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Review

# Spectral analysis: A rapid tool for species detection in meat products

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ABSTRACT

*Background:* The adulteration of meat products with undeclared or falsely declared animal species is a major concern all over the world. There are many analytical techniques for meat species identification but are time consuming and require highly skilled personnel. Thus, rapid and robust methods are needed for meat species identification. Spectral analysis techniques are rapid tools which can be used to classify and quantify different animal species in the meat products. Chemometric is data handling tool which can analyze the complex spectral data.

*Scope and approach:* This review discusses major spectral analysis techniques suitable for meat species identification. The advantages of different data pre-processing and multivariate analysis techniques are also discussed. The spectral properties or fingerprints of the reference and analyte samples have also been summarized.

*Key findings and conclusions:* Various spectral analysis techniques have been used for meat species identification. Some studies revealed the importance of spectral analysis techniques for correct classification of different meat products according to the meat species present in them. However, there are some technical limitations of these methods, and to provide a robust solution to the meat industry, a comprehensive research should be done on these techniques with due consideration of all the limitations and process variables.



## 1. Introduction

Meat and meat products contain essential nutrients of high biological values thus are important in human nutrition. The consumption of meat products has been increasing in developed as well as in developing countries (Henchion, McCarthy, Resconi, & Troy, 2014). However, the higher growth rate in meat industry leads to some malpractices or frauds in the meat supply chain especially in the processed meat products (Meza-Márquez, Gallardo-Velázquez, & Osorio-Revilla, 2010; Rahmati, Julkapli, Yehye, & Basirun, 2016) because processing (deboning, mincing, chopping, emulsification etc.) removes the external morphological features of a muscles, and in the absence of bones and their anatomical differences it is difficult to identify the meat species in the processed meat products (Sentandreu & Sentandreu, 2014). Meat frauds mean the substitution of actual ingredients from some cheaper quality or abundantly available ingredients to make more profit or in some cases to make meat products more acceptable in terms of sensory appeal. Meat species fraud means the substitution of one class of meat from another class of meat or undeclared meat from some animal species (Zając, Hanuza, & Dymińska, 2014). These substitutions are questioned by the consumers, health organizations, food safety regulators, etc due to one or another reason. Some animal species are banned as an edible ingredient in some countries e.g. horse in the USA (Boyacı et al., 2014). The consumption of some animal species is forbidden due to social taboo (religious beliefs) e.g. pork in Muslim and Jewish communities (Nakyinsige, Man, & Sazili, 2012), dog in Muslim and Buddhism (Soares, Amaral, Mafra, & Oliveira, 2010). Some animal species or their parts are not considered good for health e.g. murine species (contain more infectious agents), game horses (contain veterinary drug phenylbutazone), infected neurological tissues (Rahmati et al., 2016) etc. Moreover, the consumers want a meat products for which they are paying actually, they do not want a rat meat in place of beef or mutton with the same cost.

Several meat frauds have been found during the last decade. In Europe, the undeclared horse meat was found in 61% of the tested beef products (BBC, 2013). Moreover, in this survey the pork DNA was also detected in the frozen beef burgers from several Irish and

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British supermarkets (Lohumi, Lee, Lee, & Cho, 2015). In some cases, 100% substitution of beef with horse meat was detected in the processed beef products. In the USA, the meat products were found to contain additional meat species, even some samples were mislabeled in its entirely (Kane & Hellberg, 2016). In the South Africa, undeclared meat species were detected in 68% of the tested processed meat samples (Cawthorn, Steinman, & Hoffman, 2013). In Malaysia, around 78% samples were detected with false declaration as well as the presence of undeclared meat species was also found (Chuah et al., 2016). Similar situations of meat frauds are present in the meat supply chain around the world.

The regular meat frauds result in the loss of confidence and trust among the consumers, health organizations, and food safety regulators. Thus, there is a need of proactive meat safety management system at each level of meat supply chain in order to identify these frauds and respond promptly to prevent any potential hazard (Houghton, Kleef Van, Rowe, & Frewer, 2006; Yeung, Yee, & Morris, 2010). The labeling with the nutritional and compositional information is also an integral part of this management system which ensure that the correct information is provided on the final meat products (Barnett et al., 2016). However, a methodology (detection tools) is required to generate this information by the manufacturers and to validate this information by the government and meat inspection authorities (analyzing, assessing, and certifying) (Damez & Clerjon, 2013). An economical and rapid detection without much physical and chemical pre-processing is mandatory to inspect a large number of samples within a short time duration (Lohumi et al., 2015).

Ballin (2010) and Ballin, Vogensen, and Karlsson (2009) reviewed the methods which were used for meat species detection in different meat products. These methods include biochemical methods, immunological methods, molecular methods, etc. The polymerase chain reaction (PCR) is a molecular method which identifies a particular DNA or RNA from a complex sample, and is most specific. However, this method is time consuming, laborious as well as costly chemicals are required to process the samples (Boyacı et al., 2014; Zając et al., 2014). Thus, the research on the spectroscopic methods are now gaining priority due to rapidness and minimum pre-processing requirements. The near-infrared (NIR), mid-infrared (MIR), infrared (IR), Fourier-transform infrared (FTIR), ultraviolet–visual (UV-VIS), and Raman spectroscopy are types of spectroscopic methods which can be applied to detect the meat species in various processed meat products on the basis of spectral analysis (Fig. 1). These waves are reflected, transmitted, or absorbed by the food samples thus provide a spectrum based on the product's properties. The chemometrics is the data handling tool which ensure the accuracy of a particular spectral method. The spectral analysis has also been used for the quality analysis of fresh and processed meat products. However, this review specifically discusses the applications of different spectroscopic techniques for meat species fraud detection in various meat products.

## 2. Spectral analysis techniques and principle of meat species identification

The differences in the basic components i.e. water, proteins, fatty acids and/or lipids of meat products from different meat species are main factors which cause deviation of a spectra at a particular wavelengths. These components possess functional groups which contain certain chemical bonds (O–H, C–H, N–H, C=O, hydrogen bonds etc.). The irradiation of IR light on these bonds results in vibrational responses which are recorded as a spectrum. In the visible spectroscopy, the discrimination is based on the color values i.e. presence of different pigments and differences in their intensities. The chemometrics is applied to extract the correct information from these complex spectra to identify different meat species qualitatively and quantitatively.

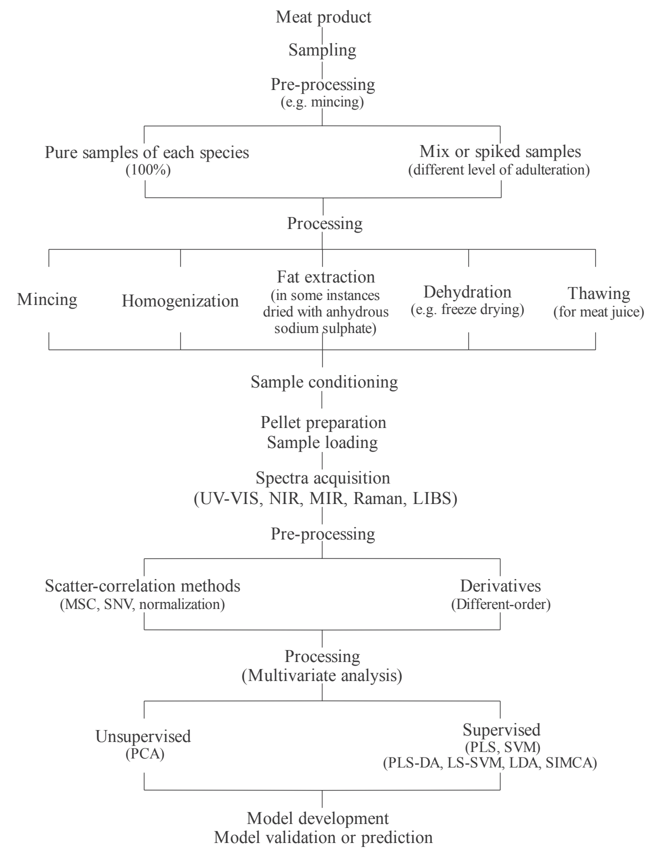


**Fig. 1.** The process of spectroscopic method development for meat species identification (one or more steps may not be used as per the requirement; in some studies, both scatter-correlation method and taking derivative have been used; similar processing conditions are necessary for validation of the developed models, for more information see the text).

Infrared spectroscopy contains spectra in the near- (12,500-4000 $cm^{-1}$) and mid-infrared (4000-400 $cm^{-1}$) region. A typical NIR spectrum consists of several bands of absorption peaks, valleys, shoulders and their overlapping signals (Mamani-Linares, Gallo, & Alomar, 2012). In NIR region, the fundamental O–H, C–H and N–H bonds produce vibration and combination overtones. MIR spectrum shows stretching, bending and wagging motions of functional groups (C–C, C–H, O–H, C=O, and N–H) which provide more details of the molecules. These bands are produced when radiation frequency or wavelength vibrates at the same frequency of specific molecular bond of a functional group present in the samples. In simpler words, the bonds in the organic molecules in the meat products absorb or emit infrared light when their vibrational state changes. Hence, the biochemical constituents of a meat sample decides the amount and frequency of absorbed, reflected or transmitted light, and this is the basis to identify the chemical constituent of that sample. The MIR region between 4000 and 1500 $cm^{-1}$ is functional group region and between 1500 and 500 $cm^{-1}$ is fingerprint region. In functional group region, the O–H and N–H (3700-2500 $cm^{-1}$), C–H (3300-2800 $cm^{-1}$), C–H stretching in aldehyde (2900-2700 $cm^{-1}$) can be detected. The triple bonds (C≡N, C≡C, C=C=C) are characteristics of 2700–1850 $cm^{-1}$ region while double bonds (C=C, C=N, C=O) are characteristics of 1950–1450 $cm^{-1}$ region of the spectrum. The NIR has the advantage over MIT like it penetrates much deeper in the