



Review

Hyperspectral imaging, a non-destructive technique in medicinal and aromatic plant products industry: Current status and potential future applications

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ABSTRACT

Due to an increasing trend for on-line monitoring of food quality, safety and authenticity, the use of rapid, reliable and non-contact devices in food industry has attracted considerable attention. Hyperspectral imaging (HSI), based on spatially resolved spectroscopy, is such a non-destructive technique. Fusion of this technique with other measurement instruments would be a promising approach to gather various types of information on the appearance, nature, and special traits of food products and ingredients including aromatic/medicinal plants. These materials play an important role in flavouring of food products and traits of supplements and pharmaceuticals. Their quality and authenticity are key properties, which can be assured by using spectroscopy techniques, including HSI. This paper reviews (a) the basic principles of HSI, (b) scientific work on HSI and aromatic/medicinal plants, as well as their related products such as spices and (c) the existing and future applications in the related industry.

1. Introduction

In the last decades, aromatic/medicinal plants, as well as their related products or derivatives such as spices, extracts, essential oils or tinctures have been widely used either by home consumers or pharmaceutical industry due to their desirable sensory, therapeutic and nutritional properties (WHO, 2003; Zhang et al., 2012b). In almost all cases, these products require storage and transport before and after processing prior to use. These products are produced all around the world and are thus cultivated in different geographical locations, and processed under different post-harvest conditions. These factors have resulted in the introduction of different quality indicators. In addition, storage conditions can affect quality and freshness, leading to quality loss and staleness (Cummins et al., 2009). Some of these products have high economic value making them prone to common issues such as contamination and adulterations (Kiani et al., 2016a). Therefore, quality and safety assurance of these products play a critical role in the industry. Food quality is a key product factor, determining the economic value which influences the international food trade. On the other hand, food safety problems may bring substantial and irreversible influences upon human health (Feng and Sun, 2012). Quality evaluation of plant products is commonly divided into qualitative (authentication

or quality grading of material) and quantitative (analysis of certain biomarkers/active substances or adulterants) (Reich and Schibli, 2006). The composition of plant materials is extremely complex, adding difficulty to their analysis. Furthermore, because of differences in geographical origin, harvest conditions, and post-harvest state, compositional variability of the plant material has to be considered as well. Methods that have been used for quality evaluation in the plant material trade and industry can be divided into two main groups: (a) conventional (mainly destructive) techniques and (b) novel and new (non-destructive) techniques. Both groups will be discussed in the following sections.

1.1. Conventional techniques

- A large number of approaches are commonly used for quality analysis and authentication of aromatic/medicinal plant products including: chromatography methods (liquid chromatography-mass spectrometry (LC/MS), high performance liquid chromatography (HPLC), high performance thin-layer chromatography (HPTLC), gas chromatography (GC), gas chromatography-mass spectrometry (GC-MS), proton transfer reaction mass spectrometry (PTR-MS)), spectroscopy methods (proton nuclear magnetic resonance (NMR), and

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Table 1

Some recent applications of traditional techniques in aromatic/medicinal plants' quality and safety assessment.

Method	Type	Objective	Reference(s)
Chromatography	LC-MS	Analysis of antioxidant and antimicrobial activities for five species of <i>mentha</i>	Moldovan et al. (2014)
		Exploiting saffron metabolome for determining its authenticity	Rubert et al. (2016)
		Determination of phenolic compounds in extracts of Amazonian medicinal plants	Faccin et al. (2017)
		Detection of saffron adulteration with gardenia extracts through the determination of geniposide	Guijarro-Díez et al. (2017)
	HPLC	Determination of catechins, caffeine and gallic acid in green tea	Wang et al. (2000)
		Determination of phenolic compounds, purine alkaloids and theanine in Camellia species	Peng et al. (2008)
		Determination of total phenolic and flavonoid contents of the <i>Cariniana domestica</i> leaves	Janovik et al. (2011)
		Analysis of chemical compounds of leaf of Vitex megapotamica	De Brum, et al. (2013)
	HPTLC	Analysis of bioactive constituents of saffron	Chaharlangi et al. (2015)
		Geographical classification of Italian saffron based on chemical constituents	D'Archivio et al. (2016)
		Quantitative analysis of Picrocrocin and Crocetins of saffron	Ahmad Pathan et al. (2009)
		Analysis of Herbal Products	Mohammad et al. (2010)
	GC/GC-MS	Analysis of bioactive components on the Leaves extract of <i>Stylosanthes fruticosa</i>	Paul John Peter et al. (2012)
		Analysis of different rganic crude extracts from the local medicinal plant	Salim Al Hashmi (2013),
Determination of volatile components of saffron		Sereshti et al. (2014)	
Characterization of the most aroma-active components in a representative aromatic extract from Iranian saffron		Amanpour et al. (2015)	
PTR-MS	Classification of gas chromatographic fingerprints of saffron	Aliakbarzadeh et al. (2016)	
	Analysis of bioactive compounds present in different extracts of an endemic plant	Casuga et al. (2016)	
	Determination of volatile organic compounds, catechins, caffeine and theanine in Jukro tea	Jeon et al. (2017)	
	Authenticity of nutmeg		
Spectroscopy (Lab-based)	UV-Vis	Rapid and direct volatile compound profiling of black and green teas	Yener et al. (2016)
		Quality control of saffron	Nenadis et al. (2016), Masi et al. (2016)
		Measurement of caffeine in coffee beans	Belay et al. (2008)
		Classification of coffees	Souto et al. (2010)
	NMR	Characteristics of Picrocrocin, Safranal and Crocins	Jouki et al. (2012)
		Differentiation of tea varieties	Palacios-Morillo et al. (2013)
		Characterisation of an Aromatic Plant-based Formula	Bunghez et al. (2013)
		Influence of drying conditions on Crocins, Picrocrocin and Safranal contents	Cossignani et al. (2014)
		Quality assessment of the saffron samples (quantitative analysis of synthetic colorants in adulterated saffron)	Masoum et al. (2015)
		Exploration of phytochemical constituents present in <i>Amphiroa anceps</i>	Antonisamy and Sankara Raj, (2016)
Molecular-Biological	SCARs	Quality control of ginseng commercial products	Yang et al. (2006)
		Quality control of herbal material	Van der Kooy et al. (2009), Heyman and Meyer (2012)
	PCR	Identify secondary plant compounds	Leiss et al. (2011)
		Discrimination of vegetable oils	Popescu et al. (2015)
	SCARs	Quality control of saffron and evaluation of saffron adulteration	Ordoudi et al. (2015), Petrakis et al. (2015)
		Detection adulterant bulking agents in commercial saffron	Javanmardi et al. (2011), Babaei et al. (2014), Torelli et al. (2014)
	PCR	Authentication of dried commercial saffron	Marieschi et al. (2012)
		Identification of <i>Smallanthus sonchifolius</i> in Herbal Tea	Žiarovská1 et al. (2016),
	PCR	Detection and quantify safflower adulteration in saffron samples	Villa et al. (2017)

UV-Vis spectroscopy), as well as molecular-biological methods (sequence-characterized amplified regions (SCARs) and polymerase chain reaction (PCR)) (Smillie and Khan, 2012; Cappellin et al., 2013; Sereshti et al., 2014; Amanpour et al., 2015; Petrakis et al., 2017). Table 1 shows some recent applications of these techniques for the analysis of aromatic and medicinal plants. Although these traditional analytical techniques are readily available as standard reference methods, they are often destructive, time-consuming, labour intensive, expensive, and require professional knowledge and operation skills (Dale et al., 2013; Cheng and Sun, 2014; Zhang et al., 2017). Due to these drawbacks, these techniques are often unsuitable for fast and on-line quality analysis especially in large scale and industrial applications (Feng and Sun, 2012; Kiani et al., 2016b).

1.2. Novel and green techniques

Over the last few decades, researchers have been exploring non-destructive and fast techniques for monitoring quality and safety

indices of several medicinal and aromatic plant products, such as e.g. computer vision (CVS) (Chen et al., 2008; Ariana et al., 2006a; Wang et al., 2010; Wang et al., 2015a), electronic nose systems (e-nose) (Carmona et al., 2005; Bhattacharya et al., 2008; Borah et al., 2008; Yu et al., 2009a; Yang et al., 2009; Rodríguez et al., 2009; Chen et al., 2013; Kiani et al., 2017), electronic tongue systems (e-tongue) (Ivarsson et al., 2001a; Palit et al., 2009; Ouyang et al., 2011; Heidarbeigi et al., 2016), and near infrared spectroscopy (NIRS) (Zalacain et al., 2005a,b; Anastasaki et al., 2009; Ribeiro et al., 2011; Zhang et al., 2012a; Barbin et al., 2014; Ordoudi et al., 2014). While these techniques present certain advantages over traditional techniques, they also have some shortcomings. CVSs only work with visible bands (RGB) in the form of color images and cannot provide information on chemical composition and spectral characteristics (Cheng and Sun, 2014). E-nose and e-tongue systems have been involved with sensor poisoning, drift, and sensitivity (Ghasemi-Varnamkhasti et al., 2012a). NIRS cannot always provide the whole spectral bands data and visual characteristic information which is regularly required and is important in food assessment (Khulal et al., 2017). Thus, these systems have some limitations in

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