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Review

# Hyperspectral imaging and multispectral imaging as the novel techniques for detecting defects in raw and processed meat products: Current state-of-the-art research advances

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ABSTRACT

In order to achieve rapid detection of defects and to increase the industrial operating efficiency of products without compromising their quality attributes, hyperspectral imaging (HSI) and multispectral imaging (MSI), as the technologies that simultaneously provides spectral and spatial information of foodstuffs, are now widely applied for inspecting both raw and processed meat items. This review first discusses the principles of HSI and MSI. Recent developments and applications of HSI and MSI directed at the raw and processed meat industry are then discussed. The advantages and disadvantages of hyperspectral imaging and its future prospects are also covered. This review provides a detailed overview of the recent efforts devoted to HSI and MSI technologies for evaluating the quality and safety of different meat products and the probability of its widespread application. Hyperspectral imaging, as a promising tool in developing rapid and non-invasive, is capable to detect defects in raw and processed meat products.



**Contents**



## 1. Introduction

Meat is a very important source for humans to obtain essential amino acid, vitamins and many other nutritional compounds (Smet & Vossen, 2016). Besides the meat processing techniques of cooling

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(Feng, Drummond, Zhang, & Sun, 2013a,b, 2016, 2014a,b,c; Feng & Sun, 2014; Feng & Li, 2015), drying (Başlar, Kiliçli, Toker, Sağdiç, & Arici, 2014), and packaging (Saenmuang, Ai-Haq, Makino, Kawagoe, & Oshita, 2012) to enhance the products' quality, rapid and reliable detection methods are also highly desirable for the fast-paced production in the processing environment (Kamruzzaman, Makino, & Oshita, 2015a). From the consumer point of view, the visual appearance, textural properties, colour and the palatability of fresh meat are the key purchasing criteria (Elmasry, Barbin, Sun, & Allen, 2012). These parameters, in the traditional way, are usually determined by sensory, mechanical, or instrumental analyses (Cheng, Nicolai, & Sun, 2017). Most of such methods are quite time-consuming, tedious, laborious, invasive, and environmentally unfriendly (Kamruzzaman et al., 2015a). It is desirable to inspect all the meat attributes at once so the chemical composition, physico-mechanical attributes, and the sensory properties can be accurately predicted.

Hyperspectral imaging (HSI) and multispectral image spectroscopy (MSI), as innovative technologies, offer numerous advantages over conventional analytical methods, with the most significant being, without doubt, its accurate prediction ability. For example, they successfully predicted in meat the moisture content (Kamruzzaman, Makino, & Oshita, 2016a), fat content (Lohumi et al., 2016), tenderness (Naganathan et al., 2016), pH (Barbin, Elmasry, Sun, & Allen, 2012a), colour (Christiansen, Carstensen, Møller, & Nielsen, 2012; Kamruzzaman, Makino, & Oshita, 2016b; Sharifzadeh, Clemmensen, Borggaard, Støier, & Ersbøll, 2014), water-holding capacity (Kamruzzaman, Makino, & Oshita, 2016c), and microbial spoilage (Dissing et al., 2013; Panagou, Papadopoulou, Carstensen, & Nychas, 2014; Tao, Peng, Gomes, Chao, & Qin, 2015; Tsakanikas, Pavlidis, & Nychas, 2015, Tsakanikas, Pavlidis, Panagou, and Nychas, 2016) in meat. Such an accurate prediction can provide many advantages to the meat processing industry, such as the rapid classification of meat quality levels (Barbin, Elmasry, Sun, & Allen, 2012b), cutting product detecting time (Kamruzzaman, Makino, & Oshita, 2015b), reducing numerous laboratory (Tao & Peng, 2014), and potentially substituting the traditional chemical-dependent analytical methods with online instrumental equipment (He, Wu, & Sun, 2013).

Chemometric analysis is a very useful procedure to analyse the hypercube data that are generated by hyperspectral imaging (Cheng, Sun, & Cheng, 2016). Since the data generated by hyperspectral imaging systems are extremely vast, chemometric methods are utilised to reduce high dimensionality to the most meaningful dimension (generating a simplified data) without compromising the information power of the original image (Elmasry et al., 2012). Furthermore, the collinear information, light-scattering, stripe, and random noise produced by hyperspectral equipment may include redundant data, which should be eliminated to increase the predictive ability of the process (Chen, Sun, Cheng, & Gao, 2016). For spectral pre-processing techniques, multiplicative scatter correction (MSC), standard normal variate (SNV), Fourier transform (FT), and wavelet transforms (WT) are usually used to calibrate the original spectra (Chen et al., 2016; Cheng et al., 2016). For quantitative assessment, both linear analyses [principal component regression (PCR), multiple linear regression (MLR), partial least squares regression (PLSR)], and nonlinear analyses [(artificial neural network (ANN), and support vector machine (SVM)] are used to establish the correlation between spectral data and real quantities or concentrations of the products measured by ordinary laboratory assessments (such as colour, texture, microbial enumeration, and so on) (Chen et al., 2016; Elmasry et al., 2012).

To date, numerous researchers have focused on evaluating meat quality and safety by using hyperspectral imaging (Chen et al., 2016; Cheng et al., 2017; Hassoun & Karoui, 2017; Iqbal, Sun, & Allen, 2014; Xiong, Sun, Zeng, & Xie, 2014). All these documents accentuate an unyielding interest in the application of hyperspectral imaging as an efficient detection method that can be applied to the different types of food products. However, a few reviews are available focusing on the applications of HSI and MSI on both raw and processed meat products. Therefore, the aim of this paper is first to comprehensively review the latest applications focusing on raw and processed meat products. Future trends in relation to hyperspectral imaging of meat products are also discussed.

## 2. Principles and processes of HSI and MSI

The spectral ranges in HSI are from circa 200 nm (ultraviolet range) to 2500 nm (NIR range). As the primary structural components of majority of food molecules contain functional groups like C—H (organic compounds), N—H (proteins and amino acids), and O—H (water, carbohydrate and fat), these groups are closely related to the overtones and combination bands in NIR spectral region (Pu, Feng, & Sun, 2015; Pu & Kamruzzaman et al., 2015). Spectral ranges of 380–800 nm or 400–1000 nm are the most comprehensively utilised in food analysis applications (Elmasry et al., 2012). HSI combines imaging with spectroscopy, which simultaneously provides physical and geometrical features of the product (shape, size, appearance, colour) and the chemical compositions of the product by spectral analysis. A hyperspectral imaging system mainly is composed of five parts, namely a light source and a light sensor, a spectrograph, a lens, a translational sample stage, and a computer supported with software to control the image acquisition process [Fig. 1(a)]. The light source, where the halogen lamp is commonly used in the reflectance and transmittance imaging systems, is of great importance in HSI systems (Nanyam, Choudhary, Gupta, & Paliwal, 2012). It is an optical probe to detect physical structure and chemical components of the products (Pu et al., 2015; Pu & Kamruzzaman et al., 2015). For fluorescence and Raman imaging, a higher intensity light unit, for instance, ultraviolet-A (Vargas et al., 2005), laser beam (Noh & Lu, 2007), and light-emitting diode (Yang et al., 2012), is required to supply sufficient exciting energy. Herein, for samples with a round shape, an indirect light source can be used to put round the edge of a hemispherical diffuser to provide a uniform illumination environment (Baranowski, Mazurek, & Pastuszka-Wozniak, 2013).

With regard to the spectrograph, it is used to disperse the captured light into a certain continuous spectral range onto a two-dimensional charge-coupled device (CCD) detector array (Pu et al., 2015; Pu & Kamruzzaman et al., 2015). In this way, the amount of light to that reaches the camera is limited and controlled by the spectrograph and so the wavelength range of the image is determined (Kamruzzaman et al., 2015a). Furthermore, it can scan the range which contains ultraviolet, visible and near-infrared regions, overcoming the limitation of the identification (Chen et al., 2016). Lens, regarded as a part of image units, is a standard zoom lens to ensure adequate focus and delineate the field of view (Kamruzzaman et al., 2015a). The translational stage is movable and the following spatial dimension of the acquired scene is then formed with the sample moving forward by the translational stage (Elmasry et al., 2012). The computer supported with software to control the image acquisition process is mainly used for further analysis of targets (Chen et al., 2016). The parameters controlled by different computer software generally include exposure time, motor rate, wavelength range, storage of acquired images and development of calibration models from stored data.

The output of the hyperspectral imaging is a stack of images representing intensities at different wavelengths bands, i.e. two-dimensional spatial information (x rows, y columns) and one