SEED OILS OF THE FAMILY LABIATAE

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At the present time, the family Labiatae numbers more than 300 genera and several thousand species [1]. There are 73 genera (913 species) of plants of this family that grow on the territory of the USSR, and of these 201 species, belonging to 41 genera, are found on the territory of the Uzbek SSR [2].

In their overwhelming majority, the Labiatae are valuable essential-oil-bearing plants, in view of which a number of them (mint, sage, rosemary, lavender, etc.) are cultivated for use as a raw material for the pharmaceutical and essential-oil industries [1, 3]. A considerable number of investigations [3, 4] has been devoted to the chemical study of the essential oils of the Labiatae, but the glyceride seed oils of this family have been studied inadequately.

In recent years, there has been as increase in the number of investigations directed to a far-reaching chemical study of the seed oils of various families, including the Labiatae, in order to find species promising for industrial use and to establish the structure of many unusual components found in the seed lipids for the purpose of the systematics of the plants within a given family.

In seed oils, fatty acids are present mainly in the form of triglycerides and represent the overwhelming bulk of the total lipids. For this reason and partially because of the relative ease of isolation of the neutral lipids from natural samples, the fatty acids are the most frequent objects of study. The widespread acids making up the bulk of plant lipids are few in number and are called the "normal" or the "main" acids. They include the saturated palmitic acid ($C_{16:0}$) and the unsaturated oleic (cis-octadec-9-enoic, $C_{18:1}$), linoleic (octadeca-cis-9, cis-12-dienoic, $C_{18:2}$), and α-linolenic (octadeca-cis-9,cis-12,cis-15-trienoic, $C_{18:3}$) acids. The saturated acids lauric ($C_{12:0}$), myristic ($C_{14:0}$), and stearic ($C_{18:0}$) are also present, as a rule, in seed oils, but they make up a very small part of the total acids and can therefore be assigned to the "minor" acids. "Unusual" acids are fatty acids differing from the main ones both in structure and in their inclusion in definite species of plants. These include acids with branched carbon chains, with olefinic bonds having positions and geometries different from those in the main acids, and with systems of olefinic and acetylenic bonds, and acids containing epoxy, hydroxy, and keto groups.

Unusual Unsaturated Acids. One of the features of the seed oils of the Labiatae is the presence in them of fatty acids with allene groups.

The first natural allenic acid, called laballenic was isolated in 1965 by Bagby et al. from the seed of *Leonotis nepetaefolia* (family Labiatae) [5]. These authors established that the acid is (−)-octadeca-5,6-dienoic acid with the high optical rotation of $[\alpha]_D^{20}$ −47.3°. The structure of the acid was later confirmed by stereospecific synthesis [6]. The synthetic analog of labellenic acid had an optical rotation of $[\alpha]_D^{20}$ −3.0° and the R configuration, on the basis of which it was assumed that the natural acid possessed a similar configuration.

In carrying out a program of searching for new oil-bearing plants capable of serving as objects of industrial processing, Hagemann et al. analyzed for their fatty-oil contents and their fatty-oil compositions 194 species of Labiatae [7]. On the basis of its IR spectrum (1960 cm^{-1}, C=C=C), laballenic acid was detected in 52 out of 156 species of the subfamily Stachyoideae and in one species of the subfamily Prasioideae. Of the 11 Central Asian species of the Labiatae that we have investigated, we found this acid in the oils of three previously unstudied species also belonging to the subfamily Stachyoideae [8, 9].

The use of modern chromatographic and spectroscopic methods in the analysis of oils enables Hagemann et al. to refine some indices of the composition of the acids of species studied previously and simultaneously to detect the presence of a series of unusual acids in the oils of other species.

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Thus, when the total methyl esters of the acids of oils of Lamium species were separated by the TLC/$AgNO_3$ method, results were obtained which permitted the hypothesis that these oils contain another allenic acid having an addition trans-olefinic bond, and hydroxy acids were found in the oils of species of Thymus (according to GLC).

An allenic octadecatrienic acid has been isolated from the seed oil of Lamium purpureum by Mikolajczak et al. and has been called lamenallenic acid [10]. The acid likewise had the allenic bond in the $\Delta^{5,6}$ position and a trans-olefinic bond in the Δ^{16} position.

$$CH_3CH \underset{trans}{=} CH(CH_2)_8CH = C = CH(CH_2)_3COOH.$$

Since lamenallenic acid proved to be levorotatory ($[\alpha]_D^{25}$ $-50°$) and its structure differed from that of laballenic acid only by an additional double bond fairly remote from the allenic group, the authors assume that it, like laballenic acid, has the R configuration.

Apart from representatives of the Labiatae, allenic acids have been found only in individual species of two plant families. Free laballenic acid and its methyl ester, together with two chlorine-containing polyynes, have been found in the lipids of the roots and leaves of the South African plant Dicoma zeyheri (family Compositae) [11], and from the seed oil of Sapium sebiferum and three related species (family Euphorbiaceae) a third allenic acid has been isolated – 8-hydroxyoctadeca-5,6-dienoic acid [12]

$$CH_3(CH_2)_9CHOHCH{=}C{=}CH(CH_2)_3COOH.$$

No hydroxyallenic acids have been found in the seed oils of the Labiatae.

The number of natural compounds having an allenic group is relatively small. They are present mainly in the metabolites of fungi and algae, are optically active compounds, and possess a broad spectrum of antimicrobial and fungicidal action. In all these compounds the allenic group forms part of a conjugated systems including polyacetylenic and dienic fragments and, to a considerable degree, it determines the nature of the activity of the compound [13]. There is no information on the physiological activity of the allenic acids isolated from the seed oils of higher plants.

A detailed study of the seed oil of Teucrium depressum showed that it contained acids unusual in relation to the positions and configurations of the first double bonds: octadeca-cis-5,cis-9,cis-12-trienoic, octadeca-trans-5,cis-9,cis-12-trienoic, and traces of octadeca-cis-5,cis-9-dienoic acids [14]. The acids were isolated by countercurrent extraction in combination with TLC/$AgNO_3$, and their structure was shown on the basis of chromatographic chemical, and spectral results.

Fatty acids having the first double bond in the chain in the Δ^5 position form a characteristic group of unusual nonconjugated olefinic acids isolated in recent years from the seeds of higher plants [15-18]. Acids with the cis configuration of the Δ^5 bond having an 18- to 22-carbon-atom chain, and containing from one to four olefinic bonds have been found in the seeds of plants of six families, apart from the Labiatae: Compositae, Ephedraceae, Limnanthaceae, Ginkgoaceae, Ranunculaceae, and Tazaceae. Monoenic, dienic, and trienic acids with the trans configuration of the Δ^5 bond and 18 carbon atoms have been isolated from the seed oils of species of Thalictrum (Ranunculaceae). It is assumed that the isomeric unsaturated acids with an olefinic bond close to the carboxylic end of the acid (Δ^2, Δ^3, Δ^4) may play definite role in the regulation of infection processes [18, p. 659], and the Δ^5 position of the double bond in the chain of an acid may have specific value in the metabolism of polyunsaturated acids [18, p. 664].

The seed oils of Thymus vulgaris and Salvia nilotica contain unsaturated acids with odd numbers of carbon atoms: heptadeca-8,11,14-trienoic acid (norlinolenic acid; S. nilotica, Th. vulgaris), heptadeca-8,11-dienoic and heptadec-8-enoic acids (S. nilotica) [19, 20].

In the last-mentioned oil, a branched $C_{17:0}$ acid has also been found in trace amounts. Branched acids with a methyl substituent on the α-C (iso-) and on the β-C (anteiso-) in relation to the methyl end of the acid or acids with odd numbers of carbon atoms in the chain, which are unusual for higher plants, have been detected in seed lipids in trace amounts only in isolated cases [16].

Hydroxy Acids. As mentioned above, according to preliminary results, hydroxy acids have been found in the oils of three species of Thymus. An acid isolated from the seed oil of Thymus vulgaris L., where its amount was 13%, had the structure of 2-hydroxyoctadeca-cis-9,cis-12,cis-15-trienoic (α-hydroxylinolenic) acid $[\alpha]_D^{25}$ $-2.1°$ [19]. The seed oil of Salvia nilotica contains – in addition to α-hydroxylinolenic acid (5.4%) –

α-hydroxylinoleic (2-hydroxyoctadeca-cis-9,cis-12-dienoic, 4.2%) and α-hydroxyoleic (2-hydroxyoctadec-cis-9-enoic, 0.6%) acids [20].

α-Hydroxy acids are usually found in sphingolipids and phytoglycolipids but they have not previously been considered as components of glyceride oils. The seed oil of Salvia nilotica is an example of the wide diversity of unusual structures of acids in the lipids of higher plants. The presence in one oil of α-hydroxyoctadecenoic and heptadecenoic acids simultaneously confirms the pathway of the biosynthesis of C_{17} acids via the oxidation of an α-hydroxy-C_{18} acid [15].

Yet another hydroxydienic acid has been isolated from the seed oil of Mentha asiatica: 9-hydroxyoctadeca-deca-cis-12,cis-15-dienoic acid [9]. An isomer of it, densipolic acid (12-hydroxyoctadeca-cis-9,cis-15-dienoic acid) is one of the main components of the seed of Lesquerella densipila (family Cruciferae) [21].

Halogen-Containing Acids. It has recently been shown that the seed oil of Eremostachys moluccelloides contains – in addition to laballenic acid – 9,10-dibromo- and 9,10,12,13-tetrabromostearic acids [22].

A large part of natural organhologen compounds in which the haolgen atom is connected by a covalent bond to a carbon atom belong to the minor components produced by certain organism (fungi, molluscs, sponges) or have been isolated from marine algae. More than 150 organochlorine, more than 50 organobromine, and not more than 10 organofluorine compounds are known as natural products [23]. Only a very insignificant part of this number belongs to the aliphatic series. It has been established that in the lipids of the phytopathogenic fungus Verticillium dahliae Kleb grown in vitro 9,10-dichlorostearic acid is present in minor amounts [24].

In the fatty oils isolated from various organs of higher plants, of haolgen-containing acids the following ω-fluorine-containing compounds have been detected: $\omega F-C_{10:0}$, $-C_{12:0}$, $-C_{14:0}$, $-C_{16:0}$, and $-C_{18:1}$ [25]. All these acids are present in the seed oil of the shrub Dichapetalum toxicarium (family Dichapetalaceae) which is toxic for ruminants. Biological tests on rats of a solution of ω-fluorooleic acid $[F-(CH_2)_8CH=CH(CH_2)_7 \cdot COOH]$ in groundnut oil have shown that the lethal dose of the halo acid is 7-9 mg per kg live weight and, thus, the toxicity of the seeds of the bush is actually due to the fluoro acids that they contain. However, no toxic action has been observed for fluoro acids with an odd number of carbon atoms in the chain [23].

There is information on the physiological action of synthetic brominated oils, which are used as additives in diets. The addition of 2% of brominated olive oil containing as the main component 9,10-dibromostearic acid to the ration of rats increased the tissue level of lipid bromine and led to an increase in the size of the liver and to fatty degeneration of the heart [26].

Leaf Lipids. Unusual fatty acids have been found in the lipids of other organs of plants of the family Labiatae. Hexadeca-7,10,13-trienoic acid has been isolated from the lipids of the leaves of Ajuga reptans and Lamium molecullifolium [27]. A complex combination of mono-, di-, and trihydroxy acids of the C_{16}, C_{17}, and C_{18} series consisting of nine components has been identified by chromatography–mass spectrometry in the lipids of the cuticle of the leaves of Rosmarinus officinalis [28]. In the neutral fraction of an extract of the dried plant Thymus caespititus, esters of 19 aliphatic acids from C_{14} to C_{32} were detected by mass spectroscopy and GLC [29].

Components Accompanying Triglycerides. The substances present with triglycerides in the neutral fractions of extracts of the seeds and other organs of plants of the family Labiatae have been studied little. The amount of unsaponifiable substances in the seed oils studied ranges from 1 to 5% [8, 9]. Among them have been found hydrocarbons of the C_{14}-C_{36} series [8, 29, 30], high-molecular-weight (C_{32}-C_{34}) alcohols [8], di-2-ethylhexyl phthalate [31], β-sitosterol [8, 29], and carotenoids [8]. The seed oil of Eremostachys moluccelloides contains di- and monoglycerides in addition to triglycerides [22].

Taxonomy. The opinion is widespread that the chemical composition of plants may and should be taken into account as a classification characteristic supplementing the morphological features upon which the botanical classification of plants is based. A deepened study of a large number of plant oils from various families has shown that plants belonging to a definite family contain oils of a similar qualitative compositions and may have some characteristic feature distinguishing them from plants of other classification units. Such features are both the fine structure of the triglycerides, the taxonomic possibilities of which have been considered by Litchfield [32] and also, in some cases, the acids of unusual structure isolated during the last 10-15 years from seed lipids [15-17].

In the systematics of the family Labiatae much has remained disputed up to the present time [33-35], and therefore information on the lipid composition of the seeds is being included as a classification characteristic.

According to their fatty-acid compositions the oils studied can be divided into groups on the basis of the acid predominating in the total: oleic acid ($C_{18:1}$ from 45 to 70%), linoleic acid ($C_{18:2}$ from 35 to 75%), and linolenic acid ($C_{18:3}$ from 45 to 78%). Another small group is formed by oils with approximately equal amounts of these acids.

Novitskaya et al. have made an attempt to establish a relationship between the fatty-acid composition and the morphological characteristics (structure of the pollen grains) or various representatives of the Labiatae and the positions of the plants in the system of the family [34, 35]. Having studied the compositions of the fatty acids of the oil seeds of 60 species belonging to 28 genera, these authors established that the seed oils of species, genera, and tribes of the family that are young in the phylogenetic respect contain a large amount of linolenic acid ($C_{18:3}$; 48-78%). In the seed oils of primitive species the predominating acid is linoleic, and the amount of linolenic is very small. On the basis of fatty-acid composition, Novitskaya et al. have suggested the possibility of reconsidering the systematics of the heterogeneous subfamily Stachyoideae.

As has been established [7], a large number of linoleic-acid-containing oils also contain the unusual laballenic acid, which is not found in the linolenic-acid-containing oils. It may apparently be considered that the presence of laballenic acid is a general characteristic of the more primitive species of the subfamily Stachyoideae.

Uses. It was mentioned above that some species of the Labiatae are cultivated for the production of valuable essential oil. Isolated attempts at the industrial use of the fatty oils of individual representatives of this family have been made both in the Soviet Union and abroad.

The seeds of clary sage (Salvia sclarea), a well-known essential-oil plant, contain 31-32% of fatty oil belonging to the drying group. Attempts have been made on the industrial scale to use clary sage in two ways: for the production of seeds and of essential oil from the mass remaining after the milling of the seeds. It has been established that from every hectare of sage crops, in addition to harvesting the seeds, it is possible to obtain 1.5 kg of sage essential oil. Judging from the composition of the seeds, sage seed cake may have food value [1, XXI, p. 313].

Lallemantia (Lallemantia iberica) oil is known as a rapid-drying oil used in the manufacture of high-quality dry oils, lacquers, and paints [1, XX, p. 486].

Perilla (Perilla ocymoides) has long been cultivated as an oil plant in regions of the Far East and has been grown in the Ukraine and the northern Caucasus [1, 36]. Perilla oil is also used for technical purposes. According to available information, an antileprosy preparation is made from perilla oil [1, XXI, p. 631].

Attempts have been made to use the industrial oil of the hemp nettle (Galeopsis speciosa) for food purposes. However, after consumption of the oil temporary paralysis of the extremities appears. A similar action is shown by hemp-nettle seeds and overwhelmingly by the oil-seed cake when it is fed to cattle [1, XXI, p. 117]. The cause of the toxicity of the oil is unknown.

Thus, seeds of more than 250 species of Labiatae belonging to 61 genera have been studied for their oil content and the fatty-acid composition of the oil [7-9, 33-36]. Three of them, according to their oil content, belong to the high-oil content seeds (from 30 to 40% of oil) and a small number of species (not more than 15) has a low fatty-oil content (from 6 to 11%).

Many of the oils contain from 30 to 80% of polyunsaturated linoleic or linolenic acid, which determines the use of some of them for technical purposes. More than 15 unusual fatty acids have been detected in the seeds and leaves of plants of this family, among which there are acids with odd numbers of carbon atoms, with branched chains, with unusual positions and geometries of olefinic bonds, and allenic, and hydroxy-group- and bromine-group-containing acids. Laballenic acid is considered as a chemotaxonomic characteristic of the subfamilies in the system of Labiatae.

The role of the majority of these unusual acids in the plants and their metabolism and physiological action has not been definitively elucidated or are completely unknown. It is not excluded that the seed oils of this family also contain other acids of unusual structure and therefore form a promising subject for study.

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