

Smart coffee aromas: A literature review on electronic nose technologies for quality assessment

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Abstract

One of the most important aspects of coffee's sensory experience is its scent, which is affected by roasting, microbial contamination, and place of origin. Electronic noses (ENs), which provide quick and precise identification of intricate odor patterns linked to microbial activity, have become highly effective instruments for evaluating coffee odors. This study examines the most recent uses of EN technology for evaluating coffee scent and emphasizes how important it is for assuring the safety and quality of the final product. The integration of ENs with artificial neural networks (ANNs) improves their precision in fragrance profile prediction and classification. Moreover, real-time smell profile monitoring is made possible by automated systems that use ENs, which helps with quality control in the coffee manufacturing process. Beyond the coffee business, EN technology is used in many other areas, including food safety, medical diagnostics, and environmental monitoring. Through innovation in fragrance analysis and quality control, this multidisciplinary approach promotes customer confidence and product integrity across industries.

Keywords: Sensor Array; Smart Coffee Aromas; Electronic Nose; Quality Assurance; Microbial Detection

1. Introduction

Coffee is one of the most widely consumed drinks in the world, with multitudes of people embracing its rich flavor and energizing effects [1]. Aroma, a symphonic of its volatile compounds, contributes the overall enjoyment of the coffee, its uniqueness reflects the origin of the coffee [2][3]. Aroma is also affected by the degree to which coffee beans are roasted [4], coffee's flavor is greatly influenced by the bitter alkaloids trigonelline and caffeine. During the roasting process, a compound naturally found in coffee beans partially breaks down and helps to produce a desired flavor profile [5]. Lighter roasts retain more of the bean's natural qualities and may have floral or fruity undertones, whilst darker roasts usually have smokier and more robust aromas [6]. Nevertheless, single-origin coffee market is thriving because roast profiles may be tailored to match the unique characteristics of green coffee beans from certain regions or nations, resulting in excellent sensory outcomes. Furthermore, roasting separate batches of green coffee from various origins separately and then mixing them is becoming more and more popular as a way to highlight the unique flavors of coffee and create the desired quality in the finished cup [7]. However, pathogenic bacteria present a substantial hazard to consumer health if the coffee are not processed properly, with potentially devastating repercussions. To reduce the hazards associated with consuming products containing hazardous bacteria, contamination must be avoided at all stages of food manufacturing [8][9].

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Electronic noses for tracking environmental scents have advanced significantly over the last twenty years, from experimental devices to useful tools used by industrial plant operators and municipal government agencies [10, 11]. In recent years, electronic noses (ENs) have evolved as very efficient and speedy methods for monitoring microbiological deterioration [12] and maintaining food quality management [13]. Nowadays, samples' aromatic profiles are examined using electronic noses, which eliminate the requirement to first divide the volatile fraction into its component parts. These devices are equipped with a system for data processing [14] and pattern recognition and a range of non- or partially selective gas sensors. This technology can effectively recognize complex aromatic signatures [15]. By employing a variety of sensors to identify patterns in various scents, they simulate the functions of the human olfactory system [21]. In order to prevent subjectivity, the most popular techniques for evaluating fragrance rely on costly technology or sensory evaluation using human senses [2]. The human sense of smell served as the model for the electronic nose concept, which was created to mimic this function in artificial systems [16].

ENs success stems from its ability to detect and analyze complex scents associated with microbial activity in a timely manner, making it a significant resource for improving food safety and quality assurance operations [17], ENs can be utilized to forecast sensory characteristics of food quality, therefore ENs is a useful tool [18].

In addition, using artificial neural network (ANN), For the optimization [18] and prediction of parameters in food [19], drink [20], agriculture [21], and medicine [22], artificial neural networks (ANN) have gained popularity [23]. combined with an electronic nose (ENs) had a capability to distinguish between two varieties of coffee bean which displayed a remarkable 91.90% accuracy rate, demonstrating the effective identification of the coffee bean by the used ANN with scent sensor as input [24]. Compounds resulting from the metabolism of bacteria, fungus, and spoilage microorganisms can provide unwanted scents, or contaminants. These compounds can inadvertently or naturally contaminate the products before or during their manufacturing [25]. Using a standard operating procedure to prevent hazardous contamination, it was possible to identify and recognize the distinct scents that the coffee beans gave off, leading to another inventive development: a system that could distinguish between different stages of mold growth on coffee beans. As a result, the suggested system's accuracy level was 91.77%. [26].

An automated system can easily identify differences in aroma profiles caused by unanticipated factors such as water quality [27][28], temperature fluctuations [29], or other difficulties during the brewing process that may impact consumer perception by using low-cost sensor technologies. Electronic noses technology provides a dependable system for detecting and correcting possible errors, guaranteeing that coffee drinkers get a consistent and high-quality sensory experience [30].

1.1. Purpose of the Literature Review

The literature review's main goal is to examine the vital function that electronic nose (EN) technologies play in assessing and ensuring the caliber of coffee aromas. This investigation includes a thorough analysis of the desired flavor components that add to coffee's attractiveness on a worldwide scale as well as the health risks associated with possible bacterial contamination during the processing phases. The literature review highlights the crucial role that electronic nose technologies play in improving the evaluation of coffee aromas. It also highlights how adaptable these technologies are in terms of handling potential contaminants and ensuring that consumers receive a consistent and dependable sensory experience regardless of the varied and ever-changing coffee production and consumption landscape.

2. Materials and Methods

This review will methodically look at pertinent studies in order to provide a thorough assessment of the state of electronic nose (EN) applications in coffee aroma assessment. This includes the most recent developments in EN technology as well as how they are specifically applied in the coffee business. The search will be conducted mainly on academic databases, including Scopus, Web of Science, and Google Scholar, using keywords such as "electronic nose," "coffee aroma," "quality assessment," "microbial detection," and "artificial neural networks." The studies that are found will be further filtered according to their type, language, and relevance to the determined research objectives. The evaluation will take a multifaceted approach to guarantee a comprehensive and impartial study. The technical features of ENs used in coffee research will be covered first, along with a description of the many types of sensors, data gathering techniques, and pattern recognition algorithms used. This investigation will clarify the advantages and disadvantages of various EN configurations as well as whether or not they are appropriate for a certain application. The usefulness of ENs in recognizing and categorizing various coffee aroma profiles will also be reviewed in this paper. This involves examining research that distinguishes between different types of coffee according to factors including roasting intensity, provenance, and microbial contamination. The integration of artificial intelligence (AI) with ENs, namely the application of artificial neural networks (ANNs) for data analysis and prediction, will be the subject of the third review section. The

paper attempts to offer a thorough and critical assessment of the present situation and potential applications of ENs in coffee aroma assessment by utilizing this multidimensional method. In addition to providing insightful information for scholars and business experts, it will aid in the creation of cutting-edge technologies and procedures that guarantee customers receive consistently excellent coffee experiences.

3. Results

3.1. Electronic Noses' Efficiency in Aroma Detection

Research has repeatedly shown how well electronic noses (ENs) identify and detect complex odors linked to microbiological activity [31]. Several research works offer compelling evidence for the effective abilities of ENs to identify complex odor patterns associated with microbial activity in a range of food items, [32] in coffee beans [33, 34]. A substantial portion of the flavor of the product is said to be determined by the chemical composition of volatile and semi-volatile organic molecules in the headspace, where electronic nose sensors conduct measurements [35] showed the potential of ENs as effective tools for fragrance detection in coffee by demonstrating the excellent accuracy rates of ENs in identifying a variety of aroma profiles.

3.2. Artificial Neural Network (ANN) Integration

The notable advancement in fragrance recognition and prediction is the integration of artificial neural networks (ANN) with electronic nose (EN) devices, artificial neural networks tend to be the most robust due to their nonlinearity and good capacity of finding patterns among the inputs and targets [36, 37]. With the use of artificial neural networks (ANN), researchers were able to obtain an excellent prediction accuracy of 94.4% when combining gas chromatography-mass spectrometry with the electronic nose [38]. By employing FCM and SOM feature extraction methods with an RBF neural network, the researchers achieved an astounding feat: 100% perfect classification accuracy for five different samples with different attributes [39]. This indicates that the algorithm performed a very good job of correctly predicting some outcomes associated with the scents it observed [40]. These results demonstrate the effectiveness of artificial neural networks in augmenting the capacity for scent detection and prediction when combined with electronic nose sensors. Researchers are opening the path for more accurate and dependable fragrance analysis in a variety of industries, including food quality management, environmental monitoring, and healthcare diagnostics, by utilizing the capabilities of these technologies.

3.3. Automated System for Quality Assurance

The need for coffee roasters who can guarantee the quality of their product through the use of risk assessment and real-time procedures has increased recently. In the last many years, there has been a lot of research done on determining the roast degree of coffee [41, 42, 43].

The automated system measured roasted coffee beans in the following ways: First, samples of freshly roasted coffee, about 50 grams each, were taken and put in the concentration chamber of the device for measurement. This system made use of EN technologies and demonstrated a strong ability to recognize changes in scent profiles brought on by outside influences. Ground coffee was then put to the test, and samples were taken by roasting green coffee beans in a special lab apparatus. After roasting, the beans were ground in a coffee grinder to a medium consistency. Given that liquid coffee creates more volatiles, this made the measurement process easier [44].

3.4. Principles of Electronic Nose Technology

The idea behind electronic noses (EN) is to identify and analyze complex scents and fragrances by simulating the human olfactory system [45]. A variety of sensors are used in EN devices to identify volatile organic compounds (VOCs) that are present in a sample's headspace [46, 47]. These sensors respond to different VOCs, generating a unique pattern or "fingerprint" of the scent [48]. Artificial neural networks and other sophisticated algorithms are used to process the sensor data in order to interpret and categorize the odor patterns [49]. This makes it possible for EN devices to identify particular smells, judge how strong they are, and even pinpoint their source [50]. The concept of electronic noses offers a flexible and effective instrument for a range of uses, such as environmental monitoring [51], medical diagnostics [52], homeland security [53], and food and beverage quality control [54, 55, 56]. In general, the idea behind electronic noses emphasizes how quickly, precisely, and non-intrusively they can analyze smells in a variety of environments. Electronic noses provide essential insights into the world of smell by utilizing advanced sensor technology and powerful data processing algorithms. This opens up new possibilities for quality control, environmental management, and healthcare applications.

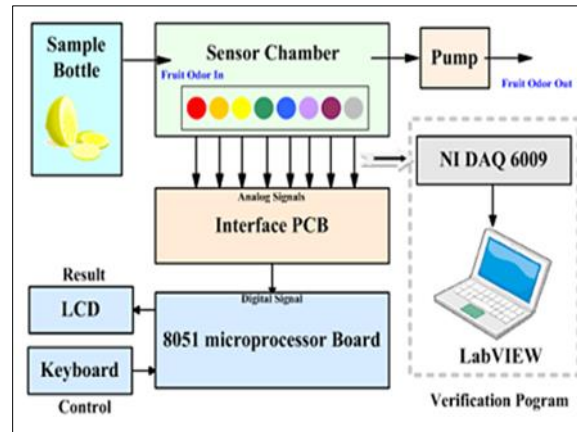


Figure 1 A prototype of the E-nose system [43]

3.5. Challenges and Future Directions

A wide range of opportunities for further investigation has developed, including the need for standardized standards and ongoing study to address specific issues associated with different coffee kinds and processing techniques [57]. This covers a broad range of possible research avenues, from creating generally recognized procedures for evaluating the quality of coffee to examining the effects of various processing methods on fragrance profiles [58, 59]. Additionally, learning about the subtle differences between various coffee varieties and their distinctive sensory qualities may provide insightful information about how to improve cultivation techniques and flavor consistency [60]. Considering these developments, problems with standards and practical implementation obstacles were noted [61]. Furthermore, addressing challenges such as environmental sustainability [62], socioeconomic factors [63], and consumer preferences [64] within the coffee industry presents an expansive landscape for interdisciplinary collaboration and innovative solutions.

4. Discussion

4.1. Significant Advancements in Electronic Nose (EN) Technology

The development of electronic nose (EN) technology is a noteworthy accomplishment in the fields of quality assurance and fragrance analysis. With the help of the human olfactory system, ENs have developed into highly advanced devices that are able to precisely and accurately identify and analyze complex odors. The incorporation of sophisticated algorithms, especially artificial neural networks (ANN), is one of the most noteworthy developments. ANNs have greatly improved the ability of ENs to recognize and anticipate scents. In order to interpret the data gathered by EN sensors and produce more robust and dependable fragrance analysis results, ANN algorithms take advantage of the nonlinearity and pattern recognition capabilities. Because of this integration, EN technology has reached new heights and is now equipped to handle a wide range of challenges in a variety of industries [65]. Furthermore, the creation of automated quality assurance systems is a noteworthy accomplishment in EN technology. Real-time smell profile monitoring is made possible by these systems' use of ENs, which allows for a quick and reliable evaluation of product quality. These systems simplify quality control procedures, lower human mistake rates, and guarantee product integrity by automating the detection of odor changes linked to spoiling, contamination, or adulteration. The limits of smell analysis are also being pushed by continuous research and improvement in EN technology, which is further boosted by developments in sensor technologies, data processing strategies, and integration with other analytical approaches [66].

4.2. Applications of Electronic Nose (EN) Technology Across Industries

Electronic nose (EN) technology has been widely used by a variety of industries because to its efficacy and versatility [67]. These businesses gain from EN's special qualities in fragrance analysis and quality assurance. ENs are essential for maintaining product safety and quality in the food and beverage industries because they can identify odor changes that could be signs of adulteration, contamination, or spoiling. When it comes to determining whether perishable foods are fresh or not, as well as spotting flavor irregularities, ENs offer insightful information that supports manufacturers in upholding strict guidelines for product integrity and customer pleasure [68]. ENs are also used in environmental monitoring to track industrial emissions, identify contaminants, and evaluate air quality. Through their ongoing monitoring of fragrance profiles in the surrounding environment, ENs support initiatives to protect public health [69], preserve natural ecosystems, and reduce pollution. ENs are also used in environmental monitoring to track industrial

emissions, identify contaminants, and evaluate air quality. Through their ongoing monitoring of fragrance profiles in the surrounding environment, ENs support initiatives to protect public health, preserve natural ecosystems, and reduce pollution [70].

5. Conclusion

To sum up, the investigation of coffee scents and the application of electronic nose (EN) technology signify a noteworthy progress in the domain of sensory analysis and quality assurance. Coffee is quite popular because of its taste, but it is also known for its complex aroma, which is a reflection of its origin, roasting method, and natural characteristics. But maintaining coffee products' safety and quality in the face of possible microbial contamination highlights the need for strong quality assurance protocols.

In this attempt, ENs have shown to be indispensable instruments, providing unmatched efficacy in the detection and analysis of intricate odor patterns linked to microbial activity. With ongoing developments in data processing algorithms and sensor technology, ENs have emerged as essential tools for scent analysis, allowing for prompt actions to protect consumer health and product integrity. Furthermore, the incorporation of artificial neural networks (ANN) amplifies the prediction powers of ENs, enabling accurate smell identification and categorization.

Applications of EN technology extend beyond the coffee industry; all benefit from its special powers in scent analysis and quality control. ENs are essential to maintaining strict standards and fostering customer confidence in a variety of fields, including environmental monitoring, healthcare diagnostics, and food safety and quality assurance.

In summary, investigating coffee scents and utilizing EN technology represent an interdisciplinary way to handling difficult problems in sensory analysis and quality assurance. Researchers and industry professionals can continue to innovate and build solutions that guarantee product integrity, consumer safety, and environmental sustainability across varied industries by utilizing the capabilities of ENs and embracing improvements in ANN integration.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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