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Trends in Food Science & Technology 43 (2015) 63–82

TRENDS IN FOOD SCIENCE & TECHNOLOGY

Review

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# Recent developments of green analytical techniques in analysis of tea's quality and nutrition

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Public attention in tea quality and nutrition has increased significantly in recent decades, due in part to changes in consumer behavior and the gradually increasing consumption of tea. Demand for high quality tea products obviously requires high standards of quality assurance and process control; satisfying this demand in turn requires appropriate analytical tools for analysis of tea quality and nutrition. Green analytical tool, as an alternative to conventional analysis methods, has the desirable features in terms of operating speed, ease-of-use, minimal or no sample preparation, and avoidance of sample destruction. This paper reviews recent developed technologies, such as near infrared (NIR) spectroscopy, electronic tongue (E-tongue), electronic nose (E-nose), computer vision, integration of multiple sensors, and latest research efforts to assess tea quality and nutrition. Particularly, we have reviewed some relevant data processing algorithms involved in each green analytical tool. Finally, we provided the technical challenges and outlook for the application of these green analytical technologies in analysis of tea quality and nutrition.

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http://dx.doi.org/10.1016/j.tifs.2015.01.009


## Introduction

Tea is known to be one of the most popular beverages in the world with a long history, which has formed its own culture in a specific area (Soylak, Tuzen, Souza, Korn, & Ferreira, 2007). It is extremely season-specific and climate dependent with different categories all over the world, which is manufactured by a series of processes producing a range of variants from green, nonfermented tea to black fermented tea. Of the approximately 2.5 million metric tons of dried tea manufactured, only 20% is green tea and less than 2% is oolong tea (Graham, 1992). Thus we can find various tea in the market, almost all of which are from the top leaves of the plant *Camellia sinensis* (Bhattacharyya, Seth, Tudu, Tamuly, Jana, Ghosh, Bandyopadhyay, Bhuyan, *et al.*, 2007a, 2007b). Tea also provides a dietary source of biologically active compounds that helps to prevent a wide variety of diseases, including catechins, flavonols, anthocyanin, depsides etc., which contributes to its beneficial medicinal properties. Wherein, catechins are believed as an anti-inflammatory and neuroprotective agent, help to regulate food intake and have an affinity for cannabinoid receptors, which may suppress pain and nausea and provide calming effects (Mandel *et al.*, 2005). Other active components such as enzymes, carbohydrate, vitamins and minerals, also exert an important effect on improving health and even curing diseases. A growing body of evidence suggests that moderate consumption of tea may protect against several forms of cancer, cardiovascular diseases the formation of kidney stones, bacterial infections, and dental cavities (Trevisanato & Kim, 2000), and substantial references worldwide have interpreted the role of tea in nutrition and disease (Bhoo Pathy *et al.*, 2010; Deka & Vita, 2011; Dominguez-Perles, Moreno, Carvajal, & Garcia-Viguera, 2011; Hsu, 2005; Mukhtar & Ahmad, 2000; Setiawan *et al.*, 2001; Weisburger & Chung, 2002; Zhou, Wang, *et al.*, 2009). Therefore, it is of great significance to analyze tea quality and nutrition during tea processing in order to keep high quality of the commercialized tea products. In addition, owing to the high value of tea products, the adulteration issue often happens, and as a result, abominable fake brand of tea products flood the market and illegal merchants capitalize on the nondescript counterfeits for huge profits. Consequently, it is also important to distinguish certified products from counterfeited ones.

However, tea quality and nutrition analysis is a complex problem due to the presence of innumerable compounds and their unpredictable reaction mechanism, and numerous national and international authorities are setting criteria for quality attributes (Airy, 1999). Wet chemical analysis and human panel test are the most elementary and commonly used conventional methods for tea analysis. For example, colorimetric measurements and titration using potassium permanganate were used for measurement of total polyphenol content (Wang, Helliwell, & You, 2000; Zuo, Chen, & Deng, 2002). But both of them are time-consuming, laborious, and non-green methods. Human panel test for assessing tea quality is carried out by some skilled 'tea tasters', thus the practical evaluation of tea quality is entirely subjective, leading to inaccurate results owing to adaptation, fatigue and state of mind (Yang *et al.*, 2006). In the last few decades, increasing interest on the use of accurate screening techniques or instrumental methods to determine quality characteristics of foods has been of great interest to the food industry. These techniques are subjective, highly repeatable, reproducible and environmentally friendly. But some of them are not purely instrumental methods, for example, gas chromatography–mass spectrometry (GC–MS) and high performance liquid chromatography (HPLC) are applied to determine the internal components in tea (Del Rio *et al.*, 2004; Pongsuwan, Bamba, Yonetani, Kobayashi, & Fukusaki, 2008), which involves expensive instrumentation and time-consuming sample preparation using solvents as well as analysis (from a few to several minutes). Therefore, they are not suitable to be used or adopted by the industry for rapid analysis or online monitoring of quality.

In order to enable food industries to rapidly respond to the changing demands of both consumers and the market, there is the immediate need of appropriate analytical tools for tea quality and nutrition analysis. Green analytical techniques are the use of analytical chemistry techniques and methodologies that reduce or eliminate the use of hazardous chemical reagents or solvents (de la Guardia, 2010). These techniques are easy-to-use, and can be used in-line or at-line to obtain results quickly. With the technological improvement in green analytical tools, there are an increasing number of researches with respect to the utilization of some advanced green analytical tools in tea quality analysis; however, there has been no systematic article survey on green analytical tools in tea quality analysis. Therefore, we intended to give a general view of green analytical techniques that have been recently employed for tea quality analysis, including NIR spectroscopy, E-tongue, E-nose, computer vision, and data fusion technology by integrating multiple sensors. Besides, we focused more on exploiting the corresponding data preprocessing and modeling algorithms in their studies, and at the end of this review, we provided the technical challenges and future outlook for these green analytical tools, and also a summary was given.

## Specific green analytical techniques

### Near infrared spectroscopy

Near infrared (NIR) spectroscopy is a spectroscopic method that uses the near infrared region of the electromagnetic spectrum ranging from 780 nm to 2500 nm. It is based on the principle that different chemical bonds in organic matter absorb or emit light of different wavelengths when the sample is irradiated. Organic matter in samples has distinct spectral fingerprints owing to the specific vibrational frequencies of chemical bonds, which are determined by the mass of the constituent atoms, the shape of the molecule, the stiffness of the bonds, and the periods of the associated vibrational coupling. The most prominent absorption bands are associated with molecular overtone and combination vibrations of some hydrogen-based functional groups, such as O–H, C–H, C–O, N–H etc. (Weyer, 1985; Workman Jr., 1996). More complicated molecules have many bonds, and vibrations can also be conjugated, resulting in two possible vibration patterns: stretch vibration and bent vibration. Therefore, specific absorption of organic molecules in NIR region can express the chemical composition of the material being analyzed (Alishahi, Farahmand, Prieto, & Cozzolino, 2010; Rohman & Man, 2010). Moreover, different modes in NIR spectroscopy measurement are employed for different samples, and the commonly used modes are transmittance and diffuse reflectance (Huang, Yu, Xu, & Ying, 2008). Liquid samples, such as tea infusion, often adopt transmittance mode in glass or quartz chamber with different sizes; while solid samples, like tea leaves or powder, usually use diffuse reflectance with carrier accessories (Cen & He, 2007).

Generally, the whole evaluation procedure consists of the following four steps: (1) spectral data acquisition; (2) spectral data preprocessing; (3) calibration models developing with a set of samples; and (4) models validating with a set of independent samples. Organic molecules in samples have their specific absorption patterns in NIR region, which indicates chemical composition of the analyzed materials. However, the molecular overtone, and combination bands observed in NIR region are typically very broad, leading to complex spectra. Thus, it can be difficult to assign specific features to specific chemical components. Multivariate calibration techniques are often employed to extract useful information and eliminate redundant information (Alishahi *et al.*, 2010). Spectral data preprocessing should be implemented initially in order to eliminate noise and baseline shift from instrument and background,