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Volatile profile and its application on species authentication of meat-based food

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ABSTRACT
Meat and meat-based food produce a certain composition of volatile compounds, which can be used to identify its origin and, consequently, for food authentication. Numerous studies have explored the application of volatile compounds in identifying meat-based food using volatilomics, an emerging analytical technique. This review focuses on the volatile compound profiles, the factors influencing their production, method of extraction and detection, and their application in meat and meat-based products, with a brief discussion on their potential use for Halal authentication. The major volatile compounds associated with meat aromas include aldehydes, ketones, and alcohols, with variation in composition among different types of meat, though no definite pattern has been identified. Most of these volatile compounds are byproducts of the Maillard reaction, Strecker degradation, or interaction of both, as well as thiamine degradation. Head space-solid phase microextraction (HS-SPME) is meat's standard volatile compounds extraction method due to its convenience, solvent-free process, high sensitivity, and practicality. Gas chromatography-mass spectrometry (GC-MS) is the primary analytical technique for detecting volatile metabolites and is considered the most effective among available methods. The volatilomics approach has also been applied in Halal authentication to distinguish among different animal species. The volatile compound profiles can differentiate meat-based products derived from chicken, beef, and pork. While the volatilomics approach shows great potential for use in Halal authentication, additional complementary methods are still required to obtain more comprehensive data.

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INTRODUCTION

Analysis of volatilome is an emerging research area due to its rapidness and economically favorable diagnostic ability for identification purposes (Maurer et al., 2019). Volatilomes are the total volatile organic compounds (VOCs) emitted from all living organisms. At the same time, VOCs are small molecular mass substances within metabolites with low boiling points and high-vapor pressure characteristics (Rioseras et al., 2017). VOCs produced by each living organism are different or unique and called 'signatures' of the organism. The volatilome has a wide variety of applications, usually for diagnostic purposes such as the diagnosis of infectious diseases (Burciaga-Robles et al., 2009), differentiation of diet composition in humans (Pérez-Calvo et al., 2019; Recharla et al., 2017) and plays an important role in food science and technology since VOCs are an essential component in food aroma and flavor. The origin of food, including meat and meat-based products, can be identified by its aroma (Khomenko et al., 2017), which comes from volatile organic compounds in food.

Meat-based food is made partly from meat, poultry, beef, or lamb. As it contains partly meat, just like the meat itself, it could produce a specific composition of volatile compounds when exposed to heat. Hence, based on this idea, it could be used as a tool to help identify its origin. This can be of great help for food products that are highly processed, such as meatballs, sausages, and patties, where judging from its appearance alone could not justify the type of meat that is being used. Authenticity testing of the animal species in food is important for economic, safety, legal, religious, and health reasons (Doosti et al., 2014). One way for this authenticity testing was to study the volatilomics of this meat/meat-based food, the composition of VOCs produced from chemical reactions of metabolites of its animal origin.

It was reported by Tenrisanna & Kasim (2021) that Indonesia's meat price was expected to increase every year due to an increase in its consumption and low supply. This results in the idea of adulterating the food or food fraud. For example, beef meatballs (*bakso*) have been reported to be mixed with cheaper rat meat with no obvious difference in aroma, taste, and appearance. Another case for adulteration in processed meat, such as sausage, can be found in Korea, Japan, and China, where pork meat was added to products that are labeled "beef only" due to the price of pork meat being rather cheap (Singh & Neelam, 2010; Soares et al., 2010). As Indonesia is a Muslim-majority country, it is important to ensure that the food is free of prohibited (non-Halal) constituents for Muslims. With the advancement of technology, food adulteration or fraud can no longer be detected merely by their physical characteristics. Rather, it should be chemical as well since sometimes non-Halal products or origins are mixed with other items having similar characteristics, raising difficulty in identifying the differences. To address this issue, Halal authentication must be done through scientific procedures from food control laboratories that can differentiate and detect animal species in food products (Luo et al., 2008).

Volatilomes are widely known for their use in food sciences. Profiling volatile compounds is useful for identifying the origin of food products and has potential for Halal authentication purposes. Thus, there is a need for a comprehensive review to summarize the latest research. This review highlights the volatile compound profiles, the various factors that influence their production, the methods of extraction and detection, their application in meat and meat-based foods, and their potential use for Halal authentication.

RESEARCH METHOD

The method used for this study was a literature review from a recent international scientific publication (2011-2021) classified under Q1/Q2/Q3/Q4 journals. Relevant scientific journals were sourced from platforms such as Google Scholar, ScienceDirect, universities repository, ResearchGate, Elsevier, and Wiley Online Library.

RESULT AND DISCUSSION

Volatilomes and volatilomics

Volatile compounds are carbon-based chemicals with high volatility and a molecular weight under 500 Da (Berenguer et al., 2022). They belong to various chemical functional groups, including hydrocarbons, alcohol, aldehydes, ketones, carboxylic acids, esters, furans, pyrans, pyrroles, pyrazine, pyridines, phenols, thiophenols, thiazoles, oxazoles, and other nitrogen or sulfur compounds. While many volatile compounds can be found in a single meat-based food sample, only those that contribute to aroma are significant and can be used as key volatile compounds. Aroma-active compounds have a low detection threshold and can be detected even with minimal dilution (Ba et al., 2012).

As for adulteration, the basic concept for identification was to compare the fingerprint of an authentic food (non-adulterated sample) with the adulterated ones. Thus, it was important to remove any variables that do not have any contribution, and only the useful ones remain. The useful ones will become the "marker" and be classified as the key volatile component/s of that particular meat sample type. Hence, that explains the application of chemometrics, which will be discussed later in the paragraph.

Chemometrics performed on volatile compounds is called volatilomics. After analysis, the volatile data result will undergo reduction and classification steps with the help of chemometrics or

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multivariate analysis. It was a set of mathematical and statistical methods commonly used in analytical chemistry. Volatilomics also refers to the qualitative and quantitative investigation of the volatilome, which was described as a complex mixture of VOCs released by living organisms from the environment or substrate (such as food), resulting from several biochemical pathways (Crandall et al., 2020). VOCs were tiny molecules (less than 500 Da) having a hydrophobic nature, low boiling temperatures, and high vapor pressure at room temperature (Carazzone et al., 2021). Volatilomics is critical in various food domains, including safety, quality, and authenticity. Different elements of volatile analysis were related to these domains, such as the nutritional, microbiological, chemical, and sensory quality of various commodities such as meat, fruits, vegetables, spices, fermented items, and so on (Lytou et al., 2019).

For meat, volatilomics are often utilized for authentication purposes by discrimination or differentiation between the meat type based on its constituents and concentration of volatile organic compounds emission, and interest towards it has increased over the years due to its practical and less laborious work as compared to other methods such as proteomics approach which involved using DNA. Fraud is most likely related to meat origin, substitute, processing, and non-meat addition (Ballin, 2010). Highly processed foods are often targeted for fraud because their appearance is significantly altered, making adulteration harder to detect. Each food commodity has a unique profile of volatile compounds, and analyzing these profiles can help identify adulteration in meat-based and other processed foods.

As mentioned, not all volatile compounds emitted from a sample are aroma-active; a single meat type can produce and detect hundreds of volatile compounds. Chemometrics reduces this large dataset or dimension by selecting only the relevant volatile compounds for creating an adulteration fingerprint. There are two types of multivariate analysis for this purpose: unsupervised methods such as PCA (Principal Component Analysis) and supervised methods (DA/Discriminant Analysis, LDA/Linear Discriminant Analysis, PLS/Partial Least Squares, PLS-DA/Partial Least Squares-Discriminant Analysis, etc).

Volatile compounds formation of meat and meat-based product

Meat was described as having little aroma. It was weakly flavored, but despite this, it contains many precursors of volatile compounds, which will later develop after processing. Although these precursors were non-detectable in a raw state, there was one specific type of animal whose meat was associated with a strong odor even in the raw state: lamb meat. It was attributed to have a “mutton smell.” This smell is associated with aldehyde, ketone, and volatile compounds such as 4-methyloctanoic acid, 6-methylheptanoic acid, and n-octanoic acid (Cai et al., 2015; Purnamayanti et al., 2020). Also, due to the presence of a higher content of fat (17-21% fat), the resulting fatty acids present in higher concentrations produce a stronger aroma as compared to goat (2.3-3% fat) and beef (5-12% fat). One way to reduce the strong odor was to process it further into sausages (Listyarini et al., 2018).

Raw meat is cooked to improve its taste, aroma, and texture and inactivate microbial pathogens to make it safe to consume. Cooking involves exposing the meat to high temperatures, which triggers various reactions, including the Maillard reaction, lipid oxidation, interactions between Maillard and lipid oxidation reaction, and thiamine degradation (MacLeod, 1994).

The Maillard reaction is a chemical process that occurs when reducing sugars interact with free amino compounds. This reaction begins with the carbonyl group of reducing sugar condensing with an amine group to form N-substituted glycosylamine or the Amadori product. Further sugars are broken down in the next stage, releasing the amine group. The final stage involves additional reactions such as dehydration, fragmentation, cyclization, and polymerization, which produce brown pigments and flavor compounds (van Boekel, 2006). Kosowska et al. (2017) highlighted an important aspect of Maillard reactions called Strecker degradation, where amino acids are degraded in the presence of di-carbonyl group, resulting in the formation of aldehydes and amino ketones that contribute to aromatic compounds. Ngamchuachit et al. (2020) reported that the formation of 2-methyl-butanal and 3-methyl-butanal, which were found to be caused by Strecker degradation between the meat and sugar-containing marination sauce in *Yakitori* (Japanese chicken skewer). Other aromatic compounds formed in *Yakitori* were dihydro-2-methyl- 3(2H) furanone, furfural, and furfuryl alcohol, responsible for 24% of the total volatile compounds in the sample. These compounds resulted from Maillard reactions, particularly the

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degradation of pentose sugar such as xylose, ribonucleotides, and inosine-5'-monophosphate reacting with leucine and isoleucine. The resulting compounds were associated with the sample's sweet, caramel, and burnt aroma (Peleteiro et al., 2016; Srivastava et al., 2018).

Fatty acids play a significant role in associating a specific flavor with a particular type of meat. Fatty acids were the result of lipid oxidation. Different types of species of animals have different fatty acid profiles. The degree of unsaturation in intramuscular fat is important in determining the overall concentration of volatile compounds produced from lipid oxidations (Elmore et al., 1999). These volatile compounds from such reactions include aliphatic hydrocarbons, aldehydes, ketones, alcohols, carboxylic acids, and esters. Bueno et al. (2019) study suggested that the longer the raw beef sample is exposed to lipid oxidation, the more volatile compounds such as 3-octanone, (E)-2-nonenal, and butanoic acid increase. Volatile compounds resulting from lipid oxidation have a higher sensory detection threshold than the ones produced by Maillard reactions (Kosowska et al., 2017).

The products of Maillard and oxidized lipids further interact with one another and influence the development of a certain compound over the ones formed if it were either one of the only to exist. This is due to competition between carbonyl compounds produced in lipid oxidation and carbohydrate-derived carbonyls for amino compounds to produce carbonyl-amine reaction products (Zamora & Hidalgo, 2011). Evidence of this Maillard-lipid interaction can be taken from a study by Xu et al. (2011). Study shows that the addition of pork fat in a food sample results in the production of smaller concentrations of furfurals. Alcohols, alkyl furans, and aliphatic compounds were formed instead of aldehydes.

Last, aroma-contributing compounds were also produced by thiamine degradation. Thiamine is an important vitamin that naturally occurs in meat. Through heating, thiamine degrades and forms thiazoles, thiophenes, and furans, volatile compounds. Thomas et al. (2015) conducted a study, and the result showed an increase in 3 volatile compounds found in cooked ham, which were 2-methyl-3-furanthiol, 2-methyl-3-methyl thiofuran, and bis (2-methyl-3-furyl). The increase in the addition of thiamine concentration to the sample caused this increase. A summary of volatile compounds formation through various kinds of reactions: Maillard reaction, lipid oxidation, Maillard-Lipid oxidation interaction, and Thiamine degradation was illustrated by Dashdorj et al. (2015).

Factors affecting volatile compound formation in meat and meat-based product

External and internal factors also heavily influence volatile compounds' compositions and final products. Factors were disturbance or intervention in the usual working of a system, which resulted in changes in its working. The result or product will consequently differ from the norm. Factors associated with the change in the production of volatile compounds include breed (feed), gender, and animal age as internal factors. The conditions and process by which these animals were slaughtered, the handling method of post-slaughtered animals, and the meat storage condition and duration were also discussed. The addition of food additives and the condition of how the meat was cooked (boiling, roasting, smoking, etc), which were external factors, also contributed to the development of aromatic compounds (Kosowska et al., 2017).

Post-slaughtered animals usually were stored at low temperatures to prevent any deterioration of the meat. The freezing process for storing beef meatballs for 90 days resulted in a reduced aroma profile (S. Sun et al., 2020). Another study by Schilling et al. (2019) also resulted in a pattern that showed decreased volatile aroma profiles found in pork sausage after 90 days of storage under freezing temperatures. However, before a decrease, there was an increase in the volatile aroma within 14 days. A study by Karabagias (2018) showed an increase in the volatile content of raw lamb meat chilled at 1°C for 9 days. In contrast, there has been a reported decrease in volatile content produced from yak meat when stored in two conditions: chilled and frozen for about 18 days. Therefore, low temperature affects the changes in the volatile compounds profile found in these samples. The longer it was stored, the more volatile compounds were lost from the commodity, thus decreasing the aromatic profile of the meat or meat products.

On the other hand, aging is a process that increases the carcass's flavor, partly or as a whole, at refrigerated temperature combined with a specific aging period, aging time, relative humidity, and airflow. This was one of the traditional ways of enhancing flavor in meat due to the increase in density of flavor components of tissues by losing its water content and breaking down of connective tissues by natural enzymes, which also resulted in tenderization of the meat (Gürbüz & Kahraman, 2018). This can be confirmed by studies conducted by Beldarrain et al. (2022) and Insausti et al. (2021), where aging horse and lamb meat for approximately 4 and 12 days, respectively, increased flavor components and reduced unwanted aroma profiles in meat such as livery and bloody aroma.

Cooking processes have a definite influence on the volatile composition of meat. Qi et al. (2017) reported an increase in the volatile composition of chicken when stewed over a longer period. Another study was done for a volatile composition comparison of foal meat cooked using four different cooking methods: roasting, grilling, microwaving, and frying. The roasting method of cooking yields the highest amount of volatile aroma composition. Hence, the longer it was exposed to heat and the higher cooking temperature used, the more formation of volatile compounds (Domínguez et al., 2014).

Lastly, the meat's internal makeup or nature strongly correlates with its volatile compositions. Different breeds of animals are brought up in different conditions and fed with different kinds of diet, resulting in a different composition of fatty acids within the meat. Bacon, made from different pig breeds, such as white and black pig, gives a different profile in volatile compounds; white pig was more abundant in volatile than black pig (Deng et al., 2021). The *Hanwoo* and *Chikso* cow breeds, the two most superior breeds for beef, result in different volatilome profiles, where *Chikso* beef releases a more intense aroma than *Hanwoo* beef when roasted. Although the two did not have a significant difference in their fat content, *Hanwoo* (15.37%) and *Chikso* (12%) (Utama et al., 2020). One possible reason for these differences was the presence of different indigenous enzymes, which help in the reaction that produces aromatic volatile compounds. Table 1 summarises different external factors that affect the volatile compounds produced.

Table 1. External factors and their effect on the volatile profile of meat and meat-based products.

Meat group	External factor	Results	References
Raw Meat			
Lamb meat	Chilling for 9 days	Volatile compound content increases during storage time, in particular, aldehyde	Karabagias (2018)
Lamb meat	Aging for 4 days	Decreases in livery and bloody flavor, increases in fresh green grass and fat aroma	Insausti et al. (2021)
Yak meat	Chilling and freezing for 18 days	Decrease in volatile compounds such as nonanal, benzaldehyde, and myristate.	S. Sun et al. (2020)
Horse meat	Aging for 21 days	Increased in aldehyde (hexadecanal and 2- and 3-methylbutanal) compositions; major contributor to horse meat aroma.	Beldarrain et al. (2022)
Foal meat	Roasting, grilling, microwaving and frying	Roasting resulted in a higher formation of volatile compounds.	Domínguez et al. (2014)
Cooked/Processed Meat			
Beef meatball	Freezing for 90 days	Overall aroma profile weakens as storage time increases	S. Sun et al. (2020)
Pork sausage	Freezing (15, 90 and 180 days)	Volatile aroma increases within 14 days and is reduced after 90 days	Schilling et al. (2019)
Stewed chicken	Stewing for 3 hours	Increasing stewing time improved the aroma levels	Qi et al. (2017)
Bacon	Different breed: white and black pig	Volatile compounds detected in bacon from white pigs are more abundant than black pigs.	Deng et al. (2021)
Roasted Beef	*Hanwoo* and *Chikso* breed	Roasted *Chikso* beef releases a more intense aroma than *Hanwoo* beef	Utama et al. (2020)

Volatile profiles in species identification of meat and meat-based food product raw meat

Taste Due to the nature of raw meat having few volatile compounds, it is less unfavorable for conducting analysis; hence, not many scientific journals have been published regarding its volatile compounds analysis (Pérez-Calvo et al., 2019). Some of these recent studies conducted on volatile

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organic compounds analysis were on raw ham (Bosse (née Danz) et al., 2017), where 38 volatiles were successfully identified, of which ketone was found to be the most dominating group, followed by alcohols, hydrocarbons, and esters. Another study was conducted on the volatile profiling of rabbit meat (Xie et al., 2016), where 17 volatile compounds were identified, of which esters were found to be the most dominant, followed by alcohols. Key volatile compounds were hexanal, heptanal, octanal, nonanal, (E, E)-2, 4-decadienal, 1-octen-3-ol and (Z)-2-decenal. A recent finding on poultry raw meat volatile profiling was conducted by Ayseli et al. (2014), where raw chicken breast meat was used as a sample. Results showed that 33 volatiles were identified, of which dominant groups were found to be acids, esters, and alcohol. Key volatile compounds were hexanal and (E)-2-heptanal. Bueno et al. (2019) also analyzed raw beef, where 30 volatile compounds were identified. Aldehydes were the most dominant group, followed by ketones and acids.

Besides analyzing raw meat, which consists of only a single type of meat, it can also be utilized to identify and discriminate an adulterated sample containing two mixed meat types. This was done in a study conducted by Pavlidis et al. (2019), where he was able to discriminate raw minced beef adulterated with pork. Heptanal, octanal, butanol, pentanol, hexanol, octanol, 1-penten-3-ol, 2-octen-1-ol, 3-hydroxy2-butanone, 2-butanone and 2-heptanone were positively correlated with beef samples. Pentanal, hexanal, decanal, nonanal, benzaldehyde, trans-2-hexenal, trans-2-heptenal, trans-2-octenal and 1-octen-3-one were positively correlated with pork. Alcohols, 2-butanol, and 1-octen-3-ol were correlated with minced beef adulterated with pork meat samples. Table 2 summarizes the analysis of volatile compounds in different raw meat.

Table 2. Application of volatilomics in the identification of various types of raw meat.

Meat sample	Extraction method	Detection method	Multivariate analysis	Result	References
Single-origin					
Ham	Headspace Trap (HS)	GC-MS and GC-FID	-	38 volatile compounds were identified: ketones (12), alcohols (8), hydrocarbons (7), and esters (3).	Bosse (née Danz) et al. (2017)
Rabbit	Simultaneous distillation extraction (SDE)	GC-MS	-	17 volatiles were detected: alcohols (4), ketones (2), acids (2), heterocyclic compounds (1), alkanes (2), and esters (7). Key volatile compounds were hexanal, heptanal, octanal, nonanal, (E, E)-2, 4-decadienal, 1-octen-3-ol and (Z)-2-decenal	Xie et al. (2016)
Chicken	Simultaneous distillation extraction (SDE)	GC-MS	-	33 volatiles were identified; acids, esters, and alcohols were dominant. Key volatile compounds were hexanal and (E)-2-heptanal.	Ayseli et al. (2014)
Beef	Headspace-solid phase micro-extraction	GC-MS	-	30 volatiles identified; dominant in aldehydes, followed by ketones and alcohols	Bueno et al. (2019)
Mixed Origin					
Beef and Pork	Headspace-solid phase micro-extraction (HP-SPME)	GC-MS	PCA and PLS-DA	Alcohols, 2-butanol, and 1-octen-3-ol showed a positive correlation with mixed samples. Beef sample; heptanal, octanal, butanol, pentanol etc. In pork; pentanal, hexanal, decanal, nonal etc.	Pavlidis et al. (2019)

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Meat-based product

Volatile compounds profiling on meat-based food, whether a single origin or contained a mixture of meat, has been utilized and could identify specific volatile and discriminate compounds associated with a particular meat-based food. Almost all the reported studies on the analysis of volatile compounds in processed food were highly aromatic, meaning they consist of higher amounts of volatile compounds, which are odor-active, present as a result of multiple interactions between the precursor compounds in their raw meat.

Duan et al. (2015) conducted voluntary profiling on braised chicken on poultry-based food. A total of 135 volatile compounds (both aroma active and non-active) were identified, of which the dominant volatile groups belong to the carbonyl group; specifically, 2-Enals and 2,4-dienals were the most important constituents. Zhang et al. (2018) analyzed chicken broth, resulting in 36 volatiles identified. Heptanal, benzaldehyde, (Z)-2-decenal, (E,E)-2,4-decadienal, 1-pentanol, 2-undecanone, 2-pentyl-furan were positively correlated with the chicken broth sample. Another study was conducted by Ngamchuachit et al. (2020) on the volatile profiling of Yakitori, which was a Japanese grilled chicken skewer. 82 volatiles were identified, and aldehyde groups were abundant, specifically 2-methyl-butanal and 3-methyl-butanal. Another major contributing compound was 2,5-dimethyl pyrazine, which contributes to the roasted aroma of grilled chicken.

Takakura et al. (2014) and Zhao et al. (2017) conducted studies on profiling the volatiles produced from pork soup and pork broth. Pork soup resulted in 15 aroma-active compounds, and the key volatile aromas were acetol, octanoic acid, δ-decalactone, and decanoic acid. Meanwhile, pork broth has higher active aroma compounds of 27. Higher constituents of compounds present in pork broth were 2-methyl-3-furanthiol, 3-(methylthio)propanal, c-decalactone, 2-furfurylthiol, e-3-hydroxy-2-butanone, hexanal, pentanal, and 1-octen-3-ol. Similarly, another study was conducted on Chinese spicy and spiced beef, in which 82 and 67 volatiles were identified, respectively. Key compounds in Chinese spicy beef include 3-methyl-butanal, pentanal, hexanal, ρ-xylene, heptanal, limonene, terpinene, octanal, linalool, 4-terpinenol, α-terpineol, and (E)-anethole. Meanwhile, spiced beef had more variations in its key volatile components; p-allyl-anisole, 1-methoxy-4-(1-propenyl)-benzene, 3-methyl- 1-butanol, linalool, chavicol, α-phellandrene, myristicin, (Z)-3-hexenol, 1-terpinen-4-ol, furfuryl alcohol, dimethyl pyrazine, and 3-mercaptothiophene.

A study conducted on highly processed food was done by Ozkara et al. (2019) on sausage made out of turkey, chicken, and beef. Meatballs made from beef (S. Sun et al., 2020) were also conducted. In the case of sausage made out of chicken, positively correlated compounds were found to be (E)-sabinene hydrate, β-cubebene, 2-hexanol, 5-methyl-2-heptanol, 2-heptanol, 2-nonanol, 4- methyl-3-hexanol, and heptanoic acid. For turkey; (Z)-p-mentha-1(7)8-dien-2-ol, dimethylallyl alcohol, 1,2-ethanediol, furfuryl alcohol, furfural, 2-ethyl-6-methylpyrazine, trimethyl pyrazine, and 2(5H)-furanone and the least found for beef; 2-butoxyethanol, octanoic acid, and nonanoic acid. As for the meatballs, beef-based key odorant was found to be hexanal, 1-octene-3-ol, linalool, 2-ethyl hexyl acetate, diallyl disulfide, eugenol, α-pinene, and anisole (Y. Sun et al., 2021).

Based on the findings above, HS-SPME is the most frequent meat/meat-based food extraction method. This is due to its quick and simple procedure in operating the method; it requires no experienced user, has a high sensitivity, requires no solvent, and is the most economical method for preparation analysis before GC compared to the rest (Kataoka et al., 2000). The most frequently used method for analyzing volatile compounds is GC-MS or gas chromatography and mass spectrometry in tandem. Gas Chromatography is the most powerful and suitable analysis instrument for separating volatile compounds produced from metabolites. Mass spectrometry is the most superior for detecting these volatile compounds as it can produce spectral information, which helps us to identify specific analytes, even the untargeted ones, which could not be obtained using other detection methods (Bartle & Myers, 2002). Performing chemometrics on volatile compounds in meat or meat-based food samples was not so common as most studies on its use are limited. Possible reasons are that the volatile compounds identified were not large enough; thus, there is no need for data reduction, and the sole purpose of studies is mostly to identify what kinds of volatile compounds are present in the sample rather than to classify which is the purpose of the use of chemometrics. However, the studies aiming for classification and with big data results use PCA and PLS-DA. No previous studies have been

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reported on which type of multivariate analysis method is the best, as statistical analysis is performed depending on the suitability of the data type obtained. Research on the application of volatilomics in the identification of various types of processed/cooked meat is provided in Table 3.

Table 3. Application of volatilomics in identifying various types of processed/cooked meat.

Meat sample	Extraction method	Detection method	Multivariate analysis	Result	References
Braised Chicken	Accelerated solvent extraction followed by solvent-assisted flavor evaporation (ASE-SAFE)	(GC x GC/HR-TOFMS) and GC-qMS	-	A total of 135 volatiles were identified, dominant in carbonyl groups.	Duan et al. (2015)
Chicken Broth	Headspace-solid phase microextraction (HS-SPME)	GC-MS	PLSR (Partial Least Squares Regression)	Heptanal, benzaldehyde, (Z)-2-decenal, (E,E)-2,4-decadienal, 1-pentanol, 2-undecanone, 2-pentyl-furan were positively correlated with the chicken	Zhang et al. (2018)
Yakitori (Grilled Chicken)	Dynamic Headspace Trap and Headspace stir bar sorptive extraction (SBSE)	GC-O-MS	-	Aldehydes (2-methyl-butanal and 3-methyl-butanal) were the most dominant volatile compounds, followed by 2,5-dimethyl pyrazine.	Ngamchuachit et al. (2020)
Pork broth	solvent-assisted flavor evaporation (SAFE)	GC-MS	-	27 volatiles were identified, some of these were present in higher quantities: 2-methyl-3-furanthiol, 3-(methylthio)propanal, c-decalactone, 2-furfurylthiol	Zhao et al. (2017)
Pork Soup	Aroma extract dilution	GC-MS	-	Acetol, octanoic acid, δ-decalactone and decanoic acid were the key odorants.	Takakura et al. (2014)
Chinese Spicy Beef	SPME	GC-MS	PCA and LDA	Key volatile compounds were 3-methyl-butanal, pentanal, hexanal, ρ-xylene, heptanal, etc.	Gong et al. (2017)
Spiced Beef	HS-SPME	GC-O-MS	PCA	Some of the key compounds identified include p-allyl-anisole, 1-methoxy-4-(1-propenyl)-benzene, 3-methyl- 1-butanol, linalool, chavicol, α-phellandrene etc.	Zang et al. (2020)
Sausage (beef, turkey and chicken)	Solvent-assisted flavor evaporation (SAFE)	GC-O-MS	PCA	Key compounds in chicken: (E)-sabinene hydrate, β-cubebene, 2-hexanol, 5-methyl-2-heptanol, 2-heptanol, 2-nonanol, etc. In the turkey sample; (Z)-p-mentha-1(7)8-dien-2-ol, dimethylallyl alcohol, 1,2-	Ozkara et al. (2019)

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Meat sample	Extraction method	Detection method	Multivariate analysis	Result	References
				ethanediol, furfuryl alcohol etc. The beef sample used 2-butoxyethanol, octanoic acid, and nonanoic acid.	
Beef meatballs	Solid-phase microextraction (SPME) and solvent-assisted flavor evaporation (SAFE)	GC-O-MS	-	Key compounds were hexanal, 1-octene-3-ol, linalool, 2-ethyl hexyl acetate, diallyl disulfide, eugenol, α-pinene, and anisole.	S. Sun et al. (2020)

As for the volatile profiles, it is confirmed that raw meat possesses less volatile compounds than cooked meat or meat-based products. No fixed pattern of the volatile profile, be it in its constituents or concentration, is observed for specific meat species. However, most aroma-contributing compounds generally revolve around these three functional groups: aldehydes, ketones, and alcohols.

Halal authentication of meat and meat-based food using volatile profile: Challenges and future outlook

Halal comes from the Arabic words permitted, allowed, approved, and legitimate. All land animals are Halal, except pigs and other animals mentioned in the Holy Quran and As-sunnah. Therefore, Muslims need to be aware of the meat that they are going to consume as well as to guarantee that the meat that is provided for them is Halal. This is done through Halal authentication.

Authentication is a process where a product is verified through analytical processes if it has fulfilled what it is claimed to be (Dennis, 1998). The current issues arise when food manufacturers choose to substitute pork derivatives in food due to their lower prices. As mentioned before, Muslims are strictly prohibited from consuming such meat. With that being said, and also due to the advancement of technology, adulteration and fraud have become common. It is also reported that non-Muslims have started consuming Halal meat, and their interest in it has increased over the years, especially in the UK, due to its association with decreased risk or lowering the likelihood of getting infected with a transmitting disease called bovine spongiform encephalopathy (BSE) or commonly known as mad cow disease. Halal meat does not only apply to meat that is obtained from Halal animals along with Halal slaughtering, but it should also be free from najs or impurities which could be present in the meat as a result of poor quality or hygienic feed of livestock and mishandling of the post-slaughtered meat. Mad cow disease is said to be caused by such conditions of meat. This strongly urges the detection or quantification of adulterants to protect consumers (Nakyinsige et al., 2012). Various analytical procedures to perform Halal authentication have been developed, and each method is used according to the sample being analyzed. For example, a commonly used method relies on protein or DNA analysis through polymerase chain reaction (PCR). It is more commonly used as many experimental studies have been found revolving around using DNA for the adulteration detection of pork. FTIR (Fourier Transform Infrared) spectroscopy is common; its analysis relies on the sample's fatty acids. Another potential method for the identification of adulteration of pork is relying on the food's aroma or the volatile compounds that are produced from its particular food. Gas chromatography could be used to detect these volatile compounds quantitatively. In contrast, the newly developed instrument known as the electronic nose has also successfully detected and discriminated against lard adulteration qualitatively.

These two instruments work based on emitted volatile organic compounds from the meat sample. Different animal-sourced meat has different amino acid compositions and sequences differ from one another (Hassan et al., 2018), with differences in fatty acid composition and pro- and anti-oxidant content or the meat structure (Resconi et al., 2013). All these combinations will undergo different chemical reactions, which result in the production of various VOCs. Therefore, similarity or diversity

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in the profiles of VOCs could give information on their origin. The same origin of meat gives similar VOC profiles; likewise, if it is from a different origin, it should give different profile results (Lytou et al., 2019).

A study by Nurjuliana et al. (2011) aimed to identify pork in meat and meat products, such as sausage, for Halal authentication. The result shows that volatile compounds in the pork sample were positively identified and mostly detected from the aroma analysis, such as aldehydes and ketones. This is due to the lipid oxidation of linoleic and oleic acids, pork's most abundant unsaturated fatty acids (Meinert et al., 2007; Wettasinghe et al., 2001). Using an electronic nose, another similar study by the same author analyzed the discrimination of pork or pig fats from other fats, such as chicken, beef, and mutton. The result was interpreted in the form of VapoPrint. It is a graphical presentation of odor amplitude, with radial angles representing the sensors. The aroma of the sample will cause chemical changes in the sensor, producing a specific and unique image pattern in the form of amplitude (Chin et al., 2009). The result shows that the adulterated sample consisting of a variation level of pork fats mixed with chicken fats slowly resembles that of chicken fat alone as its pork content decreases.

Another Halal authentication analysis using an electronic nose was done by Sarno et al. (2020). He stated that it is capable of detecting beef adulteration. This is shown by differences in the sensors' response to e-nose. This difference is influenced by gas or volatile compounds emitted from different combinations of pork and beef samples due to their protein and lipid composition differences. A very recent study was conducted by Pranata et al. (2021). The result shows the volatile profile of wild boar alone shares the same discriminating volatile compounds as that of the adulterated sample with wild boar sample but in different concentrations, and its key volatile compounds were found to be pentanal, 2,6-dimethylcyclohexanone, 1-undecanol, cyclobutanol, 2,4,5-trimethyl-thiazole, and 5-ethyl-3-(3-methyl-5-phenyl pyrazole-1-yl)-1,2,4-triazol-4-amine. Another key finding of this study was that alcohols were the most abundant volatile compounds in wild boar meat. Besides this study, there were very limited reports on previous studies regarding the volatile compound profile of wild boar meat.

Although not many journals have been found on utilizing volatile compound profiles of different meat species for Halal authentication, the above findings suggest that it could be used for such purposes. However, more thorough, in-depth studies are required for more supporting evidence. Meanwhile, the above findings also lacked information regarding other meat species that are forbidden to be consumed by Muslims, such as rats, dogs, etc., and were limited to pork and wild boar; they also needed further investigation.

Due to the complexity of the food matrix, none of the studies have reported having shared the same volatile profile between the same meat types; sometimes, it can be completely contradictory to what the previous studies had reported. Therefore, it is always a different case. This leads to difficulty identifying unknown meat types, judging merely by their key characteristics and compounds. Efforts need to be made to establish a database for volatile profiles in meat as an index, just like the DNA database for identification purposes. This can be of great help as an index that stores information on the previous analysis done on meat volatile compounds and to check and ensure if there is any common pattern in the volatile profile in one specific type of meat. Optimization of the extraction and analysis of volatile compounds also needs to be investigated further in meat or meat-based food to achieve the best time and temperature combination for maximum extraction of volatile compounds.

As for Halal authentication, there are very limited studies regarding volatilomics, and it is used for such purposes, considering that volatilomics utilized in the Halal field for Halal authentication had just been recently introduced and is not very common. Thus, further experimental research is needed on foods commonly associated with their Halal status.

CONCLUSION

Interest in the volatile compound profiles, specifically in the utilization in the identification of meat or its derivative food product, has increased over the years; one of the reasons is that the presence of food fraud or adulteration has become common. Based on the review of the selected journals regarding the use of volatilomics for the aforementioned purpose, it has successfully differentiated or discriminated several meat or meat-based products originating from different meat species, including determining their key volatile compounds. As for Halal authentication, a small considerable amount of

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journals have been found, of which all state the capability and great potential of utilizing volatile compounds for identification of haram adulterants, but regardless, further investigation needs to be carried out to be able to have enough scientific evidence, especially for identifying sample with an unknown type of meat, and establish further solid validation step in order to rule out a proper and valid hypothesis on the use of volatile profiles of meat species for Halal authentication as to determine whether meat or its derivatives product for its Halal status is fatal and required a careful and clear analytical procedure to avoid false positive.

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