# Detection of lard contamination in five different edible oils by FT-IRspectroscopy using a partial least squares calibration model

**Article** *in* Turkish Journal of Chemistry · August 2019

DOI: 10.3906/kim-1902-17

**5 authors**, including:

Fazeelah Munir
University of Karachi
**2** PUBLICATIONS **17** CITATIONS

SEE PROFILE

Syed Ghulam Musharraf
International Center for Chemical and Biological Sciences
**337** PUBLICATIONS **5,161** CITATIONS

SEE PROFILE

Syed Tufail Hussain Sherazi
University of Sindh
**297** PUBLICATIONS **6,952** CITATIONS

SEE PROFILE

Muhammad Imran Malik
University of Karachi
**160** PUBLICATIONS **1,944** CITATIONS

SEE PROFILE

**Turkish Journal of Chemistry**

http://journals.tubitak.gov.tr/chem/

Research Article

Turk J Chem
() : –
© TÜBİTAK
doi:10.3906/kim-1902-17

# Detection of lard contamination in five different edible oils by FT-IR spectroscopy using a partial least squares calibration model

**Fazeelah MUNIR**[1], **Syed Ghulam MUSHARRAF**[1], **Syed Tufail Hussain SHERAZI**[1,2,*], **Muhammad Imran MALIK**[1], **Muhammad Iqbal BHANGER**[1]

[1]International Center for Chemical and Biological Sciences, University of Karachi, Karachi, Pakistan
[2]National Center of Excellence in Analytical Chemistry, University of Sindh, Jamshoro, Pakistan

**Received:** 08.12.2019 • **Accepted/Published Online:** 30.05.2019 • **Final Version:** ..201

**Abstract:** Lard is defined as animal fat acquired from the adipose tissue of pigs and is not permitted for human consumption or external use by certain religions such as Islam and Judaism. Due to its low-cost availability for commercial use, it is often mixed with other vegetable oils mistakenly or deliberately and causes loss of consumer trust; hence, its detection in food products is essential. Consumers tend to know the authenticity of commercially available edible oils. However, edible oils are subjected to adulteration risks with lard, which breaches consumer rights. In the present study, we designed a transmission Fourier transform infrared spectroscopy (FT-IR)-based method for the rapid detection of lard in sunflower, canola, coconut, olive, and mustard oils. For this purpose, the selected oils were adulterated with lard in different concentration ratios (10:0, 9:1, 7:3, 6:4, 4:6, 3:7, 0:10). A single calibration model was developed for 35 standards (seven standards from each individual five oils) in the frequency range between 1078.01 and 1246.75 $cm^{-1}$ to determine the relationship between actual adulterant concentration and FT-IR predicted concentrations using a partial least squares (PLS) method. The results of the present study indicated that FT-IR in combination with PLS has the potential to evaluate adulteration of edible oils with lard through single calibration as a rapid, nondestructive, and effective alternative method.

**Key words:** Edible oils, lard, detection, Fourier transform infrared spectroscopy

## 1. Introduction

The credibility and transparency of vegetable oils available in the market is an important topic of concern for consumers [1]. All vegetable oils contain triglycerides, diglycerides, and free fatty acids, beside other minor components such as phospholipids, terpenes, tocopherols, and sterols. Good quality oils and many phenolic compounds play important roles in lowering plasma cholesterol levels of consumers [2].

Generally, vegetable oils consist of monounsaturated and polyunsaturated fatty acids and fats along with plenty of saturated fatty acids. When one oil is mixed with any other oil in small concentration ($<1\%$) it becomes very difficult to differentiate through a single technique [3]. The industrial use of lard along with vegetable oils is commonly practiced for producing shortenings, margarines with a specific solid content profile, for taste enhancements and introducing unique textural properties in several food products [4–6]. The food industry needs a quick, robust, reliable, and applicable method for the assurance of pure edible oils without any mixing of a contaminant, e.g., lard, to maintain consistent product quality [7]. For commercially available

---

*Correspondence: tufail.sherazi@gmail.com edible oils in local markets a systematic, economical, and consistent approach is required to ensure their purity [8]. Consequently, the development of new, facile, and efficient analytical methods is imperative due to commercial, ethical, religious, and aesthetic reasons. Several analytical methods including GC-MS, HPLC-MS-MS, NMR, and Fourier transform infrared (FT-IR) spectroscopy, and electronic nose and voltammetric analysis are available for the quality assurance of vegetable oils and fats [3,9]. Over the last 20 years, FT-IR spectroscopy has been widely used in research related to various fields due to substantial improvements in FT-IR spectroscopic instrumentation [10–14]. In the study of edible oils and fats, FT-IR has been recognized as an authoritative analytical tool. It is a nondestructive and rapid tool with no or minimal sample preparation. It permits the qualitative determination of organic compounds. Each organic molecule has the characteristic vibrational mode of each functional group. Therefore, each molecular group causes the appearance of bands in the infrared region at a specific frequency between 400 and 4000 $cm^{-1}$. Absorption frequency can be further influenced by the neighboring functional groups [14–18].

FT-IR alone is used just to confirm the presence of different functional groups for qualitative analysis. However, for quantitative analysis, chemometric models such as partial least squares (PLS) and Beer's law are applied to determine the actual concentration of analyte present in the sample. FT-IR combined with chemometrics is an excellent tool for quantitative analysis since the intensities of the spectral bands are proportional to concentration. Chemometric techniques are extensively applied, especially when the numbers of independent variables are significantly greater than the number of data points. The analyte can be quantitatively determined by multivariate data analysis techniques such as principal component analysis (PCA), PLS regression, and Beer's law. Among the chemometric techniques, PLS has been frequently used for quantitative determinations. PLS regression is a statistical model that provides linear regression by projecting the predicted values and the actual values into a new space. The benefits of PLS are only applicable when the true correlation between the actual values and predicted values is linear or at least near to linear. The performance of PLS regression is considered to be poor if it is not linear [19–24]. FT-IR together with chemometric analysis has also been already used to detect the presence of lard in chocolates, ham sausages, meatballs, and animal fats with the combination of PLS, PCA, and discriminant analysis [4,5,25–27]. The method reported by Rohman et al. [28] is arduous and focused on analyzing different oils individually at various IR frequencies by referring to first and second derivatives to detect lard, which is a laborious and lengthy procedure. Previous reported FT-IR methods related to the determination of lard are based on a single oil and their developed calibrations could be used for just that specific oil. If the oil is changed then a new calibration will be required with changed parameters. For the first time in the present study a general calibration model is reported for all studied oils and only one calibration model is applicable using the same wavelength and the same parameters. The majority of consumers use industrial vegetable oils and the chances of adulteration in them are higher than in oil extracted from natural sources. Therefore, it was planned to establish a method based on the actual scenario. Furthermore, when oil is extracted from the seeds or fruits it is known as crude oil and after industrial processing (neutralization, bleaching, deodorization, etc.), it can be used for human consumption. Therefore, the authors selected industrial vegetables oils for the present study. To the best of our knowledge, to date no study has been reported in which FT-IR spectroscopy is used for detection of lard through common or single calibration for five different oils. Therefore, the aim of the present study was to use FT-IR spectroscopy for the detection of lard adulteration in commonly used edible oils and to develop a robust, rapid, green, and solvent-free FT-IR method for the detection of lard present in five different vegetable oils through a single PLS calibration model.

## 2. Materials and methods

### 2.1. Test samples, reagents, and standards

Five samples of pure edible oils, namely sunflower, canola, coconut, olive, and mustard oils, were collected from edible oil processing facilities in Karachi, Pakistan. Lard and IR grade potassium bromide for making IR pellets were purchased from Sigma Aldrich.

Thirty-five standards were prepared by mixing lard in sunflower, canola, coconut, olive, and mustard oils (w/w) in the ratios of 10:0, 9:1, 7:3, 6:4, 4:6, 3:7, and 0:10. Before mixing, the lard and edible oils were heated at 60 °C to make them homogenize. The prepared standards were transferred to 5-mL amber glass reagent bottles after passing through nitrogen gas. The ratio of prepared standards (edible oils:lard oil) and the actual concentrations of lard in the sunflower, canola, coconut, olive, and mustard oils are presented in Table 1, while the mixing ratio of lard in the edible oils for the preparation of KBr pellets and their codes are provided in Table 2. The same procedure was applied for the preparation of corn oil samples purchased from the local market to check the efficiency of the FT-IR method developed.

**Table 1**. Ratio and concentration of lard in the sunflower, canola, coconut, olive and mustard oils.

| Ratio of prepared standards (Edible oil:lard) | Concentrations of lard in the sunflower, canola, coconut, olive, and mustard oils |
|---|---|
| 10:0 | 0.500 mg lard + 0.000 mg pure edible oils |
| 9:1 | 0.050 mg lard + 0.450 mg edible oils |
| 7:3 | 0.150 mg lard + 0.350 mg edible oils |
| 6:4 | 0.200 mg lard + 0.300 mg edible oils |
| 4:6 | 0.300 mg lard + 0.200 mg edible oils |
| 2:8 | 0.400 mg lard + 0.100 mg edible oils |
| 0:10 | 0.000 mg of lard + 0.500 mg pure lard |

**Table 2**. Mixing ratio of vegetable oils and their codes.

| Sample Code | Sunflower:lard (%) | Sample code | Canola:lard (%) | Sample code | Coconut:lard (%) | Sample code | Olive:lard (%) | Sample code | Mustard:lard (%) |
|---|---|---|---|---|---|---|---|---|---|
| FM1A | 10:0 | FM2A | 10:0 | FM3A | 10:0 | FM4A | 10:0 | FM5A | 10:0 |
| FM1B | 9:1 | FM2B | 9:1 | FM3B | 9:1 | FM4B | 9:1 | FM5B | 9:1 |
| FM1C | 7:3 | FM2C | 7:3 | FM3C | 7:3 | FM4C | 7:3 | FM5C | 7:3 |
| FM1D | 6:4 | FM2D | 6:4 | FM3D | 6:4 | FM4D | 6:4 | FM5D | 6:4 |
| FM1E | 4:6 | FM2E | 4:6 | FM3E | 4:6 | FM4E | 4:6 | FM5E | 4:6 |
| FM1F | 2:8 | FM2F | 2:8 | FM3F | 2:8 | FM4F | 2:8 | FM5F | 2:8 |
| FM1G | 0:10 | FM2G | 0:10 | FM3G | 0:10 | FM4G | 0:10 | FM5G | 0:10 |

### 2.2. FT-IR spectral measurements

A Bruker Vector 22 spectrometer was used to record the FT-IR spectra, and 0.50 mg of pure edible oils and standards (prepared by mixing of lard in five edible oils in the ratio shown in Figure 1) was added to 99.50 mg of KBr to make a pellet of 100 mg{Mallah, 2015 #28}. In order to get similar and reproducible results, homogeneous pellets were made with the same pressure. The FT-IR region of 4000–400 $\text{cm}^{-1}$ was selected to record the spectra at 10 scans/min with the resolution of 2 $cm^{-1}$ and deuterated triglycine sulfate was used as a detector. Three spectra were recorded for each sample and a fresh background was recorded prior to each sample collection.

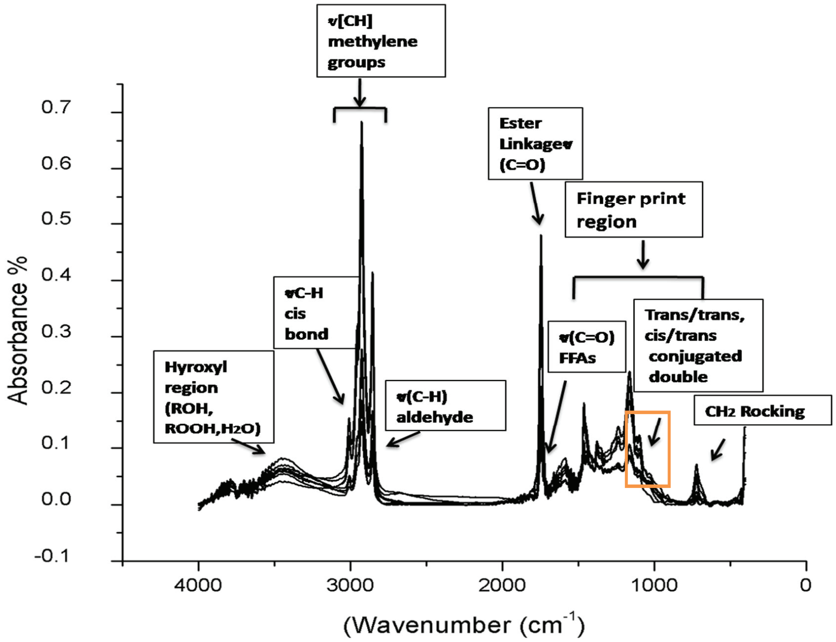

**Figure 1**. Group FT-IR spectra of the selected five oils and lard.

For validation, different samples of each vegetable oil containing lard were prepared other than the calibration set. All prepared calibration and validation sets were analyzed by FT-IR spectrometer.

### 2.3. Partial least squares chemometric analysis

Chemometric techniques coupled with FT-IR analysis have been used for a wide range of applications in food products due to their capability of assessing the fragmented range of infrared regions and extracted required information in the form of a calibration model [21]. This factorial multivariate model of calibration works on the assessment of scores and loadings along with process systems containing independent variables in relation to the data points [16].

Turbo Quant (TQ) Analyst 9 software was used to assess the spectra and convert them into a PLS calibration model for detection in the five edible oils. It imports directly the group spectra file of all standards from OMNIC 9 software, in which all spectra were recorded. It generates the PLS calibration and provides the predicted value on the basis of actual values using a specific FT-IR region (1246.75–1078.01 $cm^{-1}$). A series of 35 calibration standards covering the edible oil to lard ratios of 10:0, 9:1, 7:3, 6:4, 4:6, 3:7, and 0:10 were analyzed by transmission FT-IR mode. Group spectra of the five pure oils (sunflower, canola, coconut, olive, and mustard) along with spectra of these oils spiked with known concentrations of lard were imported from OMNIC software into the TQ Analyst program to develop PLS calibrations. Different spectral regions were tried but the specific FT-IR region was selected on the basis of the maximum values of the coefficient of determination ($R^2$) and the minimum values of the root mean standard error of calibration (RMSEC). A suitable calibration region was identified, which was used for the single calibration for the five selected oils. The PLS regression model used for calibration between the actual values and predicted values was in the frequency range of 1078.01–1246.75 $cm^{-1}$. The performance of the calibrations was assessed by the results of linear regression and evaluated by running the samples of known concentrations of lard in the selected oils. To evaluate the competence of the models to fit the calibration data and to calculate the deviation of the models, the RMSEC was used. The RMSEC is basically the calibration error related to the residuals of the calibration data. The value of RMSEC was provided by TQ Analyst 9 [16,17,21].

### 2.4. Efficacy of the FT-IR method

The efficacy was determined by recovery through the standard addition method [29]. The same ratios of lard and corn oil were mixed that were used for the calibration and then the developed FT-IR calibration model was applied to check the amount of lard added to the corn oil. Percent recovery was calculated by the following equation:

$$R(\%) = D \times 100/B,$$

where R is recovery (%) of lard, B is total concentration of lard added, and D is the total concentration of lard determined by FT-IR.

## 3. Results and discussion

### 3.1. FTIR spectra of oils

All vegetable oils showed weak infrared absorbance in the range 4000–3100 $cm^{-1}$. In the region of 3100–400 $cm^{-1}$, certain shoulders and peaks are responsible for the presence of specific functional groups and are dedicated to certain fatty acids [30]. Figure 1 shows group FT-IR spectra of the selected five oils and lard.

The wavelength of 3010 $cm^{-1}$ is specified to trans=CH stretching vibration; 2954 $cm^{-1}$ for asymmetrical stretching of $–CH_3$; 2922 $cm^{-1}$ for symmetric stretching of $–CH_2$; 2853 $cm^{-1}$ for asymmetric stretching of $–CH_2$; 1715 $cm^{-1}$ for carbonyl stretching frequency; 1665 $cm^{-1}$ for cis C=C stretching frequency; 1462 $cm^{-1}$ for bending frequency of $–CH_2$; 1417 $cm^{-1}$ for bending frequency of cis =CH; 1337 $cm^{-1}$ for bending frequency of $–CH_2$; 1120 $cm^{-1}$, 1098 $cm^{-1}$, and 1032 $cm^{-1}$ for carbonyl stretching frequency; 965 $cm^{-1}$ for the out of plan bending frequency of trans –CH=CH–; 871 $cm^{-1}$ for the wagging of $CH_2$; and 723 $cm^{-1}$ for the out of plan bending of –CH=CH– [31].

In Figure 2 the comparative spectra of the five edible oils and lard are represented. Visually the spectra seem to be equivalent except for some minor differences. The major peaks are the same in all of these spectra due to the presence of common functional groups. In the spectrum of coconut, a peak at 3010 $cm^{-1}$ is not visible and at 1100 $cm^{-1}$ only one peak is observable, which is shown in the circle [32]. Moreover, the peak at 750 $cm^{-1}$ is also smaller than that for the other oils. The position of the peak at 1747 $cm^{-1}$ and the shape of the peak at 1650 $cm^{-1}$ in the FT-IR spectrum of lard is different than that of the other edible oils. A minor difference is noticeable in the height of peaks present in the FT-IR spectral region between 1130 and 1090 $cm^{-1}$ [33].

In Figure 3, some specific regions are displayed that show differences in the absorption frequency of the concerned oils. By zooming in on the individual spectra, one can distinguish the lard and canola, sunflower, olive, coconut, and mustard oils from each other. In the region of 3006 $cm^{-1}$ the absorbance is due to the

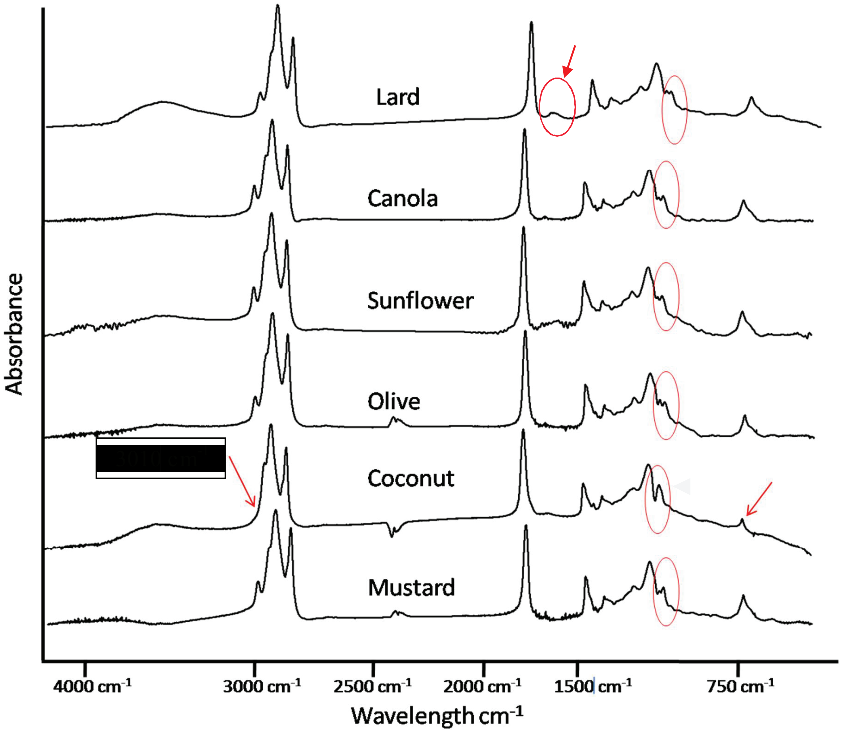

**Figure 2**. Stacked spectra of the edible oils and lard.

presence of methyl oleate (C18:1), which is in descending order as olive, canola, lard, sunflower, mustard, and coconut [34]. The absorbance at 3010 $cm^{-1}$ is due to the degree of unsaturation attributed to methyl linoleate (C18:2), which is in ascending order as olive, lard, mustard, coconut, canola, and sunflower, as predicted by FT-IR spectra. The maximum absorbance in the region of 1753 $cm^{-1}$ represents high content of the short carbohydrate chain and is in the descending order of coconut, lard, sunflower, mustard, canola, and olive. The region at 1665 $cm^{-1}$ gives information about the C=C link and is representative of polyunsaturated fatty acid in the molecule and is in ascending order as coconut, lard, olive, mustard, canola, and sunflower. The region at 1440–1445 $cm^{-1}$ represents vibration of deformation (CH) and total unsaturation, which is greatest in olive and least in coconut [35].

### 3.2. PLS calibration model

In order to build a calibration model, initially all the spectra were scanned in the full frequency region (4000–400 $cm^{-1}$) and afterwards two specific regions were selected for the development of a regression curve as predicted by the TQ Analyst software. The first range in this context was 713.53–732.82 $cm^{-1}$, while the other range was 1246.75–1078.01 $cm^{-1}$. The results obtained using the first range were not very useful; however, the second range revealed brilliant regression output. The results were obtained in normal mode without using first or second derivative FT-IR spectra.

Initially, an FTIR-PLS calibration model was developed for each individual oil using the region of 1246.75–1078.01 $cm^{-1}$ and excellent regression results were achieved. Then using the same parameters and the same FT-IR region, a single calibration model for canola, sunflower, coconut, olive, and mustard oils for the detection

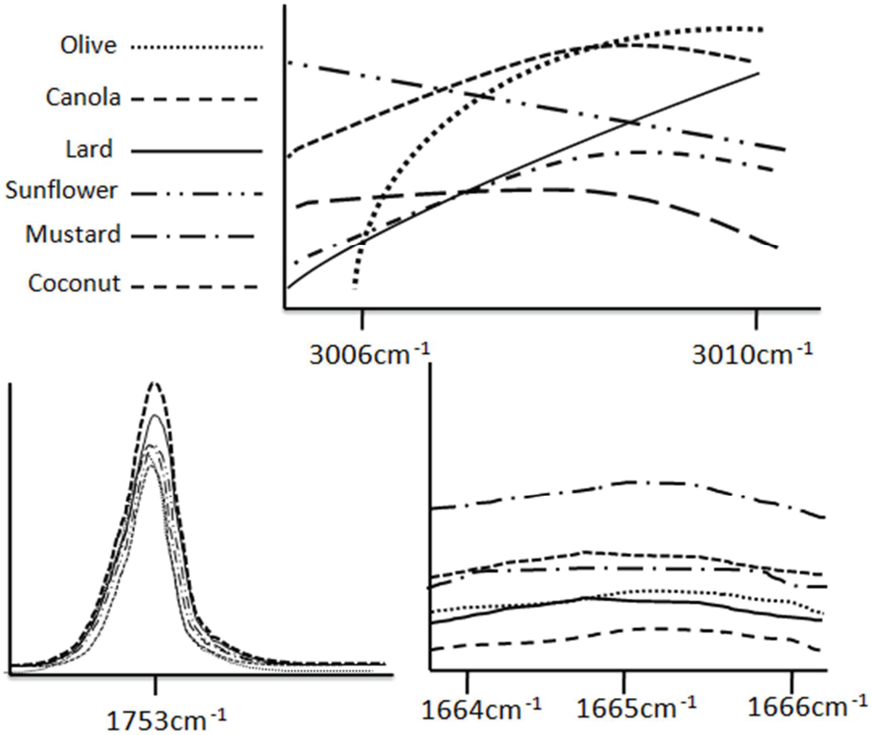

**Figure 3**. Representative spectra of the oils at different wavelengths.

of lard adulteration was developed, which also provided encouraging results. PLS regression was performed and the relationship between the actual values of lard in the edible oils and the selected FT-IR region was developed as shown in Figure 4. Moreover, the details of the actual concentration of lard and the FT-IR predicted values obtained by TQ Analyst are shown in Table 3.

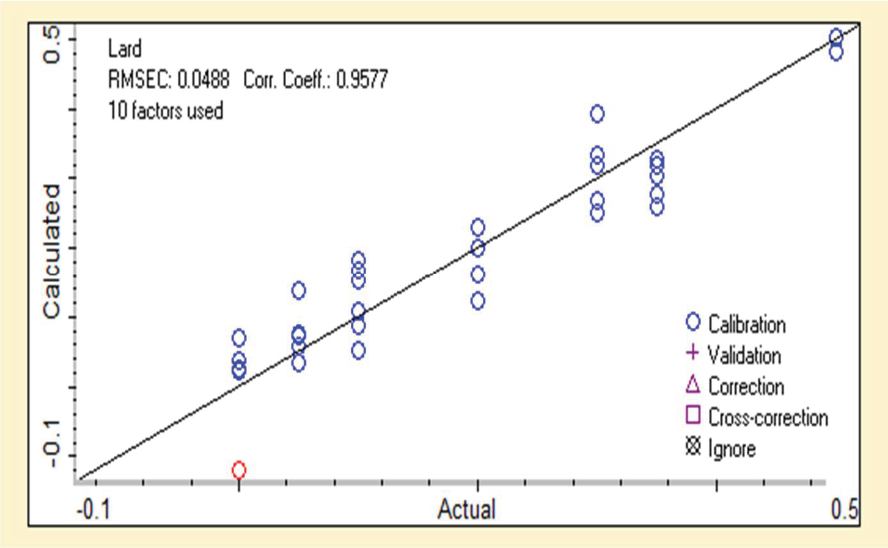

**Figure 4**. TQ Analyst calibration for lard mixing in the region of 1246.75–1078.01 cm$^{-1}$ using PLS.

**Table 3**. Actual concentration of lard mixing in all vegetable oils and FT-IR predicted values of lard obtained by TQ Analyst.

| Actual values of lard in each oil (mg) | FT-IR predicted values for the five edible oils (mg) | | | | |
|---|---|---|---|---|---|
| | Sunflower | Canola | Coconut | Olive | Mustard |
| 0.000 | 0.049 | 0.013 | 0.047 | 0.037 | 0.042 |
| 0.050 | 0.071 | 0.126 | 0.071 | 0.087 | 0.070 |
| 0.150 | 0.175 | 0.167 | 0.119 | 0.194 | 0.171 |
| 0.200 | 0.210 | 0.246 | 0.165 | 0.220 | 0.180 |
| 0.300 | 0.329 | 0.303 | 0.270 | 0.270 | 0.331 |
| 0.400 | 0.382 | 0.362 | 0.333 | 0.333 | 0.371 |
| 0.500 | 0.496 | 0.468 | 0.470 | 0.480 | 0.500 |

A quantity of lard is added gravimetrically (w/w) to the individual oil to develop the PLS model and obtain the relationship between actual and predicted values. In the PLS model 35 calibration standards were used to develop the regression curve. The difference between the calculated values and the predicted values is very small and the developed PLS model works as an accurate tool to measure lard in vegetable oils. A correlation coefficient of 0.9577 was achieved with the developed model. For the calibration of individual oils and common calibration, the regression coefficient was found to be excellent but combined PLS calibration is quick in determining the presence of lard in different types of edible oils. The RMSEC of the model is 0.0488. The major success of the developed model lies in its capacity to differentiate lard from other oils in a single calibration set.

### 3.3. Validation of the FT-IR method

Method validation was performed according to AOAC Guidelines for Single Laboratory Validation of Chemical Methods for Dietary Supplements and Botanicals [36]. A recovery test on the corn oil was carried out by the addition of a known amount of lard as used for the preparation of calibration standards. The recovery test (Table 4) and statistical figures of merit (Table 5) for the validation of the FT-IR method indicated satisfactory performance. These results clearly revealed that there is no substantial effect of the type of oil, which was different from the oils used in the calibration. Therefore, it could be assertively claimed that the proposed FT-IR method is an accurate, rapid, and green approach to evaluate the level of lard in edible oils.

## 4. Conclusion

FT-IR along with PLS multivariate calibration proved to be an accurate technique for detecting and quantifying the amount of lard mixed with sunflower, corn, coconut, olive, and mustard oil. The results are comparable to the concentration of lard in binary mixtures with other oil. The correlation coefficient of 0.9577 is produced in the region of 1078.01–1246.75 $\text{cm}^{-1}$ and the RMSEC of the model is 0.0488. The best feature of this model is its robustness and accuracy. The proposed method is ecofriendly, economical, and solventless, and avoids the lengthy procedure of sample preparation compared to techniques such as gas chromatography. This method can effectively be adopted by food certifying agencies and food departments, which regularly check the authentication of vegetable oils for identification and quantification of lard in vegetable oils.

**Table 4**. Recovery test of neutral oil by standard addition method by FT-IR.

| A (mg) | B (mg) | C (Total of A & B) (mg) | D Amount of lard by FT-IR (mg) | Difference between B and D (mg) | Relative difference (RD %) | Recovery (%) | Acceptable recovery [39] (%) |
|---|---|---|---|---|---|---|---|
| 0.500 | 0.000 | 0.5 mg | 0.003 | –0.003 | - | - | 90–108 |
| 0.450 | 0.050 | | 0.045 | 0.005 | 10 | 90 | |
| 0.350 | 0.150 | | 0.16 | –0.01 | –6.666 | 105.3333 | |
| 0.300 | 0.200 | | 0.213 | –0.013 | –6.500 | 106.5 | |
| 0.200 | 0.300 | | 0.313 | –0.013 | –4.333 | 104.3333 | |
| 0.100 | 0.400 | | 0.355 | 0.045 | 11.250 | 98.75 | |
| 0.000 | 0.500 | | 0.53 | –0.03 | –6.000 | 106 | |

A = corn oil; B = actual amount of lard; C = total concentration of corn oil and lard; D = amount of lard determined by FT-IR.

**Table 5**. Statistical figures of merit for FT-IR method validation.

| Parameters | Figures of merit |
|---|---|
| Mean recovery (%) | 101.375 |
| Correlation coefficient | 0.9836 |
| Limit of detection (LOD) (mg) | 0.010 |
| Limit of quantification (LOQ) (mg) | 0.030 |

## Acknowledgments

The authors would like to thank the Islamic Development Bank (IDB) for its partial funding of the project and also thanks to the International Center for Chemical and Biological Sciences, University of Karachi, for providing good research facilities.

## References

1. Osorio M, Haughey S, Elliott C, Koidis A. Evaluation of methodologies to determine vegetable oil species present in oil mixtures: proposition of an approach to meet the EU legislation demands for correct vegetable oils labeling. Food Research International 2014; 60: 66-75. doi: 10.1016/j.foodres.2013.12.013
2. Seedi E, Said E, Khalifa S, Göransson U, Boglin L et al. Biosynthesis, natural sources,
3. dietary intake, pharmacokinetic properties, and biological activities of hydroxycinnamic
4. acids. Journal of Agriculture and Food Chemistry 2012; 60 (44): 10877-10895. doi:10.1021/JF301807g
5. Marikkar M, Mirghani M, Jaswir I. Application of chromatographic and infrared spectroscopic techniques for detection of adulteration in food lipids: a review. Journal of Food Chemistry and Nanotechnology 2016; 2: 3241. doi: 10.1080/10942912.2010.498544
6. Dahimi O, Hassan M, Rahim A, Abdulkarim S. Differentiation of lard from other edible fats by gas chromatography flame ionisation detector (GC FID) and chemometrics. Journal of Food and Pharmaceutical Sciences 2014; 2: 27-31. doi:10.14499/jfps
7. Kurniawati E, Rohman A, Triyana K. Analysis of lard in meatball broth using Fourier transform infrared spectroscopy and chemometrics. Meat Science 2014; 96: 9498. doi: 10.1016/j.meatsci.2013.07.003

8. Marikkar J, Dzulkifly M, Nadiha M, Man YBC. Detection of animal fat contaminations in sunflower oil by differential scanning calorimetry. International Journal of Food Properties 2012; 15: 683-690.doi: 10.1080/10942912.2010.498544
9. Malaysia JKI. Jabatan Kemajuan Islam Malaysia. Putrajaya, Jabatan Kemajuan Islam Malaysia (JAKIM), Malaysia: Firdous Press, 2015.
10. Gurdeniz G, Ozen B. Detection of adulteration of extravirgin olive oil by chemometric analysis of midinfrared spectral data. Food Chemistry 2009; 116: 519525. doi: 10.1016/j.foodchem.2009.02.068
11. Tsopelas F, Konstantopoulos D, Kakoulidou A. Voltammetric fingerprinting of oils and its combination with chemometrics for the detection of extra virgin olive oil adulteration. Analytical Chimica Acta 2018; 1015: 8-19. doi: 10.1016/j.aca.2018.02.042
12. Adeeba, Siddiqui A, Sherazi S, Ahmed S, Choudhary M et al. A comparative profiling of oral cancer patients and high risk niswar users using FT-IR and chemometric analysis. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 2018; 203: 177-184. doi: 10.1016/j.saa.2018.05.107
13. Fahim F, Naseer A, Ahmed S, Sherazi S, Bhanger M. A green method for the determination of selected antidiabetic drugs in pharmaceutical formulation by transmission FT-IR spectroscopy. Journal of Brazilian Chemical Society 2014; 25: 2032-2038. doi: 10.5935/0103-5053.20140188
14. Mallah M, Sherazi S, Bhanger M, Mahesar S, Bajeer M. A rapid Fourier-transform infrared (FT-IR) spectroscopic method for direct quantification of paracetamol content in solid pharmaceutical formulations. Spectrochimica Acta, Part A 2015; 141: 6470. doi: 10.1016/j.saa. 2015.01.036
15. Voort R, Sedman J, Sherazi S. Improved determination of isolated trans isomers in edible oils by Fourier transform infrared spectroscopy using spectral reconstitution. Journal Association of Analytical Chemists 2007; 90: 446-451.
16. Sherazi S, Bhuttol A, Mahesar S, Bhanger M. Application of Fourier-transform infrared (FT-IR) spectroscopy for determination of total phenolics of freeze dried lemon juices. Journal of Chemical Society Pakistan 2017; 39 (6): 955-961. doi: 10.1016/j.vibspec.2010.09.010
17. Vlachos N, Skopelitis Y, Psaroudaki M, Konstantinidou V, Chatzilazarou A et al. Applications of Fourier transforminfrared spectroscopy to edible oils. Analytica Chimica Acta 2006; 573-574: 459-465.
18. Talpur M, Hassan S, Sherazi S, Mahesar S, Kara H, Kandhro AA, Sirajuddin. A simplified FTIR chemometric method for simultaneous determination of four oxidation parameters of frying canola oil. Spectrochimica Acta, Part A 2015; 149: 656-661. doi: 10.1016/j.saa.2015.04.098
19. Naz S, Sherazi S, Talpur F, Mahesar S, Kara H. Rapid determination of free fatty acid content in waste deodorizer distillates using SB-ATR-FTIR. Journal of Association of Official Analytical Chemists 2012; 95: 1570-1573. doi: 10.5740/jaoacint.11-034
20. Sherazi S, Talpur M, Mahesar A, Kandhro A, Arain S. Main fatty acids classes in vegetable oils by SB-ATR-Fourier transform infrared (FTIR) spectroscopy. Talanta 2009; 80: 600-606. doi:10.1016/j.talanta.2009.07.030
21. Ley C, Revilla D, Ochoategui A, Ortiz G, Velazquez T. Prediction of coumarin and ethyl vanillin in pure vanilla extracts using MID FTIR spectroscopy and chemometrics. Talanta 2009; 197: 264-269. doi: 10.1016/j.talanta.2019.01.033
22. Wong Y, Goh K, Abas F, Maulidiani M, Nyam K et al. Rapid quantification of 3-monochloropropane-1,2-diol in deep-fat frying using palm olein: using ATR-FTIR and chemometrics. Food Science Technology 2019; 100: 404-408. doi: 10.1016/j.lwt.2018.10.088
23. Sherazi S, Kandhro A, Mahesar S, Bhanger M, Talpur M et al. Application of transmission FT-IR spectroscopy for the trans fat determination in the industrially processed edible oils. Food Chemistry 2009; 144: 323-327. doi: 10.1016/j.foodchem.2008.09.058

24. Voort F, Sedman J, Sherazi S. Correcting for underlying absorption interferences in FT-IR trans analysis of edible oils using 2d correlation techniques. Journal of Agriculture and Food Chemistry 2008; 56: 1523-1537. doi: 10.1021/jf0725068
25. Sherazi S, Mahesar S, Bhanger M. Rapid determination of free fatty acids in poultry feed lipids extracts by SB-ATR FT-IR spectroscopy. Journal of Agriculture and Food Chemistry 2007; 55: 4928-4932. doi: 10.1021/jf063554f
26. Jawaid S, Talpur F, Sherazi S. Rapid detection of melamine adulteration in dairy milk by SB-ATR-Fourier transform infrared spectroscopy. Food Chemistry 2013; 141: 3066-3071. doi: 10.1016/j.foodchem.2013.05.106
27. Suparman W, Sundhani E, Saputri S. The use of Fourier transform infrared spectroscopy (FTIR) and gas chromatography mass spectroscopy (GCMS) for halal authentication in imported chocolate with various variants. Journal of Food and Pharmaceutical Sciences 2015; 2: 6-11. doi: 10.14499/jfps
28. Xu L, Cai C, Cui H, Ye Z, Yu X. Rapid discrimination of pork in Halal and non-Halal Chinese ham sausages by Fourier transform infrared (FTIR) spectroscopy and chemometrics. Meat Science 2012; 92: 506-510. doi: 10.1016/j.meatsci.2012.05.019
29. Beale D, Morrison P, Karpe A, Dunn M. Chemometric analysis of lavender essential oils using targeted and untargeted GC-MS acquired data for the rapid identification and characterization of oil quality. Molecules 2017; 22: 1339.
30. doi: 10.3390/molecules22081339
31. Rohman A, Che Man YB, Hashim P, Ismail A. FTIR spectroscopy combined with chemometrics for analysis of lard adulteration in some vegetable oils. CyTA - Journal of Food 2011; 9: 96-101. doi: 10.1080/19476331003774639
32. Kamboh M, Chang A, Ibrahima W, Sanagi M, Mahesar S et al. A green method for the quantitative assessment of neutral oil in palm fatty acid distillates by single bounce attenuated total reflectance Fourier transform infrared spectroscopy. Royal Society of Chemistry
33. Advances 2015; 5: 50591-50596. doi: 10.1039/C5RA06987D
34. Javidnia K, Parish M, Karimi S, Hemmateenejad B. Discrimination of edible oils and fats by combination of multivariate pattern recognition and FT-IR spectroscopy: a comparative study between different modeling methods. Spectrochimica Acta, Part A 2013; 104: 175-181. doi: 10.1016/j.saa.2012.11.067
35. Rohman A, Man YC. Fourier transform infrared (FTIR) spectroscopy for analysis of extra virgin olive oil adulterated with palm oil. Food Research International 2010; 43: 886-892. doi: 10.1016/j.foodres.2009.12.006
36. Rohman A, Man Y. The use of Fourier transform mid infrared (FT-MIR) spectroscopy for detection and quantification of adulteration in virgin coconut oil. Food Chemistry 2011; 129: 583-588. doi: 10.1016/j.foodchem.2011.04.070
37. Alexa E, Dragomirescu A, Pop G, Jianu C, Dragos D. The use of FT-IR spectroscopy in the identification of vegetable oils adulteration. Journal of Food Agriculture and Environment 2009; 7: 20-24. doi: 10.1234/4.2009.1525
38. Siddiqui N, Ahmad A. Infrared spectroscopic studies on edible and medicinal oils.
39. International Journal of Science Environment & Technology 2013; 2: 1297-1306.
40. doi: 10.1.1.682.2485
41. Liang P, Wang H, Chen C, Liu D et al. The use of Fourier transform infrared spectroscopy for quantification of adulteration in virgin walnut oil. Journal of Spectroscopy 2012; 7 (2): 20-24. doi: 10.1155/2013/305604
42. AOAC International. AOAC Guidelines for Single Laboratory Validation of Chemical Methods for Dietary Supplements and Botanicals, Association of Official Analytical Chemists, Arlington, VA, USA, 2002.