UFT Academic Publishing House, Plovdiv

Food Science and Applied Biotechnology
e-ISSN: 2603-3380

Journal home page: www.ijfsab.com
https://doi.org/10.30721/fsab2020.v3.i1

OPEN ACCESS

Review

"Electronic tongue" in the Food Industry

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Abstract

"Electronic tongue" (e-tongue) is instrumental system are designed to crudely mimic human taste sensory organs and are composed of an array of sensors. Complex data sets from „e- tongue" signals combined with multivariate statistics represent rapid and efficient tools for classification, recognition and identification of samples, also for the prediction of concentrations of different compounds. A wide variety of sensors can be employed into the design of these instrumental systems, especially that of "e-tongues", offering numerous practical applications. In this study are review, characteristics of sensors and possibilities „e-tongue" applications in the food industry. Practical applications: The "e-tongue" can be used in various applications, including on quality control in the food industry and pharmacy.

Keywords: sensory analysis, taste sensitivity, e-tongue, food quality

Abbreviations:

ISEs – Ion-Selective Electrodes
ISFETs – Ion-Sensitive Field-Effect Transistors
NT2-IM – dual-channel ion-meter

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Article history:
Received 7 June 2018
Reviewed 4 August 2018
Accepted 13 December 2018
Available on-line 19 March 2020

https://doi.org/10.30721/fsab2020.v3.i1.74

Introduction

The taste is an expression of the reaction between certain substances and the corresponding sensory cells. They represent a certain type of chemical sensitivity to soluble substances in the mouth. The taste (taste sensitivity) is of biological importance for determining the condition of the food taken, as well as the effect on the digestive process. Unlike other senses, taste is characterized by a very good adaptation. In eating we perceive a complex combination of taste perceptions. It has been found that there are four basic tastes - sweet, bitter, sour and salty. According to Ayurveda Indian teaching about food and health, to these four are added savouriness. In 1985, scientists recognize the existence of this fifth basic taste, „umami" named, and the fact that our language has special receptors, distinguishing this taste. Each of these basic tastes plays an important role for humans. Saltiness, which is caused mainly by ionic materials, is a good indicator of electrolyte balance in foods; sourness, which is produced by organic acids, signals decomposition; bitterness, which is often considered distasteful, prevents intake of poisonous materials; umami, which is evoked by some amino acids, provides information on the presence of amino acids; sweetness, which is produced by sugars or sugar alcohols, has a role in indicating nutrient sources (Kobayashi et al. 2010). It is possible, however, that food may cause mixed feelings of salty and bitter, for example. The taste sensation in some cases may depend on the concentration of the substance. The identification of a taste is widely used to assess the condition and quality of food and beverages. In many applications, the assessment methods are based on organoleptic analysis and a qualitative description level. From another perspective, here participate mental apparatus of the individual, in which sensitivity are processed and analyzed in order to make an appropriate conclusion on the performance levels of the products. Using the methods of expert assessments and the corresponding procedures to achieve consistency, somewhat obtained assessments can be made objective. An example is sensory organoleptic analysis in the food industry, which is one of the most commonly used methods (Maximo et. al. 1997). Based on the idea of reliable measurement and identification of qualitative indicators and the development of sensor technology, consisting of the compilation of new sensitive materials, it logically follows the development of the so-called "e-tongue". The main advantages of the method are the possibilities for fast, low-cost and automated analysis. The purpose of this work is to systematize the application of the "e-tongue" in the food industry and to present opportunities it holds for the control of food products.

The „Electronic tongue"

The taste or smell of products manufactured in the food industries can be of vital importance to the commercial success of the product. The expectations of consumers regarding the quality of products in these fields are continually increasing as a result of greater range of choices in the marketplace, which emphasizes product quality. The term "e-tongue" or "taste sensor" arises in 1995 like the idea of "electronic nose" but it is a matter of taste sensitivity. The name "e-tongue" is taken in analogy to the human, which contains receptor molecules that can trigger nerve signals when confronted with different types of tastes. The "e-tongue" consists of an array of sensors react when immersed in various chemical solutions. An „e-tongue" is an instrument which comprises of electrochemical cell, sensor array, measurement control module and appropriate pattern recognition system, capable of recognizing simple or complex soluble non-volatile molecules which forms a taste of a sample.

Types and characteristics of taste sensors. When designing an "e-tongue" system similar to an "e-nose", different types of sensors can be used. A wide variety of chemical sensors can be employed: electrochemical (potentiometric, voltammetric, impedimetric), optical or enzymatic sensors (biosensors). The use of electrochemical measurements for analytical purposes has found a vast range of applications in food industry and pharmacy. All commercially systems are based on potentiometric measurements, especially interest has been on Ion-Selective Electrodes (ISEs). Besides ISEs, Ion-Sensitive Field-Effect Transistors (ISFETs) are nowadays also gaining greater interest as sensors forming „e-tongue" sensor arrays

(Winquist et al. 2002, 2005; Ciosek and Wróblewski 2011). The features of „e-tongue" sensors are different from those of traditional chemical sensors: instead of high selectivity in substance detection, „e-tongue" sensors have an overall selectivity that provides for global information on the analyzed solution (Wei et al. 2013; Kalit et al. 2014).

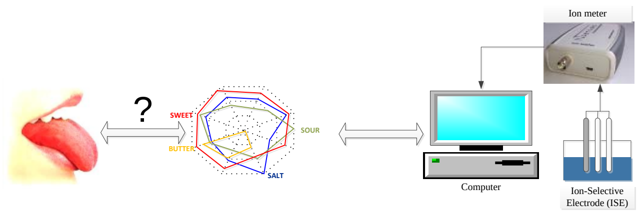

Figure 1. "E-tongue" system with application for analysis of foods and beverages - principle scheme

Figure 1 presents a principle scheme of an „e-tongue". A reference ion-selective electrode Ag/AgCl is included in the measuring cell. The system also contains dual-channel ion-meter (NT2-IM) and specialized software with the ability to constantly measure the measurement and customize the calibration from 1 to 5 points. Interface for data collection and processing developed in the Matlab program. With rapid growth in technology and computation technics, started more often standardized identification through sensors. „E-tongue" technology has generated a lot of interest recently because of its versatile applicability in terms of identification and classification of processed food and consumer items. The emerging non-destructive food quality analysis techniques are capable of evaluating the finished products quality by analyzing their sensory outputs which may be in the form of flavor, odor, color, texture and taste one of the signs of this care is development and optimization of monitoring and control methods of both, food materials and their processing. Valuable source of information about quality of the particular product is the analysis of volatile compounds based on either classic sensor analysis or application of instrumental methods (Bartlett et al. 1997; Magro et. al. 2019). The received results of „e-tongue" can be seen as a promising technique in qualitative and quantitative analysis for different types of solutions.

Application of "e-tongue" in the food industry. Food and beverage analysis is an intensely developing field, which in line with modern quality, safety and healthy food. The objectives of food analysis may be different: establishment of legality and compliance of labelling, quality assessment, component content determination, authentication and authentication and identity, research and development, etc. Developed methods for determining indicators such as chemical composition, structural and physical properties are based on a specific analytical approach and the results of experiments and analysis of the data obtained. These methods are for the most part resource-intensive, destructive, and the results depend on the expertise and expertise of the analyst. There are express immunological and genetic methods that can replace microbiological methods, but they are too costly and again require highly qualified personnel and specialized equipment (Wardenck et al. 2013). There is a wide range of "e-tongue" applications, for example: continuous quality control of products; detection of pollutants in the water; detection of substances and compounds at low concentrations difficult to distinguish from humans (Baldwin et al. 2011; Jiang et al. 2018)

Application in dairy industry. Studies have shown that multiple applications of the "e-tongue" in the dairy industry, such as: classification of samples, determination of compounds responsible for aroma decomposition, microbial quality, mastitis detection, determination of antibiotic residues, milk adulteration et al. The main purpose of „e-tongues" is qualitative analysis, and thus several works on the application of „e-tongues" devices in recognition, classification or identification of milk and fermented milk samples have been reported. Winquist et al. (2005) in they work used „e-tongues" in dairy industry process. The results of this study showed that milk from different sources and thus also of different quality, can be mutually separated. These studies have shown possibility of monitoring in the incoming milk, indicating that an „e-tongues" could be a valuable security measure to prevent economic loss suffered due to the contamination of a large volume of raw milk (Judal et al.; Dias et. al. 2009). Winquist et al. (1998) described an „e-tongues" measurement principle based on pulsed voltammetry, used to follow the deterioration of quality of the milk stored at the room temperature, arising on the grounds of microbial growth. The obtained data were subject to Principal Component Analysis and to compile prediction models, Artificial Neural Networks were used, being proven to satisfactorily predict the course of bacterial growth in milk samples (Winquist et al. 1998). Mottram et al. (2007) in their paper demonstrated that a multi-sensor system can distinguish between the control and clinically mastitic milk samples. The results showed that a multisensor system offers a novel method for mastitis detection and discrimination between milk samples coming from cows suffering from clinical mastitis and those coming from healthy animals.

Application in meat industry. Kaneki et al. (2004) introduced an „e-tongue" with potentiometric solid state electrodes for pork freshness evaluation. Pt, CuS, and Ag2S electrodes were selected as solid-state electrodes to detect the organic compounds such as putrescine and dimethyl sulphide which were produced during the initial stage of putrefaction on meat. Xinzhuang Zhang et al. (2015) in their study, different breeds of beef had different chemical composition and flavor. PCA analysis showed an easily visible separation of different breeds of beef and proved that „e-tongue" system could make the rapid identification of different breeds of beef according to the flavor values. In addition, "e-tongue" could be also used to predict the chemical composition based on the regression formula between chemical composition and flavor.

Assessment of coffee and tea. In the quality control of coffee, organoleptic characteristics are a determining factor for its quality, therefore, they are a significant factor in highlighting coffee defects that could negatively affect its aroma and smell. Control over coffee production is identical and strongly dependent on the historical traditions and cultural knowledge of those involved in the process. Often, diseases such as fungal and other crop diseases and the need for chemical treatment have a significant impact on the quality of the finished product. Another important factor is the climatic and geographic conditions. The traditional way of grading through tasters is much slower, more expensive and subjective. In research on Almario et al. (2014) for an „e-tongues" elaborated from a polymeric sensors array was used to classifying coffee samples. The electrochemical responses to the analyzed samples were collected through an electronic instrument of multichannel measures which was able to differentiate a group of substances with different taste properties. The classification and analysis of graphics shows an excellent separation of clusters representing each studied sample.

Wine production application. The „e-tongues" comprising an array of 23 potentiometric chemical sensors was developed and applied to discrimination and qualitative analysis of Italian wines. The „e-tongues" were capable of distinguishing the wines from different geographical areas as well as the wines of the same vintage but produced at different vineyards (Legin et al. 2003). Furthermore, the „e-tongues" could quantify taste and flavour parameters of the wine in terms of complex scores typically produced by human tasters. For wine, Parra et al. (2006) studies custom-designed „e-tongues" with a hybrid sensor array consisting of voltammetric electrodes modified chemically with different electro-active substances (polymerized aqueous solution of pyrrole using six doping agents) was used to discriminate and recognize among 12 Spanish red wines based on denomination, origin, grape variety and vintage due to the cross-selectivity of the electrodes.

Conclusions

The „e-tongues" can be used for a wide variety of analytical applications including quality control and product matching. Just like a human taster, „e-tongues" can be used for both quantitative and qualitative applications. Quantitative applications include sensory score correlation and the measurement of the concentration of components. Qualitative sensory applications include the determination of the origin and quality of raw materials, consistency of finished products, and taint-free products. Other applications of the technologies include shelf life measurements and the evaluation of any interactions between packaging and the product.

Acknowledgements

This research was supported in part by the framework of the 06/18-H "Monitoring and analysis of fresh meats based on multisensory data fusion, mechatronic modules and intelligent algorithms for deciding", financed by the Science Fund of the University of Food Technologies- Plovdiv.

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