

When Machines Learn to Smell: E-Nose for Meat Freshness Detection

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Abstract: -

Ensuring the freshness and safety of meat is a major concern for the meat industry and consumers. During storage, microbial growth and biochemical reactions produce volatile organic compounds (VOCs), resulting in changes in the odour and overall quality of meat. Conventional methods of meat quality evaluation, including sensory assessment and laboratory-based techniques, can be subjective, time-consuming and costly. Therefore, rapid, reliable and non-destructive approaches are gaining increasing attention. The electronic nose (e-nose) is a promising sensing technology that mimics the human sense of smell using an array of gas sensors combined with pattern-recognition and machine-learning techniques. By detecting changes in the overall volatile profile of meat, e-nose systems can help distinguish fresh, aged and spoiled samples. Recent developments have expanded their application from laboratory-based assessment to portable, automated and real-time monitoring systems. This article discusses the working principle, applications, advantages, challenges and future potential of e-nose technology in meat quality assessment.

Keywords: *Electronic nose, meat quality, meat freshness, volatile organic compounds, spoilage detection, gas sensors, machine learning etc.*

Introduction:

Meat is a nutrient-rich food that undergoes quality deterioration during storage. Microbial growth and biochemical reactions produce volatile organic compounds (VOCs), leading to changes in odour and freshness.

Therefore, timely monitoring of meat quality is essential to ensure safety and minimize spoilage-related losses.

Conventional methods such as sensory evaluation and GC-MS can be time-consuming, costly and dependent on trained

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personnel. Electronic noses (e-noses) offer a rapid and non-destructive alternative by detecting overall odour patterns using gas sensors and pattern-recognition techniques, making them promising tools for meat freshness and spoilage assessment.

What is an Electronic Nose?

An electronic nose (e-nose) is an instrument designed to mimic the human sense of smell. It consists of multiple gas sensors that respond to volatile compounds released from a sample. Rather than identifying each compound individually, the e-nose recognizes the overall odour pattern or “fingerprint” produced by the mixture of volatile compounds. The generated signals are then processed using statistical and machine-learning techniques to classify the sample according to its quality status.

A typical e-nose system consists of:

- ☞ **Sensor array** – detects different groups of volatile compounds.
- ☞ **Sample delivery system** – carries headspace gases to the sensors.
- ☞ **Signal processing unit** – converts sensor responses into measurable signals.
- ☞ **Pattern-recognition software** – interprets the sensor response pattern.
- ☞ **Data display system** – provides the final classification or prediction.

The technology is rapid, non-destructive and requires minimal sample preparation, making it suitable for food quality monitoring. Electronic noses have been successfully applied in food industries for evaluating freshness, authenticity and quality attributes.

How Does an Electronic Nose Work?

The operation of an electronic nose is based on detecting volatile compounds emitted from meat.

The process involves:

- ☞ **Odour collection** – Volatile compounds released from meat enter the sensing chamber.
- ☞ **Detection by sensors** – Different sensors respond to different groups of volatile compounds.
- ☞ **Signal generation** – Sensor responses are converted into electrical signals.
- ☞ **Pattern formation** – The combined signals create an odour fingerprint.
- ☞ **Data analysis** – Software and machine-learning algorithms analyse the fingerprint.
- ☞ **Quality prediction** – The sample is classified as fresh, aged or spoiled.

Unlike conventional analytical methods that identify individual compounds, an electronic nose evaluates the overall aroma profile, allowing rapid quality assessment.

Electronic Nose for Meat Quality Assessment

Electronic nose technology has shown considerable potential for assessing meat freshness and detecting spoilage. By monitoring changes in volatile compounds released during storage, e-nose systems can distinguish fresh meat from spoiled or low-quality products. Shtepliuk et al. (2025) demonstrated that a machine-learning-assisted e-nose could accurately differentiate fresh pork from urine-contaminated and aged pork samples, highlighting its usefulness in meat inspection and quality control.

Beyond pork quality assessment, e-nose technology has also been applied to monitor beef spoilage through the detection of gases such as carbon dioxide, ammonia and ethylene, which are associated with microbial deterioration (Damdam et al., 2023). Recent advances in hybrid sensor arrays have further improved the accuracy of pork freshness monitoring, making the technology suitable for real-time applications in slaughterhouses and cold-chain systems (Zhao et al., 2026).

In addition, the development of soft e-nose systems integrated with machine-learning algorithms has demonstrated the potential of artificial intelligence to enhance food quality assessment and classification (Pulluri and Kumar, 2022). Together, these developments indicate that electronic noses can serve as rapid, objective and non-destructive tools for modern meat quality evaluation.

Together, these studies indicate that e-nose technology can provide rapid and objective information about meat quality without requiring extensive sample preparation.

Advantages of Electronic Nose Technology

The growing interest in e-nose technology is associated with several practical advantages:

- Rapid analysis and decision-making
- Non-destructive assessment
- Reduced dependence on sensory panels
- Objective and reproducible measurements
- Minimal sample preparation
- Potential for automation
- Integration with machine learning
- Compatibility with IoT and wireless systems
- Possibility of real-time monitoring

These features make e-noses attractive for use in slaughterhouses, meat-processing plants, storage facilities and cold-chain transportation.

Challenges and Future Prospects

Despite their potential, electronic noses still face challenges that can affect their accuracy and reliability. Sensor responses may vary with temperature, humidity and changes in the surrounding environment. Sensor drift over time can also influence results, making regular calibration and standardization important. In addition, e-nose systems may

require large and diverse datasets to perform reliably across different meat types and storage conditions.

The next generation of e-noses is expected to combine improved sensors with artificial intelligence, machine learning and IoT technology. Portable and wireless systems could enable real-time monitoring of meat quality during processing, storage, transportation and retail. With continued improvements in sensor sensitivity and data analysis, e-noses could become practical tools for faster and more accessible meat freshness assessment.

Conclusion

The electronic nose represents an exciting advancement in meat quality assessment. By mimicking the human sense of smell, it can rapidly detect aroma changes associated with freshness and spoilage. The combination of sensor technology and machine learning has significantly improved the accuracy of meat quality evaluation, making e-noses promising tools for modern meat inspection and quality assurance. As technology continues to advance, electronic noses may play an increasingly important role in ensuring safer, fresher and higher-quality meat products for consumers.

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