutrition and can be associated to the terminology “soul food,” as the information of scents transcend our entire being, both physically and intellectually contributing to a holistic point of view. According to the Aroma-Vital cuisine, addition of spice with essential oils combines sensuality with therapeutic potential. Essential oils extracted from aromatic plants and spices are not supposed to supersede fresh herbs but complement them. For cooking, solely, 100% pure essential oils from controlled organic cultivation should be used. Oils that are not sourced from a controlled organic source should be checked for pesticide content.

Importance of terpenes terpenoids found in essentials oils

Terpenoids are the most important numerous and structurally diverse group of natural products as far as EOs are concerned. Many terpenes have biological activities and are used for clinical purposes. For example, the antimalarial drug artemisinin and the anticancer drug Taxol (paclitaxel) are two of a few terpenes with established medical applications. Monoterpenes are referred to as most important constituents of EOs, floral, and scents. Monoterpenes and monoterpenoids have antioxidant, anticonvulsant, antiulcer, anti-inflammatory, antiseptic, antitumor, antiviral, analgesic, antihypertensive, antibacterial, and therapeutic antidiabetic properties. The general mechanism of action of monoterpenes including its antimicrobial and antitussive activity which is especially associated with their volatility. Their hydrophobicity, as well as the EO’s as a whole, determines their impact on bacterial cell structures with a subsequent antimicrobial effect. α-Terpineol is used to enhance skin penetration and also has insecticidal properties. Monoterpenes have been shown to exert chemopreventive as well as chemotherapeutic activities in mammary tumor models and thus may represent a new class of therapeutic agents. Linalool is an unsaturated alcohol monoterpene found as principal constituent in many EOs known to exhibit various biological activities that include antibacterial, antiplasmodial, and antinociceptive effects in different animal models. Linalool also plays an important role in nature as a key compound in the complex pollination biology of various plant species to ensure reproduction and survival. It is also a key compound for the industrial production of a variety of fragrance chemicals such as geraniol, nerol, citral and its derivatives, as well as a lead compound in the synthesis of vitamins A and E. Its repellent properties on various crop-destroying insects are well studied and documented, hence accentuating the application of linalool in eco-friendly pest management. Limonene is among the most abundant monoterpene constituents found in nature and it occurs in a variety of trees and herbs that include *Citrus* species.

Conclusion

Among plant secondary metabolites, terpenoids are the most abundant and diverse class of natural compounds. Terpenoids are generally found in higher plants, and normally produced in vegetative tissues, flowers, and,

occasionally, roots. The diversity of terpenoids is probably a reflection of their many biological activities in nature, which have made them a widely used resource for traditional and modern human exploitation. Naturally occurring terpenoids provide new opportunities to discover new drugs with minimum side effects. They are usually the constituents of essential oils of economic importance as flavors and perfumes. These are also commonly used as natural flavoring compounds in food industries. Hence it can be concluded that the terpenoids may have potential clinical applications in treating microbial infections alone or in combination with different EO constituents. Volatile terpenoids possess antimicrobial, pesticidal and antifungal activities, so it can additionally enhance the shelf life of stored fruits or reduce pesticide use.

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