

An Overview of the Food and Dairy Industry's Use of Electronic Nose and Electronic Tongue

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ABSTRACT

The food and dairy industries are particularly focused on customer demand and product quality, and they strive to attain targeted productivity. These food and dairy industries received a lot of technological help as a result of growing technological advancements. The use of E-nose and E-tongue among the various developments made it possible to manage the manufacturing without any form of diversion. Product perfection, consistent flavor, and scent are crucial in the food industry since they dictate the marketing plan. The electronic nose (E-nose) is a non-destructive intelligent electronic sensing device that detects, distinguishes, and categorizes odor samples by imitating the human olfactory system. An electronic tool called E-nose and E-tongue is used as a quick screening method to provide information about the product quality, which is difficult to accomplish using manual methods because they take a lot of time. This essay explains the E-nose and E-tongue principles and their uses in the food and dairy industries.

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

The use of different technological tools in the food industry is expanding quickly since they provide conflicting information about the product's quality. Sensors that receive and analyze signals from complicated media and provide the result numerically have been used in the creation of numerous electronic tools. These sensors work in a manner akin to that of human nerve systems. Artificial sensors that replicate the olfactory nerve system of the human nose make up e-nose. Since E-tongue reduces the time required for sensory analyzes, interest in its development has increased following the use of E-nose for odor recognition. These devices are preprogrammed, and the sensors identify the input signal and provide the output in numerical form based on the data.

Electronic nose (E-nose) and Electronic tongue (E-tongue)

- An electronic sensor

An analytical tool called E-nose imitates the olfactory nerve system found in the human nose. According to Ampuero and Bosset (2003), this device has programd sensors that can analyze the volatile components found in food samples in a variety of physical states, including solid, liquid, semi-solid, and gaseous. The way this gadget operates is by producing an odor profile, also known as a fingerprint or output, which is produced by the sensor that creates the interaction between the volatile molecules in the food sample. The standard odor profile, which is pre-programmed to identify the compound contained in the food mixture sample, is compared to the gathered odor profile data after it has been submitted to a data processing system. A conductometric sensor is based on variations in conductivity, which

indicates the interaction between volatile substances. Fig. 1 depicted the E-nose schematic. The Department of Food Safety and Quality Assurance, College of Food and Dairy Technology, Koduvalli, Chennai-600 052, Tamil Nadu, India, offers a variety of sensors.

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MOS (Metal-oxide semiconductor) sensors are the most popular and extensively utilized because to its low cost, ease of use, and high sensitivity. In particular, these sensors are more dependable when used in quick gas chromatography-based authenticity investigations. The quick identification, accuracy, and analysis of a large number of samples are the main benefits. The primary drawback is the ongoing requirement to clean chromatographic columns (Dymerski et al., 2011; Du and Lee, 2002).

The E-tongue is an analytical tool that uses a sensor to acquire information about a food sample by simulating the membrane of gustatory cells found in the human tongue's taste buds. Fig. 2 showed the schematic representation of E-nose. E-tongue is most frequently used to evaluate flavor and taste. The five basic sensations that affect a food's overall flavor are sweet, salty, bitter, sour, and umami (or excellent) (Lvova, 2016). Potentiometry with an ion-selective electrode is one of the methods utilized for E-tongue (Escuder-Gilabert and Peris, 2010).

Additionally, a voltammetry-based e-tongue was created, and subsequent advancements made it appropriate for industrial uses, such as tracking the quality of incoming raw milk and identifying various microbial species that are utilized online in the dairy sector. According to Baldwin et al. (2011), E-tongue can measure the qualitative and quantitative composition of multivariate food products if it is configured and calibrated correctly.

Principle and concept of electronic nose and electronic tongue

E-nose

Moncrieff in 1961, first attempted to develop 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

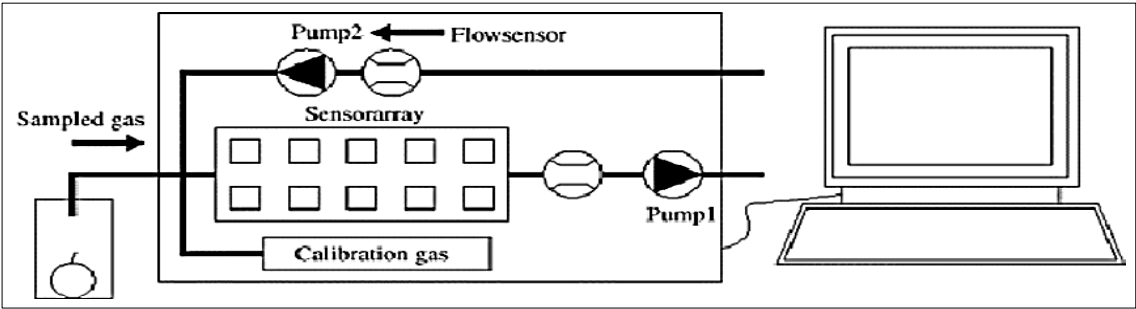


Fig 1: Electronic nose schematic diagram (Gomez *et al.*, 2008).

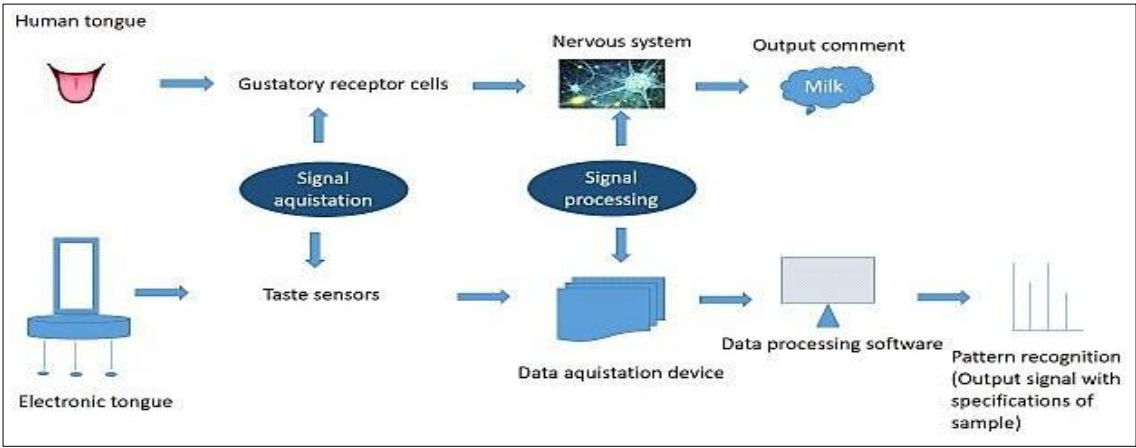


Fig 2: Electronic tongue schematic diagram.

Table 1: Summary of research done using nose.

E-nose configuration	Discrimination type	Reference
E-nose made using single semiconductor gas sensor	Determination of fruit ripeness	Benady <i>et al.</i> , 1995
Electronic sniffer using semi-conductor gas sensors	by sensing aromatic volatiles	
Portable E-nose with micro machined resistive sensor arrays	Assess blueberry quality	Simon <i>et al.</i> , 1996
E-nose machine using Fuzzy KNN algorithm	Quality measurement in wine	Aleixandre <i>et al.</i> , 2008
	Identification of fresh-chilled and frozen-thawed chicken meat shelf life	Mirzaee-Ghaleh <i>et al.</i> , 2020
Metal oxide semiconductor based E-nose	Determination of odor components in Antarctic krill defluoridated hydrolysate before and after Maillard reaction.	Zhang <i>et al.</i> , 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 <i>et al.</i> , 2014
Low cost paper-based electronic tongue- A novel sensor matrix	To differentiate mineral content in water sample	Witkowska Nery <i>et al.</i> , 2015
Voltammetric electronic tongue	Monitoring off-flavours in incoming raw milk	Winqvist, 2008
Taste sensor array including 12 sensors with neural networks system	Identification of corn juice	Liu <i>et al.</i> , 2012
Volummetric E-tongue	Quantification of total polyphenol content in olive oil	Apetrei and Apetrei, 2013

been taken, and numerous studies have concentrated on the creation of a particular sensor for the identification of a certain scent molecule. However, since it was discovered that each food matrix has more than 6000 molecules that contribute to scent, this attempt was abandoned in 1990 and no additional research was conducted. Such a vast number of sensors cannot be developed (Gardner and Barlett, 1994). A formalized prototype of E-nose was created in 1982, adding a significant milestone to this idea by utilizing fuzzy logic, artificial neural networks, and other mathematical data-based pattern recognition systems (Li et al., 2006).

Finding food rotting involves identifying volatile chemicals in the food matrix. E-nose is an odor detection device that categorizes food types and identifies and distinguishes volatile aroma molecules. Because e-nose technology may incorporate inexpensive, eco-friendly electronics, it has advanced quickly (Ampuero and Bosset, 2003). This electronic device's detection limit is determined by a number of factors, including the assessment of odor impact. Volatile molecules found in the food matrix are converted into electrical signals in the form of digital output as part of the odor detecting system. In addition to monitoring food spoilage, this detection technology aids in decision-making across many food supply chains. According to Gardner and Bartlett (1994), E-nose requires the following compounds:

- (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

E-tongue, another electronic device with a variety of sensors that detects the quality parameters of a food substance, such as sample condition, process status, and sensory qualities, is studied after E-nose. The first electronic tongue is thought to have been shown at the 10th European Conference on Solid State Transducers in 1996, the same year that the taste sensor concept was published (Sehra et al., 2004). For the past ten years, e-noses and tongues with various sensor arrays have been sold commercially in the United States. Potentiometry, voltammetry, and conductometry are the most well-known methods employed in E-tongue (Peris and Escuder-Gilabert, 2016). E-tongue is created by mimicking human receptors. E-tongue's sensors are comparable to the human nervous system. In order to determine the sensory information, the sensory array gathers the excited signals and transmits the data to the computer, where it is processed and analyzed by an appropriate software system (Yao et al., 2014). Principal components analysis (PCA) is the primary method used in multivariate data analysis (MVDA) to process the data gathered from any type of E-tongue sensor device. The potential of an electrode across an ion-sensitive membrane in the absence of current flow serves as the basis for the measuring principle. Table 2 listed research based on E-tongue.

Application of electronic nose in the food and dairy industry

E-nose

In the modern world, the food and dairy industries are experiencing steady growth. Dairy goods are one of the food groups that are studied the most. They comprise a wide range of dairy products, such as fluid milk, frozen dairy products like ice cream, fermented dairy products like curd, yogurt, Yakult, kefir, and numerous types of cheese. Because raw milk is a delicate liquid, it must be handled under constant observation during the whole production process (Chaudhari and Judal, 2015; Peris and Escuder-Gilabert, 2016). According to Peris and Escuder-Gilabert (2013) and Winquist et al. (2005), the quality of the entering raw milk is crucial for the development of a fermented dairy product because the presence of antibiotics might negatively impact the fermentation process. The e-nose operates on the same concept as the mammalian nose, which is made up of several olfactory neurons that can react to various odorants by stimulating an electrical impulse and transmitting it into the brain (Wilson and Baietto, 2009). E-nose investigates the different volatile components in food samples using a variety of sensors that generate and transfer chemical information into an electrical signal, such as resistance, voltage, and frequency, which is collectively referred to as an odor profile (input signal) to the data processing system where the input fingerprint data is processed and the volatile component is predicted.

A computer uses pattern recognition programs like principal component analysis (PCA), linear discriminant analysis (LDA), and artificial neural network (ANN) to process the signals from the sensor. To perform a variety of tasks and solve problems with food processing, a sophisticated sensor array was devised. Depending on the processes to be detected, many types of sensors are employed, including conducting organic polymer sensors (CP), metal oxide sensors (MOS), metal-oxide semiconductor field-effect transistors (MOSFET), piezoelectric sensors, and mass spectrometry-based sensors (Tudor Kalit et al., 2014). An electronic nose made up of 14 conducting polymer sensors can distinguish between milk that is unspoiled and milk that has varying concentrations of spoilage bacteria like *Bacillus cereus* or *Staphylococcus aureus* or yeasts like *Kluyveromyces lactis* or *Candida pseudotropicalis* (Magan et al., 2001). A voltammetric E-tongue made of five metallic electrodes was created by Wei and Wang (2011) to identify the residues of six distinct antibiotics in cow's milk. In their attempt to characterize strawberry juices on both a qualitative and quantitative basis, Qiu et al. (2014)

discovered that, when compared to E-nose, which has an accuracy of 99% for the original group and 98% for the cross-validation procedure, the qualitative predictions based on LDA, E-tongue, show high accuracy with 100% for the original groups and 98% for the cross-validation procedure. According to Shanshan et al. (2015), using E-nose and E-tongue at the same time makes assessing qualitative and quantitative parameters in strawberry juices quicker and simpler.

Peng et al. (2015) investigated the usage of electronic nose in conjunction with chemometric analysis and came to the conclusion that an e-nose set up with chemometric array sensors may be a useful fingerprinting method for safeguarding Chinese liquor identification. Using a solid-phase microextraction-mass spectrometry method, Majcher et al. (2015) investigated the possibility of verifying and identifying authenticated and imitated polish cheese, oscypek. The results of this study show that SPME-MS can be used in conjunction with chemometric tools to successfully detect mislabeling in polish cheese. Banach et al. (2012) found that metal oxide-based E-nose and ion mobility spectroscopy can be used for quality assessment in spice mixtures by detecting volatile compounds in the headspace. They also found that these techniques can be a cost-effective method. Lu et al. (2015) used electronic tongue and nose combinational techniques to distinguish between 120 indica rice samples and conventional and hybrid rice varieties. The combined electronic system with a locally linear embedding (LLE) based model can be effectively used for prediction, according to the research findings. Hygiene procedures and food handling during production have a significant impact on food quality and safety. In this way, the safety and well-being of the customer are greatly influenced by microbial quality. Foodborne illness outbreaks may result from food contaminated with harmful microorganisms. One such example is a salmonellosis outbreak caused by tainted ice cream (Falasconi et al., 2012). One important indicator of food decomposition is the sense of smell. As a result, food microbiology has effectively used E-nose. Using MS-based E-nose to detect fungal spoilage as a measure of ergosterol content, Marin et al. (2007) discovered that the accuracy of prediction was between 87 and 96%. According to (Ali et al., 2020), e-tongue signals can estimate the quality parameters, however e-nose is unable to forecast parameter changes in the regression model.

E-tongue

Analysis of particular food matrix components is still a topic of increased interest in the food and dairy industries, particularly for scientific communication. High performance liquid chromatography (HPLC), gas chromatography-mass spectrometry (GC-MS), mid-infrared (MIR) spectroscopy, and other experimental techniques are used to determine the composition of food. While these techniques yield more precise findings, they have certain disadvantages, such as being time-consuming and costly. In response to these limitations, Bougrini et al. (2014) developed a novel analytical method that uses hybrid e-nose and voltammetric e-tongue along with a pattern recognition technique to distinguish between various pasteurized milk brands. Their research provides compelling evidence for the use of this method, particularly for monitoring the quality of milk products. Hruskar et al. (2009) assessed E-tongue's ability to distinguish between milk and yogurt samples from various manufacturers, which leads to precise analysis or quality monitoring. The sensor's output has a strong correlation with human sensory expression, and the taste of milk is quantitatively described.

Garcon and colleagues used cross-reactive sensor arrays with surface plasmon resonance imaging (SPRi) to create a novel taste system. Eleven detecting receptors make up this straightforward sensor matrix, which successfully distinguishes between several milk samples, including UNT milk, soy milk, pasteurized milk, soy milk with chocolate, and rice milk. The adsorption and desorption properties of the components under study were also revealed by the SPR technique. Food adulteration results in a decline in quality and standards. The identification of food adulterants was one of the most promising uses of E-tongue in the food business (Dias et al., 2009). In order to identify adulteration in honey, Sobrino-

Gregorio et al. (2018) created an automatic E-tongue that uses pulse voltammetry. The produced E-tongue effectively distinguishes between the many varieties of honey that have been tainted with syrup. Bougrini et al. (2014) conducted another intriguing study that used an electronic tongue manufactured with 7-voltammetric electrodes and an E-nose system based on a 5-TGS (Taguchi Gas Sensor) sensor to detect adulteration in argon oil. Dairy products like cheese are highly nutritious and come in a wide range of flavors and varieties. In order to analyze fresh and matured cheeses made from raw and pasteurized cow's milk, Valente et al. (2018) created an E-nose using piezoelectric quartz sensors and an electronic tongue based on potentiometric chemical sensors.

The E-tongue was used to measure the whey, a byproduct of cheese. The analysis's findings demonstrated that E-tongue could effectively differentiate between cheeses prepared from pasteurized and raw milk and track the ripening process for a week. Lipkowitz et al. (2018) and Newman et al. (2014) used sensory and potentiometric electronic tongues to distinguish the aging and protein-to-fat ratio of Cheddar cheese. E-tongue was said to be more sensitive, quick, and economical than human panelists. It was proposed that cheddar cheese may be regularly and online monitored using e-tongue. Using integrated signals of E-nose, E-tongue, and E-eye with chemometric methodologies, Xu et al. (2019) evaluated the qualitative and quantitative assessment of chemical components in tea. The results demonstrate 100% accuracy for the qualitative evaluation of tea quality classes. In their study, Zhang et al. (2015) attempted to distinguish between cattle breeds with varying flavors and chemical compositions. PCA analysis revealed a clear separation of various beef breeds, and it was proposed that the "E-tongue" approach leads to quick identification of various beef breeds based on flavor values. According to their findings, "E-tongue" might also be utilized to precisely determine the chemical composition using the regression relationship between chemical composition and flavor. According to Haddi et al. (2014), fruit juice samples can be successfully discriminated when E-nose and E-tongue are used in conjunction with the data fusion technique. A wireless swallowable capsule, a potentiostatic electrochemical sensor that operates at 433 MHz and is powered by a lithium ion cell, is an emerging technique in contemporary medical science for accessing the human gastrointestinal tract (Caffrey et al., 2015). Although electronic sensor technology is still in its early stages of development, it is frequently utilized in the food business as a quality control tool due to its high accuracy and sensitivity when compared to human sensory panels. It is commercially accessible in both software and hardware varieties. Loss of sensitivity, sensor drift, aberrant sensory array, use of short-lived sensors, and calibration errors are some of this technology's limitations.

CONCLUSION

Based on chemical sensors or hyphenated approaches, E-nose and E-tongue have a wide range of applications in the food and dairy industries. A highly suitable alternative to the sensory analysis carried out by testers is the speed analysis and discretionary screening of a large number of samples. E-nose and E-tongues are important tools for solving a variety of challenging analytical issues. Therefore, the use of sophisticated electronic sensing devices with additional study on straightforward configuration and simplicity of handling still need a lot of focus for future progress.

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