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An Overview of Applications of Electronic Nose and Electronic Tongue in Food and Dairy Industry

R. Heema, K.S. Gnanalakshmi

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ABSTRACT

The dairy and food industries aims to achieve targeted productivity and very keen on product quality and consumer demand. Due to increasing technological advances, these food and dairy industries gained numerous technological support. Among the diverse development, the usages of E-nose and E-tongue paved the way to handle the production without any kind of deviation. In the food industries product perfection, uniform taste and aroma plays a supreme role because these parameters determine the marketing strategy. The electronic nose (E-nose) is a non-destructive intelligent electronic sensing instrument, which mimics the human olfactory system to detect, discriminate and classify odour samples. E-nose and E-tongue is an electronic tool used as a fast screening method to provide information about the product quality which is not easily done by manual methods as it is a time-consuming process. In this paper, the principle of E-nose and E-tongue and their applications in the dairy and food industries are explained.

Key words: Electronic sensing, Electronic tool, Sensor, Quality analysis, Volatile compounds.

There is a rapid growth in using various electronic tools in food industries as they record and give information about the quality of the product inconsistent manner. Various electronic tools have been designed using sensors that receive and process signals from complex media and numerically delivers the result. These sensors function similarly to human nervous sensors. E-nose is made up of artificial sensors that mimic the human nose olfactory nervous system. After the utilization of E-nose for odor, recognition interest has been raised for the development of E-tongue for taste recognition as it minimizes the time spent for sensory analyses. These devices are pre-programmed and based upon the data the sensors recognize the input signal and deliver the output in numerical form.

Electronic nose (E-nose) and Electronic tongue (E-tongue) - An electronic sensor

E-nose is an analytical device that mimics the olfactory nervous system present in the human nose. This device is equipped with programmed sensors which are capable of analyzing the volatile components present in food samples in a different physical state such as solid, liquid, semi-solid, gaseous stages (Ampuero and Bosset, 2003). This device works by generating an odour profile which is termed as fingerprint or output this odour profile is created by the sensor which makes the interaction between volatile compounds present in the food sample. The collected odour profile data is sent to a data processing system where the output data is compared to the standard odour profile which is pre-programmed for identification of the compound present in the food mixture sample. The operation is based on the changes in the conductivity which means the interaction between volatile compounds is called a conductometric sensor. The schematic representation of E-nose was shown in Fig 1. Among the different types of available sensors, the most common and widely used are MOS (Metal-oxide semiconductor) sensors as they are inexpensive, easy to use and very sensitive. These sensors are more reliable specifically employed in authenticity studies that are based on fast gas chromatography. The major advantages is the short time of detection, precision and analysis of a huge number of samples. The main disadvantage are the constant need for cleaning chromatographic columns (Dymerski *et al*., 2011; Du and Lee, 2002).

E-tongue is an analytical device that mimics the membrane of gustatory cells present in the taste buds of the human tongue through which the information about the food sample is obtained via sensor. The schematic representation of E-nose was depicted in Fig 2. The most common application of E-tongue is to assess the flavor and taste determination. Sweet, salty, bitter, sour and umami (or delicious) are the five basic tastes influencing the overall flavor of food (Lvova, 2016). Different techniques are used for E-tongue which includes potentiometry using an ion-selective electrode (Escuder-Gilabert and Peris, 2010).

Department of Food Safety and Quality Assurance, College of Food and Dairy Technology, Koduvalli, Chennai-600 052, Tamil Nadu, India.

Corresponding Author: R. Heema, Department of Food Safety and Quality Assurance, College of Food and Dairy Technology, Koduvalli, Chennai-600 052, Tamil Nadu, India.
Email: heemaravidrapandian@gmail.com

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Also, E-tongue based on voltammetry is developed and its further developments made it suitable for industrial applications such as monitoring the quality of incoming raw milk, recognize different microbial species also used online in the dairy industry. Baldwin *et al*., (2011) stated that if E-tongue is properly configurated and calibrated it is capable of measuring both qualitative and quantitative composition of multivariate nature of food products.

Principle and concept of electronic nose and electronic tongue

E-nose

Moncrieff in 1961, first attempted to develope instrumental nose to detect odours. In 1964, Wilkens and Hatman reported the first electronic nose based on redox reactions of odorants at an electrode. After 1964, many efforts have

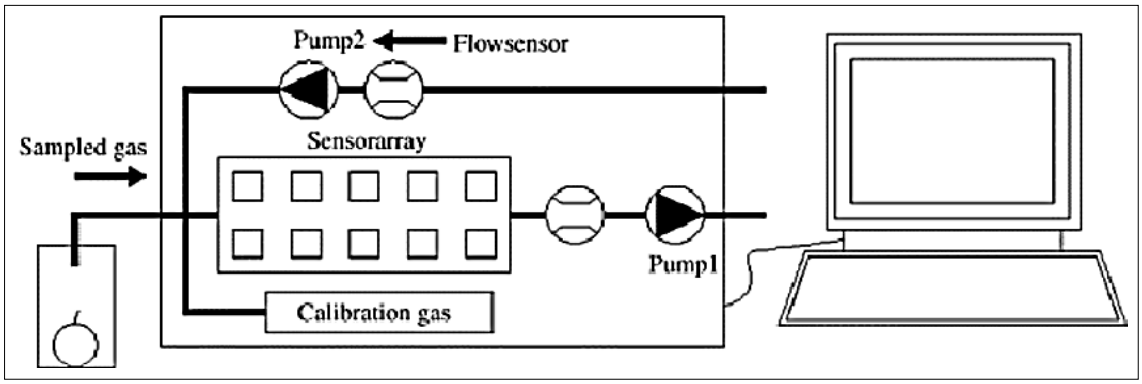

Fig 1: Electronic nose schematic diagram (Gomez *et al*., 2008).

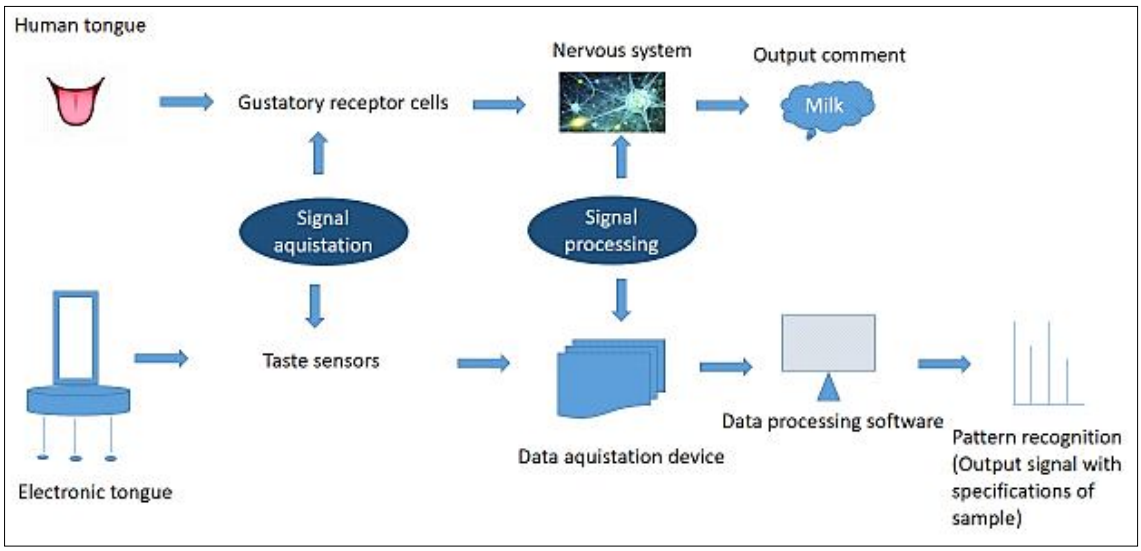

Fig 2: Electronic tongue schematic diagram.

Table 1: Summary of research done using E-nose.

E-nose configuration	Discrimination type	Reference
E-nose made using single semiconductor gas sensor	Determination of fruit ripeness by sensing aromatic volatiles	Benady *et al*., 1995
Electronic sniffer using semi-conductor gas sensors	Assess blueberry quality	Simon *et al*., 1996
Portable E-nose with micro machined resistive sensor arrays	Quality measurement in wine	Aleixandre *et al*., 2008
E-nose machine using Fuzzy KNN algorithm	Identification of fresh-chilled and frozen-thawed chicken meat shelf life	Mirzaee-Ghaleh *et al*., 2020
Metal oxide semiconductor based E-nose	Determination of odor components in Antarctic krill defluoridated hydrolysate before and after Maillard reaction.	Zhang *et al*., 2020

Table 2: Summary of research done using E-tongue.

E- tongue type	Discrimination Type	Reference
Potentiometric E-tongue	Quality and microbial detection in Liquor	Yao *et al*., 2014
Low cost paper-based electronic tongue- A novel sensor matrix	To differentiate mineral content in water sample	Witkowska Nery *et al*., 2015
Voltammetric electronic tongue	Monitoring off-flavours in incoming raw milk	Winquist, 2008
Taste sensor array including 12 sensors with neural networks system	Identification of corn juice	Liu *et al*., 2012
Volummetric E-tongue	Quantification of total polyphenol content in olive oil	Apetrei and Apetrei, 2013

been taken and various research has been focused on the development of specific sensor for the detection of one specific aroma compound. But this attempt has been terminated in 1990 and no further research have been done when it was found that each food matrix consists of more than 6000 compounds contributes aroma. It is impossible to develop such a large quantity of sensors (Gardner and Barlett, 1994). In 1982 a formalised prototype of E-nose was developed which added milestone to this concept by implementing mathematical data based on pattern recognition system which includes fuzzy logic, artificial neural network, *etc* (Li *et al*., 2006). Detection of volatile compounds in the food matrix plays a role in finding food spoilage. E-nose is an odour sensing system that detects and differentiates the aroma volatile compounds and classifies food varieties. E-nose technology has been progressed rapidly due to its ability to include environmentally friendly and low-cost devices (Ampuero and Bosset, 2003) The detection limit of this electronic device depends on certain criteria such as odour impact evaluation. The mechanism of odour detection includes the conversion of volatile compounds existing in the food matrix into electronic signals in the form of digital output. This detection system not only checks the food spoilage also helps in decision-making in various food supply chains. Gardner and Bartlett, (1994) explained the necessary compounds in E-nose which includes:

(1) An aroma delivery system that passes the volatile aromatic compounds to the sensory array system.
(2) Configured sensors chamber usually with fixed temperature and humidity for sample analysis.
(3) An electronic transistor amplifies the converted electric signal from the chemical signal.
(4) A digital converter that converts the analog to digital.
(5) A computer microprocessor process the digital signal and displays the output.

The completion period of one sample depends upon various factors which include the aroma compound being analyzed, sensor material, temperature, humidity, the method used to analyze the result and accuracy. Research done on E-nose was shown in Table 1.

E-tongue

Studies of E-nose is followed by E-tongue which is also an electronic device that consists of a different array of sensors that senses the quality parameters of a food substance like sample condition, state of a process and sensory qualities. It was believed that the first electronic tongue was introduced at the 10th European Conference on Solid State Transducers in 1996 and also the concept of taste sensor were published on the same year (Sehra *et al*., 2004). E-nose and tongue with different sensor array have been commercially available in USA for the past 10 years. The most widely recognized techniques are used in E-tongue are potentiometry, voltammetry and conductometry (Peris and Escuder-Gilabert, 2016). E-tongue is developed by imitating human receptors. The sensors used in E-tongue is equivalent to human nerve sensory system. The sensory array collects the excited signals and transfer the data to the computer, where the processing of data takes place and analysed by suitable software system to find out the sensory information (Yao *et al*., 2014). The data collected from any form of E-tongue sensor device is processed by means of multivariate data analysis (MVDA), mainly by using principal components analysis (PCA). The principle of measurement is based on the potential of an electrode across an ion-sensitive membrane without any flow of current. Research based on E-tongue was listed in Table 2.

Application of electronic nose in the food and dairy industry

E-nose

The food and dairy industries are facing consistent growth in today's world. Dairy products one of the most frequently studied food groups it is a vast sector compressing several dairy products which include fluid milk, frozen dairy products like ice cream, fermented dairy products like curd, yogurt, Yakult, kefir and so many varieties of cheese. As raw milk is a sensitive liquid that should be handled with continuous monitoring throughout the entire production process (Chaudhari and Judal, 2015), Peris and Escuder-Gilabert, 2016). To develop a fermented dairy product the incoming raw milk quality is most important as bacterial load have negative influence on further fermentation process so, it is most important to assess the presence of an antibiotic (Peris and Escuder-Gilabert, 2013, Winquist *et al*., 2005). The mammalian nose consists of several olfactory neurons having the ability to respond to several odorants these neurons stimulate an electrical impulse and transmitted it into the brain likewise e-nose works under the same principle

(Wilson and Baietto, 2009). By using E-nose the various volatile components in food sample are investigated by the use of a different array of sensors which generates and transfer chemical information into an electrical like resistance, voltage, a frequency which is overall called as an odour profile (input signal) to the data processing system where the input fingerprint data is processed and prediction of the volatile component is take placed this processing of signals from the sensor is carried out by a computer via pattern recognition program like principal component analysis (PCA), linear discriminant analysis (LDA) and artificial neural network (ANN)A well-developed sensor array was introduced to carry out various operations and to overcome food processing issues. Metal oxide sensors (MOS), metal-oxide semiconductor field-effect transistors (MOSFET), conducting organic polymer sensors (CP), Piezoelectric sensors, mass spectrometry-based sensors are the various types of sensors used based on the operations to be determined (Tudor Kalit *et al*., 2014). An electronic nose composed of 14 conducting polymer sensors is capable of discriminating between unspoiled milk and milk containing spoilage bacteria such as *Bacillus cereus* or *Staphylococcus aureus*, or yeasts like *Klyveromyces lactis* or *Candida pseudotropicalis* in different concentrations (Magan *et al*., 2001). Wei and Wang (2011) have developed a voltammetric E-tongue composed of five metallic electrodes to detect the residues of six different antibiotics in bovine milk. Qiu *et al*. (2014) attempted on the characterization of strawberry juices both qualitative and quantitative basis which is processed on different ways like microwave pasteurization, steam blanching, high-temperature short time pasteurization, frozen-thawed and freshly squeezed and found that the qualitative predictions based on LDA, E-tongue shows high accuracy with 100% for the original groups and 98% for cross-validation procedure when compared to E-nose which possesses accuracy of 99% for original group and 98% for cross-validation procedure. Shanshan *et al*., (2015) observed that when E-nose and E-tongue are used simultaneously it results in a faster and easiest way for estimating qualitative and quantitative-based parameters in strawberry juices. Peng *et al*., (2015) studied the utilization of electronic nose combined with chemometrics analysis and it was concluded that E-nose configurated with chemometric array sensors could be effectively used to fingerprinting technique for protecting authentication for Chinese liquor. Majcher *et al*., (2015) examined the possibility for verifying and identification of authenticated and imitated polish cheese, oscypek using a solid-phase microextraction-mass spectrometry method and the result of this study demonstrate that SPME-MS when combined with chemometric tool can be use for successful detection of mislabeling in polish cheese. Work done on quality assessment in spice mixture by using metal oxide based E-nose and ion mobility spectroscopy by Banach *et al*., 2012 have concluded that e-nose or ion mobility spectroscopy can be effectively used for quality assessment by headspace detection of volatile compounds and it also stated that e-nose and ion mobility spectroscopy can serve as cost efficient device. Lu *et al*., (2015) conducted a research on differentiating the conventional and hybrid rice variety from one hundred twenty indica rice samples by make use of combinational approaches of electronic tongue and nose. From there research it was concluded that the combined electronic system with locally linear embedding (LLE) based model can be successfully use for the prediction. Food quality and safety is greatly governed by hygiene practices and handling of food during production. In this sense, microbial quality plays a major role for the consumer's safety and health. Food containing pathogenic microbes may lead to foodborn disease outbreaks. An outbreak of salmonellosis from contaminated ice cream is a major example (Falasconi *et al*., 2012). Sensing the aroma is one of the significant parameter which indicates the spoilage of food. Therefore, using E-nose have been successfully implemented in food microbiology. Marin *et al*., (2007) found the detection of fungal spoilage as a measure of ergosterol concentration by using MS-based E-nose and it was revealed that the accuracy of prediction was between 87 and 96% by using MS- based model. It was mentioned by (Ali *et al*., 2020) for quality checking parameters the e-nose could not able to predict the parameter changes in the regression model but E-tongue signals can able to estimate the quality parameters.

E-tongue

In food and dairy industry analysis of specific component in food matrix is still a subject of greater interest especially for scientific communication. For the determination of composition in food involves instrumental techniques such as high performance Liquid Chromatography (HPLC), gas chromatography-mass spectrometry (GC-MS), Mid Infrared (MIR) spectroscopy etc. Although these methods give more specific results but having some drawback such as time consuming, relatively expensive. On consideration of these drawback Bougrini *et al*., (2014) have come up with an innovative analytical technique which involves hybrid e-nose and voltammetric E-tongue and a pattern recognition method for differentiating different pasteurized milk brands and there research gives strong evidence for utilizing this technique especially for monitoring the quality in milk products. Hruskar *et al*., (2009) evaluated the differencing ability of E-tongue for milk and yogurt samples from different producers which results in accurate analysis or monitoring quality. The taste of milk is quantitatively characterized and the output of the sensor shows a high correlation with human sensory expression.

Garcon and co-workers developed a new taste system by coupling surface plasmon resonance imaging (SPRi) with cross-reactive sensor arrays. This simple sensor matrix consists of 11 sensing receptors which effectively discriminate different types of milk samples such as UNT milk, soy milk, pasteurized milk, soy milk with chocolate and rice milk). Additionally SPR system provided information about the

adsorption and desorption parameters of studied components. Adulteration in food leads to decrease the quality and standard. One of the most promising application of E-tongue in food industry was the detection of adulterants in food (Dias *et al*., 2009). Sobrino-Gregorio *et al*., 2018 developed an automatic E-tongue, which includes pulse voltammetry for the detection of adulteration in honey and the developed E-tongue shows efficient discrimination of the different types of honey adulterated with syrup. Another interesting research was done by Bougrini *et al*., (2014) used the combined effect of E-nose system based on 5-TGS (Taguchi Gas Sensor) Sensor and electronic tongue made by using 7-voltammetric electrodes for the detection of adultration in argon oil. Cheese is a dairy product comes in variety of flavours and types with high nutritional properties. Valente *et al*., (2018) developed an E-nose made using piezoelectric quartz sensors and electronic tongue based on potentiometric chemical sensors for analysing the fresh and matured cheeses manufactured from raw and pasteurized cow's milk and the whey which is the by-product of cheese were measured using E-tongue. The result from the analysis showed that E-tongue could efficiently distinguish cheese made from raw and pasteurized milk and also follow the cheese ripening for one week. Discriminating the aging and protein-to-fat ratio in Cheddar cheese using sensory and potentiometric electronic tongue was done by Lipkowitz *et al*., (2018) and Newman *et al*., (2014). It was mentioned that using E-tongue will be cost effective, rapid and sensitive compared to human panellist. It was suggested that e-tongue can be used for regular and online monitoring of cheddar cheese. Xu *et al*., 2019 assessed the qualitative and quantitative measurement of chemical components in tea by using combined signals of E-nose, E-tongue and E-eye with chemometric methods and the result shows 100% accuracy for the qualitative estimation of tea quality grades. Zhang *et al*., (2015) made an attempt in there study to differentiate the breeds of beef which having different chemical composition and flavor. PCA analysis showed an easily visible separation of different breeds of beef and it was suggested that "E-tongue" system results in rapid identification of different breeds of beef according to the flavor values. It was also mentioned their findings that "E-tongue" could be also used to find the chemical composition accurately based on the regression formula between chemical composition and flavour. Haddi *et al*., (2014) stated that successful discrimination can be done when E-nose and E-tongue use together with data fusion technique for the analysis in fruit juice samples. An emerging technology in modern medical science for accessing the human gastrointestinal tract involves wireless swallowable capsule which is a potentiostatic electrochemical sensor operates at 433 MHz, powered by lithium ion cell (Caffrey *et al*., 2015).

Electronic sensor technology is still in its developing phase and commercially available in both software and hardware types and widely used in food industry as a quality control instrument as it shows high accuracy and sensitivity compared to human sensory panel. The limitation for this technology includes loss of sensitivity, sensor drift, abnormal sensory array, usage of short life sensor, mislead in calibration.

CONCLUSION

The application of E-nose and E-tongue in the food and dairy industry is very particular and vast which is based on chemical sensors or hyphenated techniques. The speed analysis, elective screening of a large number of samples made a most acceptable substitute technology to sensory analysis performed by testers. E-nose and E- tongues play a significant role in the resolution of various complex analytical problems. As a result, the utilization of advanced electronic sensing devices with more research on simple configuration and ease of handling still needs much attention for future development.

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