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Review

Electronic noses and tongues to assess food authenticity and adulteration

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A R T I C L E I N F O

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A B S T R A C T

Background: There is a growing concern for the problem of food authenticity assessment (and hence the detection of food adulteration), since it cheats the consumer and can pose serious risk to health in some instances. Unfortunately, food safety/integrity incidents occur with worrying regularity, and therefore there is clearly a need for the development of new analytical techniques.
Scope and approach: In this review, after briefly commenting the principles behind the design of electronic noses and electronic tongues, the most relevant contributions of these sensor systems in food adulteration control and authenticity assessment over the past ten years are discussed. It is also remarked that future developments in the utilization of advanced sensors arrays will lead to superior electronic senses with more capabilities, thus making the authenticity and falsification assessment of food products a faster and more reliable process.
Key findings and conclusions: The use of both types of e-devices in this field has been steadily increasing along the present century, mainly due to the fact that their efficiency has been significantly improved as important developments are taking place in the area of data handling and multivariate data analysis methods.

1. Introduction

The rigorous, objective assessment of food authenticity has become of paramount importance, mainly due to the problem of adulteration (a legal term meaning that a food product fails to meet legal standards, *i.e.* noncompliance with health or safety regulations). Unfortunately, major food adulteration events seem to occur with worrying regularity, and there is no doubt that the concern for this fact will increase concurrent with population pressures. Therefore, there is a growing need for nonstop vigilance, which means research and development of rapid analytical and detection techniques in the field of food authenticity assessment. In this sense, two approaches are emerging as promising tools in the attempt to efficiently address this issue (Borràs et al., 2015), namely: electronic noses (e-noses) and electronic tongues (e-tongues). Both are sensor systems, but they do not look at the same features when applied to a given liquid sample; the former are in contact with its headspace, whereas the latter are immersed in the sample (Cosio, Benedetti, Scampicchio, & Mannino, 2015).

Electronic noses are devices which mimic the sense of smell. These instruments generally consist of an array of sensors utilized to detect and distinguish odors in complex samples and at low cost. These characteristics make them very useful for different applications in many areas, including food industry. In this context, a lot of papers have appeared in the present century in the literature describing the use of e-noses in food analysis processes.

On the other hand, e-tongues are analytical devices (groups of sensors) mainly employed to identify and classify the tastes of several chemical substances in beverages or liquid phase food samples, their mode of operation "imitating" the human sense of taste. E-tongues can be utilized to characterize multicomponent mixtures for both qualitative and quantitative purposes, hence the increasing attention they are receiving in the field of food analysis, as shown in recent surveys in the literature.

In the last years, many reviews on e-noses and/or e-tongues fundamentals and applications in several research areas have been published in the literature, mainly in the field of food analysis (e.g., Boeker, 2014; Ciosek & Wróblewski, 2011; del Valle., 2012;; Escuder-Gilabert & Peris, 2010; Kiani, Minaei, & Ghasemi-Varnamkhasti, 2016; Loutfi, Coradeschi, Mani, Shankar, &

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Balaguru Rayappan, 2015; Peris & Escuder-Gilabert, 2009; Rodríguez-Méndez, 2016; Śliwińska, Wiśniewska, Dymerski, Namieśnik, & Wardencki, 2014; Tahara & Toko, 2013; Vlasov, Legin, Rudnitskaya, Di Natale, & D'Amico, 2005). This paper will then focus on the employment of both e-noses and e-tongues in food authenticity assessment (and hence the detection of food adulteration). After briefly commenting the fundamentals of this type of devices, the most relevant contributions in this field over the past ten years will be dealt with. In this sense, and as a general overview, in a recent chapter of a book (Karoui, 2012) devoted to food authenticity and fraud, Karoui discusses the relative potential and ease of application of different technologies for the confirmation of food quality and adulteration. Special emphasis is put on e-nose technology (combined with chemometric tools) as a promising technique in this field. Some examples clearly show that there has always been a risk of fraud, since food became a trade object. The chapter also describes the different kinds of food adulteration and related fraudulent practices, with details of detection methods, including the use of e-noses. In a similar way, Cappozzo (2013) has presented recent analytical innovations for quality assurance in the detection of food adulteration through the utilization of e-noses. Panchariya, Anga, Kumar, Prasad, and Sharma (2013) have reported an overview of the applications of e-noses and e-tongues for classification and authentication of beverages. As far as e-tongues are concerned, Śliwińska et al., (2014) have also dealt with their potential in the authenticity and falsification assessment of foodstuffs.

2. General concepts

Major components of both electronic devices are widely described in the literature and their details are therefore omitted in this paper. Nevertheless, in this section the general concepts of the electrochemical methods applied in these e-systems are briefly mentioned in order to help potential readers to better understand the principles behind these techniques.

2.1. Fundamentals of e-noses

E-noses are designed to detect and distinguish among complex odors (from food samples) making use of a sensor array, which is composed of broadly tuned (non-specific) sensors that are treated with different odor-sensitive (bio)chemical substances. An odor stimulus now yields a characteristic fingerprint (or smellprint) from the group of sensors. These patterns from known odors are then utilized to generate a database that is subjected to multivariate analysis, so that unknown odors can therefore be identified and classified. Nevertheless, it should be remarked that, in recent years, the usual sensor types used for e-nose instruments have been considerably improved by new technologies developed in this field, and either a set of gas sensors or mass spectrometry (or their combination) are commonly utilized for this purpose. Anyway, and in a broader sense, electronic noses basically consist of three elements (Fig. 1a), namely: (i) a sample handling system, (ii) a detection system, and (iii) a data processing system.

The basis of electrochemical gas sensor operation involves interactions between gaseous molecules and sensor-coating materials which modulate electrical current passing through the sensor, detectable by a transducer that converts the modulation into a recordable electronic signal (Rodríguez-Méndez, 2016), which is then amplified and conditioned. Thereafter, a digital converter transforms the signal from electrical (analog) to digital, and finally a computer microprocessor reads the digital signal and displays the output after which the statistical analysis for sample classification or recognition is performed.

There are many different types of electrochemical sensors (e.g. metal-oxide gas sensors, metal-oxide semiconductor field effect transistors, acoustic wave gas sensors, electrochemical gas sensors, quartz crystal microbalance sensors, conducting polymer gas sensors, surface acoustic wave devices, field-effect gas sensors, fiber-optic gas sensors, and others) and many different types of sensor-coating materials which are classified according to additive doping materials, the type and nature of the chemical interactions, the reversibility of the chemical reactions and running temperature. A summary of the types and mechanisms involved with some common gas sensor technologies is contained in the work of Wilson and Baietto (2009).

Transducer recording devices of various types in electronic-nose sensors are ranked according to the nature of the physical signal they measure. The most common methods make use of transduction principles based on electrical measurements, including

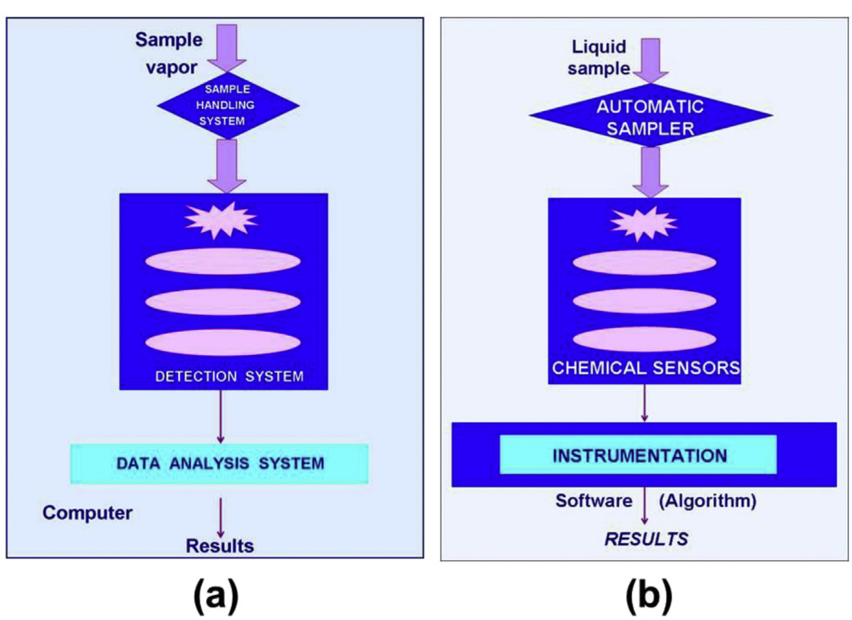

Fig. 1. Schematic representation of (a) an electronic nose, and (b) an electronic tongue.