The FTIR-ATR Spectroscopy and Multivariate Data Analysis (MVDA) for Halal Authentication on Animal Fatty Acids

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The authentication of *halal* products is crucial for adherents of Islam, as consuming non-permissible substances contradicts religious mandates. Recent widespread adulteration of food and pharmaceutical products with porcine-derived ingredients has necessitated the development of robust analytical methods for halal verification. This study presents an approach for rapid *halal* authentication using Fourier transform infrared spectroscopy with attenuated total reflectance (FTIR-ATR) combined with multivariate data analysis (MVDA). Animal fats from beef, chicken, pork (lard) and goat, along with palm oil, were extracted via Soxhlet apparatus utilizing petroleum ether as solvent. The FTIR-ATR spectra were acquired in the mid-infrared region (4000 – 650 cm^{-1}), encompassing both fingerprint and functional group region. The principal component analysis (PCA) was employed to identify unique spectral patterns and develop classification models for *halal* authentication. The combination of FTIR-ATR and MVDA techniques meanwhile enables the identification of characteristic spectral features and the development of classification models for halal authentication. The PCA result revealed clear clustering of samples based on their origin, with total variance range of 74.75 – 98.79% explained by the first two principal components based on all FTIR spectra of wavenumber 4000 – 650 cm^{-1}, respectively. This FTIR-ATR coupled with MVDA approach offers a rapid, non-destructive and cost-effective method for *halal* authentication. The technique's high sensitivity and specificity make it a promising tool for regulatory bodies and food manufacturers to ensure compliance with *halal* standards.

Key words: Animal oils; FTIR spectroscopy; Multivariate data analysis; Principal component analysis; Halal authentication

INTRODUCTION

Halal is a term coined from Arabic that describes any goods that, in accordance with Islamic law, that Muslims are permitted to consume [1]. Moreover, unless extremely exceptional circumstances apply, the members of Muslim society are not permitted to consume any products containing non-halal ingredients [2]. In the meanwhile, *halal* products—which include foods and pharmaceuticals, are any goods mean, that contain components that are allowed by Islamic law and meet certain requirements : (a) do not include any animal products or parts that are not permissible by Islamic law to be consumed, nor do they contain any animal parts that are not slaughtered in accordance with Islamic law; (b) do not include *najs* (animals such as amphibians, pig and its derivatives, blood and carrions); (c) safe for human consumption, as such., not dangerous, not intoxicating, or not harmful to health when used in accordance with recommended dosage; (d) not prepared, processed or manufactured using equipment contaminated with *najs;* (e) do not contain any human parts or its derivatives that are not permitted by Islamic law; (f) during its preparation, processing, handling, packaging, storage and distribution, the halal pharmaceutical products are physically separated from any other pharmaceutical products that do not meet the requirements stated in items (a), (b), (c), (d) and (e), or any other items that have been decreed as non-halal and *najs* through Islamic law [3].

Aforementioned above, all the *halal* products must be free from the non-halal components which are pig and all its derivatives such as pork, lard and porcine gelatines, carrion, blood (flowing or congealed), animals slaughtered not according to the Islamic law, animals that were killed accidentally or on purpose through means such as strangling or beating, intoxicants including drugs and alcohol [3], carnivorous animals, predator birds and certain land animals [4]. Among all, pig derivatives and alcohols are typically found in halal food products, thus, researchers are continuously do the research works on the halal-related issues including developing instrumental analytical methods for detecting the non-halal components intended for halal authentication [5].

Edible fats and oils are considered as important components of the food products. Besides that, in the recent year, animal fats and vegetable oils are considered as economic sources to be used not only in the food but also in oleochemical and pharmaceutical industries [6]. Nutritionist recommended that people consume vegetable oil as a source of essential fatty acids such as oleic, linoleic and α-linolenic acids and fat-soluble vitamins as such A, D, E and K needed by human metabolism [7]. Noteworthy, the quality of food products containing fats and oils is dependent on their qualities, including the authenticity, purity and some intrinsic quality parameters [8]. However, adulteration of fats and oils has been widespread in the food industry, involving the replacement of higher value products with lower grade, cheaper and more easily available substitutes. Authenticity of fats and oils has been extensively investigated because they can easily be adulterated due to economic purposes [9]. Mixing of animal fats with vegetable sources is a cause of concern to certain groups of consumers due to religious obligations and health complications [10].

Infrared spectroscopy has drawn interest in the analytical community for use in the quantitative measurement of fats and oils. Meanwhile, because infrared is a vibrational type of spectroscopy and offers quick evaluation while being cost-effective, it is a great analytical approach for analyzing food and pharmaceutical products. The most common technique for food analysis is infrared spectroscopy, specifically in the mid-infrared region (4000 - 400 cm^{-1}) and near-infrared region (14000 – 400 cm^{-1}) [11]. The fundamental concept underlying infrared

spectroscopy is that samples interact with electromagnetic radiation in the infrared range, which causes vibrational transitions in the molecules in the sample. The samples can be placed directly on an ATR crystal for measurement, which requires less time for analysis and less solvent application. Another advantage of adopting the attenuated total reflectance (ATR) spectroscopic technique for FTIR is the simplicity of in-sample preparation [12]. This simplification not only reduces the time and effort required for analysis but also minimizes the risk of sample contamination or alteration, thereby enhancing the reliability and reproducibility of spectral data. The use of FTIR spectroscopy in combination with chemometrics for the analysis of non-halal components, including pig derivatives and several non-halal meats such as wild boar, dog, and rat meats, is widely reported due to its functionality. This is because of its advantages, particularly in the fingerprint analytical technique of the FTIR instrument [13]. The use of FTIR spectroscopy in conjunction with chemometrics, principal component analysis (PCA), and cluster analysis, in the identification of and confirmation of lard adulteration of oil, respectively, has been previously described [14].

Noteworthy, the FTIR/MVDA methodology has proven particularly effective in detecting porcine-derivatives and other non-*halal* meats, including wild boar, dog, snake and rat. The widespread adoption of this approach can be attributed to the unique fingerprinting capabilities of FTIR spectroscopy, which allows for the identification of specific molecular structures and functional groups characteristic of these non-halal components. The synergy between FTIR spectroscopy and chemometric methods, such as principal component analysis (PCA) and cluster analysis, has been demonstrated to be particularly powerful in the detection and quantification of lard adulteration in oils [13]. The PCA facilitates the reduction of complex spectral data into manageable principal components, enabling the visualization of patterns and differences among samples. Cluster analysis further enhances this approach by grouping similar spectra, thereby aiding in the identification of adulterated samples. This combination of techniques offers a robust, rapid, and non-destructive method for ensuring food authenticity and compliance with halal standards, addressing a critical need in the food industry and regulatory sectors [14].

EXPERIMENTAL

Materials

The adipose tissues of chicken, pork and beef were obtained from local supermarkets at Pagoh, Muar, Johor, Malaysia (Coordinate: 2°09′N 102°46′E). The analytical solvents used for fat extraction was petroleum ether (boiling range: 60 – 80 °C, R&M Chemicals) and palm oil (). All chemicals used were analytical grade and used without further purification. The lard and goat FTIR spectrum were obtained from International Institute of Halal Research and Training (INHART), International Islamic University of Malaysia (IIUM) through freeze dried method and were used as it is. The freeze-dried lard and goat then, was used for the FTIR measurement directly without any modification.

The Treatment of the Animal Adipose Tissue

All the animal (chicken, pork and beef) adipose tissue were cut into smaller pieces using commercial cutter by 1 cm × 1 cm cube and were put into vacuum drying oven (Memmert, Germany) for drying at 80 °C of temperature, 0.32 bar of pressure for 24 h. The dried animal adipose tissues were collected and stored in commercial freezer (Sharp, Japan).

The Fat Extraction from Animal Adipose Tissue

The fats from the chicken and beef were extracted according to the established methodology with minor modification [15]. In general, 20 g of the dried meats were weighed and grinded as fine powder using commercial blender before was put into cellulose extraction thimble. Then, the top of the thimble was covered by cotton wool as to prevent the sample floating before inserted into the Soxhlet apparatus. The extraction process was done in 6 h using petroleum ether as the solvent. The obtained extracts were mixed with spoonful of $MgSO_4$ as to remove water, filtered through filter paper, which then, later evaporated using a rotary evaporator, as the resultant oil were stored in glass vials.

The FTIR Measurement

The Nicolet iS5 spectrophotometer model (Thermo Scientific, USA) was used in the measurements. An ATR accessory equipped with diamond cell was used. All spectra were recorded within a range of 4000 – 600 cm^{-1} with 4 cm^{-1} resolution and 32 scans. Three replicate spectra were obtained from three independent experiments and the average spectrum was taken for further investigation. All measurements were performed in a dry atmosphere at room temperature (25 ± 0.5 °C). A single beam spectrum was obtained for all samples. These spectrums were subtracted against a background air spectrum and the results were presented in transmittance units. All sample spectra were read in triplicate and averaged using the OMNIC operating software from Thermo Nicolet.

Data Pre-Processing

The spectra were converted into comma-separated values (CVS) and imported to the dataset table in XLSTAT 2024 software [16]. Firstly, the FTIR wavenumber were separated into 4000 – 3501 cm^{-1}, 3500 – 3001 cm^{-1}, 3000 – 2501 cm^{-1}, 2500 – 2001 cm^{-1}, 2000 – 1501 cm^{-1}, 1500 – 1001 cm^{-1} and 1000 – 650 cm^{-1}. Then, DA was carried out on all FTIR wavenumber of 4000 – 650 cm^{-1}, respectively. Subsequently, the Kaiser-Meyer-Olkin (KMO) test verified dataset adequacy before carrying out second DA with the combined wavenumbers [17]. The most significant wavenumbers were selected from DA and proceeded with principal component analysis (PCA) to find the apportionment of wavenumber on the animal's fatty acid.

The Kaiser-Meyer-Olkin Test

The dataset was analysed for dataset adequacy by the KMO test. An adequate dataset determines the ability to generated model to extract latent variables from the dataset. In this study, the KMO test was employed at significant level (α) of 0.01. The calculated KMO was ranked as KMO < 0.5 = inadequate, 0.5 < KMO < 0.7 = mediocre, 0.7 < KMO < 0.8 = good, 0.8 < KMO < 0.9 = very good and KMO > 0.9 = excellent to indicate the dataset adequacy [18].

The Dataset Transformation

To ensure that the dataset followed a normal distribution before the PCA, the dataset normality was tested using Shapiro-Wilk test at α = 0.01. The dataset was transformed using standard deviation (n-1) methods [19].

The Analysis using Principal Component Analysis (PCA)

The whole FTIR spectra was extracted its transmittance value to obtain dataset for PCA. The FTIR spectra at the combination wavenumber of 1500 – 1000 cm^{-1} and 1000 – 650 cm^{-1} at the fingerprint's region were chosen to build the PCA model because it can be used for clear difference for Halal authentication purpose. Analysis of PCA was performed using XLSTAT software [16], and the data were scaled using Pareto scaling technique prior to PCA analysis to maximize the variation. After Pareto scaling, the variables used for PCA model were more normally distributed shown by its Gaussian curve. The number of principal components (PCs) was optimized to obtain optimum differentiation among samples. The differentiation result of samples was observed using PCA score plot. Moreover, PCA model was evaluated using its R^2 and Q^2 value to justify the good of fitness and predictivity of the PCA model, respectively.

RESULTS AND DISCUSSION

The FTIR-ATR Spectra Analysis

The extracted oils from dried beef and chicken meats have a similar physical appearance which is yellow whereas the palm oil is in colours. On top of that, all the fatty acids demonstrated similar FTIR spectrum and is it obviously difficult to distinguished among them as depicted in **Figure 1** as overlay and in **Figure 2** as stacked manners, respectively. Furthermore, all the oil samples in animals and palm oil represents the triacylglycerols, triglycerides and fatty acids as the main compositions of fats in oils reported beforehand [20]. All the spectra show the typical characteristic of absorption bands of animals oils. The resulting FTIR vibrations from all oil samples are mainly from those compounds. The stretching vibration of -CH, CH_2 and CH_3 from aromatic and alkene could be observed at a peak of 3000 cm^{-1} whereas the stretching vibration of –CH, CH_2 and CH_3 from aliphatic alkane was found at peaks of ~2900 – 2800 cm^{-1}. It is observed that all the oils samples regardless animal/plant origin has a sharp and intense peak at the carbonyl (C=O) region of ~1700 cm^{-1}. Next, the absorption band at ~1400 cm^{-1} was correlated to the stretching vibration of C=C. On the other hand, absorption bands at 1100 – 1000 cm^{-1} arise from the vibration of C–O stretching. In addition, vibrations at 1200 – 700 cm^{-1} were associated with bending vibrations of –CH, CH_2 and CH_3 fatty acid aliphatic backbone [21].

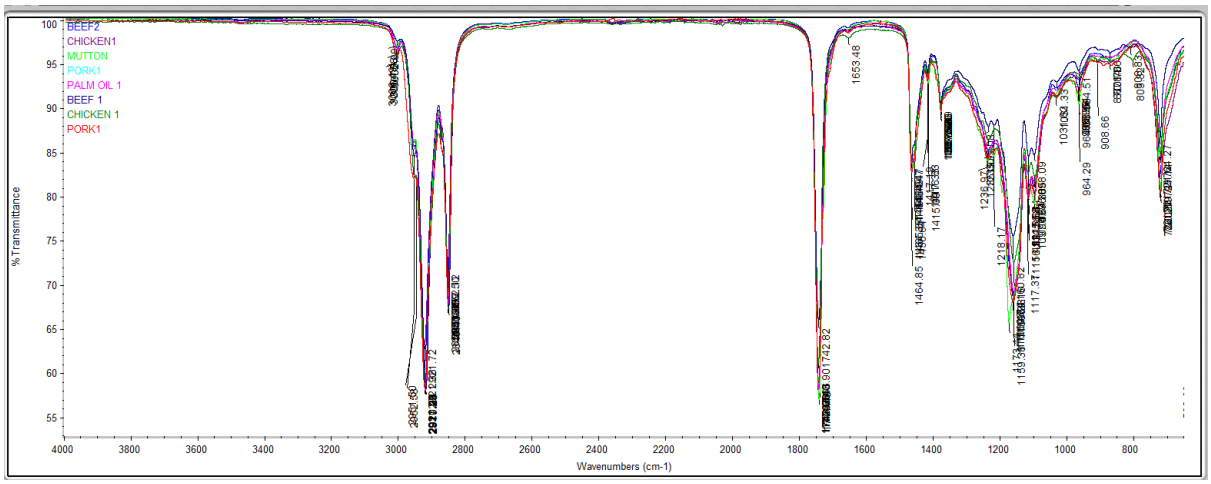

Figure 1. The full overlay of FTIR spectra animals' oil (beef, chicken, mutton, pork) and palm oil of the wavenumber 4000 – 600 cm^{-1}

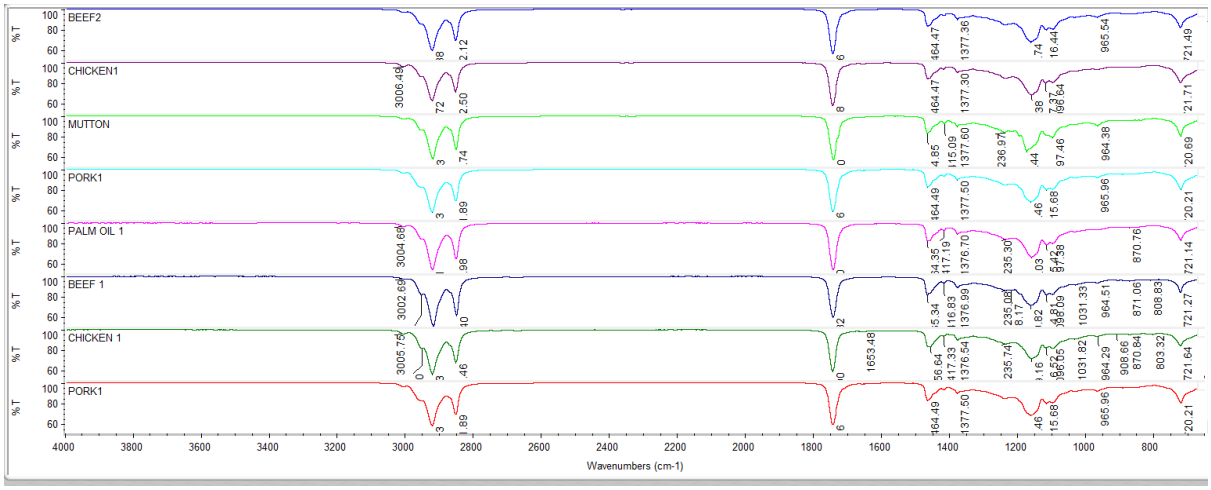

Figure 2. The stacked of FTIR spectra animals' oil (beef, chicken, mutton, pork) and palm oil of the wavenumber 4000 – 600 cm^{-1} noticing that there are undistinguishable spectrum peaks among all the oil samples

The Validation and Verification of the Data Model

To achieve the relevant findings, pre-requisite MVDA must be carried out, beginning with choosing the appropriate dataset for the study using the KMO test [20]. For the 728 datasets, the KMO test produced a KMO score in the range from 0.641 – 0.888 for all FTIR wavenumber ranging from 4000 – 650 cm^{-1} as depicted in **Table 1**. A lack of the KMO test may result in reporting inaccurate findings and interpretations due to small data set. Based on the general report, the KMO value of 0.8 – 0.9 was deemed good [22].

Table 1. The KMO test produced a KMO score of 728 datasets

The Kaiser-Mayer Measure of Sampling Adequacy
KMO (for the 1000 – 650 cm^{-1} region) : 0.757
KMO (for the 1500 – 1001 cm^{-1} region) : 0.641
KMO (for the 2000 – 1501 cm^{-1} region) : 0.791
KMO (for the 2500 – 2001 cm^{-1} region) : 0.861
KMO (for the 3000 – 2501 cm^{-1} region) : 0.838
KMO (for the 3500 – 3001 cm^{-1} region) : 0.847
KMO (for the 4000 – 3501 cm^{-1} region) : 0.888

However, there is a lack in the studies that have mentioned any dataset transformation. Hence, this study recommended that all the variables be transformed by using the standard deviation (n-1) method. The dataset transformation simultaneously corrects the linearity issues as well. Hence, the linearity test is on a case-by-case basis. The last step before the MVDA is performing the assumption testing, which involves normalization. The normalization of the dataset was conducted by performing the Shapiro-Wilk test at $\alpha = 0.01$, which allows only a 1% chance of false positive at this study was designed for authentication analysis. Thus, it should be very effective on reducing errors.

The Principal Component Analysis (PCA)

The principal component analysis (PCA) was used as an unsupervised method to classify all the oils sample based on the correlation between the variable. Before the analysis, all the outliers were removed from the dataset. The KMO verified the sampling adequacy as a statistic, indicating the proportion of variance underlying factors might cause in the variable. In the authentication application, KMO values (close to 1) indicate that factor analysis may be helpful for the data. Otherwise, with a value less than 0.5, the result of the factor analysis may not be beneficial [23]. At the same time, Bartlett's sphericity was used to test the hypothesis that the correlation matrix is an identity matrix to determine whether the variables are unrelated, and therefore, are unsuitable for structure detection. Smaller than 0.05 significant level values indicate the usefulness of the factor analysis in the dataset.

Meanwhile, this paper also provides a series of PCA plots for all oils extracted from animal including the palm oil which each focusing on a different region of the FTIR spectrum. Moreover, PCA is a powerful statistical technique used to reduce the dimensionality of complex datasets while retaining most of the variation. In this case, it is applied to FTIR spectral data to identify patterns and differences in the chemical composition of animal-derived oils. The FTIR spectroscopy is a widely used analytical method that provides information about the molecular structure and functional groups present in a sample. However, different regions of the FTIR spectrum correspond to different types of molecular vibrations and, consequently, different chemical functionalities. By applying PCA to specific regions of the FTIR spectrum and focusing more on particularly chemical features and better understand the similarities and differences among all the oil samples.

The percentage values in parentheses represent the total variance explained by the principal components shown in each plot. Noteworthy, the scree plot is also generated in **Figure 3** to explain the percentage of variance associated with each principal component (PC) obtained by showing a graph between eigenvalues and the PC numbers. Moreover, in PCA variance values are remarkably high, ranging from 74.75% to 98.79%, indicating that the PCA has successfully captured most of the data's variability in each spectral region using just two or three principal components. To each PCA plot, each point represents an individual oil sample. Points that are close together have similar spectral features in that specific region, indicating similar chemical composition. Points that are far apart have different spectral features, suggesting differences in chemical composition [24].

The high variance explained in each region suggests that there are indeed significant differences among the oil samples [25]. For example, in the 3501– 4000 cm^{-1} region, a staggering 98.79% of the variance is explained, indicating substantial differences in the presence and nature of O–H and N–H bonds. This could reflect differences in the fatty acid composition such as the presence of hydroxy fatty acids or the presence of amino acids/peptides in the oil samples. Similarly, the high variance explained in the 1501 – 2000 cm^{-1} region (88.045%) suggests significant differences in unsaturated fatty acids (C=C bonds) and oxidation products (C=O bonds). This could indicate variations in the degree of unsaturation and oxidative stability among the oils. The region with the lowest explained variance is 1001 – 1500 cm^{-1} (74.75%), which still represents a substantial portion of the total variance.

This region's complexity, reflecting various functional groups, might contribute to its lower explained variance. The PCA analysis of FTIR data provides a rich, multifaceted view of the chemical differences among the animal-derived oils. By examining different spectral regions,

we are able to infer differences in fatty acid composition, degree of unsaturation, oxidation state, and the presence of minor components like amino acids. This information is valuable for understanding the nutritional, functional, and stability properties of these oils, which can guide their use in food, cosmetic, or industrial applications. Further research could involve identifying the specific animals or diets that lead to these compositional differences [26].

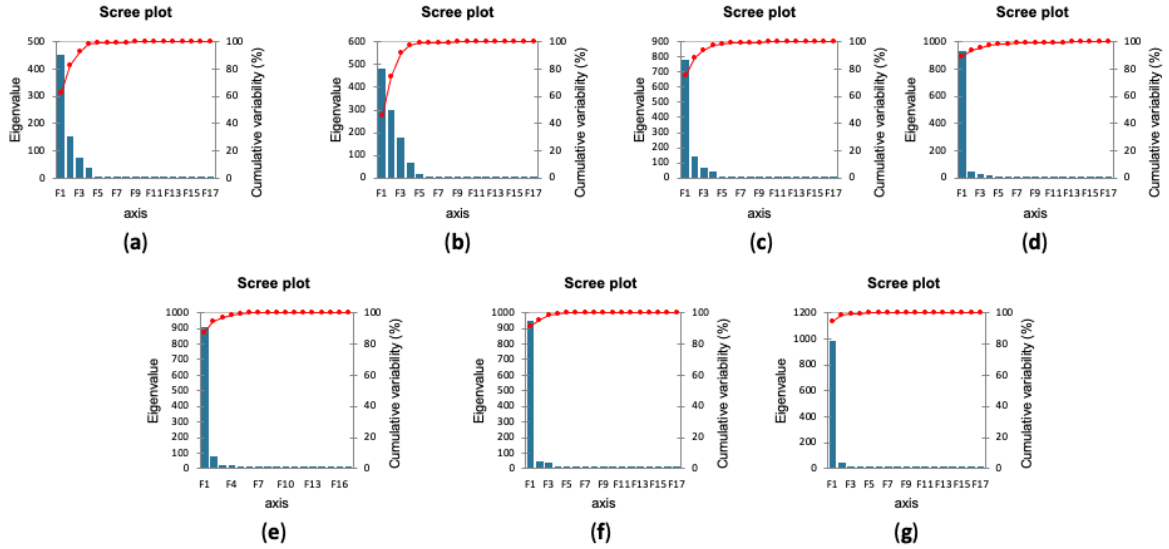

Figure 3. The scree plot after 728 dataset transformation of the beef, chicken, pork, mutton and palm oils FTIR spectra based on wavenumber of (a) 1000 – 650 cm^{-1}; (b) 1500 – 1001 cm^{-1}; (c) 2000 – 1501 cm^{-1}; (d) 2500 – 2001 cm^{-1}; (e) 3000 – 2501 cm^{-1}; (f) 3500 – 3001 cm^{-1} and (g) 4000 – 3501 cm^{-1}

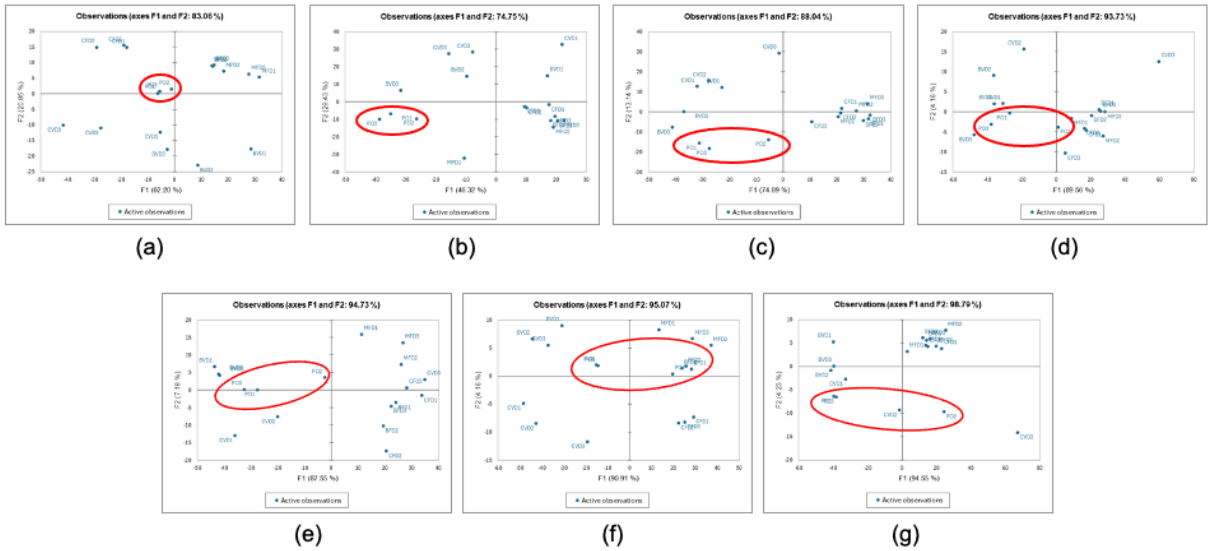

Figure 4. The principal component analysis (PCA) after 728 dataset transformation of the beef, chicken, pork, mutton and palm oils with the observation value ranging between 74.75 – 98.79% of FTIR wavenumber (a) 1000 – 650 cm^{-1}; (b) 1500 – 1001 cm^{-1}; (c) 2000 – 1501 cm^{-1}; (d) 2500 – 2001 cm^{-1}; (e) 3000 – 2501 cm^{-1}; (f) 3500 – 3001 cm^{-1} and (g) 4000 – 3501 cm^{-1}

The Exploitation of the PCA for Effective Halal Authentication of Oils

Based on the analytical approach of the FTIR with the multivariate data analysis of PCA is particularly relevant in the context of *halal* authentication, a critical issue in the global food industry, especially in regions with significant Muslim populations. In this context, all the *halal* products must meet strict requirements, including the type of animal for instance pork, the method of slaughter, and the absence of any *haram* (forbidden) substances. Furthermore, authentication of *halal* status is not just a religious concern but also a matter of consumer trust, food safety, and ethical trade practices [27]. Next, the PCA analysis of FTIR spectrum data provides a powerful tool for *halal* authentication of animal-derived oils. The FTIR spectroscopy offers a "molecular fingerprint" of a sample, reflecting its chemical composition. By applying PCA toward the FTIR data, we can identify patterns and differences that might not be apparent from raw spectra alone. This is particularly useful in *halal* authentication, where the goal is to distinguish between permitted and forbidden animal products, or to detect any adulterants. The study shows PCA plots for seven different FTIR regions, each capturing a substantial portion of the data's variance (74.75 – 98.79%). This high explained variance suggests that there are indeed significant chemical differences among the oil samples.

There are factors that corresponding of the spectroscopic spectrum with the multivariate data analysis within this research scope. Firstly, at the FTIR fingerprint's region of 1000 – 650 cm^{-1} (83.06% variance explained) is particularly valuable for animal species identification. Each species has a unique molecular signature in this region. For halal authentication, this could help distinguish between oils from *halal* animals (beef, chicken and goat) and *haram* animals such as pig. The high variance explained suggests substantial differences, which is promising for accurate species identification. Next, due to fat composition of all the extracted oils, FTIR regions of 2000 – 1501 cm^{-1} (84.04% variance) and 3000 – 2501 cm^{-1} (94.73% variance) reflect differences in fatty acid composition. The former shows variations in unsaturated fats (C=C bonds), while the latter indicates differences in saturated fats (C-H bonds). Different animal species have distinct fat profiles which is lard tends to be more unsaturated than beef fat. These spectral differences could help identify the animal source, supporting halal authentication. Also, the presence of adulterants of high variance in regions like 3001 - 3500 cm^{-1} (95.07%) and 3501-4000 cm^{-1} (98.79%), which show O–H and N–H bonds, could indicate the presence of adulterants. For example, some unethical producers might add cheaper, non-*halal* oils likely lard to *halal* oils. These adulterants could introduce different types of fatty acids for instance, hydroxy fatty acids or minor components of different peptides, detectable in these spectral regions [28].

The power of this PCA-FTIR approach lies in its ability to provide a holistic view of the oil's chemical composition. Unlike targeted methods that look for specific compounds, this technique captures the overall molecular profile. This is crucial in *halal* authentication, where differences can be subtle, and adulterants might be chemically similar to genuine products. Moreover, the high variance explained in each region suggests that this method is sensitive enough to detect these subtle differences. For instance, the staggering 98.79% variance in the 3501 – 4000 cm^{-1} region indicates that even minor components, which might be key to distinguishing *halal* from *haram*, are captured [29,30]. However, it's important to note that while PCA-FTIR can flag differences, it doesn't automatically identify the cause. A sample that stands out in the PCA plot isn't necessarily *haram*; it's just chemically different. Further analysis, like mass spectrometry or DNA testing, would be needed to confirm the exact compounds and their sources. In conclusion, the PCA analysis of FTIR data offers a promising tool for *halal* authentication of animal-derived oils. Its ability to capture a wide range of

chemical features, coupled with its sensitivity to subtle differences, makes it well-suited to this complex task. By providing a comprehensive molecular fingerprint, this technique can help verify animal species, detect adulterants, and even offer insights into production practices. As the global halal market continues to grow, such advanced analytical methods will be crucial in ensuring the integrity of halal products, maintaining consumer trust, and facilitating fair, ethical trade.

CONCLUSION

This study demonstrates the powerful synergy of FTIR-ATR and multivariate data analysis for rapid, non-destructive *halal* authentication of animal-derived oils. The PCA of FTIR spectral data revealed distinct clustering patterns among beef, chicken, pork, mutton, and palm oil samples, with remarkably high total variance explained (74.75 – 98.79%) across different spectral regions. The fingerprint region (1000 – 650 cm^{-1}) proved particularly decisive for species identification, while regions associated with fatty acid composition (2000 – 1501 cm^{-1} and 3000 – 2501 cm^{-1}) showed promising in distinguishing *halal* from non-halal sources. Notably, the high variance in regions reflecting O–H and N–H bonds (3001 – 4000 cm^{-1}) suggests potential for detecting adulterants or minor components critical to *halal* status. This FTIR-ATR/MVDA approach offers a holistic view of oil composition, capturing subtle differences that might elude targeted methods, while providing the speed and cost-effectiveness necessary for industrial and regulatory applications. While additional confirmatory tests may be needed for definitive identification of non-*halal* components, this method represents a significant advancement in *halal* authentication technology. Its high sensitivity and specificity make it a promising tool for ensuring product integrity, maintaining consumer trust, and facilitating ethical trade practices in the rapidly growing global *halal* market. Future research should focus on expanding the sample set and integrating this approach with other analytical techniques for comprehensive *halal* authentication, potentially revolutionizing quality control in the halal food industry.

CONFLICT OF INTEREST

All the author(s) declare that they have no competing interests that could have appeared to influence the work reported in this research paper.

AUTHOR'S CONTRIBUTION

M. Z. Nazri: Conceptualization (lead); data curation; formal analysis; investigation; methodology; writing – original draft preparation. **N. A. Latiff**: Conceptualization (equal); data curation; formal analysis; investigation; methodology; writing – review & editing. **S. N. A. A. Rashid**: Conceptualization (equal); data curation; formal analysis; investigation; methodology; writing – review & editing. **S. A. Malik**: Conceptualization (equal); data curation; formal analysis; investigation; methodology; writing – review & editing. **H. A. A. Karim**: Conceptualization (supporting); validation (equal); writing – review & editing (supporting). **M. S. A. Sani**: Conceptualization (lead); validation; software; writing – review & editing (supporting). **N. Basar** & **D. N. A. Zaidel**: Validation (supporting); funding acquisition; supervision; writing – review & editing (supporting).

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