ISSN: 3049-3293
Volume: 1, Issue: 2, April 2025
Article No.: 02

Progress and Applications of E-Nose and E-Tongue in Horticultural and Food Industries

Ranjani M, Ramakrishna A, Abarna S, Vathsala V, Shalini Gaur Rudra*

Division of Food Science and Postharvest Technology, Indian Agricultural Research Institute, New Delhi-110012
***Email: ranjani99mr@gmail.com**

Abstract

E-sensing technologies are current trends in developing digitalized horticulture, food, and other industrial sectors. Mimic human olfaction and taste perception artificial sensing systems connected through sensory arrays and sophisticated data processing techniques, further performing pattern recognition algorithms to provide output. Technologies such as electronic nose (E-nose), electronic tongue (E-tongue), and electronic ear (E-ear) are providing top-tier solutions against various pre-harvest and postharvest horticultural management and food control. These recent technologies are rapid, non-destructive, and offer good quality control, detection of adulteration, flavour profiling, etc. Furthermore, it helps in overcoming limitations of traditional sensory evaluation, minimising human error, and chemical analysis methods. Additionally, enhance food authentication, safety monitoring, and product standardization. Integration of technologies with machine learning improves classification accuracy, making them for manufacturers, regulatory agencies, and researchers in ensuring food integrity and consumer trust.

Key words: E-sensing, minimising human error, artificial sensing, product standardization

Introduction

Digitalised technologies such as electronic noses and electronic tongues play important roles in ensuring the quality and safety of horticultural food produce and processed products through detection and monitoring. Lu et al. (2022) quoted applications ranges from food production includes quality control, shelf life monitoring; supervision includes safety detection, adulteration and authenticity; and daily life includes freshness assessment and recognition. These mimic models have ability to assess aroma and taste is basic in food quality evaluation, product authentication, and consumer preference analysis. Over all advantageous including reliable, objective solutions reduce human error, and chemical analysis methods, still approaches that are often subjective, time consuming, require extensive training and sensor issues.

ISSN: 3049-3293
Volume: 1, Issue: 2, April 2025
Article No.: 02

E nose is designed to mimic the human olfactory system by detecting and analysing volatile organic compounds emitted. E-nose is mainly used in areas such as food, bioprocess control, medical diagnosis and environmental monitoring. By using an array of various chemical sensors (optical, thermal, electrochemical and gravimetric sensors) and pattern recognition algorithms, system can classify and differentiate between products based on their unique odour profiles. E-nose used as an analytical tool in food industries including food authentication, freshness assessment, and adulteration detection, making it a valuable tool in industries such as dairy, tea, coffee, wine, and meat processing. This technique is an effective alternative to sensory methods, chromatographic, and spectrometric methods. Cost effective and can perform real time analysis.

Similarly, the E-tongue mimics human taste perception through electrochemical sensor arrays (potentiometric, voltametric) that analyze taste components such as sweetness, bitterness, acidity, saltiness, and umami. After sensor analysis, electronic interface device generates output, converts it to digital signal. By generating digital taste fingerprints, E-tongue technology enables rapid and precise quality control in various liquid food products, including juices, honey, edible oils, and dairy products. Also, e-tongue have ability to detect various organic and inorganic compounds. It predicts the chemical composition and flavour. It was used in determination of the origin and quality of raw and finished products. It helps in assessment of tea and coffee, taste profile of wine and other beverages.

E sensing technologies are comprehensive, non-destructive, and automated approach to food analysis, reducing the reliance on human sensory evaluation, improves efficiency and consistency, and provide real-time analysis. Limitations such as sensitivity, selectivity, and cross-sensitivity, leading to inaccuracies in complex sample analysis. Mahanti et al., (2024) stated that environmental factors, sensor drift, and aging require frequent calibration, while limited dynamic ranges hinder trace detection. Some challenges including external conditions like temperature, humidity, and background odors affect precision, and high costs for maintenance and calibration. Overall future focus on these areas are to improve their reliability and expand their applications in food safety and quality control.

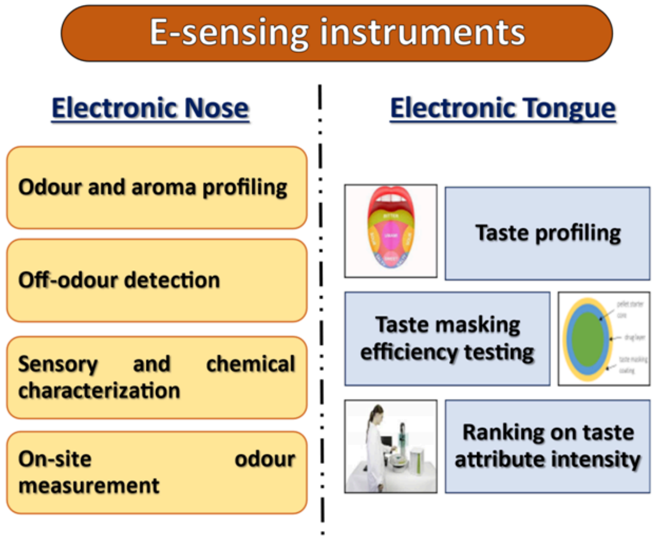

Fig. 1. Roles of E-Sensing instruments in Horti-Food Industries

History: Timeline of E-Nose and E-Tongue Development

Beginning in the 1960s with foundational reaserch on artificial olfaction, followed by theoretical studies on sensor-based volatile compound detection (1970s). Metal oxide semiconductor (MOS) sensors used in 1980s. By the 1990s, the term "electronic nose" gained recognition, with MOS and conducting polymer sensors enabling food quality applications, while the first electronic tongue was introduced in 1994 for taste analysis. In 20th centuries, significant advancements in sensor materials and data processing, improving E-nose and E-tongue performance, including the miniaturization of E-nose devices using MEMS technology are emerged. Also, widespread of applications areas such as e-nose (environmental monitoring and medical diagnostics) and e-tongue (pharmaceutical and water quality analysis) (Fig. 3 E-nose and Fig. 4 E-tongue).

Electronic Nose - Principle and Functionality

An electronic nose (E-nose) is a sensor-based system designed to mimic the human olfactory system. It plays a crucial role in assessing food quality and detecting hazardous gases in the environment. Industries such as food and beverage, perfumery, cosmetics, and chemicals traditionally rely on human sensory panels for odor evaluation. However, while the human nose can reportedly detect over one trillion scents through approximately 400 scent receptors, individual perception biases and an inability to reliably detect toxic gases limit its effectiveness.

E-nose systems utilize sensor arrays that generate unique response patterns (fingerprints) when exposed to volatile compounds. These responses are analyzed using pattern recognition algorithms, including Artificial Neural Networks (ANN), to simulate human olfactory processes such as sensing, interpreting, and differentiating odors. When volatile molecules interact with sensor materials, changes in electrical properties—such as conductivity—are detected and analyzed to classify and discriminate odors. Compared to traditional analytical methods like Gas Chromatography–Mass Spectrometry (GC-MS) and High-Performance Liquid Chromatography (HPLC), E-noses provide a cost-effective and time-efficient approach for odor detection and classification. They offer consistent, reproducible measurements.

Electronic Tongue :Principle & Functionality

An electronic tongue (E-tongue) complements the E-nose by mimicking human taste perception, which plays a critical role in food and beverage quality evaluation. E-tongues provide rapid, objective, and cost-effective taste assessments. The human taste system identifies five basic tastes—sweetness, sourness, bitterness, saltiness, and umami—essential for evaluating food palatability. Traditionally, sensory panels assess these attributes, but the process is time-consuming, expensive, and subject to variability due to differences in individual perception.

E-tongues employ arrays of chemical sensors, including electrochemical sensors, biosensors, and optical mass sensors, to detect taste compounds in food samples. These sensors generate specific response patterns that are processed using pattern recognition algorithms. The system configuration varies depending on the type of sensors and data processing strategies used, enhancing versatility in taste analysis.

Different Types of Sensors Used in E-Nose and E-Tongue:

Electronic nose (E-nose) and electronic tongue (E-tongue) technologies rely on various sensors to detect and analyze volatile compounds and taste molecules. These sensors play a crucial role in food authentication, quality control, and safety monitoring (Mahanti et al., 2024).

Electrochemical Sensors

1. Metal Oxide Semiconductor (MOS) Sensors – Detect gases by measuring conductivity changes in metal oxides like tin dioxide. Sensitive to VOCs but affected by humidity and temperature.
2. Polymer Sensors exhibit alterations in their electrical along with optical properties during gas exposure. This sensing technology comes at an affordable price however its performance declines because of drift issues as well as interference factors.
3. The electric potential which forms when sensors track ion interactions serves as their detection method. Highly sensitive but require careful calibration.
4. Amperometric Sensors – Detect analytes via electrochemical reactions. Effective for the device responds to liquids although its performance depends on both pH conditions and temperature variations.

Piezoelectric Sensors

1. Quartz Crystal Microbalance (QCM) Sensors – Detect mass changes by measuring shifts in resonance frequency. Highly sensitive but need frequent calibration.
2. Surface Acoustic Wave (SAW) Sensors – Monitor changes in acoustic wave propagation upon gas interaction. Enable real-time detection but are sensitive to environmental factors.

Optical Sensors – This type of sensors are sensitive to changes in light properties such as fluorescence or absorbance when in contact with the target molecules. Result in fast analysis with no detriment to the evidence but requires initial calibration. While Biosensors include the biological parts as enzymes/antibodies for sensing the particular species

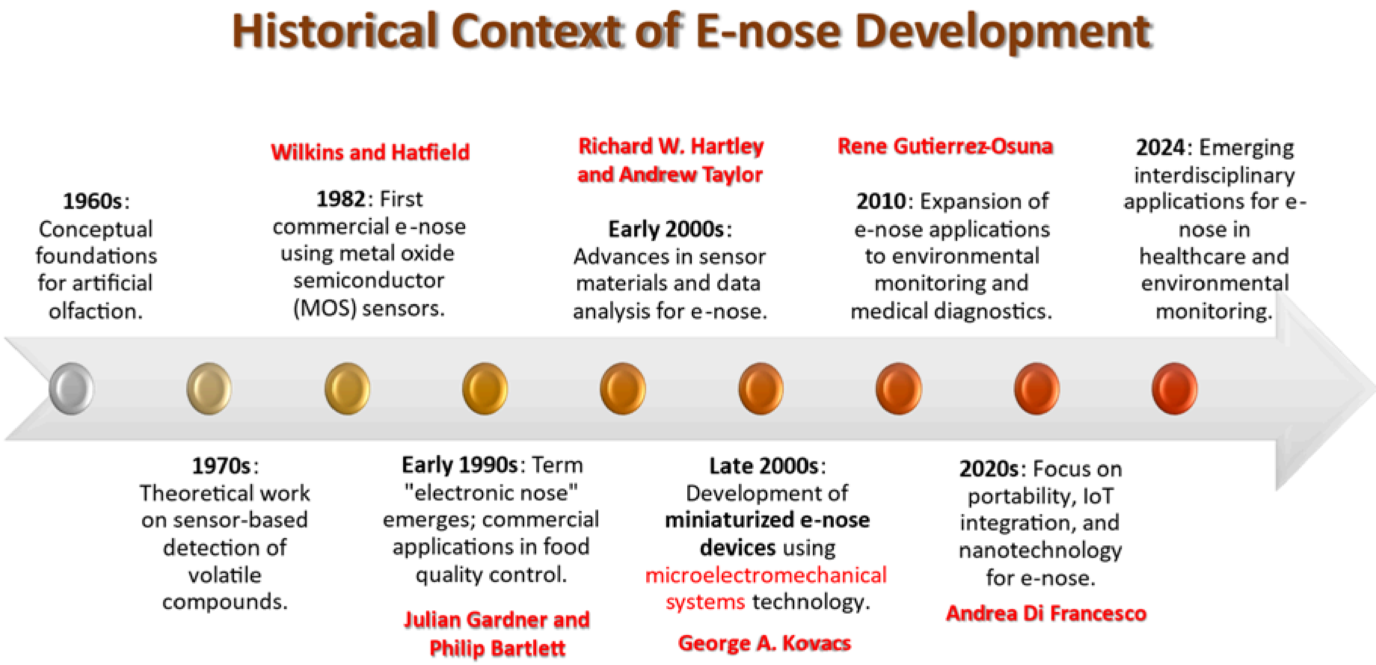

Fig. 2. Historical advancements in E-nose technology

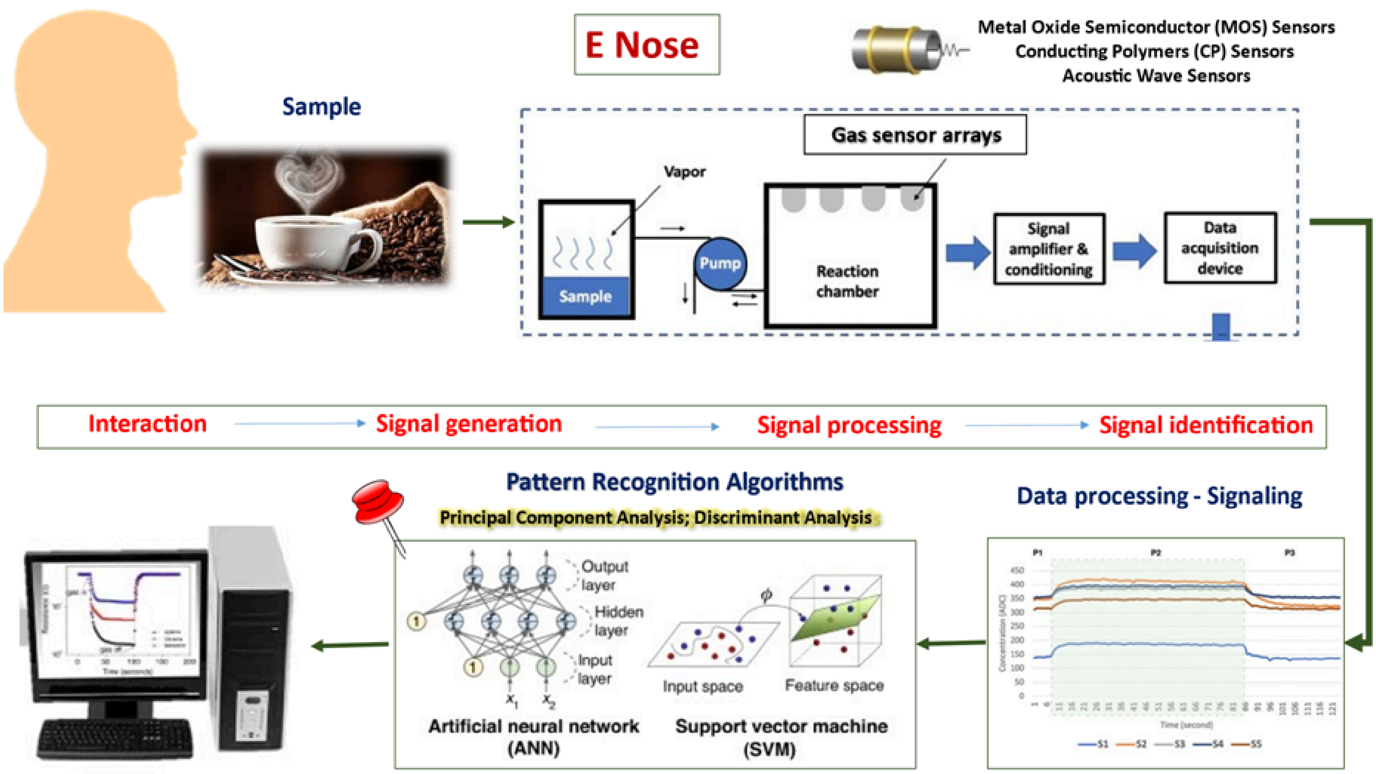

Fig . 3. Functional mechanism of the E-nose

ISSN: 3049-3293
Volume: 1, Issue: 2, April 2025
Article No.: 02

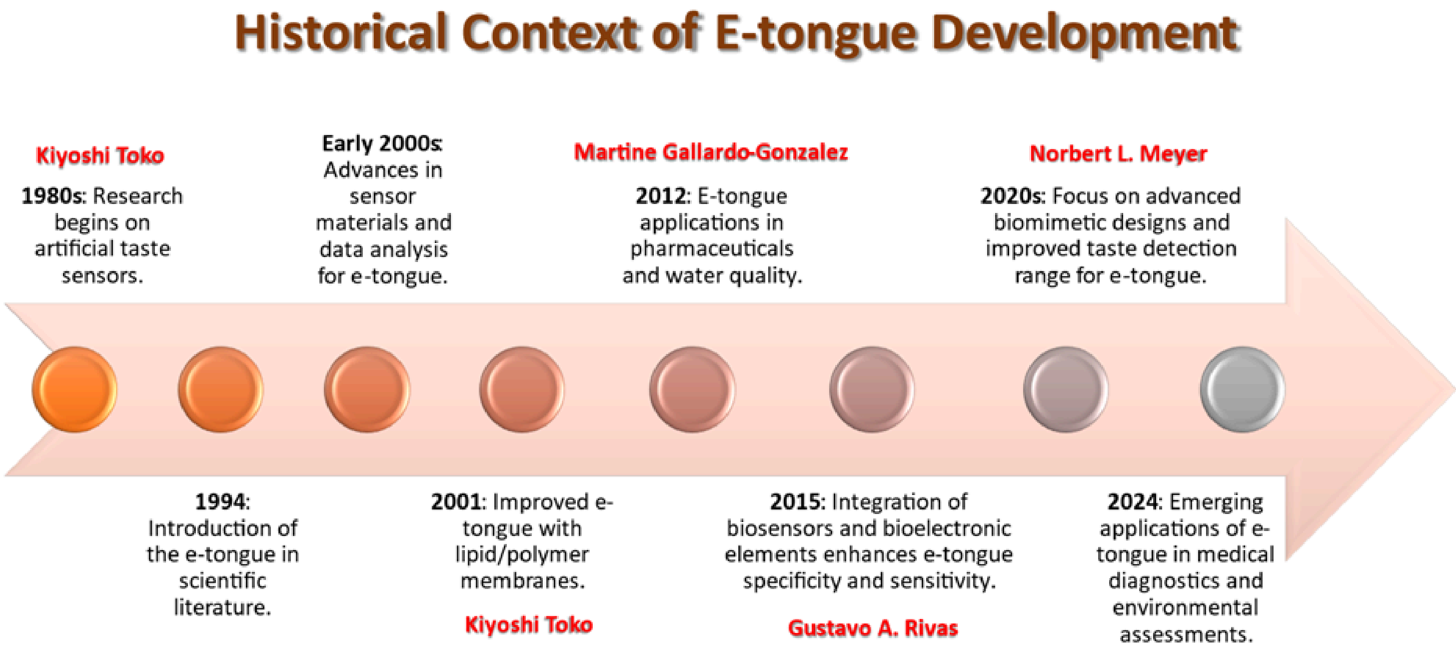

Fig. 4. Historical advancements in E-tongue technology

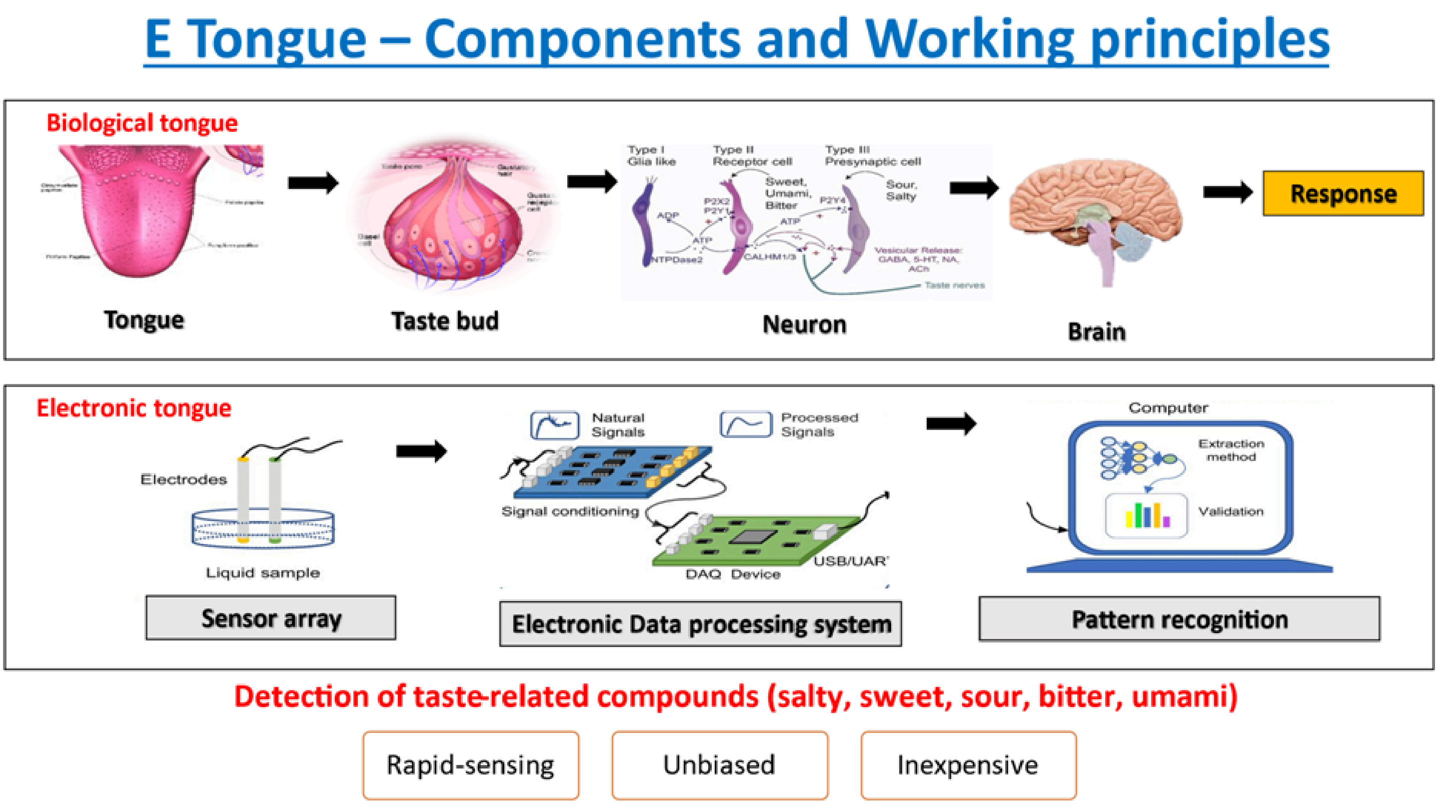

Fig. 5. Functional mechanism of the E-tongue

of interest. They are usually highly selective and sensitive; however, their accuracy depends on specific conditions of the environment.

Application of E-Nose and E-Tongue in Horti-Food Processing

The electronic noise (E-nose) together with the electronic tongue (E-tongue) represents emerging artificial sensor technology that transformed quality control and food evaluation processes in industry. New artificial sensing technologies from the recent generation achieved revolutionary results in food quality control, quality assessment safety, and product development in the food industry. Using the E-tongue to detect these devices examine contaminants while verifying taste quality and determining shelf duration and authenticating ingredients. Its identification work in detecting adulteration combined with food flavor analysis and additive perception plays a major role taste are immense. The E-nose, on the other hand, serves applications like quality control, this instrumentation enables testing of product flavors as well as measurements of storage stability through the evaluation of product maturity levels and ripeness states. The devices determine the ripeness condition of fruits and vegetables through their maturity assessment. It does especially well with monitoring food processing such as cocoa bean fermentation and coffee. The E-nose system performs effectively at both meat freshness and spoilage detection and in the processes of bean roasting. Together, these the combination of these technologies enables the generation of important data regarding food composition features along with sensory attributes. The combination of sensors enables better food quality safeguards as well as safer food products that fulfill consumer requirements. Recent advances in the recent advances in this field can be found in the following table:

(Table .1) Recent advances of E-Nose and E-Tongue in Horti-Food Processing.

Technology	Application	Findings	Reference
E-Nose	Apple ripeness classification	Achieved100% accuracy in ripening stage classification of 'Golden Delicious' apples based on VOC emissions using machine learning.	Trebar et al., (2024)
E-Nose	Mango quality assessment	An ensemble-learning model combined image processing and sensor data, achieving high accuracy in mango sorting.	Nguyen et al., (2024)
E-Nose	Fungal contamination in fruits	Identified fungal infections in peaches and apples with over 97% accuracy.	Martínez et al., (2025)
E-Nose	Tomato disease detection	Used metal-oxide sensors to detect early-stage anthracnose fruit rot (Colletotrichum coccodes) before visible symptoms appeared.	Khlaif et al., (2024)
E-Nose	Food authentication	Reviewed portable sensors like NIR, E-nose, and nanozyme-based sensors for food authenticity in supply chains.	He et al., (2024)
E-Nose	Wine quality control	Identified origin, fermentation process, and defects when combined with E-Tongue.	Zheng et al., (2025)
E-Nose	Floral scent classification	Classified ten cut lily varieties based on VOC emissions with 91.5% PCA variance explained.	Zhou et al., (2025)

E-Nose	Postharvest floral scent monitoring	Differentiated postharvest scent changes in cut Lilium and various Iris species.	Sun et al., (2023); Cai et al., (2024)
E-Nose	Chilli adulteration	Identified adulterants in chili powder using the Histogram of Oriented Gradients algorithm.	Peng et al., (2024)
E-Nose	Environmental VOC monitoring	Applied in air quality assessment but faces challenges in sensitivity at low concentrations.	Li et al., (2024)
E-Tongue	Taste profile	Evaluated the impact of fixation temperature on the taste profile of Longjing tea by analyzing bitterness, astringency, and chemical composition changes.	Shan et al., (2023)
E-Tongue	Coffee beans	Analyzed the impact of roasting conditions on physicochemical, taste, volatile, and odor-active compound profiles of Coffea arabica L. (cv. Yellow Bourbon).	Hong et al., (2024)
E-Tongue	Coconut water classification	Microfluidic impedimetric E-tongue distinguished fresh and industrialized coconut water samples with >90% accuracy using PCA and PLSR.	da Silva et al., (2024)
E-Tongue	Capsaicin detection	ZnO/ITO-based electrochemical E-tongue exhibited high sensitivity and stability for detecting capsaicin.	Ahmed et al., (2024)
E-Tongue	Rice quality analysis	Integrated E-tongue, NIR grain testing, and machine vision to automate amylose content and rice genotype classification.	Fayaz et al., (2024)
E-Tongue	Coffee adulteration detection (coffee shell & stick)	Successfully identified adulterants and quantified impurity levels in roasted coffee after pattern recognition analysis.	de Morais, Rodrigues, Souto, & Lemos et al., (2019)
E-Tongue	Roasted coffee adulteration detection	PLS-DA analysis achieved 100% accuracy in identifying doped samples and 96% for undoped samples.	Rodrigues, Fragoso, & Lemos et al., (2021)

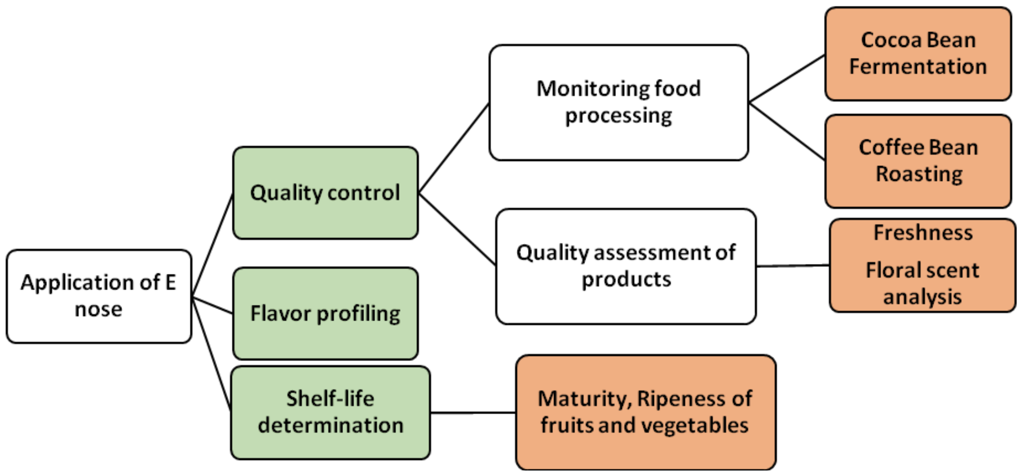

Fig. 6. Glimpses of Application of E-nose in Horti-food Industries

ISSN: 3049-3293
Volume: 1, Issue: 2, April 2025
Article No.: 02

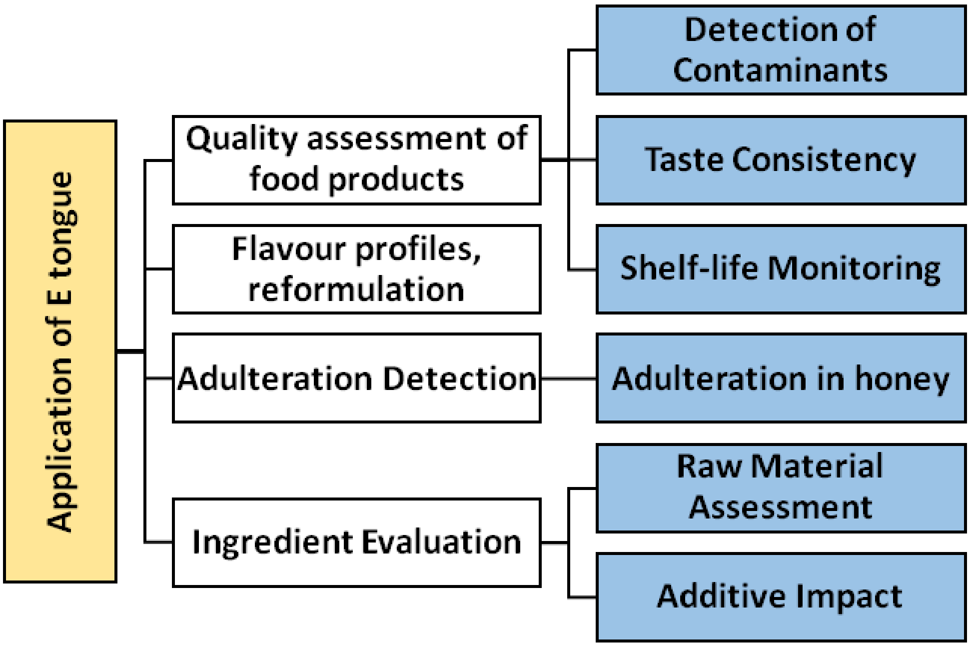

Fig. 7. Glimpses of Application of E-tongue in Horti-food Industries

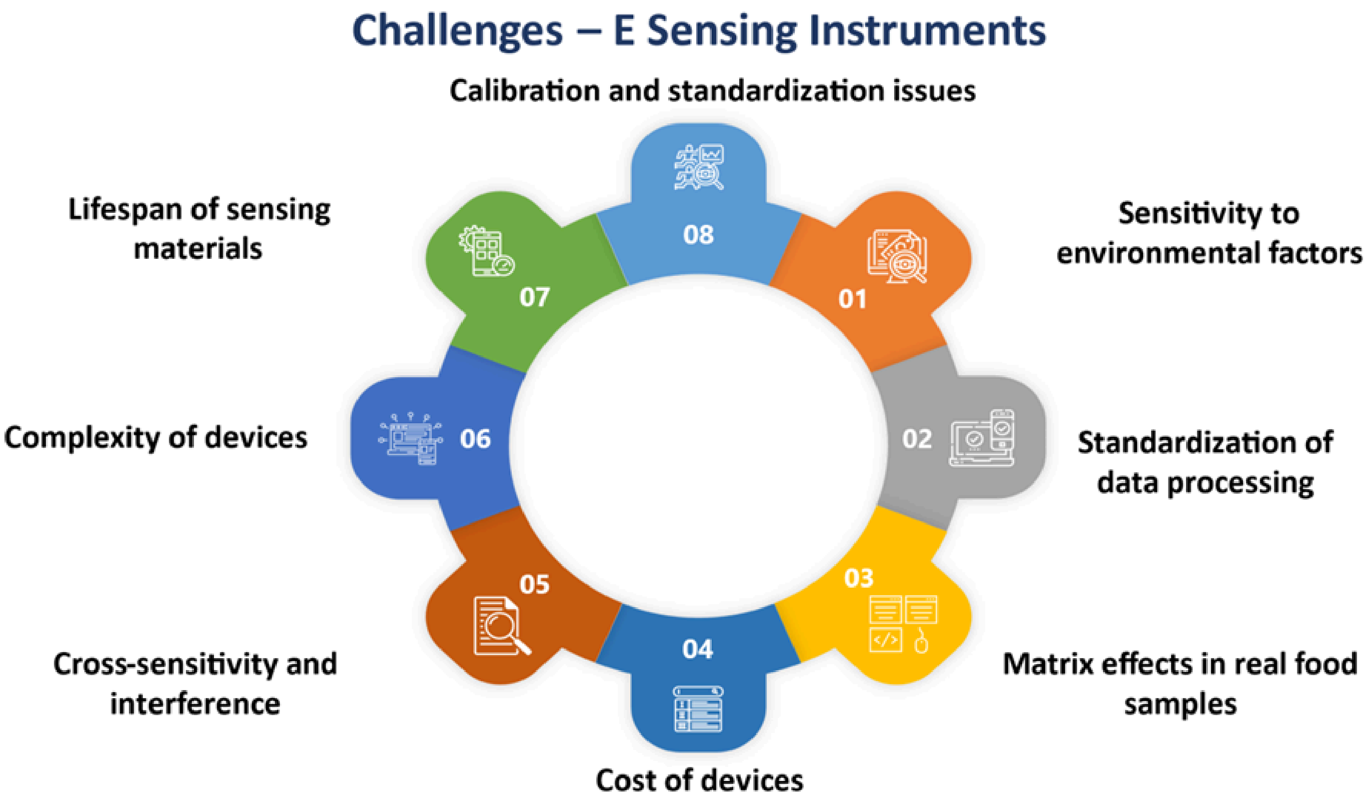

Fig. 8. Challenges of E-Sensing Instruments

Conclusion

Through E-nose and E-tongue technologies the industry has revolutionized food authentication and quality assessment and safety evaluation by performing quick reliable assessments. The latter implies in the use of machine learning that makes the work accurate and helps in achieving better production and less cost especially in terms of manpower though resultant quality is very constant. Such systems link capability of computing with intelligence factor and the ability to use the feeling of touch to create a comprehensive food inspecting technique. It is, however, important to note that while there is room for advancing on the aspects of sensor technology and data processing to tackle non-algorithm adaptability and misidentification that ranges from 4 to 20%, there are the benefits of these systems. Technological development in the future aims to minimize equipment size as well as integrate systems smoothly to enhance accessibility and operational efficiency of these systems. The evolution of E-nose and E-tongue systems presents a vital opportunity for food safety realization and industrial standardization and advancement throughout the food sector.

References:

Ahmed, S., Ansari, A., Bishwanathan, S., Siddiqui, M. A., Tailor, S., Gupta, P. K., Negi, D. S., & Ranjan, P. (2024). Electronic tongue based on ZnO/ITO@glass for electrochemical monitoring of spiciness levels. Langmuir, 40(8), 4434–4446. https://doi.org/10.1021/acs.langmuir.3c03763

de Morais, L. C., Rodrigues, R. M., Souto, U. T. C., & Lemos, S. G. (2019). Identification and quantification of coffee adulteration using a voltammetric electronic tongue and pattern recognition analysis. Food Chemistry, 281, 131–139. https://doi.org/10.1016/j.foodchem.2019.01.049

Fayaz, U., Hussain, S. Z., Naseer, B., Bej, G., Pal, A., Sarkar, S., Wani, N. R., Mushtaq, K., Yasmin, S., Dhekale, B. S., Richa, R., & Manzoor, S. (2024). Innovative technology integration: E tongue, near infrared grain tester & machine vision approaches for amylose content & quality characterization. Food Chemistry: X, 24, 101805. https://doi.org/10.1016/j.fochx.2024.101805

He, H.-J., Ferreira, M. V. da S., Wu, Q., Karami, H., & Kamruzzaman, M. (2024). Portable and miniature sensors in supply chain for food authentication: A review. Critical Reviews in Food Science and Nutrition. https://doi.org/10.1080/10408398.2024.2380837

Hong, S. J., Boo, C. G., Yoon, S., Jeong, H., Jo, S. M., Youn, M. Y., Kim, J. K., Kim, Y. J., & Shin, E. C. (2024). Impact of roasting conditions on physicochemical, taste, volatile, and odor-active compound profiles of Coffea arabica L. (cv. Yellow Bourbon) using electronic sensors and GC-MS-O using a multivariate approach. Food Chem X, 21, 101119.

Khlaif, S., Mudalal, S., Ruiz-Canales, A., & Abu-Khalaf, N. (2024). Electronic nose for detecting Colletotrichum coccodes causing anthracnose fruit rots in tomatoes. Smart Agricultural Technology, 8, 100451. https://doi.org/10.1016/j.atech.2024.100451

Li, Y., Wang, Z., Zhao, T., Li, H., Jiang, J., & Ye, J. (2024). Electronic nose for the detection and discrimination of volatile organic compounds: Application, challenges, and perspectives. TrAC Trends in Analytical Chemistry, 180, 117958. https://doi.org/10.1016/j.trac.2024.117958

Lu, L., Hu, Z., Hu, X., Li, D., & Tian, S. (2022). Electronic tongue and electronic nose for food quality and safety. Food Research International, 162, 112214.

Mahanti, N. K., Shivashankar, S., Chhetri, K. B., Kumar, A., Rao, B. B., Aravind, J., & Swami, D. V. (2024). Enhancing food authentication through E-nose and E-tongue technologies: Current trends and future directions. Trends in Food Science & Technology, 150, 104574.

Martínez, A., Hernández, A., Arroyo, P., Lozano, J. S., Córdoba, M. G., & Martín, A. (2025). E-nose detection of changes in volatile profile associated with early decay of 'Golden Delicious' apple by Penicillium expansum. Food Control, 168, 110907. https://doi.org/10.1016/j.foodcont.2024.110907

Nguyen, D. T., Lin, W. C., Trieu, N. M., & Thinh, N. T. (2024). Development of a mango-grading and -sorting system based on external features, using machine learning algorithms. Agronomy, 14(4), 831. https://doi.org/10.3390/agronomy14040831

Peng, P., Ba, F., Zhang, Y., Jiang, F., & Zhao, Y. (2024). Identification of adulterants in chili powder based on the histogram of oriented gradients algorithm by using an electronic nose. Applied Sciences, 14, 1007.

Rodrigues, R. M., Fragoso, W. D., & Lemos, S. G. (2021). Detection of roasted coffee adulteration using an impedance spectroscopy electronic tongue and supervised pattern recognition. Food Control, 123, 107770. https://doi.org/10.1016/j.foodcont.2020.107770

Shan, X., Deng, Y., Niu, L., Chen, L., Zhang, S., Jiang, Y., Yuan, H., Wang, Y., & Li, J. (2023). The influence of fixation temperature on Longjing tea taste profile and the underlying non-volatile metabolites changes unraveled by combined analyses of metabolomics and E-tongue. LWT - Food Science and Technology, 181, 115560. https://doi.org/10.1016/j.lwt.2023.115560

Silva, T. A. d., Juncá, M. A. C., Braunger, M. L., Riul Jr, A., & Barbin, D. F. (2024). Application of a microfluidic electronic tongue based on impedance spectroscopy for coconut water analysis. Food Research International, 187, 114353. https://doi.org/10.1016/j.foodres.2024.114353

Trebar, M., Žalik, A., & Vidrih, R. (2024). Assessment of 'Golden Delicious' apples using an electronic nose and machine learning to determine ripening stages. Foods, 13(16), 2530. https://doi.org/10.3390/foods13162530

Zheng, Z., Liu, K., Zhou, Y., Debliquy, M., Bittencourt, C., & Zhang, C. (2025). A comprehensive overview of the principles and advances in electronic noses for the detection of alcoholic beverages. Trends in Food Science & Technology, 156, 104862.

***

.