

ANALYSIS OF PALM OIL AS OIL ADULTERANT IN OLIVE AND PUMPKIN SEED OILS IN TERNARY MIXTURE SYSTEMS USING FTIR SPECTROSCOPY AND CHEMOMETRICS

IRNAWATI^{1,2}, RIYANTO S.¹, MARTONO S.¹, ROHMAN A.^{1,3*}

¹Department of Pharmaceutical Chemistry, Faculty of Pharmacy, Universitas Gadjah Mada, Yogyakarta, ²Faculty of Pharmacy, Universitas Halu Oleo Kendari, Southeast Sulawesi 93232 Indonesia, ³Institute of Halal Industry and Systems, Universitas Gadjah Mada, Yogyakarta 55281 Indonesia
Email: abdulrohmanugm@gmail.com

Received: 23 May 2019, Revised and Accepted: 25 Jul 2019

ABSTRACT

Objective: The study was designed to develop Fourier transform infrared (FTIR) spectroscopy in conjunction with chemometrics techniques of multivariate calibration and discriminant analysis (DA) for analysis of palm oil in a ternary mixture with EVOO and PSO.

Methods: FTIR spectra of pure palm oil (PO), extra virgin olive oil (EVOO), pumpkin seed oil (PSO) and its ternary mixtures randomly prepared were scanned using FTIR spectrophotometer at wavenumbers of 4000-650 cm^{-1} corresponding to mid-infrared region, with resolution of 8 cm^{-1} and 32 scanning using sampling technique of attenuated total reflectance (ATR). Two calibrations in multivariate models, namely principle component (PCR) and partial least square (PLS) regressions were used to facilitate quantification of PO.

Results: The PLS using first derivative FTIR-ATR spectra at 3100-2750 combined with 1500-663 cm^{-1} showed the best prediction models for quantification of PO in ternary mixtures with EVOO and PSO. Using this condition, correlation coefficient (R) values for the relationship between actual values and FTIR predicted values of 0.9967 and 0.9906 were achieved in calibration and validation models, respectively. The errors in calibration and prediction models, expressed by RMSEC and RMSEP, were low, i.e. 0.0080% and 0.0152%, respectively. DA using absorbance values at the same wavenumbers also offered the optimum discrimination model for discrimination between PO and PO mixed with EVOO and PSO in ternary mixtures.

Conclusion: This result concluded that FTIR spectra in conjunction with DA (for classification) and PLS (for quantification) is fast and accurate tools during the analysis of PO as oil adulterant in EVOO and PSO.

Keywords: Discriminant analysis, Multivariate calibration, Palm oil, Olive oil, Pumpkin seed oil

© 2019 The Authors. Published by Innovare Academic Sciences Pvt Ltd. This is an open-access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>)
DOI: <http://dx.doi.org/10.22159/ijap.2019v11i5.34274>

INTRODUCTION

Known as the highest olive oils, extra-virgin olive oil (EVOO) command high priced vegetable oil because EVOO is only obtained by means of the physical and mechanical processes of fresh and healthy fruits of olive (*Olea europaea*) in the appropriate maturation stage without any treatments which cause its original composition changed [1, 2]. As a consequence, EVOO is taken into account as high-quality edible oil due to its nutritional benefits; the appreciated features, pleasant taste, and enjoyable flavor [3, 4]. The evidence from epidemiological studies (especially from dietary intervention and cohort studies) trials revealed that the consumption of EVOO is associated with increased longevity [5]. Besides, EVOO is also reported in inhibiting some disease risk factors, such as diabetes, metabolic syndrome and obesity [6] and preventing certain cancers, especially breast and digestive tract cancers [7]. EVOO is rich phenolics compound which contributed to antioxidant activities and its stability [8]. In addition, pumpkin seed oil (PSO) is also considered as one of the functional edible oils [9]. PSO contained high levels of vitamin E, carotenoids and unsaturated fatty acids, contributing to beneficial effects on human health in prevention of high cholesterol levels, prostate cancer, and molecular degeneration [10, 11]. As a consequence, PSO may also be adulterated with cheaper seed oil like palm oil [12].

In fats and oils industry, both EVOO and PSO revealed advantageous effects to human health, desirable characteristics and limited production; therefore, they commanded expensive price which attracted to be adulterated intentionally with other edible oils [13]. Among the adulteration practices, the addition of EVOO with low price edible vegetable oils including palm oil and seed oils like soybean, corn, sunflower, pomace, and rapeseed oils is the most common fraud [5, 14]. As a consequence, numerous methods based on chemical or molecular biology properties have been developed and used for analysis of oil adulterants in EVOO, and among the most reported ones is FTIR spectroscopy [15, 16].

The combination of FTIR spectroscopy with multivariate analysis or chemometrics has been used for authentication studies of EVOO

from palm oil [17], corn, soybean, sunflower, rapeseed [18], corn, sunflower, soybean and hazelnut oils [19], and analysis of palm with canola oil [20] and lard in binary mixtures [21]. From literature, there are limited studies reporting the combination of FTIR spectroscopy and chemometrics employed for analysis of palm oil as adulterant in EVOO and PSO in ternary mixtures; therefore, this study was intended to analyze palm oil mixed with EVOO and PSO in ternary mixture.

MATERIALS AND METHODS

Materials

Palm oil (SunCo), pumpkin seed oil (Happy Green), canola oil (Mazola), coconut oil (Kara), corn oil (Mazola), extra virgin olive oil (Bertolli), garlic oil (Double Pagoda), ginger oil (Double Pagoda), grape seed oil (Borges), black seed oil (Al-Afiat), hazelnut oil (Fora), rice bran oil (Oryza Grace), soya bean oil (Mazola), sesame oil (Lee Kum Kee) and sunflower oil (Mazola) were obtained from local markets in Yogyakarta. The other chemicals and solvents used in this study were in the level of pro-analytical grade.

Determination of fatty acids composition

The composition of fatty acids composed PO, PSO, and EVOO was determined by gas chromatography equipped with a detector of flame ionization (GC-FID). Before being analyzed using GC-FID, the studied oils were subjected to derivatization procedure to obtain derivate methyl ester of fatty acid (FAME). The derivatization procedure and GC-FID analysis were performed according to the literature [22]. The studied oils (50 μl) were added with 1.0 ml of *n*-hexane and 0.2 ml of 0.2 N NaOCH_3 . The solutions were subjected to heating at 70 $^\circ\text{C}$ (10 min). Every 2 min, solutions were shaken vigorously, added with 1.5 ml of BF_3 , and heated at 70 $^\circ\text{C}$ (10 min). The solutions were cooled and followed by addition of 1.5 ml of saturated NaCl solution. The supernatant containing FAME was injected into GC-FID (GC-FID Agilent 7890B GC (Germany)).

Separation of analytes was performed using column HP-5 (30 m × 0.32 mm × 0.25 μm). The carrier gas used was ultrapure helium with the flow rate of 2.99 ml/min. The temperatures of injector and detector were set at 260 °C. The injection was carried out in split manner with ratio of 15:1. The column temperature was set in gradient manner as follows: 160 °C and hold for 2 min, 160-270 °C (10 °C/min rate), and finally hold for 5 min. In addition, flow rate of the air and hydrogen ultrapure were adjusted at 400 and 40 ml/min, respectively. The retention times of FAME standards (Sigma, Aldrich, USA) were used to identify FAMES in studied oils. The percentage of fatty acid was computed as relative percentage (%) using internal normalization technique as in [23].

Preparation of calibration and validation samples

Preparation of calibration and validation samples was adopted from Rohman *et al.* [28]. For making calibration samples, 20 samples consisting of PO, EVOO, and PSO in ternary mixtures at concentration ranges of 0–100.0% v/v were prepared randomly using random number with the aid of Excel (Microsoft Inc., USA), as shown in table 1.

For preparing validation samples, a series of different samples was preparing in the concentration ranges covered by calibration samples. All samples were analyzed using FTIR spectrophotometer.

Table 1: The composition of palm oil (PO) in ternary mixtures with extra virgin olive oil (EVOO) and pumpkin seed oil (PSO)

No	Concentration (% v/v)		
	PO	EVOO	PSO
Sample 1	23	34	42
Sample 2	5	0	95
Sample 3	18	2	80
Sample 4	46	44	10
Sample 5	25	28	47
Sample 6	26	3	71
Sample 7	36	41	23
Sample 8	26	19	55
Sample 9	15	46	39
Sample 10	40	1	59
Sample 11	31	24	45
Sample 12	25	43	32
Sample 13	23	27	50
Sample 14	18	46	36
Sample 15	12	8	80
Sample 16	34	13	53
Sample 17	39	49	12
Sample 18	18	24	58
Sample 19	23	26	51
Sample 20	27	18	55

Discriminant analysis

Discriminant analysis (DA) for grouping samples was carried out, according to Putri *et al.* [29]. Discriminant analysis (DA) was used for discriminating between pure PO and PO in ternary mixture with PSO and EVOO. For training sets, pure PO and ternary system of PO-PSO-EVOO were prepared in the range of 0.5–50.0% (v/v) of PO was prepared. Both groups (pure PO and PO-PSO-EVOO) were classified and discriminated using DA on the basis of Cooman's plot using FTIR spectral absorbance at specific wavenumbers as variables.

FTIR spectra acquisition

The scanning of FTIR spectra of oil samples was done using FTIR spectrophotometer (Thermo Scientific Nicolet iS10, Madison, WI), equipped with the Omnic software for spectral processing. The measurements were performed in horizontal attenuated total reflectance (HATR) at wavenumbers (1/λ) of 4000-650 cm⁻¹ using 32 scanings with the resolution of 8 cm⁻¹. All FTIR spectra were corrected against FTIR spectrum of air as background. After every scan, a new reference air background spectrum was taken. These spectra were recorded as absorbance values at each data point in triplicate.

Chemo-metrics analysis

Chemometrics analysis including discriminant analysis and multivariate calibrations of principle component regression (PCR) and partial least square (PLS) was performed using TQ Analyst software version 9 (Thermo Fisher Scientific, Inc.). Statistical parameters used for evaluation of multivariate calibrations performance were coefficient of determination (R²) and root mean square error of calibration (RMSEC), as well as root, mean square error of prediction (RMSEP).

RESULTS AND DISCUSSION

Table 2 compiled fatty acid (FA) composition of studied oils in which palmitic and oleic acids are main FAs composed PO. In addition, oleic acid was present as main FA component in EVOO, while PSO is mainly composed from linoleic and oleic acids. All FAs in PO and EVOO were in agreement with those specified in Codex Alimentarius Commission, while FAs in PSO in this study was in accordance with those reported in the literature [24]. These FAs data indicated that studied oils (PO, EVOO and PSO) were not previously mixed with other oils. The difference of fatty acids determined the different intensities of functional groups of studied oils in which oils with higher levels of oleic acids would have higher intensities in peaks related to unsaturated fatty acids.

Table 2: Fatty acid composition of fatty acids in palm oil, extra virgin olive oil and pumpkin seed oil

Fatty acids	Palm oil		Extra virgin olive oil		Pumpkin seed oil	
	Exp.	Codex	Exp.	Codex	Exp.	According to literature [24]
Palmitic acid (C16:0)	38.45±0.17	39.3-47.5	11.25±0.58	7.5-20	11.05±0.12	9.39–12.48
Palmitoleic acid (C16:1)	0.15±0.02	nd-0.6	0.68±0.02	0.3-3.5	0.12±0.01	0.10–0.14
Stearic acid (C18:0)	6.67±0.32	3.5-6.0	3.12±0.09	0.5-5.0	4.62±0.04	4.15–5.67
Oleic acid (C18:1)	40.79±0.45	36.0-44.0	75.12±1.05	55.0-83.0	30.56±1.15	29.20–36.44
Linoleic acid (C18:2)	9.85±0.05	9.0-12.0	6.97±0.07	3.5-21.0	45.45±2.45	42.73–55.33
Linolenic acid (C18:3)	0.31±0.01	nd-0.5	0.29±0.02	<1.5	0.22±0.01	0.14–0.30
Arachidic acid (C20:0)	0.20±0.01	nd-1.0	0.43±0.01	<0.8	0.36±0.01	0.29–0.39

Exp: results obtained from the experiment in this study

Due to its nature as fingerprint analytical technique, Fourier transforms infrared (FTIR) spectroscopy is an ideal method for analysis of complex mixtures such as edible fats and oils and other secondary metabolites extracted from specific part of plants [25]. Fig. 1 showed FTIR-ATR spectra of three edible oils, palm oil (PO), extra virgin coconut oil (EVOO), and pumpkin seed oil (PSO) scanned at mid-infrared regions corresponding to $1/\lambda$ of 4000–650 cm^{-1} . Each peaks and shoulders in FTIR spectra come from the IR absorption by functional groups present in these oils. The

interpretation of each peaks and shoulders in relation to functional groups in FTIR spectra was compiled in table 3. All Peaks in FTIR-ATR among PO, EVOO and PSO spectra are very similar. This is not surprising because the main components composing edible fats and oils were triglyceride (95-98%), glycerol esterified with three fatty acids [27]. However, upon detailed investigation, FTIR-ATR spectra of PO, EVOO and PSO reveal slight differences in terms of band intensities (absorbance's) and the exact wavenumbers in each peak and shoulders [28].

Table 3: Functional groups responsible for absorption of peaks and shoulders in palm oil, extra virgin olive oil, and pumpkin seed oil [26]

Wavenumbers region (cm^{-1})	Functional groups and vibration modes
3007	<i>cis</i> C=CH, stretching vibration
2953	methyl (-CH ₃), asymmetric stretching vibration
2922 and 2853	methylene (-CH ₂), asymmetric and symmetric stretching vibrations
1744	carbonyl (C=O), stretching vibration
1654	C=C, stretching vibration
1460	methylene (-CH ₂), bending vibration
1376	methyl (-CH ₃), bending vibration
1237, 1160, 1118, 1098	C-O, stretching vibrations
996	-HC=CH- (<i>trans</i>), bending out of a plane
850	-HC=CH- (<i>cis</i>), bending out of plane

Table 4: The performance of principle component regression (PCR) and partial least square (PLS) for prediction of palm oil in ternary mixtures with extra virgin olive oil and pumpkin seed oil along with wavenumbers regions and FTIR spectral modes used (normal and derivatives)*

Multivariate calibrations	Wavenumber (cm^{-1})	Spectra	Calibration		Validation	
			R	RMSEC	R	RMSEP
PCR	3100-663	normal	0.9856	0.0166	0.9641	0.0282
		derivative 1	0.9778	0.0206	0.9883	0.0230
		derivative 2	0.9486	0.0311	0.9582	0.0293
	1800-663	normal	0.9855	0.0167	0.9505	0.0370
		derivative 1	0.9605	0.0273	0.9683	0.0300
		derivative 2	0.9040	0.0420	0.9136	0.0413
	3100-2750	normal	0.9836	0.0177	0.9720	0.0246
		derivative 1	0.9806	0.0192	0.9760	0.0241
		derivative 2	0.9620	0.0268	0.9589	0.0298
	1500-663	normal	0.9548	0.0292	0.9028	0.0433
		derivative 1	0.9365	0.0344	0.9271	0.0381
		derivative 2	0.8488	0.0519	0.8491	0.0525
	3100-2750 and 1800-663	normal	0.9824	0.0183	0.9693	0.0270
		derivative 1	0.9787	0.0202	0.9887	0.0255
		derivative 2	0.9227	0.0379	0.9484	0.0321
	3100-2750 and 1500-663	normal	0.9740	0.0223	0.9486	0.0316
		derivative 1	0.9762	0.0213	0.9875	0.0158
		derivative 2	0.8661	0.0491	0.8827	0.0465
PLS	3100-663	normal	0.9927	0.0119	0.9713	0.0269
		derivative 1	0.9959	0.0088	0.9861	0.0256
		derivative 2	0.9861	0.0163	0.9811	0.0210
	1800-663	normal	0.9933	0.0114	0.9623	0.0326
		derivative 1	0.9795	0.0198	0.9836	0.0262
		derivative 2	0.9613	0.0271	0.9587	0.0297
	3100-2750	normal	0.9844	0.0173	0.9723	0.0246
		derivative 1	0.9799	0.0196	0.9782	0.0230
		derivative 2	0.9911	0.0130	0.9732	0.0251
	1500-663	normal	0.9718	0.0232	0.9428	0.0334
		derivative 1	0.9776	0.0207	0.9762	0.0225
		derivative 2	0.8450	0.0525	0.8544	0.0515
	3100-2750 and 1800-663	normal	0.9935	0.0112	0.9670	0.0305
		derivative 1	0.9843	0.0173	0.9868	0.0255
		derivative 2	0.9978	0.0064	0.9806	0.0264
	3100-2750 and 1500-663	normal	0.9962	0.0085	0.9798	0.0207
		derivative 1	0.9967	0.0080	0.9906	0.0152
		derivative 2	0.8338	0.0542	0.8450	0.0527

*The selected variables were marked with bold. R = correlation coefficient; RMSEC = root mean square error of prediction; RMSEP = root mean square error of prediction.

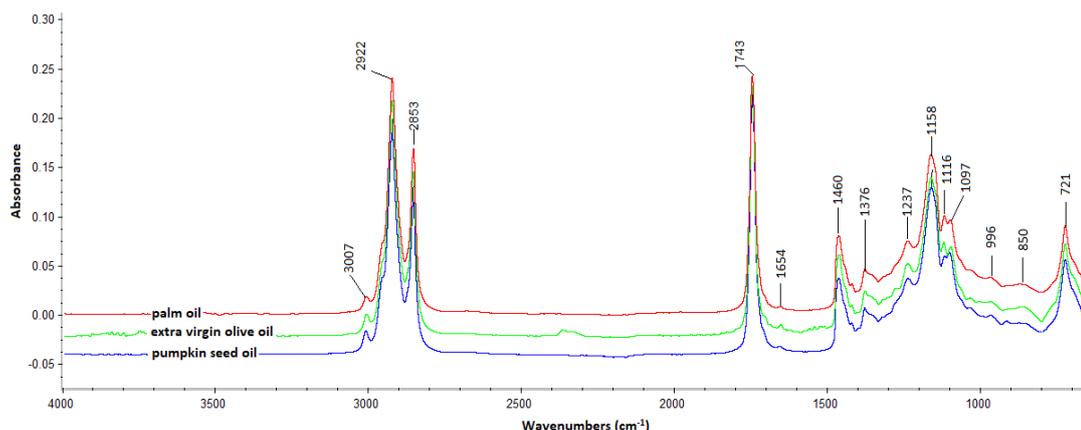
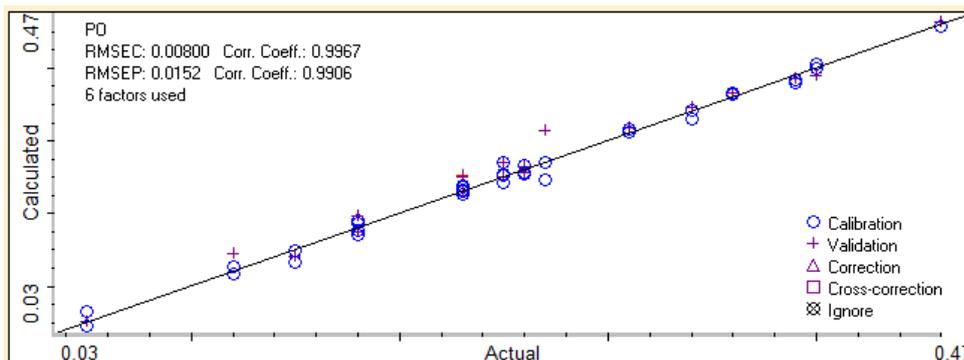


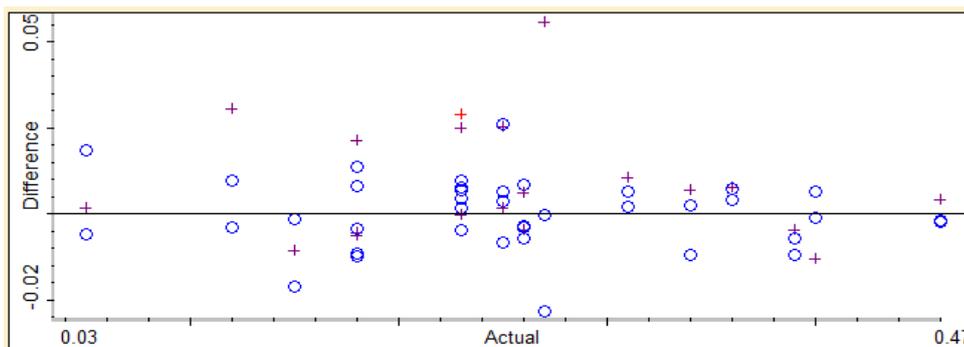
Fig. 1: FTIR spectra using attenuated total reflectance mode of palm oil, extra virgin olive oil, and pumpkin seed oil acquired at mid-infrared region (4000-650 cm⁻¹)

Quantitative analysis of PO in ternary mixtures with EVOO and PSO was performed by the assistance of two multivariate calibrations, namely principle component regression (PCR) and partial least square (PLS). Table 4 compiled the performance of PCR and PLS for prediction of PO in ternary mixtures with EVOO and PSO along with wavenumbers regions and FTIR spectral modes used (normal and derivatives). The wavenumbers regions were selected based on the variation existed among PO, EVOO, and PSO. In addition, derivatization was intended to resolve any extensive overlapping peaks. The selection of FTIR spectroscopy conditions (multivariate calibrations, spectral modes, and wavenumbers regions) was based on the highest coefficient of correlation (R) and the lowest errors in calibration and prediction, expressed with root mean square error of calibration (RMSEC) and root mean square error of prediction (RMSEP). Finally,

the first derivative FTIR spectra at the combined $1/\lambda$ regions of 3100-2750 and 1500-663 cm⁻¹ aided with PLS regression offered the best prediction models for quantitative analysis of PO in ternary mixtures with EVOO and PSO. The R values obtained for the correlation between actual values and FTIR predicted values were 0.9967 and 0.9906 in calibration and validation models, while RMSEC and RMSEP values were 0.0080% and 0.0152%, respectively (fig. 2). The low errors either in calibration and prediction models were confirmed by residual analysis (fig. 2B) in which no systematic errors were observed. The high R values and lowest values of RMSEC and RMSEP indicated that FTIR spectroscopy aided with PLS offered a reliable technique for analysis of PO. This results could be extended for analysis of PO as adulterants in high valuable oils such as EVOO and PSO either in binary or ternary models.



[A]



[B]

Fig. 2: The correlation between actual values (x-axis) and FTIR predicted values (y-axis) of palm oil in ternary mixtures with extra virgin olive oil (EVOO) and pumpkin seed oil (PSO) with a coefficient correlation of 0.9967 and 0.9906 in calibration and validation models. RMSEC = root mean square error of calibration; RMSEP = root mean square error of prediction

Discriminant analysis (DA), one of the supervised pattern recognition techniques, was used for discrimination between pure PO and PO in ternary mixtures with EVOO and PSO. Both classes (pure and the mixture) were clearly separated, indicating that PO was different from EVOO and PSO (fig. 3), the accuracy levels of discrimination capacity were 100%, meaning that no training

samples were misclassified in the wrong groups. Misclassification may occur if both groups are very similar. This result could be extended that DA based on Mahalanobis distance of variables used (absorbances at wavenumbers of 3100-2750 and 1500-663 cm^{-1}) was an effective means for authentication of EVOO and PSO from the possible adulteration with low-value edible oils such as palm oil.

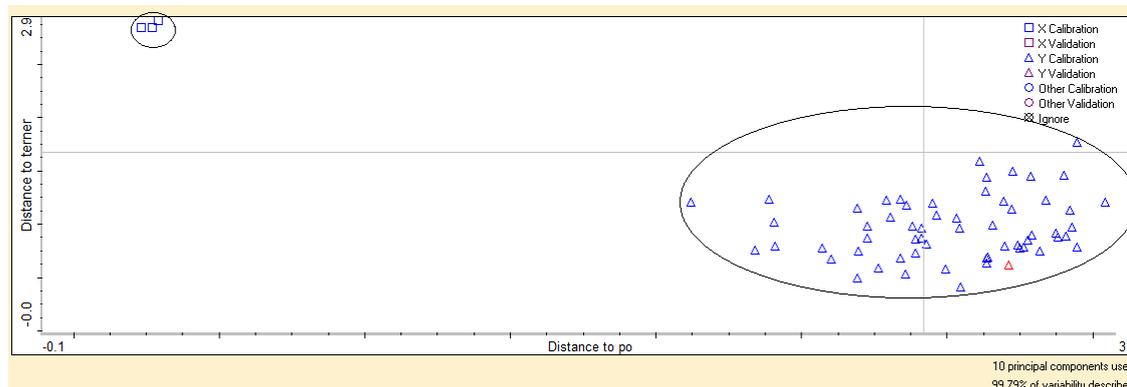


Fig. 3: The discriminant analysis expressed by Cooman's plot for the discrimination of palm oil and palm oils in ternary mixtures with extra virgin olive oil and pumpkin seed oil

CONCLUSION

Fourier transform infrared (FTIR) spectroscopy in combination with PLS and discriminant analysis could be successfully used for analysis of palm oil (PO) in ternary mixtures with extra virgin olive oil (EVOO) and pumpkin seed oil (PSO). The first derivative FTIR-ATR spectra at combined wavenumbers regions of 3100-2750 and 1500-663 cm^{-1} were selected for analysis of PO in ternary mixtures with EVOO and PSO with acceptable results. FTIR spectroscopy in combination with multivariate calibration of PLS and DA could be effective means to quantify and to discriminate PO mixed into EVOO and PSO.

ACKNOWLEDGMENT

The authors thank to the Ministry of Research, Technology and Higher Education, Republic Indonesia for financial support during this study through Hibah Penelitian Dasar Unggulan Perguruan Tinggi (PUPT) 2019 with contract number 2519/UN1. DITLIT/DIT-LIT/IT/2019.

ABBREVIATION

FTIR = Fourier transform infrared; ATR = attenuated total reflectance; PCR = principle component regression; PLS = partial least square; RMSEC = root mean square error of calibration; RMSEP = root mean square error of prediction; DA = Discriminant analysis; PO = palm oil; PSO = pumpkin seed oil; EVOO = extra virgin olive oil; $1/\lambda$ = wavenumbers; R = coefficient of correlation

AUTHORS CONTRIBUTIONS

Irnawati performed research activities and analyzed data. AR, SM and SR designed research, prepared manuscript and made critical thinking on manuscript.

REFERENCES

1. Frankel E, Bakhouch A, Lozano Sanchez J, Segura Carretero A, Fernandez Gutierrez A. Literature review on production process to obtain extra virgin olive oil-enriched in bioactive compounds. Potential use of by-products as alternative sources of polyphenols. *J Agric Food Chem* 2013;61:5179-88.
2. Monasterio PR, Fernandez AM, Silva FM. Olive oil by capillary electrophoresis: characterization and genuineness. *J Agric Food Chem* 2013;61:4477-96.
3. Hassen I, Casabianca H, Hosni K. Biological activities of the natural antioxidant oleuropein: exceeding the expectation-a mini-review. *J Funct Foods* 2015;18:926-40.
4. da Silveira R, Vagula JM, de Lima Figueiredo I, Claus T, Galuch MB, Junior OOS, et al. Rapid methodology via mass

spectrometry to quantify addition of soybean oil in extra virgin olive oil: a comparison with traditional methods adopted by food industry to identify fraud. *Food Res Int* 2017;102:43-50.

5. Buckland G, Gonzalez CA. The role of olive oil in disease prevention: A focus on the recent epidemiological evidence from cohort studies and dietary intervention trials. *Br J Nutr* 2015;113:S94-101.
6. Perez Martinez P, Garcia Rios A, Delgado Lista J. Mediterranean diet rich in olive oil and obesity, metabolic syndrome and diabetes mellitus. *Curr Pharm* 2011;17:769-77.
7. Psaltopoulou T, Kostis RI, Haidopoulos D. Olive oil intake is inversely related to cancer prevalence: a systematic review and a meta-analysis of 13,800 patients and 23,340 controls in 19 observational studies. *Lipids Health Dis* 2011;10:127-40.
8. Gavahian M, Khaneghah AM, Lorenzo JM, Munekata PES, Garcia Mantrana I, Collado MC, et al. Review: health benefits of olive oil and its components: impacts on gut microbiota antioxidant activities, and prevention of noncommunicable diseases. *Trends Food Sci Technol* 2019;88:220-7.
9. Procida G, Stancher B, Cateni F, Zacchigna M. Chemical composition and functional characterization of commercial pumpkin seed oil. *J Sci Food Agric* 2012;93:1035-41.
10. Fruhwirth GO, Hermetter A. Production technology and characteristics of styrian pumpkin seed oil. *Eur J Lipid Sci Technol* 2008;110:637-44.
11. Potocnik T, Ogrinc N, Potocnik D, Kosir IJ. Fatty acid composition and d13C isotopic ratio characterisation of pumpkin seed oil. *J Food Compos Anal* 2016;53:85-90.
12. Butinar B, Bucar Miklav M, Valenci V, Raspor P. Stereospecific analysis of triacylglycerols as a useful means to evaluate the genuineness of pumpkin seed oils: lesson from virgin olive oil analyses. *J Agric Food Chem* 2010;58:5227-34.
13. Aued Pimentel S, Takemoto E, Minazzi Rodrigues SR, Badolato E. Olive oil: adulteration from 1993 to 2000. *Rev Inst Adolfo Lutz* 2002;61:69-75.
14. Dankowska A, Małeczka M. Application of synchronous fluorescence spectroscopy for determination of extra virgin olive oil adulteration. *Eur J Lipid Sci Technol* 2009;111:1233-9.
15. Rohman A, Che Man YB. Application of fourier transforms infrared spectroscopy for authentication of functional food oils. *Appl Spectrosc Rev* 2012;47:1-13.
16. Rohman A. Infrared spectroscopy for quantitative analysis and oil parameters of olive oil and virgin coconut oil: a review. *Int J Food Prop* 2017;20:1447-56.
17. Rohman A, Che Man YB. Fourier transforms infrared (FTIR) spectroscopy for analysis of extra virgin olive oil adulterated with palm oil. *Food Res Int* 2010;43:886-92.

18. Jimenez Carvelo AM, Osorio MT, Koidis A, Gonzalez Casado A, Cuadros Rodriguez L. Chemometric classification and quantification of olive oil in blends with any edible vegetable oils using FTIR-ATR and Raman spectroscopy. *Food Sci Technol* 2017;86:174-84.
19. Lerma Garcia MJ, Ramis Ramos G, Herrero Martinez JM, Simo Alfonso EF. Authentication of extra virgin olive oils by fourier-transform infrared spectroscopy. *Food Chem* 2010;118:78-83.
20. Mba O, Adewale P, Dumont MJ, Ngadi M. Application of near-infrared spectroscopy to characterize binary blends of palm and canola oils. *Ind Crops Prod* 2014;61:472-8.
21. Basri KN, Hussain MN, Bakar J, Sharif Z, Abdul Khir MF, Zoolfakar AS. Classification and quantification of palm oil adulteration via portable NIR spectroscopy. *Spectrochim Acta A: Mol Biomol Spectrosc* 2017;173:335-42.
22. Pebriana RB, Rohman A, Lukitaningsih E, Sudjadi. Development of FTIR spectroscopy in combination with chemometrics for analysis of rat meat in beef sausage employing three lipid extraction systems. *Int J Food Prop* 2017;20:1995-2005.
23. Rohman A, Che Man YB. Palm oil analysis in adulterated sesame oil using chromatography and FTIR spectroscopy. *Eur J Lipid Sci Technol* 2011;113:522-7.
24. Nederal S, Petrovic M, Vincek D, Pukec D, Skevin D, Kraljic K, *et al.* Variance of quality parameters and fatty acid composition in pumpkin seed oil during three crop seasons. *Ind Crops Prod* 2014;60:15-21.
25. Muchtaridi M, Pratiwi R, Alam G, Rohman A. Analysis of gartanin in the extract of mangosteen pericarp fruit (*Garcinia mangostana* L.) using spectrophotometric fourier transform infrared (FTIR) method. *Rasayan J Chem* 2019;12:874-9.
26. Arslan FN, Akina G, Elmas SNK, Yilmaz I, Janssen HG, Kenar A. Rapid detection of authenticity and adulteration of cold-pressed black cumin seed oil: a comparative study of ATR-FTIR spectroscopy and synchronous fluorescence with multivariate data analysis. *Food Control* 2019;98:323-32.
27. Ozulku G, Yildirim RM, Toker OS, Karasu S, Zeki Durak M. Rapid detection of adulteration of cold-pressed sesame oil adulterated with hazelnut, canola, and sunflower oils using ATR-FTIR spectroscopy combined with chemometric. *Food Control* 2017;82:212-6.
28. Rohman A, Che Man YB, Ali ME. The authentication of virgin coconut oil from grape seed oil and soybean oil using FTIR spectroscopy and chemometrics. *Int J Appl Pharm* 2019;11:259-63.
29. Putri AR, Rohman A, Riyanto S. Authentication of patin (*Pangasius micronemus*) fish oil adulterated with palm oil using FTIR spectroscopy combined with chemometrics. *Int J Appl Pharm* 2019;11:195-9.