## TERPENOIDS AND BIOSYNTHESIS OF TERPENOIDS

**ISOPRENOIDS**

Isoprenoids are defined as natural products whose structures may be divided into isoprene units (number of C5 saturated and unsaturated).



Isoprenoids are divided by the number of C5 into two groups: terpenes and steroids

 Oxygenated derivatives or terponoids such as alcohols, aldehydes, ketones, acids, ethers, peroxyds are biologically active compounds.

Table . Claasification of terpenoids

|  |  |  |
| --- | --- | --- |
|  Class | Carbon atoms  | Compounds |
| Hemiterpenes | C5 | Volatile oils |
| Monoterpenes | C10 | Voltaile oils, iridoids,alkaloids |
| Sesquiterpenes | C15 | Volatile oils , alkaloids, sesquiterpenes, lactones |
| Diterpenes | C20 | Resin, alkaloids, chlorophyll, vitamin K, giberellines |
| Сестеротерпены | C25 | Ophiobolin (fungal metabolite)  |
| Triterpenes, steroids  | C30 | Saponins, cardio steroids, ecdysteroids, limonoids, alkaloids and oth.  |
| Tetraterpenes | C40 | Carotenoids, xanthophylls |
| Polyterpenes | (C5)n | Caoutchoucs, gutta-percha |

Terpenoids occupy a special place among the important biologically active compounds. These natural compounds are widely used in medical practice. In addition, terpenoids are used as raw material for complex and chemical conversion, the products obtained in the result of this process are used in medicine.Terpenoids are made up of isoprene units (C5H8). Terpenes may be classified by the number of isoprene units in the molecule into the following groups:

It has been experimentally proven, terpenoids are produced from the products of sugar breakdown, for example, from acetic acid. The main role of disclosure of izoprene structure belongs to german scientist Wallach. Based on the “isoprene rule” that was recognised in 1887 by Wallach and classified the terpenoids based upon the number of isoprene. In 1953 swiss scientist Ruzicka formulated the biogenetic isoprene rule, included isoprene and special isoprene rules.

“Isoprene rule” states that the terpenoid molecules are constructed from the isoprene unit. Isoprene unit attachment is determined by the “special isoprene rule”. One of these special isoprene rules – “geraniol rule” states isoprene units are joined in “head to tall” fashion.

**«tail»**

**Head**

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 **geraniol**

“Geraniol rule” is only used for the simpliest terpenoids. In complex structures (carotenoids, steroids and triterpenoids) isoprene units are joined “tail to tail”.

For study of terpenoids biosynthesis in plants in the result of biosynthetic researches with isotops it was identified, that biosynthesis of most terpenoids occurs in 3 stages:

I. Synthesis of mevanolic acid

II. Formation of isoprene intermediate

III. Formation of acyclic monoterpene

The formation of mevalonic from acetic acid was studied by Tavromina, M.H. Gibbs, J.W. Huff for the first time. This process can be schematically described as follows:

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Isopentenyl pyrophosphate

In the second stage the mevalonic acid is phosphorylated and converted to 5-phosphomevalonic acid under the influence of mevalokinase enzyme and ATP, and in the result of further phosphorylation 5-pirophosphomvalonic acid is formed. This compound, losing CO2 and, is transformed into isopentenyl pyrophosphate..

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Geranyl pyrophosphate

Then the third stage is begun. Isopentenyl pyrophosphate is isomerized to dimethylallyl pyrophosphate by the enzyme isopentenyl pyrophosphate isomerase, then dimethylallyl pyrophosphate and isopentenyl pyrophosphate are condensed to produce geranyl pyrophosphate.

The further elongation of isoprene chain occurs by adding one molecule of isopentenyl pirophosphate to the geranyl pirophosphate. They are joined in “head to tall” fashion and the acyclic sesquiterpene farnesyl pyrophosphate is formed.

The cyclic monoterpenes originate from acyclic predecessor geraniol or linalool, farnesol or similar acyclic terpenes. Farnesyl pyrophosphate also is involved in the biosynthesis of steroids and other terpenes. For example, germacrene (II) is formed from farnesene (I), гваян (III),eudesman (IV).

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**I**

**III**

**IV**

**II**

The biosynthesis of various terpenoids based on mevalonic acid in plants is showed in scheme 3.

Terpenoids (isoprenoids) are part of many medicinal plants and plant materials, that contained volatile oils (monoterpenes and sesquiterpenes), tannins (mainly sesquiterpene lactones), resins and balsams (diterpenes), cardiac glycoside and steroidal saponines (its aglycons – steroids, formed by isoprene units), triterpenoid saponins (triterpenes and its glycosides), iridioides (monoterpenoid derivatives), carotenoids (tetratenoid derivatives), rubber and gutta-percha (polyterpenes). Rubber and gutta-percha contain 100-500 isoprene units.

Scheme 3. Biosynthesis of Terpenoids (isoprenoids)

 Carbohydrates

 CH3COOH

 CH3CO – S – KoA

 Mevallonic acid

Isopentenyl pirophosphate Dimethylallyl pirophosphate

 Gernaylpirophosphate

 polymerization Monoterpenes

 Polyterpenes

 (rubber, gutta-percha) + isopentylpirophosphate

 Farnesylpirophosphate

dimerization seskviterpenlər

 Squalene

 + isopentylpirophosphate

Steroids Triterpenes

 Geranilgeranilpirofosfat

 dimeraztion

 Diterpenes

Tetraterpenes

 (carotenoids)

 Geranylfarnesyldiphosphate Sesquiterpenoids

 Polyterpenoids

 (rubber, gutta-percha)

**Voltaile oils and and volatile oils plants**

Essential oils *Olea aetherea* – volatile aromatic compounds produced by plants. An essential oil (Aither- from greek word “pure, fresh air) is a concentrated, hydrophobic liquid containing volatile aromatic organic compounds of terpenoid or aromatic nature. They are called volatile for their “volatility”, and oils for similar appearance with fixed oils. In addition, they are similar in appearance and fatty consistency.

Volatile oils are multicomponent mixtures of organic compounds, mostly terpenes, alcohols, aldehydes, ketones and hydrocarbons produced by essential oil plants. The name “volatile oils” was used at the end of the seventeeth century when the chemical composition of volatile oils was unknown. They are called volatile as they evaporate when exposed to air at ordinary temperature, and oils because they have greasy feel . It was later discovered, that volatile oils differ entirely in chemical properties from fixed oils. Fats and fatty oils are ester of triatomic alcohol glycerol and higher fatty acids. Volatile oils do not consist of glyceril esters of fatty acids.

There are about 3000 species on the earth, from which it is possible to extract the volatile oils. The essential oil plants are higher plants fungus, mosses, lichen, algae.

In modern view the essential oils are mixtures of volatile liquid organic compounds produced by plants and give them the distinctive smells. The characteristic components of the essential oils are terpenoids. The amount of essential oils found in plant is low, can be from 0,01 percent to 10-15% of the total. Essential oils are accumulated in different plant organs: flowers, leaves, fruits, seeds, oine needles and oth. The plants of lamiaceae, apiaceae and gymnosperm families are rich in essential oils. Mint, thymus, eucalyptus, cuminum, carum, origanum, coriander, dill, fennel, parlsey, valeriana, artemisia, melissa, salvia, matricaria, pine, white pine, geranium, lavender and oth. contain a sufficient amount of essential oils.

The chemical composition of the essential oils of different parts of the same plant can vary widely. The number of organic and inorganic ingredients ofessential oils varies between 120 and 500. For example, the essential oil of Rhododendron tomentosum contains about 300 components. For this reason the essential oils of 20 plants are allowed to use in pharmacopoeias of different countires. Because the standardization of multi-component essential oils creates the difficulty.

The most reliable standards: ISO- International Standards Organization; EOA - the Essential Oil Association of the U.​S.A; Britihs Pharmacopeoia and oth.

The quality assessment of the essential oils are based on the following criterias: density, refractive indice, angle of refraction, solubility in ethanol, freezing point, acid value, methyl and carbonyl value, ether value acetylation and main components of essential oil. The essential oils change rapidly under the influence of light, air and temperature. Essential oils should be stored in tightly closed amber-coloured bottles in a cool, dark place at temperature not above 15 0C. Shelf life of the essential oils with the storage conditions is 3 years.

The cost of volatile oil is determined by percentage in plant, quality and rarity of essential oil- bearing plants. For example, 3 kg of essential oils are produced from 100 kg of eucalyptus, from juniper- 500 g, from bitter orange flowers – 50 kg. Essential oils are volatile, extracted by distillation and easily obtained from plant raw material with organic solvents. It is widely used in perfumery and cosmetics for its aroma.

Essential oils are transparent, colourless or colour (yellow, green, blue, dark or oth.) liquids with bitter spicy taste and neutral or acidic in reaction. The density of essential oils is in the range from 0,700 g/cm3  to 1,060 g/cm3. Most of essential oils are optically active. They are extracted by distillation. Volatile oils are readily soluble in benzene, ethanol, acetone, diethyl ether, petroleum ether, plant and animal fats, and they are not soluble in water. Due to oxygen and light the essential oils are oxidized, change the colour and flavor. During the cooling some essential oils solidify (mint, rose, camphora nad oth.). Unlike the fatty oils, they do not leave a permanent grease spot on paper and disappear as the oil violatilizes.

Volatile oils at room temperature (16-180C) are transparent colorless or colour (green, yellow, brown, reddish) liquids.

High volatile essential oils are the oils of tea tree, lemon, cupressus, pepermint; medium-volatile essential oils are the oils of matricaria, myrrh, rosemary, pine; and low-volatile essential oils are the oils red sandalwood, cedrus, rhododendron tomentosum..

Some essential oils are colour liquids, for example, cinnamon oil has dark brown colour, thyme oil - reddish, acorus oil -yellowish, achillea oil and matriacaria – bright blue. Most of the volatile oils is lighter than water, only a small number of them is heavier than water and its density is more than 1 (cinnamon, clove and oth.). The boiling point of volatile oils varies from 150 to 350 0C.

During the cooling of some essential oils, the components of oil sometimes will crystallize at room temperature (anethole, menthol, thymol, camphora nad oth.) The more solid constituent of volatile oil is called stearopten, the more volatile constituent is called eleoptene.

Volatile oils is a complex mixture of various types of ingredients, mainly with isoprene structure - monoterpenoids and sesquiterpenoids.

Essential oils were known in ancient Egypt, and the volatile oils and fragrance waters are obtained by steam distillation in the period of Arabian pharmacy. Essential oils are used in medicine, perfume and cosmetic, alcoholic beverage industry. Essential-oil industry is established and developed in many countries worldwide.

Essential oils were well- known in Azerbaijan since ancient times for their therapeutic and odoriferous properties.

There are dozens of essential oil-bearing plants, some of them occupy a large area of industrial scale. The natural and climatic conditions of Azerbaijan enable to develop the profitable industry of essential oil in many regions.

Nowadays in Azerbaijan (Zaqatala) the factory carries out the production activites of essential oils and plant material.

**Localization, dynamic accumulation and function of volatile oils in plants.**

All of the organs of a given species may contain an essential oil, but the composition of this oil may vary with the localization. Many of the essential oils exist in the free state, but can occur as glycosides and split into their component parts by enzymes.

In some cases essential oils are spread out over the all cells of tissue as dissolved or emulsified form in cytoplasm or cell sap, but most often they are accumulated in special endogenous and exogenous secretory tissue. Exogenous structures are external secretory tissues, they are glandular hair, glandules. Endogenous structures are internal secretory tissues and they are secretory cells, ducts and cavities. Secretory cavities can be divided into two types: schizogenous and schizolysigenous.

Secretory tissues, that produce the essential oils, are the systematic property of plants, and the diagnostic property for medicinal plants.

Environmental factors affect on the quantity and quality of the essential oil and they are changed even within 24 hours. Dynamic accumulation of volatile oils in plants is [logical consequence](http://context.reverso.net/%D0%BF%D0%B5%D1%80%D0%B5%D0%B2%D0%BE%D0%B4/%D0%B0%D0%BD%D0%B3%D0%BB%D0%B8%D0%B9%D1%81%D0%BA%D0%B8%D0%B9-%D1%80%D1%83%D1%81%D1%81%D0%BA%D0%B8%D0%B9/logical%2Bconsequence) of phenological development and the research of this process enables to collect the raw material woth maximal quantity and necessary essential oil. Many studies have shown that the essential oil can be synthesized differently in various organs of the same plant depending on phenological stage and contain various essential oil.

Essential oils are widely spread in nature and studied more than 100 years, but their role is not yet sufficiently investigated in plants.

Essential oils protect plants from various diseases, pest, exhibit antiseptic property and initiate the healing process. Some scientists think, that the scent of essential oils attracts the insects to promote the dispersion of pollens. Essential oils also regulate the humidity and transpiration. Essential oils are waste products of a plant’s metabolism and serve as reserve substances.

Essential oils are the active participants of metabolic processes in plant organism.

The stages of ontogenesis have a significant impact on accumulation of essential oils in plants. The optimal time for collection of essential oil-bearing material is determined on this indicator .Different factors affect on essential oil accumulation (for example, meteorological: dry or wet weathr, air temperature and oth.). The changes in essential oil quantity occur within 24 hours. So, most of essential oil accumulates in afternoon in lavender petals. But most of essential oils accumulates in rose at the early morning (4-6 hours).

**Methods of obtaining essential oils**

There are several methods of obtaining oils:

* 1) Steam distillation; 2) Solvent extraction; 3) Enfleurage; 4) expression

The method of obtaining essential oils depend on morphological-anatomical properties of raw material, quantity and quality of essential oil.

The quantity of essential oil in plant material is determined by quidance on laboratory exercises of pharmacognosy and State Pharmacopoeia

*Steam distillation (hydrodistillation).* This method is used if there a lot of essential oils in raw material and the distillation temperature doesn’t affect on the components of essential oil and quality of the product.

Steam distillation obeys Dalton’s law of partial pressures. According to this law the mixture of liquids (mutually insoluble and do not react on each other chemically) will boil when the sum of their partial pressures reaches the atmospheric pressure. The boiling points of individual components of essential oils range from 150 to 350 0C. For example, limonene boils at 177 0C, thymol – at 233 0C, geraniol- at 229 0C, pinene – at 160 0C and oth. But all these substances are distilled at the temperature not below 100 0C.

Steam distillation is carried out in distillation equipments and continuous distillation apparatuses.

The distillation equipment consists of a condenser, distillation stilland receiving vessel; double jacketed still, in which the vapour circulates and protects from cooling. A perforated grid placed at the bottom of the still, through which the grid steam enters for heat and distillation of essential oil. The distillation still is connected to the condenser through a pipe. The receiving vessel is also called a Florentine flask. Во флорентийской склянке располагаются 2 сливные трубки, одна из которых связана с нижней частью, а другая - с верхней частью склянки. The oil being lighter than water floats on the water surface; the oil being heavier than water, water is deleted through the pipe. So the essential oil is separated from water.

The steam passes through plant material vaporizing the volatile oil. The mixture of water vapors and volatile oil, condense back to liquid, which is then collected in the receiving vessel.

Continuous distillation apparatuses are used for processing a large amount of raw material. Steam distillation can be conducted not only at atmospheric pressure, also in superheated steam.

**Solvent extraction.** Essential oils are soluble in many volatile organic solvents. This method is used for thermolabile components of essential oils which denatured by the high heat .Petroleum ether (in most cases), ethyl ether, acetone and oth. are used to extract oils in special extractors.

Extractors work by the principle of countercurrent extraction. These equipments consists of pipe through which the plant material is moved upward, and extragent – in opposite direction. Then the extragent is condensed and sent to process. Obtained residue is pure essential oil or a mixture of essential oil, resin, wax, carotenoids and oth. These extracts are called odorous wax, used in natural or processed for extracting of essential oils (alcohol extraction and vacuum topping).

Essential oils are extracted with fixed oils. The raw material in bags is placed in receptacle with fatty casing for 24-48 hours. Then the essential oil is obtained from fat with alcohol.

Lately the extraction of essential oils is conducted by liquefied gases (carbon dioxide, butane and oth.

*Enfleurage.* This method is used for extracting essential oils from the most delicate flowers and this includes some of the oils. This method is based on the obtained essential oil that absorbed by sorbents (solid fats, activated coal and oth.). This process is conducted in special This process is conducted in special frames. Solid fat (a mixture of pork and beef fats) with 3-5 mm thickness is smeared on glass plates, the flowers were placed on the fat and left to release for 48-72 hours. The process was repeated 30 times with spent flowers being removed and fresh flowers being added to the plates until the fat on the plates was completely saturated with the essential oils of the flowers. The oil saturated fat was then dissolved by alcohol. The essential oils migrate to the alcohol and finally the alcohol is evaporated to leave the pure essential oil of the flower.

*Expression.* It is a method of extraction citrus essential oils. It is associated with that the essential oils are located in large cavities of rind of fructs and enable to obtain by pressing process. Pressing is conducted on hydraulic presses, previously the rinds are passed through rolling press. Residual essential oil (30%) in the rind is extracted by steam distillation.

Scrapping of the citrus rind is conducted by special spoons with serrated edges or mettalic disks with blunt needles.

The essential oil for medical practice is obtained from wild growing and cultivated plants.The plants, cultivated in specialized farmds, have the advantage.

Essential oil is obtained from fresh and dried plant raw material. Drying enables to obtain the essential oil during the year. Some plants (lavender, rose and oth.) is obtained from distillation of fresh plant parts.

Essential oil bearing plants should be stored in open air, ventilated area and oven drying at temperature 30-40°C.

It should be remembered, that after separation of the parts from plants in living cell during some time the active metabolism is occured. In the result, the ratio of individual components in essential oil of dried plant material is different from the oil of fresh plant material. Method of obtaining also can influence on the composition of essential oil. For example, there is no caryophyllene in essential oil of clove obtained with benzene, but this component is found in essential oil obtained by steam distillation.

Essential oil bearing plant material is stored in dry, cool place and separately from other plant material.

**Qualitative and quantitative determination of volatile oil.**

Qualitative and quantitative analysis of volatile oils is based on the determination of physical and chemical constants (colour, taste, odour, density, angle of rotation, refractive index, solubility in alcohol, acid and ether value) and studying the chemical composition.

Determination of physical and chemical characteristics assist the researcher to choose the conoditions for study of chemical composition of volatile oil. The density of volatile oils varies between 0,69 and 1,188. Deviation of density measurement shows the low quality of volatile oil.

Refractive index shows the amount of the oxygenated compounds in volatile oil. The refractive index of volatile oil is increased during the prolonged storage due to oxidation.

The volatile oil is a mixture of optically active compounds, that’s why they have various values of the rotation angle. That’s why the angle of rotation is not a main characteristic of the volatile oil. When the certain component is predominated, this constant can indicate the authenticity of the oil.

 The solubility of volatile oil in ethanol (96 or 70%) characterizes the qualitative and quantitative determination.

The saponification value is the number of mg of potassium hydroxide required to neutralize the fatty acids resulting from the complete hydrolysis of 1 g of the substance..

Acid value refers to the number of milligrams of potassium hydroxide required to neutralize free acids in 1 q of the oil

Ether value is the number of milligrams of potassium hydroxide required to neutralize the ethers freed by the hydrolysis of 1 g of the volatile oil. Ether value is calculated after the determination of acid value.

Ether value after acetylation is the number of milligrams of potassium hydroxide required to saponify the ester contained in 1 g of oil after acetylation.

Hydroxyl value is the number of milligrams of potassium hydroxide required to neutralize acetic acid combined to hydroxyl groups, when 1 g of a sample is acetylated.

The gas – liquid chromatography is used for the determination of volatile components.

In addition to the indicated physical and chemical constants the main components that characterize and contain in volatile oil are also determined.

Add several drops of volatile oil to the water on watch glass. There should not be opacity around the volatile oil during the observation on a black background (alcohol).

1 ml volatile oil is placed in a test tube закрывают ватой. Previously the crystallines of fuchsine are placed in cotton-wool. Volatile oil is heated to boiling in a test tube. If the volatile oil contains alcohol impurity, the evaporating alcohol dissolves fuchsine to giive a red colour.

Add 10 ml 90% ethanol to 1 ml essential oil in a test tube for detection of mixture of fatty oils and shake. If the oil leaves a fatty spot, it contains a fixed oil impurity.

**Collection, drying and storage of essential oil raw material.**

Various factors affect on the collection of essential oil in plants: plant developmental stages, natural and agricultural factors (latitude, humidity, altitude and oth.). That’s why these problems should be taken into account during the collection of wild growing and cultivated raw material of essential oil plants. Collecton of essential oil plants is carried out according the general rules. The properties are characteristic for some species of plants, that are reflected in normative documents.

Raw material of essential oil plants should be dried at 30-40 0C (45 0C). Drying can be carried out under the shade or in special dryers.

Store the essential oil- bearing raw materil in dry, cool places and separately from other kinds of plant raw material.

The quality of essential oil-bearing raw material, except for some cases, is determined by the quantity of essential oil.

**Pharmacological properties of essential oils**

Essential oils and essential oil-bearing plants demonstartes a wide spectrum of biological activities. They also affect on the organs, that excrete them: bronchi, kidneys, liver. Plants which have therapeutic effect due to the essential oils are grouped as follows:

1. Essential oils has a wide spectrum of antimicrobial effects, it’s non-specific, and it is one of the most valuable therapeutic properties of essential oil- bearing plants. Essential oils of various plants are not equally active optically. Essential oils exhibit bacteriostatic and bactericidal effect depending on the chemical composition, density and duration of contact with microorganisms. Its mechanism is complex, and mainly consists of cytoplasmic membrane’s destruction and futher metabolic disorder, aerobic respiration, process of synthesis.

Volatile fractions of some essential oils (garlic, onion anf oth.) have antimicrobial activities in air, and they are called phytoncides.

2. Antifungal effect may be considered as an option of antimicrobial activity. These are separate concepts. Essential oils of mint have fungicidal and fungistatic properties. мяты, caraway, fennel, parsley, catnip, garlic, ramsons.

3. The antiviral effectiveness of essential oils is scientifically unreasonable It is likely that antiviral activity of many essential bearing plants in case of viral disease of the respiratory tract and conjunctivitis is associated with destructive action on bacterial flora and anti-inflammatory effect.

4. Essential oils of most plants have anti-inflammatory properties. Anti-inflammatory activity is reflected in protecting cells from the further damage, dilution the exudative phase of process, leukocyte and macrophage infiltration. It is due to antioxidant effect, that is, ability of essential oils components to inhibit free-radical reactions by direct binding oxidizing substances.

5. Essential oils have epithelization action (wound-healing, restorative). It is associated with two properties described above. Mainly, it is realized by applying of essential oils extracts from appropriate raw material by fluid fixed oils (sunflower, olive, almond, apricot, peach oils and oth.). Among the extragents, the essential oils are used as substances restoring the epithelium in damage of mucus membrane and skin.

6. Spasmolytic effect on coronary and cerebral vessels (partly reflex), bronchi and hollow organs are widely used in medicine. It is associated with the blockade of cholino-, serotonin-, adrenergic receptors and has myotropic effect. Substances such as menthol extractedd from peppermint are able to activate the physiological vasodilator reflexes of cold and other receptors of oral activity and respiratory tract.

7. Essential oils has expectorant properties. Expectorant properties are associated with the influence on mucus membrane irritation, with mucolytic properties , that results in making easier the cough, improving the drainage function of bronchial epithelium. Extracts and herb teas of antimicrobial and anti- inflammatory plants are used by inhalation. Gargle and drops of many essential oil-bearing plants are used to reduce upper respiratory mucous membrane irritation.

8. Stimulation of digestive functions is reflected by reflexive (from olfactory and taste receptors) and probably, direct impact of essential oils on stomach and intestines. Pleasant scent or bitter taste of essential oils increase appetite and stimulate secretion of glands, involved in digestion process.

9. Essential oils have the sedative properties (valerian rhizomes, herb of lemon balm, lavender flowers and oth.)

10. Essential oils have diuretic properties (birch buds and leaves, juniper fructus ad oth.)

 11. Spasmolytic effect of described above plants plays an important role for therapeutic effect during the flatulence in organism and constipation, associated with hypokinesis of intestine and increased tonic contraction of sphincter.

**Use of volatile oils**

Ways of applying essential oils: 1. Inhalation (hot, cold); 2. Baths (warm, cool, сидячие, hand and foot baths); 3. Compress (warm and cold); 4. Rubbing; 5. Massage; 6. Acupressure massage; 7. Cosmetic use of volatile oils; 8. Ingesting essential oils (do not ingest pure undiluted essential oil!)

Natural aromatic compounds of plant origin must conform to international standards: do not contain synthetic and artificial substances, not be addictive if consider the correct dosage and toxicological characteristic and do not cause the imbalance and impairment of physiological processes.

Aromatherapy is widely used in medical practice of foreign countries as compress, massage and bath with aromatic substances. Aroma cosmetic a therapeutic effect. Medical practice of different countries finds that ingesting essential oils is possible. In this case the requirements for quality of essential oils are greatly increased, and dosages are decreased. **Classification of volatile oils**

Essential oils are not signle entities, they are complex mixtures of hundreds of compounds. The main compound classes represented in essential oils are terpenes, but the aromatic compound also can prevail.

Due to the chemical composition variety and properties, the volatile oils are classified as saturated terpene hydrocarbons, terpene alcohol, aldehydes, ketones, oxides and oth.

The classification was proposed by the former academician of the Czechoslovak Academy of Sciences F. Shormo and his school. The essential oils are classified into the following groups: 1) acyclic monoterpenes; 2) monocyclic monoterpenes; 3) bicyclic monoterpenes; 4) sesquiterpenes; 5) aromatic compounds

 **Acyclic monoterpenes**

This group of essential oils mainly contains hydrocarbons, alcohols (geraniol, linalool, citranelllol), aldehydes (citranellal, citral), ketones and acids.

Geraniol is a primary alcohol with two double bonds. It exists as a mixture, in which isopropylidine (α) predominates and turns into isopropenyle (β) in acidic medium.

H

2

C

=

C

H

2

C

H

2

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H

2

C

C

H

3

C

H

-

C

H

2

O

H

C

H

3

C

geraniol (2,6-dimethyloctadien-1,6-оl (8) (α-form)

H

3

C

C

=

C

H

C

H

2

C

H

2

C

C

H

C

H

-

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H

2

O

H

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H

3

geraniol (2,6-dimethyloctadien-1,6-оl (8) (β-form)

Citronellol is a primary alcohol with one double bond. Natural citronellol has α and β- isomers.

H

3

C

C

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C

H

C

H

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H

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CН

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Citronellol

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H

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C

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Myrcene

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3

C

C

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C

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C

H

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C

H

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C

C

H

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C

H

2

C

H

3

C

H

3

O

H

 linalool

There are complex esters of acyclic monoterpenes alcohols and various fatty acids (formic, actic, butyric, isovaleric acids and oth.).

3

H

C

C

H

H

C

C

H

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H

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H

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H

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H

3

 Geranyl isovalerate

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H

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C

H

C

C

H

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C

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2

C

C

H

C

H

2

C

H

3

C

O

O

C

H

3

Linalyl Actate

The structure of acyclic monoterpenes and their derivatives can be depictied in cyclic form:

C

H

2

O

H

C

O

H

O

H

Mirsen Geraniol Sitral Linalool

 The essential oils of medicinal plants contain acyclic monoterpenes – rose, coriander, lavender and oth., whic are practical significance.

Monocyclic monoterpenes

The basis of these grops is menthane carbon skeleton. (1-methyl-4-isopropylhexane).

C

H

3

C

H

C

3

H

C

H

3

Menthane

All natural monocylcic monoterpenes are mentadienes and have the molecular formula C10H16. Double bonds can be located in ring, or one of them - in isopropyl group.

To denote the position of a double bond in the structure, it is represented byΔ, followed by a superscript number. For example, mentha -*Δ* 1,4 (8-dien) has double bond, that located between C-1 and C-2, also C-4 and C-8.

Theoritically it is permitted the presence of 14 menthadiens. Seven of them are found in nature, the eighth (β-terpinene) is found with с α –terpinene.

Amoong the hydrocarbons in essential oils as limonen, phellandrene, terpinene, terpinolene and oth. are widespread.

Among the oxygen-containing monocylcic terpenes alcohols – terpineol, menthol, ketons- menthone, carvone and oxydes- cineole are widerspread.

C

H

3

C

H

H

3

C

C

H

3

Methyisopropyl

cyclohexane Limonene α-phellandrene β-phellandrene

O

H

O

H

α-Terpinene β-Terpinene α-Terpineol Menthol

O

4

O

O

8

O

Menthone Carvone 1,8-cineol 1,4-cineol

Monocyclic terpene alcohols with various fatty acids form a large amount of ether. For example, bornyl formate, bornyl acetate, bornyl isovalerate, terpinyl acetate and oth.

Monocyclic monoterpenes are found in the following medicinal plants: mint, melissa officinalis, sage, eucalyptus, caraway and oth.

**Bicyclic monoterpenes**

Bicyclic monoterpenes are compounds with two condensed non-aromatic rings and one ethylene bond. There are four types of this hydrocarbon group: 1) carene; 2) pinene; 3) sabinene; 4) camphene.

These four hydrocarbons have common molecular formula С10Н16, and they have a difference in the position of minor cycle called “bridge”.

 There is a great variet of oxygen – containing of byciclyc terpenes. Among the alcohols sabinol, thujol, borneol and myrtenol, among ketones- camphora, fenchone, thujone are typical.

 α-Pinene β-Pinene Sabinene α-Thujene

 β-Thujene Δ3-Carene Δ4-Carene Camphene Phenchene

O

H

O

H

O

H

C

H

2

O

H

Thujol Sabinol Borneol Myrtenol

O

O

O

C

H

2

Кафур Thujone Phenchone

Bicyclic monoterpenes are found in the following plants: juniper, tanacetum, valerian and oth.

Sesquiterpenes

Sesquiterpenes have the common molecular formula C15H24  and they are present in most essential oils as lactones, alcohols and ketones.

The skeleton of some sesquiterpenes contains 30 carbon atoms. These lactones are calles disesquiterpenoids.

Acyclic sesquiterpenes are unsaturated fatty compounds. This group includes alcohols farnesol and nerolidol, that are mixtures of isomers with terminal isopropenyl and isopropyliden groups.

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3

C

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C

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Farnesene

 Nerolidol

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C

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H

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C

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C

H

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C

H

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H

Farnseol is found in many plants, mainly in essential oils of flowers, for example, convallaria, tilia and oth. Farnseol has a pleasat scent of convallara.

Nerolidol is fond in balsam of Peru and neroli oil.

Bisabolene refers to monocyclic sesquiterpenes, one of the most spread compounds in nature. It was isolated from bergamot and lemone oils, and also from spruce needle oil.

 Bisabolene Zingiberene

Zingiberene is a monocyclic sesquiterpene of the oil of ginger. Bicyclic sesquiterpenes are reprsented in nature as cadinene, sabinene and alcohol eudesmol.

Cadinene

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O

O

O

H

Selinene Bisabolene Bisabolol Santonin

O

C

H

2

C

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O

O

H

O

O

Alantolactone Chamazulene Artabsin

8

7

6

5

4

3

2

1

O

O

C

O

C

H

3

O

Azulene Арнифолид

 The derivatives of azulene (C10H8 ) are the bicyclic sesquiterpenes. Cyclopentane ring is condensed with cycloheptane ring and 5 double bonds.

There are two types of azulenes according to the position of fnctional groups: chamazulenes (blue essential oil) and  guaiazulene (purple essential oil, sometimes green).

 Chamazulene Guaiazulene

They are liquids or crystalline substances with melting point from 40 to 100 C. Azulenes are weakly basic, soluble in concentrated sulfuric, phosphoric, perchloric acids and they are precipitated unchanged by water dilution. (only unsubstituted azulenes have chemical transformation after the contact with acids).

Tricyclic sesquiterpenes are compounds that consist of three condensed rings and often contain azulene bicycle. They are mainly fod in eucalyptus essential oil (aromadendrene), some species of pine (gelrabolene) and oth.

aromadendrene

Sesquiterpenes are found in the following plants: acorus, tilia, juniper, artemisisa cina, artemisisa absinthium, matricaria chamomilla, achillea, Rhododendron tomentosum, arnica montana and oth.

**Aromatic compounds**

The predominant aromatic compounds in essential oils are oxygenated derivatives. They can be in two types: Onlar iki formada olur: 1. Phenols with hydroxyl groups, attached to the aromatic rings; 2. Aromatic alcohols with hydroxyl groups in the side chain.

In contrast to alcohols, the hydroxyls groups of phenols (max. 3) form salts with alkalins – phenolates and phenoloesters. Ability of phenols to form phenolates, dissolved in water, is used in analysis of essential oils and extraction phenolic components in pure form. Aromatic compounds of essential oils include hydrocarbons, alcohols, ketones, phenols, aldehydes and phenol ethers.

P-cymene is often found in aromatic hydrocarbons.

p-cymene

Aromatic alcohols form different esters : fully or partially esterified. There are also compouds that contain aldehyd and ketone groups with ester groups. The essential oils contain the following aromatic alcohols: benzyl alcohol, anise alcohol, phenylpropyl alcohol.

The following phenols and phenol ethers are represented: thymol, carvacrol, anethole, methyl chavicol, eugenol and oth.

The following aromatic aldehyds are found: benzaldehyde, anise aldehyd, vanilin and oth, the aromatic ketones are also found.

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C

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Thymol Carvacrol Anethole Eugenol

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C

H

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C

H

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C

O

-

C

H

3

C

H

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C

H

3

C

H

O

Benzylaldehide Тминовый альдегид Тминовый кетон

C

H

O

O

H

O

C

H

3

 Vanilin

 The following medicinal plants that contain aromatic compounds are caraway, thymus, thymus serpullum, origanum vulgare.