Review Article

Application of E-Nose and E-Tongue for Quality Assessment of Food Products: A Review

Kamakshi Sharma*, Neeraj Gupta, Anju Bhat, Jagmohan Singh, Julie D Bandral, Monika Sood, Monica Reshi, and Gurveen Kour

Division of Post Harvest Management, Sher-e-Kashmir University of Agricultural Sciences and Technology-Jammu, Chatha-180009, Jammu and Kashmir

Abstract

Electronic tongue (e-tongue) and Electronic nose (e-nose) are analytical systems that have been utilised individually in the food and pharmaceutical industries as quality evaluation tools. The E-nose and E-tongue are created to mimic the human olfactory and taste systems, both of which have sensors that interact non-selectively with flavour molecules to generate some form of electronic signals. The sensations of smell and taste produce as a result of several particular and non-specific molecular recognition can be used as an analytical tool in many industries to assess the quality of food, beverages and chemical products. Regular chemical analysis would be expensive and take a long time, therefore it is not a practical solution. A potential alternative solution is rapid, affordable, in-situ and online testing using an electronic nose and electronic tongue.

Keywords: E-nose, e-tongue, analytical systems, non-destructive and mimics

***Correspondence**
Author: Kamakshi Sharma
Email: kamakshisharma.hp@gmail.com

Introduction

Nowadays, all food products need to be monitored, in order to ensure an acceptable level of quality and safety. The requirement for precise and quick quality assessment is expanding in response to the rising demand for high-quality food items. Consumers prefers safe, nutritious and high-quality food products, and are willing to pay more than the normal price, as long as they receive guarantees about the food they purchased [1]. It is quite difficult for conventional detection techniques to characterize most food because of the complexity of their compositions and constructions. Traditionally, the detection methods for food quality mainly consist of 3 aspects: traditional chemical analysis, high-end instrumental analysis, and sensory evaluation by human panel. However, there are certain limitations to both high-end instrumental analysis and classical chemical analysis, including the need for labor- and time-intensive sample preparation, instrument uniformity, and unreliable sample detection. Therefore, it is highly important to create alternative techniques for the accurate and economical evaluation of food products in real time. Much research has been done recently to replace the human senses with "artificial sensors," or devices that transmit signals related to the sensory qualities. This is because improvements in sensor technology, electronics, biochemistry, and artificial intelligence have made it feasible to create instruments like the E-nose and E-tongue that can measure and characterize quality elements like flavour, colour, and chemical components of various items.These techniques combine artificial taste, smell, and colour sensors, and they could produce more accurate results more quickly than using just one sensor. The main benefits include high sensitivity, ease of construction, affordability, quick analysis [2].

E Nose

The e-nose is an analytical tool that typically consists of a number of sensors that react to the gases and vapours produced by the sample. Each component of the sensor array, which comprises of non-specific sensors treated with a variety of chemical substances, measures a particular quality of the chemical being detected. The term "electronic nose" referred to methods that were used to identify and measure volatile substances in a product's headspace, such as gas chromatography-mass spectrometry (GC-MS), gas chromatography-flame ionization detector (GC-FID), and solid-phase micro extraction-mass spectrometry (SPME-MS), in conjunction with multivariate statistical analysis [3].

E-nose sensors

In the EN technology, a wide variety of sensor types are used. Gas sensors can be categorized in to a number of different categories depending on the materials used for sensing, including metal-oxide semiconductors (MOS), conducting polymers (CP), Optical Sensors quartz crystal microbalance (QCM) sensors [4].

Metal oxide sensors (MOS)

MOS is the most widely utilized sensor type in E-Nose instruments due to its compatibility for wide range of gases. Metal-oxides or semi-conducting materials, such as tin dioxide, zinc oxide, iron oxide, titanium dioxide, nickel oxide, and cobalt oxide, are the most popular MOS sensing materials. Alumina is one type of ceramic substrate onto which the sensing compounds are coated. The device typically also features a heating element [5]. The practical application for MOS-based ENs include quality assurance, process monitoring, ageing, geographic origin, adulteration, contamination, and food and beverage deterioration. MOS are divided into two main groups according to their responses react with different gases, n-type sensors and p-type sensors. The working principle of n-type sensors is based on the reactions between the oxygen molecules in the air and the surface of these sensors and the p-type sensors respond to oxidizing gases, remove electrons and produce holes. According to the specifications supplied by certain prominent MOS sensor companies, such as Figaro and Nemoto, the detection threshold of commercial MOS sensors varied between 1 ppm and 1000 ppm. Due to their excellent sensitivity and selectivity, these sensors are extensively used in numerous EN applications. The MOS sensor array's main drawback is that it must operate at temperatures between 150 and 400 °C. As a result, they require a lot of energy, and it takes them a while to heat up before they are ready for readings [6].

Conducting polymers (CP) sensors

CP consist of conducting particles like polypyrrole, polyaniline, and polythiophene scattered across an insulating polymer matrix. A prior study suggested that, behind MOS sensors, CP gas sensors may be the second most popular gas sensors. CP sensory array frequently comprise of distinctive polymers with different reversible physicochemical properties and sensitivity to groups of volatile compounds to provide a broad specificity that overlaps with that of organic vapors. Under ambient temperature conditions, these organic vapours adhere to and interact with the polymer surface, changing the resistance. CPs have good sensitives (threshold >10 ppm) to many food-derived volatile compounds. Since CP gas sensors don't require additional heating to function, they consume a lot less electricity than metal-oxide gas sensors. By copolymerization or structural derivations, the structure of CP molecular chains can be altered. Additionally, the robust mechanical qualities of CPs make them more durable and transportable. The main drawback of CP sensor arrays is that they are susceptible to humidity. Due to their affordability, quick response to odorants, and resistance to sensor poisoning, conducting polymers are a trusted sensor type utilized in numerous EN devices for the medical, pharmaceutical, food, and beverage industries [7].

Optical Sensors

Optical sensors are suitable for use in several EN applications due to their quickness, resilience to electromagnetic interference, and compactness [8].Optical sensors monitor fluorescence, optical layer thickness, colorimetric dye response, light polarization, and absorbance. Any of these optical changes are utilized to detect scents in the environment. Due to their extreme sensitivity, optical sensors can distinguish between specific chemicals in mixtures. However, the electronics and software that link to it are sophisticated and expensive. Due to the relatively limited lifetime of these sensors, the cost of detection would also rise. Due to their extreme sensitivity, optical sensors can distinguish between specific chemicals in mixtures. However, the electronics and software that link to it are sophisticated and expensive. Due to the relatively limited lifetime of these sensors, the cost of detection would also rise [9].

Quartz crystal microbalance (QCM) sensors

QCM sensors are preferred as an EN component in variety of applications including medicine, environment monitoring, security and food safety because of their sensitivity, convenience, rapidness, stability and portability. These sensors have a sensitive coating on their surface. The released gas from the atmosphere is drawn in by a selective barrier on the crystal surface, increasing the overall mass [10]. The mass shift on the gold surface of the QCM causes frequency to decrease as a result. As a result, QCM sensors measure frequency changes on the quartz crystal resonator to determine tiny variations on the sensor surface. QCM based biosensors are frequently used to analyze scents because to their affordability, ease of manufacturing, and capacity for quick analysis [11].

Application of E-nose

Applications of E-nose have been expanding in a variety of research areas, with a focus on quality assurance and process observation for the food industry.

Applications	Sensing Element	References
Identification of optimum fermentation time for black tea	MOS	[12]
Detection of aroma from green tea at different storage times	MOS	[13]
Botanical origin identification and quality determination of honey	MOS	[14]
Rapid detection of meat spoilage	MOS	[15]
Identify the freshness of the bell pepper samples during storage	MOS	[16]
To detect unspoiled and spoiled milk, bacterial contamination in milk	Conducting polymer	[17]
Identify the early infestation of Bactrocera dorsalis in citrus samples.	MOS	[18]
For early spoilage detection of potato and onion during post-harvest storage	MOS	[19]

Electronic tongue

The electronic tongue is an analytical tool that uses a variety of non-selective chemical sensors with partial specificity to various solution components and a suitable pattern recognition instrument, capable of identifying the quantitative and qualitative composition of both simple and complex solutions [20]. The sensors of an e-tongue are immersed into a sample to measure its soluble components and global characteristic response signals of the taste substances. These sensors have the characteristics of low selectivity, high cross-selectivity, and statistical analysis of the outputs from multiple sensors. Sending the relevant signals to a signal processing system for pattern recognition analysis. As a result, numerous researchers used e-tongue, a quick, impartial, and inexpensive substitute for the human tongue [21].

Taste sensors

A wide range of chemical sensors, including electrochemical (potentiometric, voltammetric, amperometric, impedimetric, and conductimetric), optical, mass, and enzymatic sensors have been used in the construction of the sensor array for e-tongues (biosensors)[22]. Potentiometric and voltammetric sensors are among the chemical sensors frequently used for an e-tongue.

Potentiometric Sensors

The most popular e-tongue sensors are potentiometric chemical sensors. The voltage difference between the working electrodes and the reference electrode is measured by potentiometric sensors. The electrolyte solution in which the reference electrode is immersed ensures consistent voltage in the reference sensor [23]. The valuable feature of employing potentiometric sensors is that they can choose from a wide variety of membranes for their electrodes, including both more and less specific membranes. Potentiometric sensors can therefore measure a huge variety of chemical substances in liquids [24]. One of the main drawback of potentiometric sensors is that they are sensitive to temperature. The components of the solution may be absorbed by the membrane, which may change how the charge is transferred. In order to reduce the effect, the temperature must be managed and the electrodes must be cleaned with solvents.

Voltammetric sensors

Voltammetry is an extremely effective analytical technique, due to features such as its very high sensitivity, versatility, simplicity and robustness. The basic idea is that to analyze the characteristics of the samples both qualitatively and quantitatively, electrochemical voltammetry is used to place the multi-sensor array in the solution to be measured, add the step-potential to the working electrode, and measure the polarization current of various solutions. Cycle, conventional large pulses, and multi-frequency pulses are the three main types of step-potential added to the voltammetry e-tongue (VE-tongue) [25]. The VE-tongue has a low detection limit, high signal-to-noise ratio, excellent sensitivity, and selectivity for multi-component measurements. This method, however, is only useful for samples where oxidation-reduction reactions take place [24].

Applications of E-tongue

Applications	Principle of detection	References
Categorizing olive oils made from a single cultivar of olive	Potentiometric Sensors	[26]
Distinguishing the honey produced in each state of the United States	Potentiometric Sensors	[27]
Recognizing the differences between commercial wines and beers	Potentiometric Sensors	[28]
Measuring the amount of sugar in solutions	Potentiometric Sensors	[29]
To determine the amounts of argan oil that have been diluted with sunflower oil	Voltammetric sensors	[30]
Evaluation of flavour, recognition of flavour, and chemical compositions in relation to flavour in beef	Voltammetric sensors	[31]
Analyzing the quality of milk adulterated with urea	Voltammetric sensors	[32]
Perform a quantitative examination of the spring water's quality indicators.	Voltammetric sensors	[33]

Conclusion

The use of the electronic nose and electronic tongue to assess food qualities. Additional developments in sensor technology, E-nose and E-tongue systems, and multivariate data analysis techniques will open up a wide range of intriguing and exciting possibilities for monitoring, automating, and controlling food processing systems. Overall, the combination of the e-nose and e-tongue are very effective analytical instruments that are affordable, quick, and accurate. In addition to being suited for both in-line and off-line measurements, e-nose and e-tongue are also highly helpful for tracking the quality of the final product and monitoring food processing. Future advances in the use of improved e-nose and e-tongue devices will therefore result in greater capabilities of electronic sensing instruments as well as faster and more reliable quality inspection of food and agricultural products.

References

[1] Kealesitse. B, Kabama. I. O. 2012. Exploring the influence of quality and safety on consumers' food purchase decisions in Botswana. International Journal of Business Administration, 2012, 3(2):.90.

[2] Apetrei. C, Apetrei. I. M, Villanueva. S, De Saja. J.A, Gutiérrez Rosales. F, Rodriguez-Mendez. M. L. Combination of an e-nose, an e-tongue and an e-eye for the characterisation of olive oils with different degree of bitterness. Analytica chimica acta, 2010, 663(1): 91-97.

[3] Zou. Y, Wan. H, Zhang. X, Ha. D, Wang. P. 2015. Electronic nose and electronic tongue. In Bioinspired Smell and Taste Sensors, 2015, 19-44.

[4] Wilson. A. D, Baietto. M. Advances in electronic-nose technologies developed for biomedical applications. Sensors, 2011, 11(1): 1105-1176.

[5] Burgués. J, Marco. S. Low power operation of temperature-modulated metal oxide semiconductor gas sensors. Sensors, 2018, 18(2): 339.

[6] Berna. A. Metal oxide sensors for electronic noses and their application to food analysis. Sensors, 2010, 10(4): 3882-3910.

[7] Slater. J. M, Paynter. J, Watt. E. J. Multi-layer conducting polymer gas sensor arrays for olfactory sensing. Analyst, 1993, 118(4): 379-384.

[8] Posch. H. E, Wolfbeis. O. S. Optical sensor for hydrogen peroxide. Microchimica Acta,1989, 97(1): 41-50.

[9] Esfahani. S, J. A. Covington. Low cost optical electronic nose for biomedical applications. Proceedings. Multidisciplinary Digital Publishing Institute Proceedings, 2017, 1(4): 589.

[10] Huang. X, Bai. Q, Hu. J, Hou. D. A practical model of quartz crystal microbalance in actual applications. Sensors, 2017, 17(8): 1785.

[11] Wasilewski. T, Szulczyński. B, Kamysz. W, Gębicki. J, Namieśnik. J. Evaluation of three peptide immobilization techniques on a qcm surface related to acetaldehyde responses in the gas phase. Sensors, 2018, 18(11): 3942.

[12] Bhattacharya. N, Tudu. B, Jana. A, Ghosh. D, Bandhopadhyaya. R, Bhuyan. M. Preemptive identification of optimum fermentation time for black tea using electronic nose. Sensors and Actuators B: Chemical, 2008, 131(1): 110-116.

[13] Yu. H, Wang. Y, Wang. J. Identification of tea storage times by linear discrimination analysis and back-propagation neural network techniques based on the eigen values of principal components analysis of E-nose sensor signals. Sensors, 2009, 9(10): 8073-8082.

[14] Huang. L, Liu. H, Zhang. B, Wu. D. Application of electronic nose with multivariate analysis and sensor

selection for botanical origin identification and quality determination of honey. Food and bioprocess technology, 2015, 8(2): 359-370.

[15] Kodogiannis. V. S. A rapid detection of meat spoilage using an electronic nose and fuzzy-wavelet systems. In Proceedings of SAI Intelligent System Conference, 2016, 1:521-539.

[16] Chen. H. Z, Zhang. M, Bhandari. B, Guo. Z. Evaluation of the freshness of fresh-cut green bell pepper (Capsicum annuum var. grossum) using electronic nose. LWT, 2018, 87: 77-84.

[17] Poghossian. A, Geissler. H, Schöning. M. J. Rapid methods and sensors for milk quality monitoring and spoilage detection. Biosensors and Bioelectronics, 2019, 140: 111272.

[18] Wen. T, Zheng. L, Dong. S, Gong. Z, Sang. M, Long. X, Luo. M, Peng. H. Rapid detection and classification of citrus fruits infestation by Bactrocera dorsalis (Hendel) based on electronic nose. Postharvest Biology and Technology, 2019, 147: 156-165.

[19] Ghosh. A, Ghosh. T. K, Das. S, Ray. H, Mohapatra. D, Modhera. B, Ghosh. D, Parua. S, Pal. S, Tiwari. S, Kate. A. Development of Electronic Nose for early spoilage detection of potato and onion during post-harvest storage. Journal of Materials NanoScience, 2022, 9(2): 101-114.

[20] Wadehra. A, Patil. P. S. Application of electronic tongues in food processing. Analytical Methods, 2016, 8(3): .474-480.

[21] Schlossareck. C, Ross. C. F. Electronic tongue and consumer sensory evaluation of spicy paneer cheese. Journal of food science, 2019, 84(6):1563-1569.

[22] Biniecka. M, Caroli. S. Analytical methods for the quantification of volatile aromatic compounds. TrAC Trends in Analytical Chemistry, 2011, 30(11): 1756-1770.

[23] Winquist. F, Krantz-Rülcker. C, Lundström. I. Electronic tongues and combinations of artificial senses. Sensors Update, 2002, 11(1): 279-306.

[24] Winquist. F. Voltammetric electronic tongues–basic principles and applications. Microchimica Acta, 2008, 163(1): 3-10.

[25] Ivarsson. P, Krantz-Rülcker. C, Winquist. F, Lundström. I. A voltammetric electronic tongue. Chemical Senses, 2005, 30(1): 258-259.

[26] Dias. L. G, Fernandes. A, Veloso. A. C, Machado. A. A, Pereira. J. A, Peres. A. M. Single- cultivar extra virgin olive oil classification using a potentiometric electronic tongue. Food Chemistry, 2014, 160: 321-329.

[27] Escriche. I, Kadar. M, Domenech. E, Gil-Sanchez. L. A potentiometric electronic tongue for the discrimination of honey according to the botanical origin. Comparison with traditional methodologies: Physicochemical parameters and volatile profile. Journal of Food Engineering, 2012, 109(3): 449-456.

[28] Nery. E. W, Kubota. L. T. Integrated, paper-based potentiometric electronic tongue for the analysis of beer and wine. Analytica Chimica Acta, 2016, 918: 60-68.

[29] Da Costa Arca. V, Peres. A. M, Machado. A. A, Bona. E, Dias. L. G. Sugars quantifications using a potentiometric electronic tongue with cross-selective sensors: Influence of an ionic background. Chemosensors, 2019, 7(3): 43.

[30] Bougrini. M, Tahri. K, Haddi. Z, Saidi. T, El Bari. N, Bouchikhi. B. Detection of adulteration in argan oil by using an electronic nose and a voltammetric electronic tongue. Journal of Sensors, 2014.

[31] Zhang. X, Zhang. Y, Meng. Q, Li. N, Ren. L. Evaluation of beef by electronic tongue system TS-5000Z: Flavor assessment, recognition and chemical compositions according to its correlation with flavor. PLoS One, 2015, 10(9): 0137807.

[32] Li. L. A, Yu. Y, Yang. J, Yang. R, Dong. G, Jin. T. Voltammetric electronic tongue for the qualitative analysis of milk adulterated with urea combined with multi-way data analysis. International Journal of Electrochemical Science, 2015, 10: 5970-5980.

[33] Carbo. N, Lopez Carrero. J, Garcia-Castillo. F. J, Tormos. I, Olivas. E, Folch. E, Alcaniz Fillol. M, Soto. J, Martinez-Manez. R, Martinez-Bisbal. M. C. Quantitative determination of spring water quality parameters via electronic tongue. Sensors, 2017, 18(1): 40.

Publication History

Received	17.01.2023
Revised	03.05.2023
Accepted	05.05.2023
Online	31.05.2023