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MINI REVIEW

The metabolomics approach used for halal authentication analysis of food and pharmaceutical products: a review

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Abstract

Motivated by economical profits, unethical producers may add or substitute halal components with non-halal ones, therefore some analytical techniques capable of detecting non-halal components is very urgent to be developed. Halal authentication analysis in the food and pharmaceutical sectors is intended to confirm that the products are free from non-halal components, especially pig derivatives (any substances derived from pig). Analysis of non-halal components in food and pharmaceutical products can be undertaken using three approaches namely specific component analysis by identifying specific marker, fingerprinting profile and metabolomics approach. The two later approaches typically need the use of some chemometrics techniques including pattern recognition and multivariate calibrations. Metabolomics is related to the science of investigating all metabolites with small molecules (< 1500 kDa) in biological systems. Metabolomic studies either target or untarget the application of chemometric methods to extract valued information from metabolites. This review highlighted some analytical techniques, mainly spectroscopic and chromatographic methods to generate the fingerprinting and metabolomics profiles of non-halal components to be used as reliable halal authentication. The metabolomics approach in combination with chemometrics offered accurate and reliable methods for the authentication of halal products.

1. Introduction

The growth of the halal products industry is estimated as the fastest-growing consumer segment along with the increased awareness among the Muslim community in the world. It is estimated to be worth over one trillion dollars. The market of halal products has become a lucrative market either in Muslim or non-Muslim societies because halal products are believed to be the best quality in terms of safety and health (Lubis *et al*., 2016). With the development of science and technology in the food and pharmaceutical industries, some producers may add non-halal components to their products to reduce production costs and to give special functions. Indonesia implemented Indonesian Act No.33 in the year 2014 on halal Product Assurance in which all products distributed in Indonesian territory must be halal through a certification procedure by an authority body (Adiarni and Fortunella, 2018). To verify the presence of non-halal components, reliable, accurate, sensitive, simple and easy-to-use analytical methods is required for successful halal certification (Rohman, Windarsih and Mustafa, 2020).

Halal is an Arabic term meaning ‘permissible’ or ‘lawful’, and traditionally Halal signifies ‘pure food’ regarding meat (pork) and alcohols in particular. In the

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modern and globalized industry, halal is not only related to food but also pharmaceuticals and cosmetics, finance, consumer goods and tourism (Fischer, 2016). In relation to food and pharmaceuticals, halal food and halal pharmaceuticals are food or pharmaceuticals which are allowed to be consumed according to sharia (Islamic law). Food and pharmaceutical products usually contain some additives to give special functions such as emulsifiers and stabilizing agents. In order to reduce the production cost, some industries may add non-halal components derived from non-halal meats such as pigs such as emulsifiers extracted from lard (pork fat). Among non-halal components, pig derivatives (any substances derived from pig) are the most used components in food and pharmaceutical products (Rohman and Che Man, 2012; Zabidi *et al*., 2020). Therefore, this review focused on the application of analytical methods for detection of pig derivatives.

Numerous instrumental techniques have been applied for the analysis of pig derivatives especially pork including polymerase chain reaction as reviewed by Salihah *et al*. (2016) and Erwanto *et al*. (2018), Fourier transform infrared spectroscopy and chromatographic-based techniques (liquid chromatography and gas chromatography especially hyphenated with mass spectrometer as detector) in combination with chemometrics for analysis of lard and porcine gelatins in food and pharmaceutical products as reviewed by (Rohman and Putri, 2019; Rohman *et al*., 2020), electronic noses and differential scanning calorimetry for analysis of lard and pork (Nurjuliana *et al*., 2011; Nurrulhidayah *et al*., 2015). These techniques used for halal authentication analysis can be classified into three approaches namely specific component analysis, fingerprinting profile and metabolomics approaches. A specific analytical method such as gas chromatography could be applied for halal authentication analysis using these three approaches by identifying specific markers of fatty acids (Indrasti *et al*., 2010), determining the fingerprint profiles of fatty acids (fingerprinting approach) or by analysing all metabolites including fatty acids, triacylglycerol composition, sterols, and others (metabolomics study). This review highlighted the fingerprinting and metabolomics approach for the analysis of pig derivatives in food and pharmaceutical products.

2. Methods

During performing this review, some databases including Scopus, Web of Sciences and PubMed are explored to get relevant literature using keywords of "metabolomics or fingerprinting AND pig derivatives" or "halal authentication analysis AND spectroscopy AND chromatography AND Chemometrics" or "pig derivatives AND Pork AND lard AND porcine gelatins". Abstracts or full articles from original articles or review articles are critically assessed before being included as references in this present review.

3. Chemometrics

The application of chemometrics to treat data obtained during metabolomics study which involves big data analysis is a must. Chemometrics is defined by the International Chemometrics Society as the science of relating chemical measurements made on a chemical system to the property of interest through the application of mathematical or statistical methods. The successful application of instrumental analysis intended for the metabolomics study was due to the development of chemometric software. Some software is available in the market including Minitab®, SIMCA®, Unscrambler®, MATLAB®PLS_Toolbox, R factoextra and FactoMineR (Gemperline, 2006).

Numerous chemometric techniques are commonly used in metabolomics studies intended for halal authentication analysis, including (1) pre-processing spectra, (2) chemometric classification analysis and (3) chemometrics for quantitative analysis facilitated with multivariate calibration (Worley and Powers, 2016). Some data pre-processing, such as mean centring, Savitzky–Golay-based derivatization, standard normal variate, baseline corrections, signal correction and compression, spectra normalizations, and multiplicative correction are used to obtain the optimum results. Chemometrics of classification consist of principal component analysis (PCA), cluster analysis (CA), discriminant analysis (DA), partial least square-discriminant analysis (PLS-DA), and orthogonal projection to latent structures-discriminant analysis (OPLS-DA) and it is aimed for sample classification and sample differentiation. PCA and CA are categorized as unsupervised pattern recognition. In PCA, the original variables used for creating models are reduced to just several variables called PC (principal components) having large variations representing the original variables. The PCs are responsible for classification by searching the differences between variables. For cluster analysis, the sample classification is performed based on the similarities of variables. Meanwhile, DA, PLS-DA, and OPLS-DA are categorized as supervised pattern recognition. DA classify samples by minimizing the class ratio between members and maximizing the class ratio within the members. PLS-DA works by finding the variables both in the X and Y matrix responsible for the classification of established classes, while OPLS-DA searches for orthogonal variables capable of class

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differentiation (Rohman *et al*., 2021).

The chemometrics of multivariate calibration is used for quantitative analysis such as predicting the concentration of oil adulterants. Partial least square (PLS) and principal component regression (PCR) are widely used for preparing the correlation between actual values of fats and oils with the predicted values using certain variables. PLS search latent variables either in the actual matrix or in the predicted matrix to create multivariate regression, whereas PCR regression uses principal components to create a regression model. The regression curve is evaluated using some statistical parameters namely R^2 (coefficient of determination) for accuracy evaluation as well as RMSEC (root mean square error of calibration) and RMSEP (root mean square error of prediction) for evaluating the precision of analytical methods used during authentication analysis.

4. Halal authentication analysis using metabolomics approaches

Halal authentication analysis is intended to confirm that the food and pharmaceutical products are free from non-halal components, especially pig derivatives (any substances derived from pig) using certain analytical tools. Analysis of non-halal component is very urgent to support the halal certification process in line with the policy of some countries like Indonesia which obligate the products declared as halal must be certified as "halal" by an authority body, therefore the development and standardization of analytical methods based on physico-chemical properties and molecular biology is a must (Nakyinsige *et al*., 2012; Mursyidi, 2013).

To perform halal authentication, there are some strategies. The first is by determining the ratios between some chemical constituents such as fatty acids in halal components and non-halal components and assuming that ratio values are constant, especially in food products. Secondly, the analyst may search for some chemical or biological markers which are specific to pig derivatives. The polymerase chain reaction is the best example of this strategy due to its capability to find specific DNA in pork as a biological marker. Third, the analysts may use some analytical methods derived from the measurements of the physical or chemical characteristics of pig derivatives present in food and pharmaceutical products (Cordella *et al*., 2002; Figueiredo *et al*., 2019).

Some analytical methods are developed, validated and routinely used for the analysis of pig derivatives in food and pharmaceutical products, mostly by determining specific components present in pig derivatives. Indrasti *et al*. (2010) have employed two-dimensional gas chromatography hyphenated with a mass spectrometer (GC x GC TOF-MS) for identifying lard and found that three fatty acids namely methyl-trans -9,12,15-octadecatrienoate (C18:3 n3t), methyl-11,14,17-eicosatrienoate (C20:3 n3t), and methyl-11,14-eicosadienoate (C20:2 n6) are specific to lard. The authors suggested that these fatty acids are used as chemical markers during the detection of lard in food and pharmaceutical products. In line with the development of statistical software (chemometrics), halal authentication analysis is recently undertaken using fingerprinting profiles and metabolomics studies.

In recent years, metabolomics has evolved as an emerging tool in many disciplines of science, to mention a few, including food and agriculture, medicine, drug discovery and pharmacy, life sciences, environmental science, etc (Rocchetti and O'Callaghan, 2021). Metabolomics can be defined as the collection of all small molecule metabolites or chemicals including fatty acids, nucleic acids, organic acids, carbohydrates, vitamins, sterols etc. which can be found in a cell, organ or organism. Metabolomics is concerned with the comprehensive, non-selective and high-throughput identification and quantification of all metabolites (<1500 Da). In the infield of food and pharmaceutical sciences, metabolomics has been applied for quality control and safety evaluation of raw materials and final products (Cevallos-Cevallos *et al*., 2009), therefore, metabolomics in combination with multivariate data analysis and processing (chemometrics) is a potential tool to become reliable approach for halal authentication analysis.

The analytical procedures usually employed within metabolomics studies can be classified into three different categories, namely (1) fingerprinting approaches, (2) targeted metabolomics analysis and (3) untargeted metabolomics analysis. Fingerprinting profiling can be referred to as the analysis of as many compounds as possible within a system, including their detection and the subsequent data treatment of the obtained results using some chemometrics techniques for differentiation or classification of the evaluated samples. In fingerprinting approach, the identification and quantification of the detected metabolites may not be a necessity (Castro-Puyana *et al*., 2017). In targeted analysis, the specific group of intended metabolites are identified and quantified. This technique is very important for assessing the behaviour of a specific group of compounds in the evaluated samples under the determined conditions. A higher level of metabolites obtained from purification and selective extraction of metabolites class is required in targeted analysis than in untargeted analysis. Untargeted metabolomics analysis, in contrast, tries to detect as many as possible of

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metabolites class to obtain the patterns without any necessitate for identifying or quantifying a specific metabolite (Wishart, 2008).

The untargeted analysis allows the generating of a large number of information from the evaluated samples which can be further to multivariate data analysis or chemometrics to find differences among the samples leading to the classification and discrimination of two groups of samples. Applying both targeted and untargeted analyses combined with chemometrics, halal authentication analysis can be directed: (1) to discriminate between halal and non-halal food and pharmaceutical products and (2) to predict the levels of non-halal components.

In metabolomics analyses, the analytical methods used are the concern. Figure 1 reveals the analytical steps for the metabolomics study intended for halal authentication analysis. Food and pharmaceutical products may be extracted using the appropriate extraction techniques before being subjected to instrumental measurements. The data obtained are very large therefore must be treated with some preprocessing and multivariate data analysis or chemometrics to obtain analytical purposes such as differentiation between halal and non-halal foods (Rocchetti and O'Callaghan, 2021). Proper separation before detection can increase the quality of the obtained results. For this reason, chromatographic-based methods including gas chromatography (GC) and liquid chromatography (LC) equipped with an accurate detecting system using mass spectrometric (MS) to obtain GC-MS and LC-MS are widely used. For GC-MS, metabolites are derivatized in order to increase the coverage of metabolites/compounds analyzed. LC-MS is used as a versatile technique capable of separating various metabolites. Particularly, in the last decades, the development of LC into ultra-high performance liquid chromatography (UHPLC) has gained considerable popularity with the main advantages of providing high efficiency, good resolution, relatively short analysis times and compatibility with mass spectrometry (MS) detector (Castro-Puyana *et al*., 2017). In addition, in recent years, nuclear magnetic resonance (NMR) was the most popular technique used for metabolomics analyses due to its capability to identify a variety of primary and secondary metabolites. Besides, NMR spectroscopy is a non-destructive technique that can be automated. The main disadvantage of NMR spectroscopy is the lower dynamic range and sensitivity than GC-MS or LC-MS. Therefore, NMR spectroscopy is typically used for metabolomics fingerprinting (Mielko *et al*., 2021). The advantages and disadvantages of GC-MS, LC-MS and NMR spectroscopy in metabolomics study were compiled in Table 1.

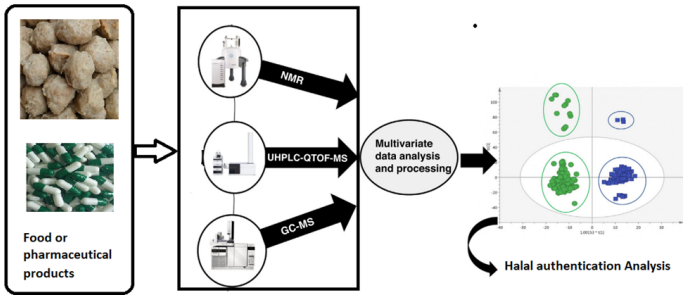

Figure 1. The schematic overview of instrumental platforms used for metabolomics studies intended for halal authentication studies. Adapted from (Rocchetti and O'Callaghan, 2021).

Metabolomic analyses using these three instruments (GC-MS, LC-MS and NMR spectroscopy) generate a complex and huge number of datasets coming from analytical responses which makes their processing and data treatment not straightforward, therefore, powerful chemometric tools are required. Chemometric techniques can be used for different purposes namely preprocessing, classification and prediction as compiled in Table 2. In preprocessing, the raw data are processed to solve artefacts such as interfering baseline, low signal-to-noise ratio, retention time shifts, and peak detection (Feizi *et al*., 2021; Candoğan *et al*., 2020). The chemometrics of pattern recognition either supervised like discriminant analysis or unsupervised such as principal component analysis and cluster analysis can assist such classification or discrimination. While, multivariate calibrations including principal component regression (PCR) and partial least square regression (PLSR) can be used for the prediction of non-halal components (Feizi *et al*., 2021).

4.1 Halal authentication analysis using a fingerprinting profile

Fingerprint profiling can be performed by Fourier transform infrared spectroscopy in combination with chemometrics because FTIR spectra are considered fingerprinting analytical techniques (Rohman, 2017). FTIR spectra in combination with chemometrics of principal component analysis (PCA) and cluster analysis (CA) have been successfully applied for fingerprinting profiling of lard and other animal fats at the mid-infrared region (4000-650 cm^{-1}). PCA and CA employed the absorbance values at 16 wavenumbers as variables. at Using PCA, lard and others could be discriminated based on PC1 or the first principal component and PC2 second principal component (PC2), in which PC1 and PC2 contributed to the largest variations of 44.1% and 30.2%, respectively. The absorbance values at wavenumbers of 2853, 2922, and 1465 cm^{-1} revealed the most contributing variable during the separation and differentiation of lard and others. CA could make clustering of lard and other fats and oils as observed in

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Table 1. The advantages and disadvantages of GC-MS, LC-MS and NMR spectroscopy in metabolomics study (Wishart, 2008).

Analytical Instruments	Advantages	Disadvantages
Gas Chromatography-Mass Spectrometry (GC-MS)	• Robust and rugged, established technology • Relatively inexpensive compared to LC-MS/MS • Can be used for qualitative and Quantitative analyses • A modest sample size needed • Good sensitivity • Large body of software and database for metabolite ID • Detects most organic and some inorganic molecules • Excellent separation reproducibility	• Sample not recoverable • Requires sample derivatization • Requires separation • Slow (20-30 min/sample) • Cannot be used in imaging • Novel compound ID is difficult
Liquid Chromatography-Mass Spectrometry (LC-MS)	• Super sensitivity • Very flexible technology • Detects most organic and some inorganic molecules • Minimal sample size requirement • Can be used in metabolite imaging (MALDI) • Can be done without separation (direct injection) • Has the potential for detecting the largest portion of the metabolome	• Sample not recoverable • Not very quantitative • Expensive instrumentation • Slow (20-30 min/sample) • Poor separation resolution and reproducibility (vs. GC) • Less robust instrumentation than NMR or GC-MS • Limited body of software and databases for metabolite ID • Novel compound ID is difficult
Nuclear Magnetic resonance (NMR) Spectroscopy	• Quantitative • Non-destructive • Fast (2-3 min/sample) • Requires no derivatization • Requires no separation • Detects all organic classes • Allows ID of novel chemicals • Robust, mature technology • Can be used for metabolite imaging (fMRI) • Large body of software and database for metabolite ID • Compatible with liquids and solids	• Not very sensitive • Expensive instrumentation • Large instrument footprint • Cannot detect or ID salts inorganic ions • Cannot detect non-protonated compounds • Required larger (0.5 mL) samples

the dendrogram obtained (Che Man *et al*., 2011).

Similarly, the application of FTIR spectra combined with chemometrics of PCA was also successful for differentiation of frog fat, extracted from non-halal meat, with other vegetable and marine oils including corn oil, canola oil, cod liver oil, etc. The comparison of FTIR spectral absorbance of studied oils demonstrated the linkage of frog fats to other edible fats and oils. Three commercially available marine oils and three vegetable oils were studied with frog fats and a clear pattern of clusters with distinctive identifiable features were obtained through PCA modelling. Based on loading plot analysis, the wavenumbers region of 2922 cm^{-1} (due to asymmetric stretching vibration of methylene), 2853 cm-1 (due to symmetric stretching vibration of methylene), 1745 cm^{-1} (due to stretching vibration of carbonyl), and 1158 cm^{-1} (due to asymmetric vibration of C-O) revealed the most discriminating variables during discrimination using PCA (Ali *et al*., 2015).

4.2 Halal authentication analysis based on targeted and untargeted metabolomics studies

Liquid chromatography-electrospray ionization-tandem mass spectrometry (LC-ESI-MS/MS) in combination with chemometrics of orthogonal partial least square-discriminant analysis (OPLS-DA) has been used for untargeted metabolomics analysis of forty chicken meat samples. The meats were differentiated as Zabiha (cutting neck without detaching spinal cord) and Non-Zabiha (completely detaching neck). During this study, five metabolites were identified and twenty-five metabolites were not identified. The identified compounds come from peptide and fatty acids namely linolenic acid, 13-Keto-9Z,11E-octadecadienoic acid, 1-(9Z-Octadecenoyl)-sn-glycero-3-phosphocholine, Lysophosphatidylcholine 16:0, and D-erythrosphinganine. OPLS-DA using the variable of identified and unidentified metabolites have successfully discriminated between Zabiha and Non-Zabiha with an accuracy (correct classification) level of 100% (Abbas *et al*., 2020). LC quadrupole time-of-flight mass

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Table 2. The chemometric techniques typically applied for metabolomics analyses.

Approaches	Method	Category
Preprocessing	Asymmetric least squares	Baseline correction
	iBRANN	Baseline correction
	Savitzky-Golay	Noise reduction
	Correlation optimized warping	Retention time alignment
	Piecewise alignment	Retention time alignment
	Dynamic time warping	Retention time alignment
Multivariate resolution	MCR-ALS	-
	PARAFAC	-
	PARAFAC2	-
Multivariate classification	PCA	Unsupervised
	HCA	Unsupervised
	SOM	Unsupervised
	PARAFAC2	Unsupervised
	LDA	Supervised
	PLS-DA	Supervised
	OPLS-DA	Supervised
	SVM	Supervised
	RF	Supervised
	ANN	Unsupervised and supervised
	SIMCA	Supervised

iBRANN: iterative training of Bayesian regularized artificial neural networks, MCR-ALS: multivariate curve resolution-alternating least squares, PARAFAC: parallel factor analysis, PARAFAC2: Parallel Factor Analysis 2, PCA: principal component analysis, HCA: hierarchical cluster analysis, SOM: self-organizing map, LDA: linear discriminant analysis, PLS-DA: partial least squares discriminant analysis, OPLS-DA: orthogonal partial least-squares discriminant analysis, SVM: support vector machine, RF: random forests, ANN: artificial neural networks, SIMCA: Soft independent modelling of class analogy.

spectrometry in combination with PCA has been successfully applied for differentiating slaughtered chicken and dead-on-arrival chickens based on untargeted metabolomics profiling. Using METLIN database and MS/MS analysis of chemical standards, the identified marker for differentiation of both classes is sphingosine which is potential for the detection of adulterated chicken meat (Sidwick *et al*., 2017).

^{1}H-NMR spectroscopy combined with high-performance liquid chromatography for triacylglycerol composition has been used for authentication of butter from lard. The suitability of 1H-NMR spectra provides an excellent approach for analysis of lard as an adulterant in butter adulterated. Peaks in the region of 2.60–2.84 ppm show special characteristics only present in lard. Only lard has its unique characteristics which only polyunsaturated fatty acids would give signals at δ 2.63 corresponding to the chemical shift of the double-allylic methylene protons. In the same way, the intensity of the signal at 2.63 ppm, due to methylenic protons in a position α to two double bonds, that is to say, due to the linoleic group (Fadzillah *et al*., 2017).

5. Conclusion

The "omics" approaches including metabolomics have evolved as emerging analytical tools in some fields including halal authentication analysis. FTIR spectroscopy (fingerprinting profiling) as well as GC-MS, LC-MS and NMR spectroscopy (targeted and untargeted metabolomics studies) offered reliable techniques for the identification of non-halal components in food and pharmaceutical products. Next, these methods need to be standardized through proficiency testing to be developed as an alternative or even as a standard method for halal authentication analysis.

Conflict of interest

The authors declare no conflict of interest.

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References

Abbas, N., Ali, A., Kumari, S., Iqbal, A., Husain, A., Saeed, T., Abdul Amer Al-Ballam, Z., Ahmed, N., El-Seedi, H.R. and Musharraf, S.G. (2020). Untargeted-metabolomics differentiation between poultry samples slaughtered with and without detaching spinal cord. *Arabian Journal of Chemistry*, 13(12), 9081–9089. https://doi.org/10.1016/j.arabjc.2020.10.032

Adiarni, N. and Fortunella, A. (2018). The analysis of halal assurance system implementation (HAS 23000) in fried chicken flour product: a case study on XXX brand, presented at International Conference on Science and Technology (ICOSAT 2017), p. 57–61. Jakarta, Indonesia: Syarif Hidayatullah Stated Islamic University. https://doi.org/10.2991/icosat-17.2018.13

Ali, M.E., Nina Naquiah, A.N., Mustafa, S. and Hamid, S.B.A. (2015). Differentiation of frog fats from vegetable and marine oils by Fourier transform infrared spectroscopy and chemometric analysis. *Croatian Journal of Food Science and Technology*, 7 (1), 1–8. https://doi.org/10.17508/CJFST.2015.7.1.03

Candoğan, K., Altuntas, E.G. and İğci, N. (2020). Authentication and quality assessment of meat products by Fourier-Transform Infrared (FTIR) spectroscopy. *Food Engineering Reviews*, 13, 66–91. https://doi.org/10.1007/s12393-020-09251-y

Castro-Puyana, M., Pérez-Míguez, R., Montero, L. and Herrero, M. (2017). Reprint of: application of mass spectrometry-based metabolomics approaches for food safety, quality and traceability. *TrAC Trends in Analytical Chemistry*, 96, 62–78. https://doi.org/10.1016/j.trac.2017.08.007

Cevallos-Cevallos, J.M., Reyes-De-Corcuera, J.I., Etxeberria, E., Danyluk, M.D. and Rodrick, G.E. (2009). Metabolomic analysis in food science: a review. *Trends in Food Science and Technology*, 20 (11–12), 557–566. https://doi.org/10.1016/j.tifs.2009.07.002

Che Man, Y.B., Rohman, A. and Mansor, T.S.T. (2011). Differentiation of lard from other edible fats and oils by means of Fourier transform infrared spectroscopy and chemometrics. *Journal of the American Oil Chemists' Society*, 88(2), 187–192. https://doi.org/10.1007/s11746-010-1659-x

Cordella, C., Moussa, I., Martel, A.C., Sbirrazzouli, N. and Lizzani-Cuvelier, L. (2002). Recent developments in food characterization and adulteration detection: technique-oriented perspectives. *Journal of Agricultural and Food Chemistry*, 50(7), 1751–1764. https://doi.org/10.1021/jf011096z

Erwanto, Y., Rohman, A., Arsyanti, L. and Pranoto, Y. (2018). Identification of pig DNA in food products using polymerase chain reaction (PCR) for halal authentication - a review. *International Food Research Journal*, 25(4), 1322-1331.

Fadzillah, N.A., Rohman, A., Salleh, R.A., Amin, I., Shuhaimi, M., Farahwahida, M.Y., Rashidi, O., Aizat, J.M. and Khatib, A. (2017). Authentication of butter from lard adulteration using high-resolution of nuclear magnetic resonance spectroscopy and high-performance liquid chromatography. *International Journal of Food Properties*, 20(9), 2147-2156. https://doi.org/10.1080/10942912.2016.1233428

Feizi, N., Hashemi-Nasab, F.S., Golpelichi, F., Sabouruh, N. and Parastar, H. (2021). Recent trends in application of chemometric methods for GC-MS and GC×GC-MS-based metabolomic studies. *TrAC Trends in Analytical Chemistry*, 138, 116239. https://doi.org/10.1016/j.trac.2021.116239

Figueiredo, M.D., Cordella, C.B.Y., Bouveresse, D.J., Archer, X., Bégué, J. and Rutledge, D.N. (2019). Evaluation of an untargeted chemometric approach for the source inference of ignitable liquids in forensic science. *Forensic Science International*, 295, 8–18. https://doi.org/10.1016/j.forsciint.2018.11.016

Fischer, J. (2016). Manufacturing halal in Malaysia. *Contemporary Islam*, 10(1), 35–52. https://doi.org/10.1007/s11562-015-0323-5

Gemperline, P. (2006). Practical Guide to Chemometrics. Boca Raton, Florida, USA: CRC Press. https://doi.org/10.1201/9781420018301

Indrasti, D., Che Man, Y.B., Mustafa, S. and Hashim, D.M. (2010). Lard detection based on fatty acids profile using comprehensive gas chromatography hyphenated with time-of-flight mass spectrometry. *Food Chemistry*, 122(4), 1273–1277. https://doi.org/10.1016/j.foodchem.2010.03.082

Lubis, H.N., Mohd-Naim, N.F., Alizul, N.N. and Ahmed, M.U. (2016). From market to food plate: current trusted technology and innovations in halal food analysis. *Trends in Food Science and Technology*, 58, 55–68. https://doi.org/10.1016/j.tifs.2016.10.024

Mielko, K.A., Pudełko-Malik, N., Tarczewska, A. and Młynarz, P. (2021). NMR spectroscopy as a "green analytical method" in metabolomics and proteomics studies. *Sustainable Chemistry and Pharmacy*, 22, 100474. https://doi.org/10.1016/j.scp.2021.100474

Mursyidi, A. (2013). The role of chemical analysis in the halal authentication of food and pharmaceutical products. *Journal of Food and Pharmaceutical Sciences*, 1, 1–4.

Nakyinsige, K., Man, Y.B.C. and Sazili, A.Q. (2012). Halal authenticity issues in meat and meat products. *Meat Science*, 91(3), 207–214. https://doi.org/10.1016/j.meatsci.2012.02.015

Nurjuliana, M., Che Man, Y.B., Mat Hashim, D. and Mohamed, A.K.S. (2011). Rapid identification of pork for halal authentication using the electronic

nose and gas chromatography mass spectrometer with headspace analyzer. *Meat Science*, 88(4), 638–644. https://doi.org/10.1016/j.meatsci.2011.02.022

Nurrulhidayah, A.F., Arieff, S.R., Rohman, A., Amin, I., Shuhaimi, M. and Khatib, A. (2015). Detection of butter adulteration with lard using differential scanning calorimetry. *International Food Research Journal*, 22(2), 832-839.

Rocchetti, G. and O'Callaghan, T.F. (2021). Application of metabolomics to assess milk quality and traceability. *Current Opinion in Food Science*, 40, 168–178. https://doi.org/10.1016/j.cofs.2021.04.005

Rohman, A. and Che Man, Y.B. (2012). Analysis of pig derivatives for halal authentication studies. *Food Reviews International*, 28(1), 97-112. https://doi.org/10.1080/87559129.2011.595862

Rohman, A. (2017). The use of infrared spectroscopy in combination with chemometrics for quality control and authentication of edible fats and oils: a review. *Applied Spectroscopy Reviews*, 52(7), 589–604. https://doi.org/10.1080/05704928.2016.1266493

Rohman, A. and Putri, A.R. (2019). The chemometrics techniques in combination with instrumental analytical methods applied in halal authentication analysis. *Indonesian Journal of Chemistry*, 19(1), 262–272. https://doi.org/10.22146/ijc.28721

Rohman, A., Windarsih, A., Erwanto, Y. and Zakaria, Z. (2020). Review on analytical methods for analysis of porcine gelatine in food and pharmaceutical products for halal authentication. *Trends in Food Science and Technology*, 101, 122–132. https://doi.org/10.1016/j.tifs.2020.05.008

Rohman, A., Windarsih, A. and Mustafa, S. (2020). The application of analytical methods for analysis of non-halal components in cosmetics products: a review. *International Journal of Pharmaceutical Research*, 12(SP2), 2959–2965. https://doi.org/10.31838/ijpr/2020.SP2.353

Rohman, A., Putri, A.R., Irnawati, I., Windarsih, A. Nisa, K. and Lestari, L.A. (2021). The employment of analytical techniques and chemometrics for authentication of fish oils: A review. *Food Control*, 124, 107864. https://doi.org/10.1016/j.foodcont.2021.107864

Salihah, N.T., Hossain, M.M., Lubis, H. and Ahmed, M.U. (2016). Trends and advances in food analysis by real-time polymerase chain reaction. *Journal of Food Science and Technology*, 53(5), 2196–2209. https://doi.org/10.1007/s13197-016-2205-0

Sidwick, K.L., Johnson, A.E., Adam, C.D., Pereira, L. and Thompson, D.F. (2017). Use of liquid chromatography quadrupole time-of-flight mass spectrometry and metabonomic profiling to differentiate between normally slaughtered and dead on arrival poultry meat. *Analytical Chemistry*, 89 (22), 12131–12136. https://doi.org/10.1021/acs.analchem.7b02749

Wishart, D.S. (2008). Metabolomics: applications to food science and nutrition research. *Trends in Food Science and Technology*, 19(9), 482–493. https://doi.org/10.1016/j.tifs.2008.03.003

Worley, B. and Powers, R. (2016). PCA as a practical indicator of OPLS-DA model reliability. *Current Metabolomics, 4(2), 97-103.* https://doi.org/10.2174/2213235X04666160613122429

Zabidi, A.R., Fauzi, F.N., Abd Razak, F.N., Rosli, D., Jamil, M.Z.M., Wan Ibrahim, W.K. and Yahaya, N. (2020). Screening porcine DNA in collagen cream cosmetic products. *Food Research*, 4(Suppl. 1), 151–156. https://doi.org/10.26656/fr.2017.4(S1).S05

