LUMINESCENCE SPECTRAL PROPERTIES AND CHROMATOGRAPHY OF LINSEED OILS WITH DIFFERENT STORAGE PERIODS

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(Received 01 August 2024; in final form 16 December 2024; accepted 16 December 2024; published online 09 May 2025)

The paper focuses on luminescence spectral properties of linseed oils obtained by the cold pressing method with different storage periods. We noted the high value of oil fluorophores (phenols, tocopherols, polyunsaturated fatty acids, vitamins, pigments) in conveying information about their original state depending on the time of oil storage in household conditions. It has been established that long-term storage of oil (more then 2 years) leads to:

a) oxidation and decay of phenols, tocopherols, polyunsaturated fatty acids (linoleic, linolenic, arachidonic), vitamins (B_2, E), carotene (precursor of vitamin A), chlorophyll pigment, accompanied by a decrease in the intensity of the luminescence bands of phenol, tocopherol, and chlorophyll pigment;

b) an increase in the intensity of the luminescence bands of the oxidation products of these components peaking at λ_{max}= 370, 390, 415, 430, 470, 515, 568 and 590 nm with a change in the structure of the luminescence excitation spectra of these fluorophores. The fatty acid composition of linseed oils was determined by using the gas chromatography method, using a 7890 B gas chromatograph (Agilent Technologies), equipped with a zb-FAME capillary column (manufactured by Phenomenex, USA), 20 m long, internal diameter 0.18 mm, phase thickness 0.15 μm. Helium was used as the carrier gas.

Key words: phenol, tocopherol, carotene, polyunsaturated fatty acids, linseed oils, chlorophyll.

DOI: https://doi.org/10.30970/jps.29.2802

I. INTRODUCTION

Fats, proteins, and carbohydrates are the main types of products that people consume throughout their life. An important part of the fat segment consists of vegetable oils, which are a solution of triglycerides of higher carboxylic acids, different kinds of phenols and tocopherols, vitamins, phospholipids, enzymes, sterols and other physiologically active components [1].

Quantitative analysis of the structure of vegetable oils actually consumed by people shows a constant deficit of polyunsaturated linolenic (ω-3) and an excess of polyunsaturated linoleic (ω-6) and monounsaturated oleic (ω-9) fatty acids. This is caused by the prevailing consumption of oils in which the amount of (ω-6) or (ω-9) fatty acids is within 60–70 % of the content of all unsaturated and saturated fatty acids, and polyunsaturated (ω-3) fatty acid is present in a small amount ($\leq$ 1 %) or completely absent [2, 3]. An excess of fatty acids (ω-6) in human nutrition leads to an increased risk of cardiovascular diseases, mental disorders, immunodeficiency, and the development of cancer. It has been established that (ω-3) fatty acids reduce blood coagulation, prevent the appearance of blood clots, protect vessels from the formation of cholesterol plaques, which contributes to the prevention of cardiovascular diseases [4–6]. It has been scientifically proven that for the normal functioning of a healthy human organism, the ratio of (ω-3) to (ω-6) polyunsaturated fatty acids should be 1:10, and in the case of treatment of cardiovascular diseases, 1:(3 ÷ 5) [7].

For the reasons stated above, it is necessary to increase the level of consumption of oils with an increased content of polyunsaturated fatty acids of the (ω-3) type for healthy human nutrition. Cold-pressed linseed oil is an effective source of polyunsaturated (ω-3) fatty acids, possessing a record high content of these fatty acids 60% [1, 2, 8]. However, polyunsaturated fatty acids, constituents of linseed oil, are very unstable and easily destroyed by exposure to the surrounding air [9], oxidized under the influence of sunlight [10], high temperatures [11, 12], and in contact with metals of variable valence (iron, copper) [13]. The purpose of our work was to study variations in the luminescence spectral characteristics of linseed oil over its storage period (up to two or more years). Changes in the luminescence spectral properties provide information about the modifications in the chemical composition of oil during its storage. The luminescence spectral characteristics of the oils studied were compared with those characteristics of freshly pressed oil.

II. EXPERIMENTAL

The oils were obtained by using the method of cold pressing (temperature of cold pressing $t \leq 46°C$) using a laboratory screw press. Samples of the oils were stored in transparent glass 200 ml bottles placed vertically in a household refrigerator (at a temperature of +4°C). The bottles were covered with appropriate lids. Figure 1 shows the block diagram of the set-up for measuring the luminescence spectral parameters of oils. During the measurement, the samples were in quartz cuvettes 10×10×45 mm in size. A certain wavelength of the excitation light was selected from the emitted continuum of deuterium lamp using the MDR-12 monochromator. Luminescence light signal was registered in single photon counting mode, using the MDR-2 monochromator and the FEP-100 photomultiplier. The signal from the FEP-100 photomultiplier was amplified and transferred to a microcontroller programmed in a certain way, which counted the frequency of pulses and transmitted the result to a personal computer. The results of the measurements were visualized on the computer monitor in both graphic and digital forms. The excitation and emission luminescence spectra were measured in steps of 1 nm. The rotation of the diffraction gratings of the monochromators was carried out with the help of stepper motors, which, in turn, were controlled by a microcontroller programmed in a specific way.

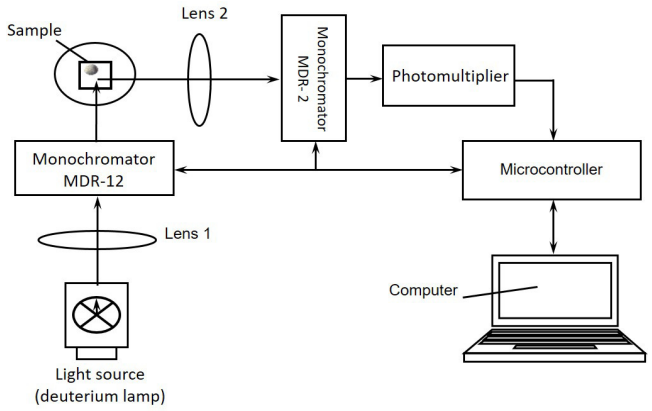

Fig. 1. Block diagram of the set-up for determining the luminescence spectral characteristics of linseed oil

The fatty acid composition of linseed oils was determined by using the gas chromatography method, using a 7890 B gas chromatograph (Agilent Technologies), equipped with a zb-FAME capillary column (manufactured by Phenomenex, USA), 20 m long, internal diameter 0.18 mm, phase thickness 0.15 µm. Helium was used as the carrier gas. Flow rate was 1.0 ml/min. The method of introduction with flow division (Split) 100:1 was used. The injector temperature was 250°C. The detector temperature (PID) was 260°C. Thermostat program: increase to 80°C, hold for 1.5 min; increase by 40°C/min to 160°C, hold for 0 min; increase by 5°C/min to 185°C, hold for 0 min; increase by 30°C/min to 260°C, hold for 2 min. The injection volume was 0.5 µl.

Fatty acids were identified by comparing the retention time of the fatty acids of the sample with those of the standard. Quantification was performed by normalization using Unichrome R software, and results were expressed in grams per 100 grams of the oil sample.

III. RESULTS AND DISCUSSION

Linseed oil contains, as indicated above, a number of components that are luminescent-active compounds. These are $\alpha-$, $\beta-$, $\gamma-$, and $\delta-$tocopherols, which are different kinds of vitamin E, polyunsaturated fatty acids such as linolenic (ω-3), linoleic (ω-6), and arachidonic, monounsaturated oleic (ω-9), vitamins (B_2, E), carotene (a precursor of vitamin A), as well as chlorophyll and pheophytin pigments [1, 2]. These fluorophores can provide information about possible destructive changes in the chemical composition of oil, and, therefore, its quality in the case of long-term oil storage.

Let us analyze these oil fluorophore components in more detail.

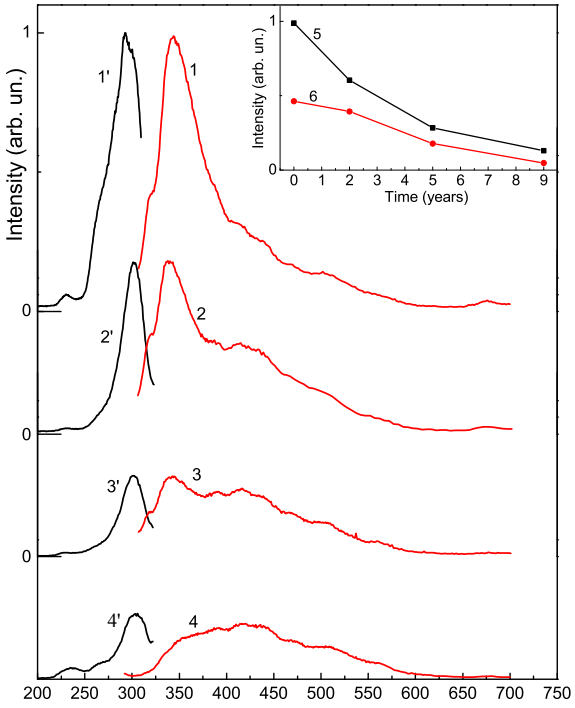

Fig. 2. Photoluminescence emission (curves 1–4) and excitation spectra (curves 1′-4′) of linseed oils with different storage periods under excitation at 280 nm (curves 1–4) 1, 1′ — freshly pressed oil; 2, 2′ — oil aged by oxidation with air access in a non-hermetically sealed container for 2 years; 3, 3′ — oil aged by oxidation with air access in a non-hermetically sealed container for 5 years; 4, 4′ — oil aged by oxidation with air access in a non-hermetically sealed container for 9 years. Inset: 5 — dependence of the intensity of the emission band of α-tocopherol in linseed oil on the storage time; 6 — dependence of the intensity of the emission band of phenol in linseed oil on the storage time

Figure 2 shows the photoluminescence spectra of freshly pressed oil samples obtained by using the cold pressing method (curve 1) and oil obtained by the same method, but aged over different storage periods: 2 years (curve 2), 5 years (curve 3), and 9 years (curve 4) under excitation at 280 nm. In all cases, the two closely spaced bands with $\lambda_{max1} = 325$ and $\lambda_{max2} = 335$ nm and emission in the spectral region from 375 to 700 nm are observed in the luminescence spectra. The spectral position of two closely spaced bands with $\lambda_{max1} = 325$ and $\lambda_{max2} = 335$ nm is identical for all linseed oil samples regardless of their prehistory, however, the luminescence intensity of these bands decreases during storage (Fig. 2, inset, curves 5, 6). Corresponding excitation spectra for the mentioned bands are also similar for all oil samples, namely: the excitation spectrum of the luminescence bands with $\lambda_{max1} = 325$ and $\lambda_{max2} = 335$ nm consists of two closely spaced intense bands with $\lambda_{exc.1} = 285$ and $\lambda_{exc.2} = 305$ nm and a weak band in the region of 265 nm (Fig. 2, curves 1′-4′) [14].

The luminescence spectral characteristics of the emission bands with $\lambda_{max1} = 325$ and $\lambda_{max2} = 335$ nm correspond well to the respective characteristics of the different kinds of phenol and α-tocopherol. Namely, the short-wave components in the excitation spectra of ultraviolet luminescence belong to phenol compounds, and the corresponding long-wave components to tocopherols, in particular, α-tocopherol [9, 13, 15].

As shown in Fig. 2 (curves 1–4), the intensity of both closely spaced emission bands with $\lambda_{max1} = 325$ and $\lambda_{max2} = 335$ nm decreases during the oil aging (inset, curves 5, 6).

The structure of the excitation spectrum of the indicated luminescence bands is also weakened (short-wavelength components of the excitation band with $\lambda_{exc.1} = 285$ and 265 nm are absent). These changes in the structure of the excitation spectrum of the luminescence bands with $\lambda_{max1} = 325$ and $\lambda_{max2} = 335$ nm and in the structure of these luminescence bands indicate significant denaturation and decomposition of phenol and α-tocopherol in the aged oil [14]. Therefore, in the oil that was stored in a closed but leaky vessel for more than two years, autooxidation processes took place under the influence of residual air. Similar results of auto- and thermal oxidation effect on excitation and emission luminescence spectra were obtained for olive oil [9, 15, 16].

Comparing the structure of the emission spectra of the oils described above (Fig. 2, curves 1-4), it can be noted that the luminescence in the region from 370 to 550 nm decays more slowly than the luminescence of the bands with $\lambda_{max1} = 325$ and $\lambda_{max2} = 335$ nm in the case of aged oils.

Emission in the region of 370–550 nm has a more complicated structure under the excitation of the oil samples with light with a wavelength of 325 nm (Fig. 3, curves 1–4). For all samples of linseed oil obtained under the above-mentioned conditions, the emission spectra are dominated by bands with maxima in the region of 390 and 415 nm; a short-wavelength shoulder in the region of 370 nm, long-wavelength shoulders in the region of 430, 470, 515 nm, and a gentle long-wave shoulder in the region of 515–600 nm are observed.

Analysis of the emission spectra of linseed oils aged over storage time (2 months $< t <$ 5 years) showed that the intensity of luminescence in the spectral range of 350–510 nm increases significantly. For older oils, a slight decrease in the intensity of the luminescence bands in the specified range is observed (Fig. 3, curves 5, 6). Based on this, the emission bands in this spectral range can be identified as the luminescence bands of oil oxidation products.

Note that the emission bands of olive and rapeseed oils in the spectral range of 350–600 nm are also attributed to oxidation products of the components of these oils [15–17]. The spectral range in 410–480 nm region is attributed to primary oxidation products [18], and in 480–540 nm region is due to products of secondary oxidation of vegetable oils. Hydroperoxides, products of primary oxidation of oil, are unstable compounds. They decompose with the formation of aldehydes, ketones, ethers, alcohols, and short-chain carbohydrates above room temperature, what causes an unpleasant aroma in oxidized oils and deterioration of their taste qualities [8, 19].

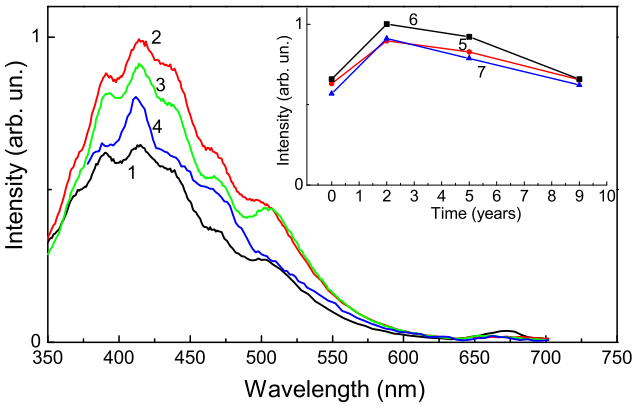

Fig. 3. Photoluminescence emission spectra of linseed oils with different storage periods under excitation at 325 nm (curves 1–4): 1 — freshly pressed oil; 2 — oil aged by oxidation with air access in a non-hermetically sealed container for 2 years; 3 — oil aged by oxidation with air access in a non-hermetically sealed container for 5 years; 4 — oil aged by oxidation with air access in a non-hermetically sealed container for 9 years. Inset: dependence of the intensity of the luminescence oxidation bands of linseed oil on storage time: 5 — $\lambda_{max1} = 390$, 6 — $\lambda_{max2} = 415$, and 7 — $\lambda_{max3} = 430$ nm

The excitation spectra of luminescence bands with $\lambda_{max} = 390$, 415, and 430 nm for freshly prepared samples of linseed oil and samples of oils aged for a long time ($5 \geq t \geq 2$ years) consist of well-structured bands in the region of 260, 295, 310, and 325 nm (Fig. 4, curves 1, 1′, 1″–3′, 3″). Similarity of the structure of the excitation spectra of the luminescence bands with $\lambda_{max} = 390$, 415 and 430 nm of freshly prepared samples of linseed oil and samples of aged oils with different storage times (not taking into account the slight difference in the structure of the band with $\lambda_{max} = 430$ nm) indicates not only

their oxidative nature. Namely, the spectral position of the emission bands with $\lambda_{max} = 390, 415, 430$ nm and the well-separated structure of their excitation spectra in the region of 260, 295, 310, 325 nm agree well with the luminescence spectral characteristics of polyunsaturated fatty acids: linolenic (ω-3), linoleic (ω-6) and arachidonic in isolated form [20]. It is possible that these polyunsaturated fatty acids made a certain contribution to the emission in the 390-430 nm region at the first stage of oxidation of freshly pressed linseed oil.

According to the results of chromatographic analysis of linseed oils with different storage periods (Table 1 and Fig. 5), the profile of fatty acids is mainly represented by linoleic, linolenic, oleic, palmitic, and stearic acids, confirming the assumption about a certain contribution of linolenic (ω-3), linoleic (ω-6) and arachidonic acids to the emission spectrum in the 390–430 nm region.

The obtained data on the fatty acid composition for the linseed oils studied correlate with literature data [8, 21, 22]. The study of the effect of the storage time of linseed oil on the composition of its polyunsaturated fatty acids showed a slight increase (within a few percent) in linolenic (ω-3) and linoleic (ω-6) fatty acids and a substantial decrease in oleic acid (ω-9) (see Table 1), which is explained by the significant amount of free polyunsaturated fatty acids in cold-pressed oils. During storage, the increase in the amount of free polyunsaturated (ω-3) and (ω-6) fatty acids in oil obtained by using the cold-pressing method is explained by the presence of residual moisture and the temperature regime of the storage of seeds from which the oil was obtained [23]. The intensity of the emission bands with $\lambda_{max} = 390$, 415, 430 nm increases with increasing (ω-3) and (ω-6) fatty acids content, which confirms the assumption that these bands belong to (ω-3) and (ω-6) fatty acids.

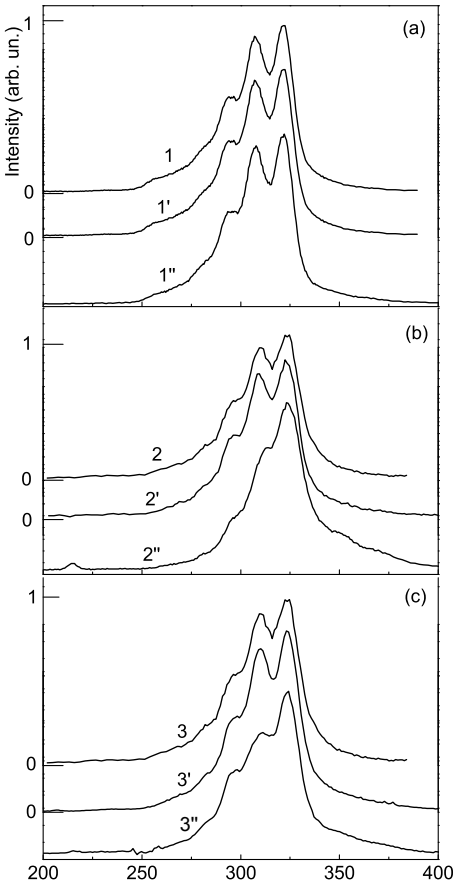

Fig. 4. Photoluminescence excitation spectra with $\lambda_{max} = 390, 415$, and 430 nm of freshly pressed oil (curves 1, 1′, 1″, respectively) and oil aged by oxidation with air access in a non-hermetically sealed container for 2 years (curves 2, 2′, 2″, respectively), of oil aged by oxidation with air access in a non-hermetically sealed container for 5 years (curves 3, 3′, 3″, respectively)

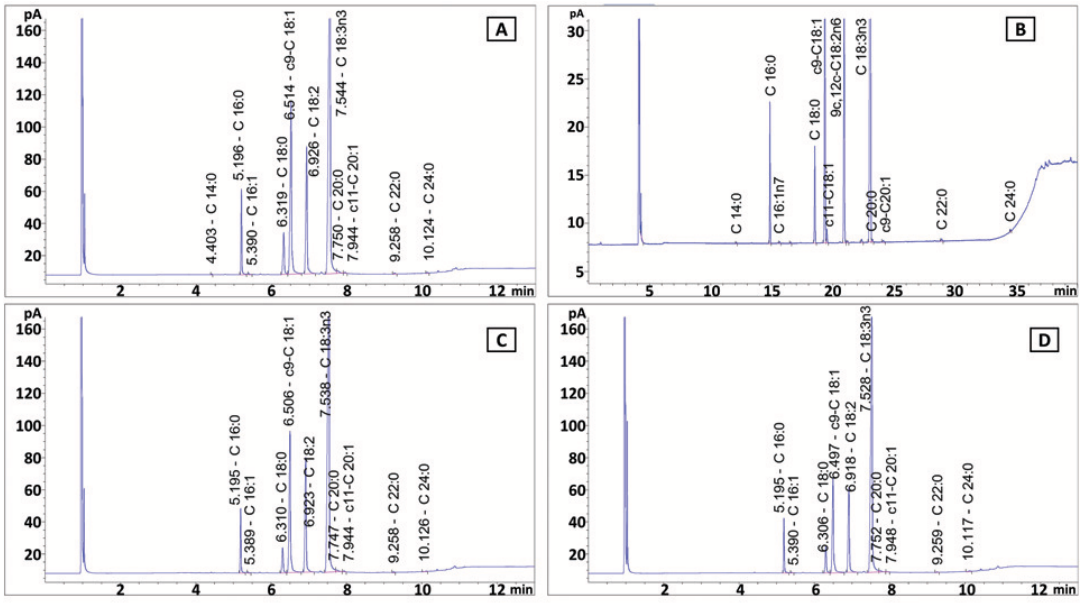

Fig. 5. Chromatogram of the fatty acid composition of linseed oils with different storage periods: 1 — freshly pressed oil, 2 — oil stored in household conditions for 8 months, 3 — oil stored in household conditions for 2 years, 4 — oil stored for 5 years

Fatty acids	Acid code	Values, %						
		2 month	8 month	3 years	12 years	[8]	[21]	[22]
Myristic	14:0	0.04	0.05	—	—	0.07		
Palmitic	16:0	5.79	5.84	5.18	5.82	5.72	5.5	5.8
Palmitoleic	16:1	0.11	0.08	0.09	0.08	0.09	—	
Stearic	18:0	4.71	5.03	3.26	4.33	4.49	4.8	2.6
Oleic	18:1	21.04	20.29	19.55	16.77	20.46	14.0	20.0
Linoleic	18:2	13.83	13.86	14.83	14.15	14.06	18.6	22.0
Linolenic	18:3	53.71	53.47	56.38	58.06	54.24	55.9	47.0
Arachinic	20:0	0.49	0.18	0.45	0.49	0.17	0.1	
Eicosenoic	20:1	0.09	0.13	0.11	0.09	0.1	0.1	
Behenic	22:0	0.11	0.17	0.08	0.09	0.17	—	
Lignoceric	24:0	0.07	0.10	0.07	0.10	0.13		
$\sum$ saturated		11.22	11.37	9.04	10.85	10.84		
$\sum^*$ monounsaturated		21.25	21.28	19.74	16.93	89.17		
$\sum$ polyunsaturated		67.53	67.33	71.21	72.21			

Table 1. The content of fatty acids in linseed oil with different storage periods

Thus, the emission bands in the region of 370, 390, 415, 430 nm can be represented as the overall result of the radiative annihilation of linseed oil components (in this case, polyunsaturated fatty acids) and the effect of auto- and photooxidation of linseed oil to a small extent, as a closed container with oil was stored in the refrigerator.

Let us analyze in more detail the emission bands with $\lambda_{max} = 470$ and 515 nm, which are more clearly seen in the emission spectra of linseed oils under excitation at 350 nm (Fig. 6). The luminescence bands with $\lambda_{max} = 470$ and 515 nm are more intense in the spectra of aged oil samples (see Fig. 3, curves 2–4 and Fig. 6, curves 2–4) than those of freshly pressed oil (see Fig. 3, curve 1 and Fig. 6, curve 1), which confirms their oxidative nature [19, 20, 24]. As the oil ages, the intensity of the luminescence bands with $\lambda_{max} = 470$ and 515 nm increases (see Fig. 6, curves 5, 6).

However, it should be pointed out that the emission in the 515 nm region and the excitation spectrum of the luminescence bands in the 470-520 nm region (Figs. 7,a and 7,b) correspond to the emission of vitamins E, B_2, and carotene [25–27]. This spectral overlap of the luminescence bands of the oxidation products of linseed oil and vitamins E, B_2, and carotene in the spectral region of 450-520 nm complicates the identification of these vitamins. However, the difference in the structure and intensity of the bands of the emission spectra (see Fig. 6) and the structure of the excitation spectra of the luminescence bands with maxima in the region of 470, 515 nm (Figs. 7,a and 7,b) in freshly pressed and aged oils, indicates the dominant presence of the oxidative luminescence component, namely, hydrolysis products [24], as well as primary and secondary oxidation products [20, 27, 28] in these spectra.

We should mention that the luminescence bands with $\lambda_{max} = 520$ and 530 nm were attributed to vitamin E and carotene (precursor of vitamin A) in olive oil also [24, 27].

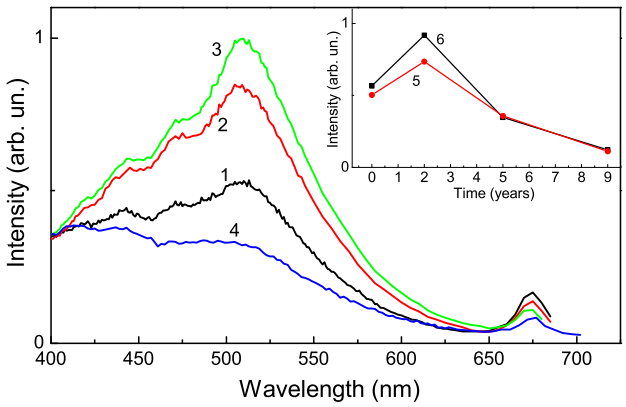

Fig. 6. Photoluminescence emission spectra of linseed oils of different storage periods under excitation at 350 nm (curves 1–4): 1 — freshly pressed oil; 2 — oil aged by oxidation with air access in a non-hermetically sealed container for 2 years; 3 — oil aged by oxidation with air access in a non-hermetically sealed container for 5 years; 4 — oil aged by oxidation with air access in a non-hermetically sealed container for 9 years. Inset: dependence of the intensity of oil luminescence bands on storage time: 5 — $\lambda_{max1} = 470$ nm and 6 — $\lambda_{max2} = 520$ nm

When the luminescence is excited at 405 nm, a broad non-elemental luminescence band with maxima in the region of 470, 515, 568, 590 nm and a band with $\lambda_{max} = 675$ nm is recorded in the emission spectra of freshly pressed oil (Fig. 8, curve 1), which is attributed to the chlorophyll pigment [27–29]. For oils aged for a

long time (> 2 years), the intensity of the main maximum of the mentioned non-elemental emission band in the region of 515 nm increases (Fig. 8, inset, curve 5), and the intensity of the luminescence band of chlorophyll with $\lambda_{max} = 675$ nm – decreases (Fig. 8, inset, curve 6), suggesting the decomposition or oxidation of this pigment during storage. A slight increase in the intensity of the bands with $\lambda_{max} = 470$, 515 and luminescence in the region of 568 and 590 nm in the emission spectrum of aged oil confirms that these luminescence bands belong to the oxidation products of linseed oil. Note, however, that the increase in the intensity of the oxidation bands with $\lambda_{max} = 568$ and 590 nm neutralizes the process of oxidation of vitamin B_2 and carotene (the precursor of vitamin A), accompanied by their decrease in the process of the oil aging, and hence the decrease in the intensity of their emission bands in the region of 568 and 590 nm, characteristic of vitamin B_2 and carotene.

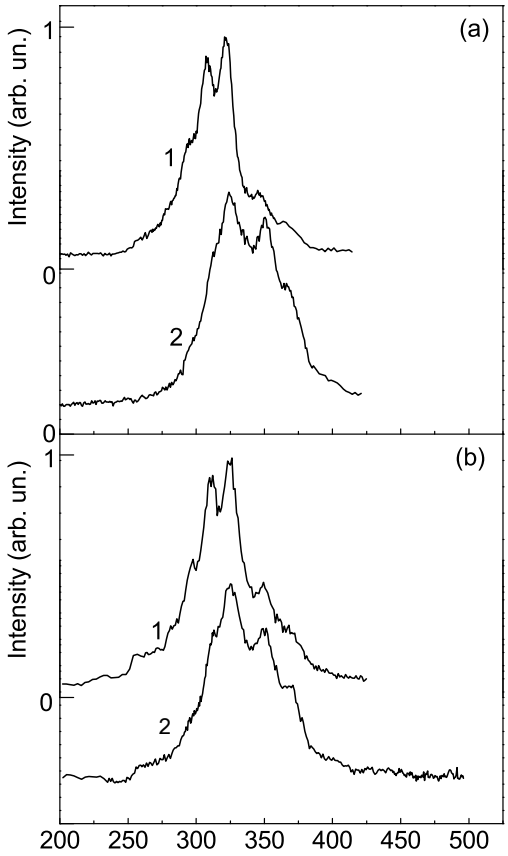

Fig. 7. a) Photoluminescence excitation spectra with $\lambda_{max} = 470$ (curve 1) and oil aged by oxidation with air access in a non-hermetically sealed container for 2 years (curve 2) b) Excitation spectra of photoluminescence bands with $\lambda_{max} = 520$ (curve 1) and oil aged by oxidation with air access in a non-hermetically sealed container for 2 years (curve 2)

Thus, the study of the spectral-luminescent characteristics of flaxseed oils with different storage durations (up to two years and beyond) allows for the identification of oxidation processes in their components. This makes it possible to distinguish flaxseed oils oxidized at an early stage of storage (less than two years) from those in which the oil components have undergone oxidation to such an extent that they can no longer be used as food products.

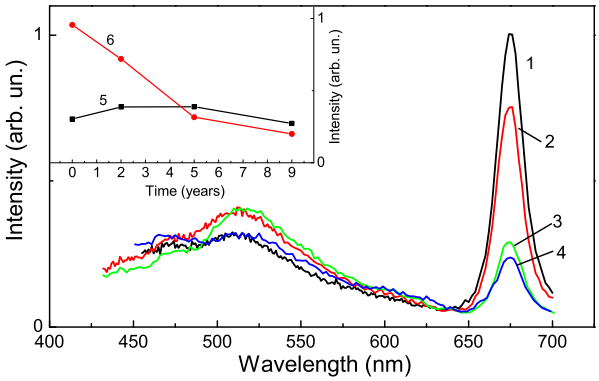

Fig. 8. Photoluminescence emission spectra of linseed oils with different storage periods under excitation at 405 nm (curves 1–4): 1 — freshly pressed oil; 2 — oil aged by oxidation with air access in a non-hermetically sealed container for 2 years; 3 — oil aged by oxidation with air access in a non-hermetically sealed container for 5 years; 4 — oil aged by oxidation with air access in a non-hermetically sealed container for 9 years. Inset: dependence of the intensity of oil luminescence bands on storage time: $\lambda_{max1} = 520$ nm — curve 1; $\lambda_{max2} = 675$ nm — curve 2

IV. CONCLUSIONS

1. Luminescence analysis confirms literature data that linseed oil contains luminescent-active compounds: phenols, tocopherols (a type of vitamin E), polyunsaturated fatty acids (linoleic, linolenic, arachidonic), B_2 vitamins, precursor of vitamin A (carotene), pigment chlorophyll and oxidation products of linseed oil components.

2. Long-term storage of oil (> 2 years) leads to: a) oxidation and decomposition of phenols, tocopherols, polyunsaturated fatty acids (linoleic, linolenic, arachidonic), and vitamins (B_2, E), accompanied by an increase in the intensity of bands with maxima $\lambda_{max} = 370, 390, 415, 430, 470, 515, 568$, and 590 nm; b) changes in the structure of the luminescence excitation spectra of fluorophores: phenols, tocopherols; polyunsaturated fatty acids (linoleic, linolenic, arachidonic) and vitamins (B_2, E), carotene; c) a decrease in the intensity of the luminescence bands of phenol, tocopherol, and chlorophyll pigment.

3. Modifications in the structure of the luminescence spectral characteristics of linseed oil fluorophores — phenols, tocopherols, polyunsaturated fatty acids (linoleic, linolenic, arachidonic), vitamins (B_2, E), carotene, chlorophyll pigment — and oxidation products of oil components can be used to identify oxidative processes in oil as a result of its storage.

[1] A. Cert, W. Moreda, M. C. Pérez-Camino, J. Chromatogr. **881**, 131 (2000); https://doi.org/10.1016/S0021-9673(00)00389-7.
[2] I. F. Drozd, Byul. Inst. Zernovoho Hospodarstva **40**, 72 (2011).
[3] A. H. Stark, Z. Madar, Nutr. Rev. **60**, 170 (2002); https://doi.org/10.1301/002966402320243250.
[4] M. R. Ogborn, E. Nitschmann, N. Bankovic-Calic, H. A. Weiler, H. Aukema, Lipids **37**, 1059 (2002); https://doi.org/10.1007/s11745-002-1001-4.
[5] G. K. Paschos, F. Magkos, D. B. Panagiotakos, V. Votteas, A. Zampelas, J. Clin. Nutr. **61**, 1201 (2007); https://doi.org/10.1038/sj.ejcn.1602631.
[6] T. Yamaguchi *et. al.*, Prostaglandins Leukot. Essent. Fat. Acids **94**, 83 (2015); https://doi.org/10.1016/j.plefa.2014.11.009.
[7] H. Pereira *et. al.*, Mar. Drugs **10**, 1920 (2012); https://doi.org/10.3390/md10091920.
[8] B. M. Berto, R. K. A. Garcia, G. D. Fernandes, D. Barrera-Arellano, G. G. Pereira, Grasas Aceites **71**, (2020); https://doi.org/10.3989/gya.1059182.
[9] E. Sikorska *et al.*, Int. J. Food Sci. Technol. **43**, 52 (2008); https://doi.org/10.1111/j.1365-2621.2006.01384.x.
[10] K. I. Poulli, G. A. Mousdis, C. A. Georgiou, Food Chem. **117**, 499, (2009); https://doi.org/10.1016/j.foodchem.2009.04.024.
[11] M. E. Khosroshahi, Opt. Photon. J. **8**, 247 (2018); https://doi.org/10.4236/opj.2018.87021.
[12] Y. Kongbonga *et. al.*, Food Nutr. Sci. **2**, 692 (2011); https://doi.org/10.4236/fns.2011.27095.
[13] L. Mei, D. J. McClements, J. Wu, E. A. Decker, Food Chem, **61**, 307 (1998); https://doi.org/10.1016/S0308-8146(97)00058-7.
[14] S. Myagkota *et. al.*, J. Fluoresc. **32**, 1991 (2022); https://doi.org/10.1007/s10895-022-02993-4.
[15] N. Dupuy *et al.*, J. Agric. Food Chem. **53**, 9361 (2005); https://doi.org/10.1021/jf051716m.
[16] M. Zandomeneghi, L. Carbonaro, C. Caffarata, J. Agric. Food Chem. **53**, 759 (2005); https://doi.org/10.1021/jf048742p.
[17] S. Kovalyshyn *et. al.*, Prz. Elektrotech. **1**, 981520 (2022); https://doi.org/10.15199/48.2022.01.13.
[18] P. Mishra, L. Lleó, T. Cuadrado, M. Ruiz-Altisent, N. Hernández-Sánchez, Eur. Food Res. Technol. **244**, 565 (2018); https://doi.org/10.1007/s00217-017-2984-1.
[19] E. Sikorska *et. al.*, Foods **8**, 665 (2019); https://doi.org/10.3390/foods8120665.
[20] E. Sikorska *et. al.*, *Analysis of Olive Oils by Fluorescence Spectroscopy: Methods and Applications* (IntechOpen, London, 2012); https://doi.org/10.5772/30676.
[21] E. N. Stepanova *et. al.*, Equipment Technol. Food Prod. **3**, 1 (2011).
[22] A. N. Nikitenko *et. al.*, Trudy Belarus. Gos. Univ. Proc. BSTU **2**(1), 54 (2019).
[23] M. Nykter, H-R. Kymäläinen, F. Gates, Agric. Food Sci. **15**, 402 (2006). https://doi.org/10.2137/145960606780061443.
[24] A. Lobo-Prieto, N. Tena, R. Aparicio-Ruiz, D. L. García-González, E. Sikorska, Food **9**, 1846 (2020); https://doi.org/10.3390/foods9121846.
[25] M. G. Corradini *et. al.*, AIMS Biophysics. **3**, 319 (2016); https://doi.org/10.3934/biophy.2016.2.319.
[26] P. Baltazar, N. Hernández-Sánchez, B. Diezma, L. Lleó, Agronomy **10**, 41 (2020); https://doi.org/10.3390/agronomy10010041.
[27] V. D. Silva *et. al.*, J. Spectrosc. **15**, 03705 (2015); https://doi.org/10.1155/2015/803705.
[28] N. B. Kyriakidis, P. Skarcalis, J. AOAC Int. **83**, 1435 (2000); https://doi.org/10.1093/jaoac/83.6.1435.
[29] M. Saleem, N. Ahmad, J. Fluoresc. **1** (2024); https://doi.org/10.1007/s10895-024-03684-y.

СПЕКТРАЛЬНО-ЛЮМІНЕСЦЕНТНІ ВЛАСТИВОСТІ ТА ХРОМАТОГРАФІЯ ЛЛЯНИХ ОЛІЙ РІЗНОГО ТЕРМІНУ ЗБЕРІГАННЯ

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Досліджено спектрально-люмінесцентні властивості лляних олій, отриманих методом холодного пресування, залежно від часу зберігання. Зареєстровано високу інформативність флуорофорів олії (фенолів, токоферолів, поліненасичених жирних кислот, вітамінів, пігментів) про їхій нативний стан залежно від терміну зберігання олії в побутових умовах. Установлено, що тривале зберігання олії (>2 років) спричиняє: а) окислення та розпад фенолів, токоферолів, поліненасичених жирних кислот (лінолевої, ліноленової, арахідонової), вітамінів (B_2, E), каротину (попередника вітаміну A), пігмента хлорофілу, що супроводжується зменшенням інтенсивності смуг люмінесценції фенолу, токоферолу, пігмента хлорофілу; б) підвищення інтенсивності смуг люмінесценції продуктів окислення цих складників з максимумами $\lambda_{\max} = 370, 390, 415, 430, 470, 515, 568$ та 590 нм зі зміною структури спектрів збудження люмінесценції вказаних флуорофорів.

Ключові слова: фенол, токоферол, каротин, поліненасичені жирні кислоти, лляна олія, хлорофіл.