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ORIGINAL PAPER

Differentiation of Lard From Other Edible Fats and Oils by Means of Fourier Transform Infrared Spectroscopy and Chemometrics

Yaakob B. Che Man · A. Rohman · T. S. T. Mansor

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Abstract Fourier transform infrared (FTIR) spectra at mid infrared regions (4,000–650 cm^{-1}) of lard and 16 edible fats and oils were compared and differentiated. The chemometrics of principal component analysis and cluster analysis (CA) was used for such differentiation using FTIR spectra intensities of evaluated fats and oils. With PCA, an "eigenvalue" of about 90% was achieved using four principal components (PCs) of variables (FTIR spectra absorbances at the selected frequency regions). PC1 accounted for 44.1% of the variation, while PC2 described 30.2% of the variation. The main frequency regions that influence the separation of lard from other evaluated fats and oils based on PC1 are 2,852.8 followed by 2,922 and 1,464.7 cm^{-1}. Furthermore, CA can classify lard into its group based on Euclidean distance.

Keywords Lard · Differentiation · FTIR spectroscopy · Fats and oils · Chemometrics

Introduction

Fats and oils, including lard, are used as food or as raw materials in food products, because they contain high calorific value and essential fatty acids necessary for the development of human tissues. As an edible fat, lard can be considered from two perspectives, i.e., religious and economical point of views. The food industry prefers to blend lard with some vegetable oils to minimize production costs because lard or industrially modified lard can be mixed efficiently with vegetable oils to produce cost-effective margarines, shortenings, and other oil-based foods. From a religious perspective, the presence of lard in any food products precludes consumption by Muslims [1, 2]. Therefore, there is a great demand for rapid and reliable techniques for lard differentiation and classification for the process of halal authentication analysis by the relevant halal authorities. One interesting and emerging technique for fats and oils differentiation is Fourier transform infrared (FTIR) spectroscopy.

In the two decades since its development, FTIR spectroscopic instrumentation has been exploited extensively in food research, and has become a powerful means of analysis in the study of oils and fats [3]. FTIR spectroscopy is a fast, non-destructive method, not requiring excessive sample preparation, for qualitative analysis of compounds including fats and oils, with each functional group being responsible for the appearance of IR absorption peaks in the FTIR spectrum at a specific wavelengths [4]. FTIR is also a promising analytical tool for quantitative analysis of analytes because, following Beer's law, the peak intensities (absorbances) of the IR spectrum are directly proportional to concentration. In addition, FTIR has been utilized for the characterization and differentiation of fats and oils because the peak intensities and the exact frequencies at which the maximum absorbance of peaks appear, differ according to the nature and composition of the sample [5].

An important factor contributing to the success of FTIR spectroscopy is chemometrics [6]. Chemometrics is the discipline of extracting chemically relevant information from data produced in chemical experiments by means of

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statistical and mathematical tools [7]. There are numerous different chemometric techniques used in the study of fats and oils, such as principal component analysis (PCA), multivariate calibration of partial least squares and principle component regressions, discriminant analysis, and cluster analysis (CA), and such methods are employed to solve several problems related to the analysis of fats and oils [8].

FTIR spectroscopy has been exploited for lard characterization. Guillen and Cabo [9] characterized lard using a potassium bromide (KBr) disc as a sample handling technique and found that frequencies at certain bands have constant values. The differentiation of lard from soybean oil was also investigated by Yang and Irudayaraj [10] using attenuated total reflection (ATR) and photoacoustic techniques. To our knowledge, there are no reports on the application of FTIR spectroscopy combined with PCA and CA to the differentiation and classification of lard from other animal fats and selected vegetable oils. Therefore, this study focused on the application of FTIR spectroscopy to differentiate lard from other selected fats and oils using PCA and CA.

Materials and Methods

Sample Preparation

Commercial edible fats and oils (cod liver, canola, corn, extra virgin olive, grape seed, palm, pumpkin seed, rice bran, sesame, soybean, sunflower, walnut, and virgin coconut oils) were purchased from a local supermarket in Selangor, Malaysia. Animal fats (lard, beef, chicken, and mutton fats) were prepared by rendering the adipose tissues from various parts of the corresponding animals as described in [11].

Fatty Acid Analysis

The composition of fatty acids as fatty acid methyl ester (FAME) was determined using gas chromatography using a flame ionization detector as described by [12] by dissolving 50 mg fats and oils samples in 0.8 ml hexane and 0.2 ml 1 M sodium methoxide. All chemicals were supplied by Merck (Darmstadt, Germany). The mixture was shaken vigorously for 1 min with a vortex mixer, and 1 μL of the clear supernatant was subsequently taken and injected into a gas chromatograph (Shimadzu GC-2010, Shimadzu, Tokyo, Japan), using the following conditions:

Column RTX-5 capillary column (0.25 mm internal diameter, 30 m length, and 0.2 μm film thickness; Restex, Bellefonte, PA).

Oven 50 °C (hold for 1 min), then increased to 180 °C (8 °C/min), 180–200 °C (8 °C/min), and finally held at 200 °C for 5 min

Detector Flame ionization detector (200 °C)

Carrier gas N_2, at 6.8 mL/min

Injector 200 °C; split ratio (1:20).

Thirty-seven standard FAME (Sigma, St. Louis, MO) were used as authentic samples to calculate the percentage of fatty acids based on peak area. Quantification of FAME was performed using a normalization internal technique.

FTIR Measurement

FTIR spectra of all oil samples were measured using an FTIR Nicolet 6700 spectrometer (Thermo Nicolet, Madison, WI) equipped with a detector of deuterated triglycine sulphate (DTGS) and KBr beam splitter, and connected to the software of an OMNIC operating system (Version 7.0 Thermo Nicolet). Using a Pasteur pipette, the samples were placed in contact with the horizontal attenuated total reflectance (HATR) element (ZnSe crystal) at controlled ambient temperature (25 °C). FTIR spectra were collected in the mid-infrared region of 4,000–650 cm^{-1} by co-adding 32 scans and at a resolution of 4 cm^{-1}. All spectra were rationed against a background of air spectrum. After each scan, a new reference air background spectrum was taken. Spectra were recorded as absorbance values at each data point in triplicate.

Statistical Analysis

All sample analyses (fatty acid composition and FTIR spectra) were performed as three replicates and averaged using Microsoft Excel software 2007. The chemometrics analysis of PCA and CA was generated using Minitab software (Release 15; Minitab, State College, PA).

Results and Discussion

Fatty Acid Composition and FTIR Spectra

Fats and oils are basically composed of esters of fatty triacylglycerol and some minor components such as diacylglycerol, monoacylglycerol, free fatty acids, and sterols. Lard can be differentiated from other fats and oils by investigating the position of fatty acids, saturation level of the chains and the specific minor components present in the fats and oils. The fatty acid (FA) compositions of lard and the other animal fats and oils studied are listed in Table 1. It is difficult to distinguish lard from other fats using solely FA profile due to the similar pattern of FA, therefore, FTIR

Table 1 Fatty acid (FA) composition of lard and other animal fats and vegetable oils

Oils	Fatty acid								
	C10:0	C12:0	C14:0	C16:0	C18:0	C18:1	C18:1	C18:3	C20:0
Lard	0.01 ± 0.00	0.01 ± 0.00	0.11 ± 0.03	21.33 ± 0.89	11.39 ± 0.68	41.01 ± 2.28	17.65 ± 3.33	0.97 ± 0.06	0.91 ± 0.03
BF	nd[a]	0.08 ± 0.00	2.84 ± 0.05	24.19 ± 0.01	16.47 ± 0.36	40.46 ± 0.31	4.44 ± 0.40	0.12 ± 0.01	0.12 ± 0.01
CF	0.01 ± 0.00	0.02 ± 0.00	0.86 ± 0.04	28.27 ± 0.13	9.49 ± 0.23	38.33 ± 0.12	14.19 ± 0.13	0.63 ± 0.03	0.15 ± 0.02
MF	0.14 ± 0.00	0.11 ± 0.00	2.64 ± 0.02	21.49 ± 0.98	27.84 ± 0.42	30.06 ± 0.36	4.90 ± 0.14	0.37 ± 0.02	0.55 ± 0.01
CLO	0.01 ± 0.00	0.02 ± 0.00	5.14 ± 0.12	12.01 ± 0.13	2.90 ± 0.23	25.87 ± 0.46	0.23 ± 0.05	2.16 ± 0.01	0.12 ± 0.01
CaO	0.01 ± 0.00	0.01 ± 0.00	0.15 ± 0.00	3.84 ± 0.22	1.65 ± 0.08	61.43 ± 1.37	21.85 ± 0.64	9.70 ± 0.40	0.83 ± 0.03
CO	0.02 ± 0.00	0.04 ± 0.00	0.12 ± 0.00	10.15 ± 0.62	2.42 ± 0.08	26.24 ± 0.72	58.60 ± 1.05	1.15 ± 0.09	0.52 ± 0.04
EVOO	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	10.78 ± 0.25	3.30 ± 0.13	74.98 ± 1.72	7.77 ± 0.35	0.63 ± 0.04	0.43 ± 0.03
GSO	0.05 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	7.87 ± 0.12	3.27 ± 0.09	21.16 ± 1.07	64.02 ± 1.24	0.77 ± 0.02	0.23 ± 0.01
PO	0.35 ± 0.01	0.12 ± 0.00	1.36 ± 0.08	42.75 ± 1.12	4.64 ± 0.18	39.33 ± 0.96	10.37 ± 0.56	0.41 ± 0.01	0.37 ± 0.01
PSO	0.01 ± 0.00	0.01 ± 0.00	0.12 ± 0.00	11.69 ± 0.10	8.69 ± 0.12	59.72 ± 1.16	17.43 ± 0.57	0.43 ± 0.02	0.16 ± 0.01
RBO	0.01 ± 0.00	0.01 ± 0.00	0.35 ± 0.01	18.85 ± 1.02	0.50 ± 0.04	43.17 ± 1.28	31.74 ± 0.84	0.85 ± 0.05	1.34 ± 0.12
SEO	0.01 ± 0.00	0.01 ± 0.00	0.02 ± 0.00	9.93 ± 0.01	6.47 ± 0.33	34.79 ± 0.33	46.95 ± 0.09	0.36 ± 0.00	0.12 ± 0.00
SO	0.02 ± 0.00	0.02 ± 0.00	0.01 ± 0.00	10.97 ± 0.12	5.10 ± 0.16	20.75 ± 0.52	52.24 ± 0.86	7.77 ± 0.28	0.01 ± 0.00
SFO	0.01 ± 0.00	0.02 ± 0.00	0.06 ± 0.00	6.70 ± 0.42	3.03 ± 0.17	18.42 ± 0.80	67.95 ± 1.27	0.87 ± 0.01	0.39 ± 0.03
WO	0.03 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	7.11 ± 0.12	3.24 ± 0.11	19.75 ± 0.32	60.34 ± 0.74	1.28 ± 0.21	0.49 ± 0.01

Oil	Fatty acid								
	C6:0	C8:0	C10:0	C12:0	C14:0	C16:0	C18:0	C18:1	C18:2
VCO	0.06 ± 0.00	7.37 ± 0.22	6.62 ± 0.18	50.01 ± 1.07	19.26 ± 0.84	10.01 ± 0.28	4.81 ± 0.32	0.90 ± 0.04	nd

Each value in the table represents the means of triplicate analysis ±SD

BF Beef fat, *CF* chicken fat, *MF* Mutton fat, *CLO* cod liver oil, *CaO* Canola oil, *CO* corn oil, *EVOO* Extra virgin olive oil, *GSO* grape seed oil, *PO* palm oil, *PSO* pumpkin seed oil, *RBO* rice brain oil, *SEO* sesame oil, *SO* soybean oil, *SFO* sunflower oil, *WO* walnut oil, *VCO* virgin coconut oil

[a] Not detected

spectroscopy in combination with PCA was proposed as a tool for such differentiation.

To the naked eye, the FTIR spectra of lard and all the fats and oils studied appear fairly similar. They describe the different profiles in FA composition present among the evaluated edible fats and oils. The FA composition of 17 fats and oils are shown in Table 1; these can be classified as saturated (SFAs), monounsaturated (MUFAs), and polyunsaturated fatty acids (PUFAs). It is difficult to differentiate lard and other fats and oils by relying just on FA profiles, therefore FTIR spectra are proposed as a potential means to achieve such differentiation because FTIR spectra are considered as "fingerprint tools", meaning that no two oils have the same FTIR spectra, in terms of either number of peaks or maximum peak intensity [13].

Comprehensive examination of the FTIR spectra of evaluated fats and oils allowed the identification of certain peaks or peak ratios that help in the characterization, differentiation, and classification of lard and other edible fats and oils [5]. The peak intensities of lard and other fat and oils at certain frequencies are listed in Table 2. However, it is still difficult and impractical to distinguish lard from the others using FTIR spectra without any additional data treatment. This fact is illustrated clearly in Fig. 1, which shows the spectra of all the sampled oils. For this reason, and for the purposes of taking advantage of FTIR spectra information, including minor differences that should not be taken into account, the chemometrics techniques of PCA and CA were exploited for such differentiation.

Principal Component Analysis

PCA is an unsupervised pattern recognition technique used in multivariate analysis. PCA projects the original data in reduced dimensions defined by the principal components (PC). This technique is useful when there are correlations present among data [14]. In this study, PCA was accomplished using FTIR spectra absorbances of 17 evaluated fats and oils at 16 frequencies as shown in Table 2. Figure 2 demonstrates the score plot of PCA of 17 fats and oils representing the projection of samples defined by the first (PC1) and second (PC2) components. PC1 accounts for the most variation in FTIR spectra absorbances, while PC2 accounts for the next largest variation. An eigenvalue of

Table 2 Peak intensities (absorbances) for each frequency in lard and other edible fats and oils

No	Oils	Frequency							
		721.6	868.3	965.7	1,031.9	1,097.3	1,116.8	1,157.6	1,236.3
1	Lard	0.986 ± 0.02	0.246 ± 0.09	0.334 ± 0.00	0.413 ± 0.00	0.966 ± 0.01	0.973 ± 0.01	1.654 ± 0.03	0.755 ± 0.02
2	Beef	0.987 ± 0.11	0.236 ± 0.10	0.397 ± 0.01	0.387 ± 0.16	0.928 ± 0.03	0.969 ± 0.02	1.583 ± 0.44	0.753 ± 0.15
3	Chicken	0.946 ± 0.02	0.244 ± 0.00	0.325 ± 0.13	0.406 ± 0.00	0.932 ± 0.01	0.990 ± 0.01	1.649 ± 0.85	0.762 ± 0.02
4	Mutton	0.683 ± 0.14	0.211 ± 0.11	0.389 ± 0.01	0.374 ± 0.00	0.869 ± 0.36	0.943 ± 0.12	1.470 ± 0.06	0.685 ± 0.29
5	CLO	1.134 ± 0.01	0.365 ± 0.00	0.437 ± 0.00	0.000 ± 0.00	0.967 ± 0.01	0.896 ± 0.00	1.630 ± 0.89	0.809 ± 0.00
6	Canola	1.068 ± 0.02	0.261 ± 0.12	0.401 ± 0.00	0.428 ± 0.00	0.963 ± 0.00	0.933 ± 0.01	1.609 ± 0.01	0.763 ± 0.00
7	Corn	1.076 ± 0.01	0.255 ± 0.11	0.375 ± 0.22	0.437 ± 0.00	0.990 ± 0.01	0.922 ± 0.11	1.661 ± 0.02	0.789 ± 0.00
8	EVOO	0.981 ± 0.18	0.247 ± 0.03	0.316 ± 0.17	0.415 ± 0.05	0.930 ± 0.16	0.964 ± 0.18	1.604 ± 0.38	0.764 ± 0.15
9	Grape seed	1.091 ± 0.02	0.260 ± 0.16	0.382 ± 0.25	0.441 ± 0.00	0.993 ± 0.03	0.918 ± 0.29	1.652 ± 0.35	0.787 ± 0.12
10	Palm	0.929 ± 0.01	0.237 ± 0.00	0.310 ± 0.08	0.397 ± 0.00	0.946 ± 0.00	1.012 ± 0.00	1.665 ± 0.02	0.769 ± 0.00
11	Pumpkin seed	1.085 ± 0.02	0.255 ± 0.28	0.358 ± 0.19	0.432 ± 0.00	0.986 ± 0.01	0.939 ± 0.01	1.612 ± 0.02	0.777 ± 0.01
12	Rice Bran	0.975 ± 0.02	0.247 ± 0.13	0.348 ± 0.21	0.429 ± 0.22	0.923 ± 0.02	0.923 ± 0.02	1.575 ± 0.05	0.767 ± 0.31
13	Sesame	1.012 ± 0.04	0.256 ± 0.09	0.359 ± 0.20	0.454 ± 0.16	0.953 ± 0.02	0.906 ± 0.02	1.589 ± 0.08	0.783 ± 0.01
14	Soybean	1.111 ± 0.01	0.266 ± 0.15	0.397 ± 0.00	0.430 ± 0.09	1.009 ± 0.45	0.919 ± 0.01	1.641 ± 0.73	0.772 ± 0.42
15	Walnut	1.166 ± 0.02	0.277 ± 0.15	0.418 ± 0.00	0.451 ± 0.15	1.026 ± 0.00	0.907 ± 0.07	1.618 ± 0.02	0.791 ± 0.01
16	Sunflower	1.116 ± 0.01	0.260 ± 0.14	0.374 ± 0.02	0.431 ± 0.21	1.002 ± 0.07	0.911 ± 0.06	1.598 ± 0.12	0.773 ± 0.05
17	VCO	0.767 ± 0.01	0.268 ± 0.13	0.375 ± 0.00	0.460 ± 0.18	1.429 ± 0.01	0.000 ± 0.00	2.187 ± 1.25	0.000 ± 0.00
No	Oils	Frequency							
		1,377.2	1,417.6	1,464.7	1,654.7	1,743.5	2,852.8	2,922	3,007.1
1	Lard	0.471 ± 0.02	0.328 ± 0.01	0.796 ± 0.01	0.076 ± 0.00	2.633 ± 1.18	1.555 ± 0.04	2.015 ± 1.89	0.217 ± 0.00
2	Beef	0.51 ± 0.11	0.342 ± 0.33	0.916 ± 0.89	0.069 ± 0.01	2.529 ± 2.21	2.069 ± 0.52	2.554 ± 1.21	0.152 ± 0.01
3	Chicken	0.465 ± 0.03	0.319 ± 0.01	0.770 ± 0.01	0.076 ± 0.01	2.698 ± 1.91	1.543 ± 0.02	2.214 ± 1.71	0.192 ± 0.01
4	Mutton	0.382 ± 0.05	0.267 ± 0.03	0.706 ± 0.29	0.061 ± 0.00	2.199 ± 1.49	1.544 ± 0.35	2.275 ± 0.03	0.106 ± 0.06
5	CLO	0.483 ± 0.00	0.367 ± 0.00	0.736 ± 0.00	0.112 ± 0.00	2.435 ± 0.10	1.300 ± 0.01	1.875 ± 0.23	0.291 ± 0.00
6	Canola	0.472 ± 0.01	0.333 ± 0.00	0.768 ± 0.01	0.099 ± 0.00	2.204 ± 0.25	1.371 ± 0.02	1.973 ± 0.03	0.283 ± 0.00
7	Corn	0.499 ± 0.00	0.347 ± 0.00	0.775 ± 0.00	0.092 ± 0.00	2.492 ± 0.13	1.352 ± 0.01	1.960 ± 0.02	0.310 ± 0.00
8	EVOO	0.489 ± 0.11	0.324 ± 0.20	0.815 ± 0.30	0.078 ± 0.03	2.497 ± 0.74	1.545 ± 0.35	2.170 ± 0.83	0.235 ± 0.09
9	Grapeseed	0.493 ± 0.08	0.348 ± 0.17	0.763 ± 0.27	0.096 ± 1.02	2.479 ± 0.18	1.305 ± 0.01	1.835 ± 0.04	0.338 ± 0.00
10	Palm	0.488 ± 0.00	0.330 ± 0.00	0.818 ± 0.00	0.062 ± 0.01	2.576 ± 0.25	1.674 ± 0.02	2.476 ± 0.10	0.174 ± 0.00
11	Pumpkin seed	0.486 ± 0.00	0.339 ± 0.00	0.773 ± 0.01	0.088 ± 0.00	2.686 ± 0.11	1.409 ± 0.02	2.085 ± 0.08	0.287 ± 0.00
12	Rice Bran	0.486 ± 0.05	0.325 ± 0.02	0.777 ± 0.03	0.080 ± 0.00	2.459 ± 0.44	1.412 ± 0.06	2.084 ± 0.13	0.248 ± 0.01
13	Sesame	0.463 ± 0.01	0.330 ± 0.15	0.746 ± 0.02	0.088 ± 0.01	2.427 ± 0.11	1.326 ± 0.05	2.007 ± 0.10	0.282 ± 0.00
14	Soybean	0.466 ± 0.05	0.341 ± 0.01	0.760 ± 0.01	0.094 ± 0.00	2.463 ± 0.31	1.326 ± 0.03	1.931 ± 0.85	0.323 ± 0.14
15	Walnut	0.485 ± 0.02	0.359 ± 0.00	0.744 ± 0.01	0.105 ± 0.00	2.750 ± 0.15	1.222 ± 0.02	1.718 ± 0.07	0.378 ± 0.01
16	Sunflower	0.486 ± 0.03	0.341 ± 0.02	0.757 ± 0.04	0.094 ± 0.00	2.674 ± 0.32	1.307 ± 0.08	1.863 ± 0.15	0.328 ± 0.02
17	VCO	0.577 ± 0.00	0.375 ± 0.00	0.836 ± 0.00	0.000 ± 0.00	3.021 ± 1.52	1.560 ± 0.02	2.303 ± 0.06	0.000 ± 0.00

Values represent the means of triplicate analysis ± SD

about 90% was achieved using four PCs. PC1 accounted for 44.1% of the variation, while PC2 described 30.2% of the variation; therefore, 74.4% of the variance is being described by the first two PCs.

Figure 3 shows the loading plot for the determination of variables (frequency regions) contributing to the separation of the samples of fats and oils. The PCA loading plot describes the projection of variables in the same plane as the score plot. The absolute value of loading in the frequency regions explains the importance of the contribution of each region. Therefore, the further away a frequency region is from the origin of variable point, the larger the contribution of that variable to the PCA model [15]. From Fig. 3, it is known that frequency regions at 1,654.7, 1,236.3, 1,157.6, 1,097.3 cm^{-1} make a larger contribution to the PCA model. In order to correlate the loading plot and

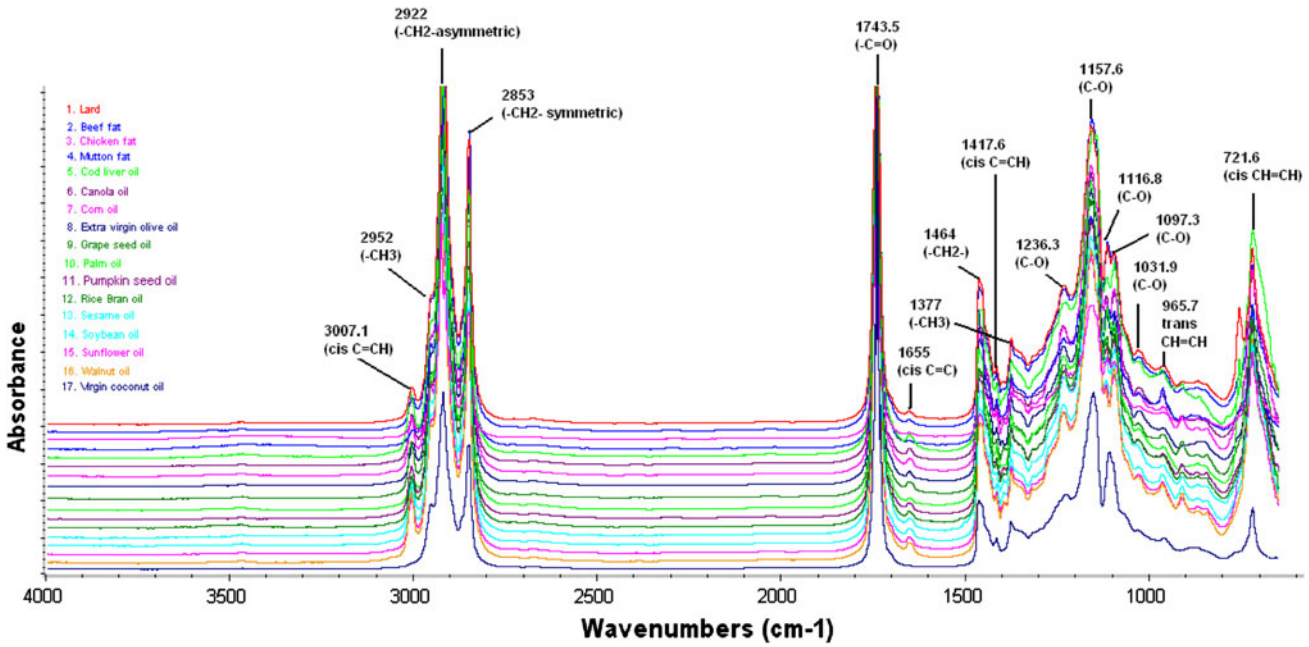

Fig. 1 Fourier transform infrared (FTIR) spectra of lard and other evaluated edible fats and oils at mid infrared regions (4,000–650 cm^{-1})

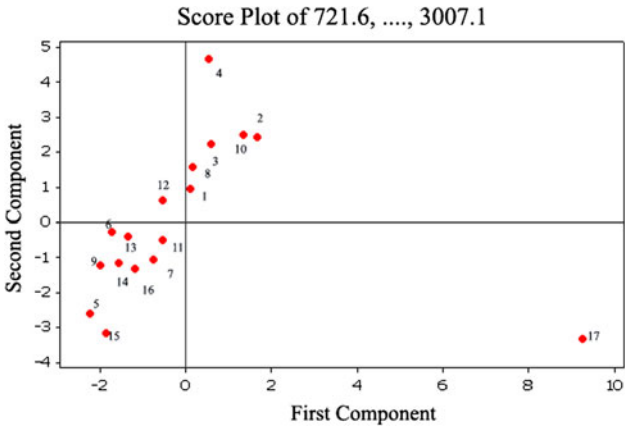

Fig. 2 The score plot for the first two principal components (PC) for 17 studied edible fats and oils: *1* Lard, *2* beef fat, *3* chicken fat, *4* mutton fat, *5* cod liver oil, *6* canola oil, *7* corn oil, *8* extra virgin olive oil, *9* grape seed oil, *10* palm oil, *11* pumpkin seed oil, *12* rice bran oil, *13* sesame oil, *14* soybean oil, *15* walnut oil, *16* sunflower oil, *17* virgin coconut oil

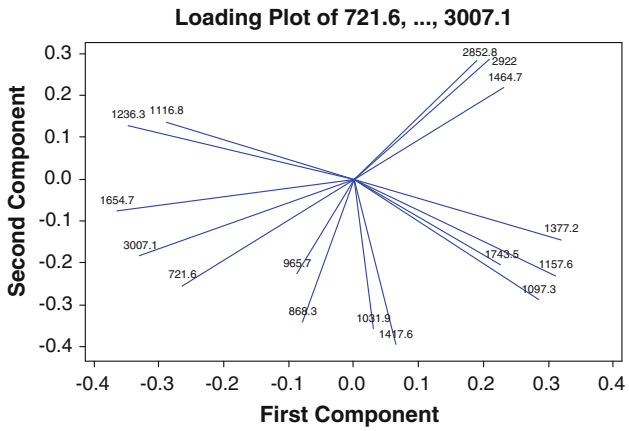

Fig. 3 Principal component analysis (PCA) loading plot of PC1 versus PC2 exploiting some frequency regions as variables

the score plot, a bi-plot explaining which frequency regions influence PC1 and PC2 is described (Fig. 4). According to Fig. 4, the main frequency contributing to the separation of lard from other evaluated fats and oils based on PC1 is 2,852.8, followed by 2,922 and 1,464.7 cm^{-1}. The bi-plot also reveals that the frequencies 1,116.8 and 1,236.3 cm^{-1} influence separation of lard from other oils on PC2.

Cluster Analysis

In order to divide a group of objects (here, the evaluated fats and oils) into classes so that similar fats and oils are in the same class, CA using the single linkage method was used. The main advantage of CA over PCA is that CA can provide numerical values of similarity among the objects evaluated. Therefore, the information obtained is more objective. In addition, CA can reduce dimensionality while retaining the required information [16]. Figure 5 shows a dendogram that illustrates the stages of linkage. It can be stated that the first two oils joined are corn and soybean oils, followed by rice bran and sesame oils, and so on until all fats and oils are grouped into one class. However, for example, if we "cut the tree", i.e., stop the grouping, at the point indicated by the horizontal line in Fig. 5, this analysis suggests that the evaluated fats and oils fall into six groups. Group 1 contained lard, cod liver oil, corn, soybean, rice

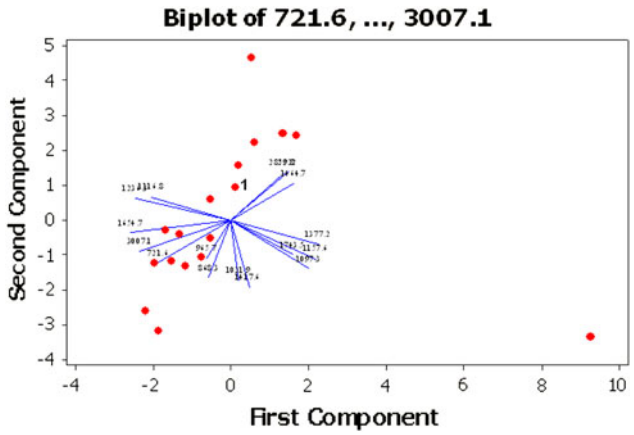

Fig. 4 Bi-plot for the correlation of score plot (PC1 and PC2) and loading plot. *1* Lard

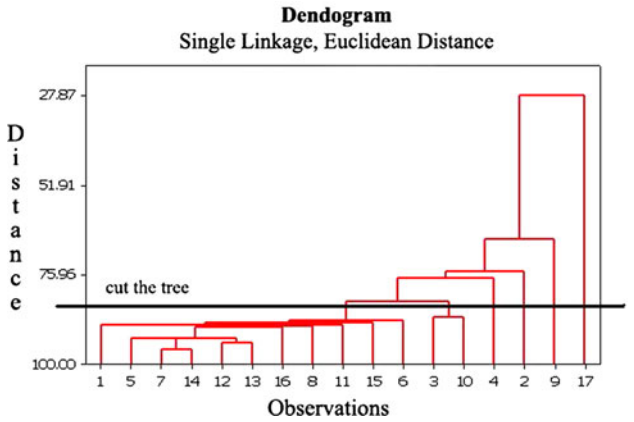

Fig. 5 Dendogram illustrating the stages of clustering of the evaluated fats and oils. See legend to Fig. 2 for assignment of numbers *1–17*

bran, sesame, sunflower, extra virgin olive, pumpkin seed, walnut, and canola oils; chicken fat and palm oil formed one cluster (group 2). Meanwhile, beef fat, mutton fat, grape seed oil, and virgin coconut oil can be considered as group 3, 4, 5, and 6, respectively.

Conclusions

From the results presented here, it can be concluded that FTIR spectra combined with the chemometrics of PCA and CA can be employed to differentiate and classify lard from other animal fats and vegetable oils. This technique is rapid, requires no excessive sample preparation, and does not use hazardous reagents and solvents; consequently, it can be considered as an environmentally friendly "green analytical technique".

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