

Acta Technologica Agriculturae 4
Nitra, Slovaca Universitas Agriculturae Nitriae, 2024, pp. 212–218

DETERMINATION OF EXTRA VIRGIN OLIVE OIL ADULTERATION USING LASER INDUCED FLUOROMETRY – CHLOROPHYLL RELATIVE INTENSITY METHOD

Tihomir KOSOR¹, Ivan MOROSAVLJEVIĆ^{2*}, Barbara NAKIĆ-ALFIREVIĆ¹,
Janko MOROSAVLJEVIĆ², Dražan KOZAK², Róbert DRLIČKA³

¹University of Split, Faculty of Chemistry and Technology, Department of General and Inorganic Chemistry, Split, Croatia, t.kosor@kalun.hr (T.K.), barbaranakicalfirevic@gmail.com (B.N.A.)

²University of Slavonski Brod, Mechanical Engineering Faculty in Slavonski Brod, Slavonski Brod, Croatia, jmorosavljevic@unisb.hr (J.M.), dkozak@unisb.hr (D.K.)

³Slovak University of Agriculture in Nitra, Faculty of Engineering, Institute of Design and Engineering Technologies, Nitra, Slovakia, robert.drlicka@uniag.sk

*correspondence: imorosavljevic@unisb.hr

A new method has been proposed for detecting the potential adulteration of extra virgin olive oil with processed sunflower oil. This method is based on analysing the laser-induced fluorescence (LIF) spectra of samples. The technique involves measuring the intensity ratio of three specific fluorescence peaks within the 650–750 nm region of the spectra, which are attributed to chlorophyll derivatives. The samples are excited with a 460 nm blue laser in an offset configuration. The results obtained indicate that the relative intensity ratio of these characteristic chlorophyll peaks is consistently correlated with the percentage of oil adulteration. A parameter named the chlorophyll relative intensity (CRI) number has been introduced, which is based on the relative intensity ratios of the chlorophyll peaks in the LIF spectra of the extra virgin olive oil sample. The CRI function demonstrates a linear relationship with the adulteration percentage up to 80%, with a high regression coefficient (R^2) value of 0.9984. This method can be applied accurately when the original fluorescence spectra of unadulterated extra virgin olive oil are known, and it can provide valuable information about the source of unknown oil samples.

Keywords: fraudulent product; analytical method; blended olive oil; fluorometry; sunflower oil

As the world population rises, so will the demand for nutritious food. Consequently, diversifying the crop output to include food and agricultural products is essential (He et al., 2024). As the demand for high-quality agricultural products increases, there has been a rise in fraudulent and mislabelled products being offered to consumers.

Olive oil is a significant food product widely available on the world food market. It is classified and priced based on acidity, with extra virgin olive oil (EVOO) being the most expensive and highly valued type. However, due to its high value, EVOO is often subject to mislabelling and adulteration. Therefore, there is a great interest in controlling the presence of potentially fraudulent olive oil products on the market. Olive oil is more expensive than most of the other food oils because of the lengthy time it takes for olive trees to grow and produce substantial quantities. Additionally, the hand-harvesting process is time-consuming, tedious, and costly (Aljaafreh et al., 2023). There have been several proposed methods in the past for detecting fraudulent oils. Before the use of fluorescence spectroscopy, most methods relied on measuring the physical properties of oils, such as dynamic viscosity, kinematic viscosity, and smoking temperature point (Hlaváč et al., 2019; Gunstone, 2011).

Fluorescence spectroscopy has become an increasingly used analytical tool in food analysis (Jolayemi et al., 2016; Jović et al., 2018; Munawar et al., 2024). Current standard and nonstandard analytical methods for determining

the quality and origin of EVOO, both spectrophotometric and fluorometric, primarily rely on the decrease in the intensity of characteristic spectrum peaks belonging to chlorophyll and carotenoids in adulterated oils (Hindman et al., 1977; Inanc, 2016; Gandul-Rojas et al., 2000). Additionally, Venturini et al. (2023b) proposed a method to extract physicochemical properties from the fluorescence spectrum using affordable equipment, mainly focusing on chlorophyll wavelengths.

While these methods are effective in detecting highly adulterated oils, they struggle to identify small amounts of adulteration due to the differences in spectrophotometric and fluorometric curves and peak intensities among different types of oils. Additionally, these methods can be deceived by the addition of chlorophyll and/or carotenoids. Furthermore, standard fluorescence spectra of extra virgin olive oil typically exhibit only one broad peak attributed to chlorophyll derivatives in the 600–700 nm region of laser-induced fluorescence (LIF) spectra, providing limited information about oil's origin and the chlorophyll itself (Cayuela et al., 2014; Giuliani et al., 2011).

In this work, we propose a novel method for determining EVOO adulteration based on the distinctive characteristic peak ratio of multiple peaks belonging to chlorophyll derivatives in the oil's LIF spectrum in the 650–750 nm region when the sample is excited with a blue 460 nm laser in an offset configuration.

Material and methods

Materials

The oils used in this study were:

1. Cold-pressed extra virgin olive oil dm-Bio, Germany; label oil properties: energy 3.389 kJ per 100 ml; fats 92 g per 100 ml of those containing 92% of oleic, palmitoleic, linoleic, and α -linoleic fatty acids and 11% of palmitic and stearic saturated fatty acids.
2. Cold-pressed extra virgin olive oil Zvijezda, Croatia; label oil properties: energy 3367 kJ per 100 ml; fats 91 g per 100 ml (saturated fats 14 g per 100 ml) of those containing 91% of oleic, palmitoleic, linoleic, and α -linoleic fatty acids and 14% of palmitic and stearic saturated fatty acids.
3. Cold-pressed extra virgin olive oil Oil of Istria, Croatia; label oil properties: energy 3367 kJ per 100 ml; fats 91 g per 100 ml (saturated fats 13 g per 100 ml) of those containing 91% of oleic, palmitoleic, linoleic, and α -linoleic fatty acids and 14% of palmitic and stearic saturated fatty acids.
4. Processed sunflower oil Zvijezda, Croatia; label oil properties: energy 3700 kJ per 100 ml; fats 100 g per 100 ml (saturated fats 12 g per 100 ml); vitamin E 50 mg per 100 ml.
5. Cold-pressed sunflower oil dm-Bio, Germany; label oil properties: energy 3404 kJ per 100 ml; fats 92 g per 100 ml (saturated fats 9.5 g per 100 ml) of those containing 93.3% of oleic, linoleic, and α -linoleic fatty acids and 11% of palmitic and stearic saturated fatty acids; vitamin E 60 mg per 100 ml; salts 0.03 g per 100 ml.

Measurement method

Instrumentation

The samples were analysed using a K-M17 laser-induced fluorometer (LIF) in an offset configuration. The equipment was equipped with a 200 mW blue laser with an excitation wavelength of 460 nm and a long-pass optical filter blocking wavelengths below 470 nm. The signal was recorded by the ASEQ instruments LR1-B spectrometer (Vancouver, Canada) and ASEQ spectra v.1_54 software. The obtained spectra have been baseline-corrected and smoothed using Spectragryph v.1.2.8 software. The peaks of interest were deconvoluted and further analysed using Fityk v.0.98 software. The diagram of the LIF system is presented in Fig. 1. The system comprises the following components: (1) pulse width modulation module; (2) continuous wave laser; (3) lens; (4) sample; (5) laser blocking lens; (6) light gathering optics; (7) optical fibre; (8) spectrometer; and (9) data acquisition and control. A 200 mW, 460 nm diode laser is powered by a pulse width modulation module (PWM), which regulates the laser's duty cycle and synchronises laser pulses with spectrometer data reading intervals according to the data acquisition and control unit settings. A laser beam is focused on the sample using a lens, and a spectrometer reads the optical signal through light-gathering optics and a cut-off long-pass filter to prevent a Rayleigh scattering effect. The acquisition and control unit controls the PWM

module and reads the data acquired from the spectrometer (Morosavljević et al., 2024).

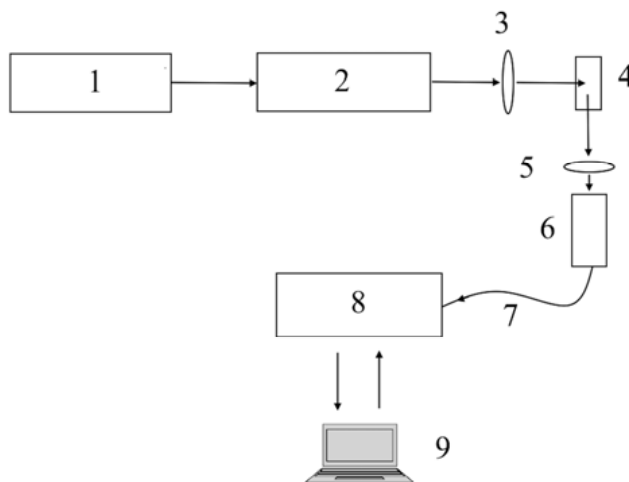


Fig. 1 A schematic representation of the LIFs system
Source: Morosavljević et al., 2024

Samples preparation

Pure, intact samples were prepared of extra virgin olive oil (EVOO1, EVOO2, and EVOO3), processed sunflower oil (SO1), and cold-pressed sunflower oil (CPSO1) as reference points. Afterwards, a series of 10 samples of adulterated extra virgin olive oil (EVOO1) were prepared by adding 0–90% of processed sunflower oil to pure extra virgin oil in the ratios shown in Table 1.

Table 1 The ratios of mixtures of the adulterated oil samples

Sample	EVOO1 (ml)	SO1 (ml)
EVOO1-1	15	0
EVOO1-2	13.5	1.5
EVOO1-3	12	3
EVOO1-4	10.5	4.5
EVOO1-5	9	6
EVOO1-6	7.5	7.5
EVOO1-7	6	9
EVOO1-8	4.5	10
EVOO1-9	3	12
EVOO1-10	1.5	13.5

Design of experiment

Samples were prepared and analysed using LIF. A total of 40 LIF scans were conducted for each sample and then averaged using ASEQ spectra v. 1_54 software before further processing.

Pure EVOO samples were analysed to identify the position of spectrum peaks characteristic of chlorophyll derivatives and vitamin E present in oils. The same analysis was performed on cold-pressed sunflower and processed sunflower oil samples.

The adulterated samples of the selected EVOO were then analysed using LIF, and changes in characteristic peak positions were analysed using the linear and nonlinear regression analysis.

Results and discussion

Three samples of EVOO from different producers were analysed by LIF, and the obtained spectra are shown in Fig. 2.

According to the obtained spectra shown in Fig. 2, it is evident that when stimulated by a 460 nm laser, the spectra of all EVOO samples display three distinct peaks (labelled A, B, and C) between 650 and 750 nm, which are attributed to chlorophyll derivatives. Additionally, there is a broad peak between 500 and 600 nm (labelled D), attributed to vitamin E. The exact wavelengths of labelled peaks are shown in Table 2.

On the other hand, the LIF spectra of SO1 and CPSO1 (sunflower oils) shown in Fig. 3, when compared to the extra virgin olive oil samples shown in Fig. 2, exhibit a higher intensity broad peak between 500 nm and 600 nm, and a broad peak near 667 nm, which can be attributed to chlorophyll derivatives.

Upon analysing the spectra of the extra virgin olive oil samples shown in Fig. 2, it is evident that all the analysed extra virgin olive oils exhibit LIF curves that are insignificantly different, with identical peak wavelengths and minor variations in relative intensities. Therefore, to conserve resources, only the EVOO1 sample was tested with varying adulterated percentages of processed sunflower oils, while the other oil combinations were not further investigated. Based on this observation, it can be inferred that other adulterated combinations

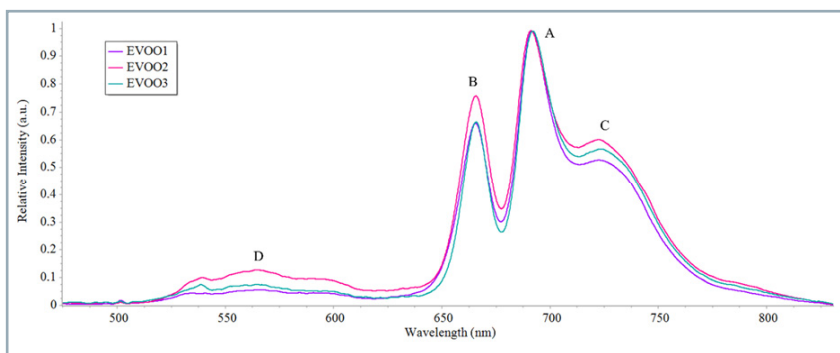


Fig. 2 The LIF spectra of the EVOO1, EVOO2, and EVOO3 samples

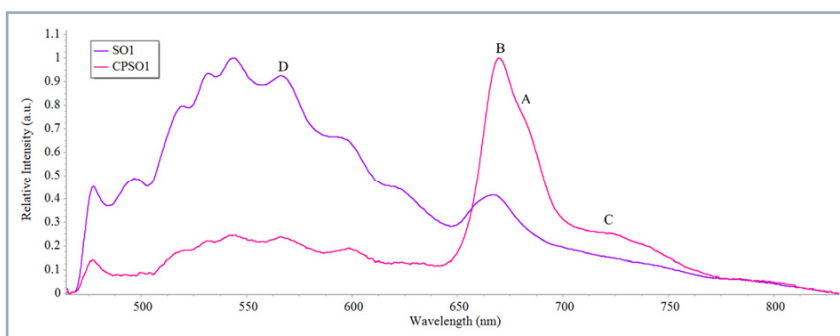


Fig. 3 The LIF spectra of the SO1 and CPSO1 samples

of the EVOO2 and EVOO3 samples with processed sunflower oils would exhibit insignificantly different spectral properties compared to the EVOO1 samples and would not impact the outcome of the proposed CRI method.

The obtained spectra of the selected extra virgin olive oil sample (EVOO1) adulterated with varying percentages of processed sunflower oil (SO1) in the ratios previously described in Table 1 are displayed in Fig. 4.

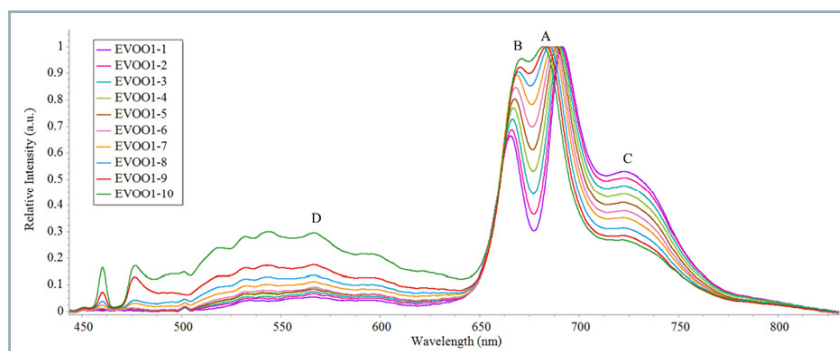


Fig. 4 The LIF spectra of the EVOO1 sample adulterated with 0% (EVOO1-1) to 90% (EVOO1-10) of processed sunflower oil (SO1)

Table 2 Obtained wavelengths of peaks attributed to chlorophyll derivatives and vitamin E

No	Peak	EVOO1	EVOO2	EVOO3	Attributed to
		wavelength (nm)	wavelength (nm)	wavelength (nm)	
1	A	691.6	691.2	692.0	chlorophyll
2	B	665.6	665.7	665.9	chlorophyll
3	C	723.1	722.2	723.2	chlorophyll
4	D	564.8	564.3	565.1	vitamin E

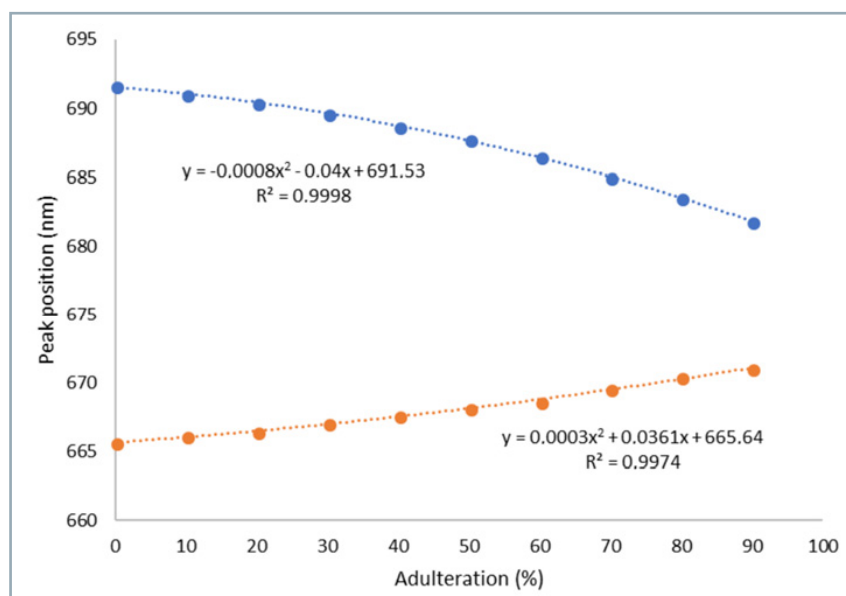


Fig. 5 The shift of the peaks A and B as a function of adulteration percentage

When EVOO1 is adulterated with sample SO1, the LIF spectra show an increase in the intensity of the peak B relative to the peak A, as well as an increase in the intensity of the peak D relative to the peak A. These changes occur as the percentage of processed sunflower oil in the mixture increases. Additionally, there is a shift of the peak A towards lower wavelengths, a shift of the peak B towards higher wavelengths, and a decrease in the relative intensity of the peak C as the percentage of processed sunflower oil in the mixture rises. The peak positions of adulterated samples' spectra are provided in Table 3.

The shift of the position of the peaks A and B as a function of adulteration percentage is shown in Fig. 5.

The shifts of the peaks A and B as a function of adulteration percentage show high regularity, which could potentially be used to determine the adulteration of an unknown

Table 3 The peak wavelength positions of the adulterated samples

No	Sample	Peak A (nm)	Peak B (nm)	Peak C (nm)	Peak D (nm)
1	EVOO1-1	691.6	665.6	722.49	566.27
2	EVOO1-2	691.0	666.1	722.76	566.37
3	EVOO1-3	690.4	666.4	722.22	566.57
4	EVOO1-4	689.6	667.0	722.49	566.69
5	EVOO1-5	688.7	667.6	721.95	566.72
6	EVOO1-6	687.7	667.8	722.22	566.94
7	EVOO1-7	686.5	668.6	721.68	566.71
8	EVOO1-8	685.0	669.5	721.68	566.67
9	EVOO1-9	683.5	670.4	721.68	566.65
10	EVOO1-10	681.8	671.0	721.41	566.65

Table 4 The intensity of the peaks B, C and D relative to peak A intensity

No	Sample	Peak A relative intensity	Peak B relative intensity	Peak C relative intensity	Peak D relative intensity
1	EVOO1-1	1	0.6653	0.5304	0.0473
2	EVOO1-2	1	0.6881	0.5074	0.0732
3	EVOO1-3	1	0.7283	0.4762	0.0746
4	EVOO1-4	1	0.7688	0.4451	0.0869
5	EVOO1-5	1	0.8031	0.4151	0.0928
6	EVOO1-6	1	0.8459	0.3933	0.1013
7	EVOO1-7	1	0.8932	0.3545	0.1150
8	EVOO1-8	1	0.9057	0.3161	0.1389
9	EVOO1-9	1	0.9227	0.2868	0.1786
10	EVOO1-10	1	0.9547	0.2699	0.2973

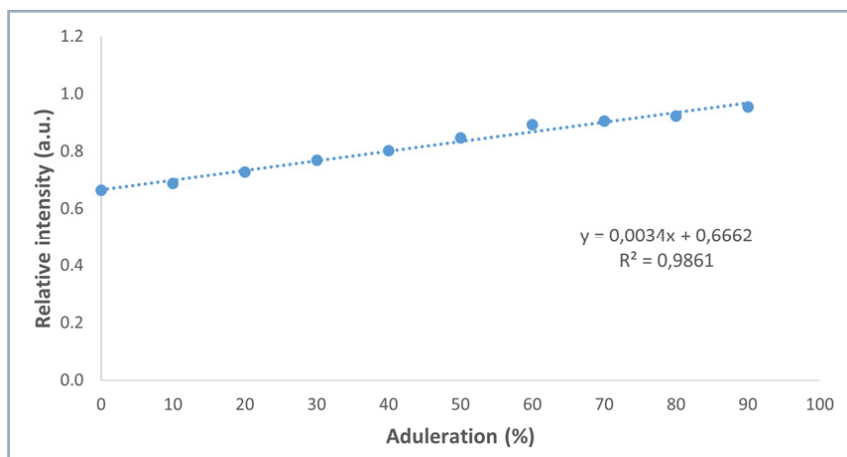


Fig. 6 Peak B to peak A intensity ratio as a function of adulteration percentage

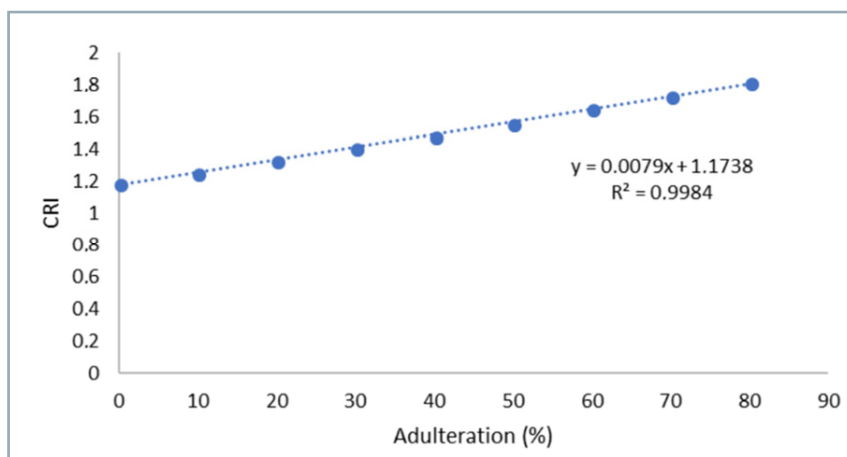


Fig. 7 The CRI parameter datasets of the EVOO1-1 to EVOO1-9 samples as a function of adulteration percentage

sample. However, it is important to note that this regularity is nonlinear, which makes things more challenging.

On the other hand, changes in the relative intensity of chlorophyll peaks can be represented as a linear function of adulteration percentage. Table 4 shows the intensity of the peaks B, C, and D relative to the peak A intensity.

The rise of the intensity of the peak B relative to the peak A is shown as a function of adulteration percentage in Fig. 6.

As can be seen from Fig. 6, the intensity ratio between two chlorophyll derivative peaks shows a linear dependence on adulteration percentage.

It is known that each signal peak mentioned above might represent more than one actual chemical compound and its fluorophore could be formed by several structurally

similar fluorescent constituents (Ali et al., 2018; El Orche et al., 2020)

It is well documented that when integrated with multivariate and multiway methods, such as Principal Component Analysis, Parallel Factor Analysis and others, fluorescence spectroscopy enables the processing of intricate overlapping fluorescent signals and yields valuable quantitative information about chemical components (Sikorska et al., 2012; Hernández-Sánchez et al., 2017; Kyriakidis and Skarkalis, 2000).

However, those methods are cumbersome and time-consuming and as such hardly applicable in the field for quick analysis. Therefore, the proposed method doesn't deal with the exact origin of fluorophores involved in fluorescence signals attributed to certain compounds but explores their mathematical dependence to detect the anomalous presence of "not belonging" compounds.

In order to make a more precise determination of whether the unknown oil sample has been adulterated, all three chlorophyll peaks and vitamin E-attributed peak changes must be taken into account. This could also be true for determining chlorophyll addition fraud, as the intensity ratio change of the three distinctive chlorophyll derivative peaks of extra virgin olive oil (EVOO) and their ratio to vitamin E peaks would be altered by foreign chlorophyll addition.

Therefore, the intensity changes of all the peaks of interest A, B, C, and D, together with changes in their wavelength position, can potentially be used as a quick approximate measure of possible adulteration of an unknown oil sample. However, if the fluorescence curve of the original unadulterated oil is known, then this simple procedure may be used with high precision. If the peaks whose relative intensity rises with raising adulteration are taken to have a "+" relative intensity value and the peaks whose relative intensity falls with raising adulteration are taken to have a "-" intensity value, then by summing the relative intensities of those peaks can establish a parameter called chlorophyll relative intensity (CRI) parameter, which would linearly increase with a raising adulteration and can be defined as the sum of relative intensities of the peaks of interest shown in Eq. (1).

$$\text{CRI} = I_A + I_B + I_C - I_D \quad (1)$$

where: CRI – chlorophyll relative intensity number, obtained from the LIF spectra of EVOO normalised to the highest peak A; I_A – the relative intensity of the peak A, and has the value of 1; I_B – the relative intensity of the peak B; I_C – the relative intensity of the peak C; I_D – the relative intensity of the peak D

Figure 7 shows the obtained CRI parameters for the EVOO1-1 to EVOO1-9 samples as a function of adulteration percentage.

The CRI function shown in Fig. 7 for the samples EVOO1-1 to EVOO1-9

demonstrates a high regression coefficient R^2 value of 0.9984, suggesting a good fit to the predicted linear CRI function model in the detection of up to 80% adulteration. However, with the inclusion of a dataset for higher adulteration (sample EVOO1-10), the R^2 value of the regression coefficient decreases somewhat due to the exponential increase in D peak intensity for the EVOO1-10 sample. Considering that the EVOO1-10 sample represents a 90% adulterated olive oil, such a high level of impurity is excessive and not particularly relevant for potential practical applications.

Further study is needed to ascertain whether the proposed CRI method is effective in detecting fraudulent extra virgin olive oils adulterated with oils other than sunflower oil, such as soybean oil, corn oil, rancid olive oil, or artificial substances. A recent study of Lazzerini et al. (2016) presented the LIF spectra of various consumer oils, including peanut oil, sunflower oil, soybean oil, corn oil, rancid olive oil, and extra virgin olive oil. The reported LIF results show distinct spectroscopic properties for each type of oil, indicating the need for further research to determine whether the proposed CRI method could be employed to accurately identify adulterated oils in fraudulent extra virgin olive oil. Rancid oils have distinct spectrophotometric properties caused by the oxidation of amino acids compared to fresh oil (Hellwig, 2020); therefore, the proposed CRI method could be utilised to detect fraudulent oils adulterated with rancid oil, but further study is required to confirm.

In a recent study of Slavova et al. (2022), it was observed that despite varying geographical origins, different types of olive oil exhibit similar fluorescent characteristics. However, from the reported results and other similar studies with olive oils from varying geographical regions (El Morabit et al., 2024; Venturini et al., 2023a; Soares et al., 2024; Lia et al., 2020), olive oil samples from different regions displayed varying intensities in the obtained spectra at specific wavelengths. As a result, further research is necessary to explore the potential of using the proposed method to identify the origins of extra virgin olive oils by determining the proposed CRI parameter values for extra virgin olive oils from diverse geographical areas beyond the Mediterranean region (specifically Croatia and Italy), which were exclusively used in the study.

Conclusion

A new, quick and affordable method suitable for the field testing of oil samples has been proposed for testing the purity of extra virgin olive oil (EVOO) using three distinct peaks in the laser-induced fluorescence (LIF) spectra. These peaks are related to chlorophyll derivatives and are observed when EVOO samples are excited with a 460 nm laser. The proposed method introduces the concept of the chlorophyll relative intensity (CRI) parameter, which is the sum of the relative intensities of the peaks related to chlorophyll derivatives and vitamin E in the LIF spectra of EVOO.

The CRI function of the analysed oil samples shows a linear dependence on adulteration percentage up to 80% adulteration with the regression coefficient R^2 value as high as 0.9984. The proposed method can be applied with high precision when the original fluorescence spectra of unadulterated extra virgin olive oil are known and can

provide valuable insight regarding the origin of unknown oil samples.

Due to the simplicity of design and high availability of needed equipment, the proposed LIF method is highly affordable and suitable for the field testing of oil samples.

References

- ALJAAFREH, A. – ELZAGZOU, E. Y. – ABUKHAIT, J. – SOLIMAN, A.-H. – ALJAAFREH, S. S. – SIVANATHAN, A. – HUGHES, J. 2023. A real-time olive fruit detection for harvesting robot based on YOLO algorithms. In *Acta Technologica Agriculturae*, vol. 26, no. 3, pp. 121–132. DOI: <https://doi.org/10.2478/ata-2023-0017>
- ALI, H. – SALEEM, M. – ANSER, M. R. – KHAN, S. – ULLAH, R. – BILAL, M. 2018. Validation of fluorescence spectroscopy to detect adulteration of edible oil in extra virgin olive oil (EVOO) by applying chemometrics. In *Applied Spectroscopy*, vol. 72, no. 9, pp. 1371–1379. DOI: <https://doi.org/10.1177/0003702818768485>
- CAYUELA, J. A. – YOUSFI, K. – CARMEN MARTÍNEZ, M. – GARCÍA, J. M. 2014. Rapid determination of olive oil chlorophylls and carotenoids by using visible spectroscopy. In *Journal of the American Oil Chemists' Society*, vol. 91, no. 10, pp. 1677–1684. DOI: <https://doi.org/10.1007/s11746-014-2515-1>
- EL MORABIT, Y. – EL MAADOUDI, M. – ALAHLAH, N. – AMHAMDI, H. – SALHI, A. – AHARI, M. 2024. Detection and quantification of olive oil adulteration using fluorescence spectroscopy and chemometric tools. In *BIO Web of Conferences*, vol. 109, article no. 01016. DOI: <https://doi.org/10.1051/bioconf/202410901016>
- El Orche, A. – Bouatia, M. – Mbarki, M. 2020. Rapid analytical method to characterize the freshness of olive oils using fluorescence spectroscopy and chemometric algorithms. In *Journal of Analytical Methods in Chemistry*, vol. 2020, article ID 8860161. DOI: <https://doi.org/10.1155/2020/8860161>
- GANDUL-ROJAS, B. – CEPERO, M. R.-L. – MÍNGUEZ-MOSQUERA, M. I. 2000. Use of chlorophyll and carotenoid pigment composition to determine authenticity of virgin olive oil. In *Journal of the American Oil Chemists' Society*, vol. 77, no. 8, pp. 853–858. DOI: <https://doi.org/10.1007/s11746-000-0136-z>
- GIULIANI, A. – CERRETANI, L. – CICHELLI, A. 2011. Chlorophylls in olive and in olive oil: Chemistry and occurrences. In *Critical Reviews in Food Science and Nutrition*, vol. 51, no. 7, pp. 678–690. DOI: <https://doi.org/10.1080/10408391003768199>
- GUNSTONE, F. D. 2011. *Vegetable Oils in Food Technology: Composition, Properties and Uses*. Chichester: Blackwell Publishing Ltd., 376 pp. ISBN 9781444332681. DOI: <https://doi.org/10.1002/9781444339925>
- HE, Y. – SONG, J. – OUYANG, W. – LI, Q. 2024. Formation mechanism and implementation path of a digital agriculture innovation ecosystem. In *Tehnički Vjesnik*, vol. 31, no. 2, pp. 402–411. DOI: <https://doi.org/10.17559/TV-20231107001080>
- HERNÁNDEZ-SÁNCHEZ, N. – LLEÓ, L. – AMMARI, F. – CUADRADO, T. R. – ROGER, J. M. 2017. Fast fluorescence spectroscopy methodology to monitor the evolution of extra virgin olive oils under illumination. In *Food and Bioprocess Technology*, vol. 10, no. 5, pp. 949–961. DOI: <https://doi.org/10.1007/s11947-017-1866-7>
- HINDMAN, J. C. – KUGEL, R. – SVIRMICKAS, A. – KATZ, J. J. 1977. Chlorophyll lasers: Stimulated light emission by chlorophylls and Mg-free chlorophyll derivatives. In *Proceedings of the National Academy of Sciences of the United States of America*, vol. 74, no. 1, pp. 5–9. DOI: <https://doi.org/10.1073/pnas.74.1.5>
- HLAVÁČ, P. – BOŽIKOVÁ, M. – PETROVIĆ, A. 2019. Selected physical properties assessment of sunflower and olive oils. In *Acta Technologica Agriculturae*, vol. 22, no. 3, pp. 86–91. DOI: <https://doi.org/10.2478/ata-2019-0016>

- HELLWIG, M. 2020. Analysis of protein oxidation in food and feed products. In *Journal of Agricultural and Food Chemistry*, vol. 68, no. 46, pp. 12870–12885. DOI: <https://doi.org/10.1021/acs.jafc.0c00711>
- INANC, A. L. 2016. Differential method to determine thermal degradation kinetics of chlorophyll in virgin olive oil. In *Italian Journal of Food Science*, vol. 28, no. 1, pp. 90–95. DOI: <https://doi.org/10.14674/1120-1770/ijfs.v462>
- JOLAYEMI, O. S. – TOKATLI, F. – OZEN, B. 2016. Effects of malaxation temperature and harvest time on the chemical characteristics of olive oils. In *Food Chemistry*, vol. 211, pp. 776–783. DOI: <https://doi.org/10.1016/j.foodchem.2016.05.134>
- JOVIĆ, O. – HABINOVEC, I. – GALIĆ, N. – ANDRAŠEC, M. 2018. Maceration of extra virgin olive oil with common aromatic plants using ultrasound-assisted extraction: An UV-Vis spectroscopic investigation. In *Journal of Spectroscopy*, vol. 2018, no. 9, article no. 7510647. DOI: <http://dx.doi.org/10.1155/2018/7510647>
- KYRIAKIDIS, N. B. – SKARKALIS, P. 2000. Fluorescence spectra measurement of olive oil and other vegetable oils. In *Journal of AOAC International*, vol. 83, no. 6, pp. 1435–1439. DOI: <https://doi.org/10.1093/jaoac/83.6.1435>
- LAZZERINI, C. – CIFELLI, M. – DOMENICI, V. 2016. Chapter 6. Pigments in extra-virgin olive oil: Authenticity and quality. In Boskou, D. – Clodoveo, M. L. (eds). *Products from Olive Tree*. London : IntechOpen, pp. 99–114. ISBN 978-953-51-4164-8. DOI: <https://doi.org/10.5772/64736>
- LIA, F. – FORMOSA, J. P. – ZAMMIT-MANGION, M. – FARRUGIA, C. 2020. The first identification of the uniqueness and authentication of Maltese extra virgin olive oil using 3D-fluorescence spectroscopy coupled with multi-way data analysis. In *Foods*, vol. 9, no. 4, article no. 498. DOI: <https://doi.org/10.3390/foods9040498>
- MOROSAVLJEVIĆ, I. – KOZAK, D. – KOSOR, T. – MOROSAVLJEVIĆ, J. – FERLIĆ, L. – GUBELJAK, N. 2024. The effects of ozone sterilization on the chemical and mechanical properties of 3D-printed biocompatible PMMA. In *Micromachines*, vol. 15, no. 4, article no. 472. DOI: <https://doi.org/10.3390/mi15040472>
- MUNAWAR, A. A. – KUSUMIYATI – ANDASURYANI – YUSMANIZAR – ADRIZAL. 2024. Near infrared technology coupled with different spectra correction approaches for fast and non-destructive prediction of chlorogenic acid on intact coffee beans. In *Acta Technologica Agriculturae*, vol 27, no. 1, pp. 23–29. DOI: <https://doi.org/10.2478/ata-2024-0004>
- SIKORSKA, E. – KHMELINSKII, I. – SIKORSKI, M. 2012. Chapter 4. Analysis of olive oils by fluorescence spectroscopy: Methods and applications. In BOSKOU, D. (ed). *Olive Oil – Constituents, Quality, Health Properties and Bioconversions*. London : IntechOpen, pp. 63–88. ISBN 978-953-307-921-9. DOI: <https://doi.org/10.5772/30676>
- SLAVOVA, V. – VLADIMIROVA-MIHLEVA, L. – MIHALEV, M. 2022. A method for fast-acting analysis of quality of unknown olive oils using fluorescence spectroscopy. In SOTIROV, S. S. – PENCHEVA, T. – KACPRZYK, J. – ATANASSOV, K. T. – SOTIROVA, E. – STANEVA, G. (eds). *Contemporary Methods in Bioinformatics and Biomedicine and Their Applications (BioInfoMed 2020)*. Lecture Notes in Networks and Systems. Cham : Springer, vol. 374, pp. 354–362. DOI: https://doi.org/10.1007/978-3-030-96638-6_37
- SOARES, W. M. – ORLANDO, R. M. – MENEZES, H. C. 2024. Enhanced detection of benzo[a]pyrene in olive oil through low temperature liquid-liquid extraction coupled with constant energy synchronous fluorescence spectroscopy. In *Journal of the Brazilian Chemical Society*, vol. 36, no. 6, pp. 1–8. DOI: <https://doi.org/10.21577/0103-5053.20230200>
- VENTURINI, F. – SPERTI, M. – MICHELUCCI, U. – GUCCIARDI, A. – MARTOS, V. M. – DERIU, M. A. 2023a. Dataset of fluorescence spectra and chemical parameters of olive oils. arXiv:2301.04471. DOI: <https://doi.org/10.48550/arXiv.2301.04471>
- VENTURINI, F. – SPERTI, M. – MICHELUCCI, U. – GUCCIARDI, A. – MARTOS, V. M. – DERIU, M. A. 2023b. Extraction of physicochemical properties from the fluorescence spectrum with 1D convolutional neural networks: Application to olive oil. In *Journal of Food Engineering*, vol. 336, article no. 111198. DOI: <https://doi.org/10.1016/j.jfoodeng.2022.111198>

