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Review Article

Application of artificial intelligence in the food industry

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Abstract

The article examines innovative automated methods and approaches based on algorithms for artificial intelligence, data analysis, machine learning and deep learning in the food industry, which, in combination with modernized intelligent equipment, lead to sales growth, reduce product counterfeiting, increase the quality of the produced production, identify and track food products, evaluate their characteristics and qualities, improve health and customer satisfaction, etc. With the development of automation, computer-aided design, integration and management, the food industry reaches a peak and exponential progress. The paper aims to show verified practical applications of artificial intelligence (AI) in the food industry. In support of the thesis, developed and implemented technological solutions in sustainable industrial applications such as electronic noses, electronic palates, computer vision systems, the Internet of Things, and tools for identifying and distinguishing individual qualities of food products are presented.

Keywords

food industry, AI solutions, electronic noses and tongues, computer vision, artificial intelligence

Abbreviations

AI – artificial intelligence; ANN – artificial neural network; e-eye – electronic eye; e-nose – electronic nose; e-tongue – electronic tongue; IoT – internet of things; RFID – radio frequency identification; QR code – quick response code; SNN – spiking neural network;

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Introduction

The food industry, including the quality of products and their safety during distribution, is of vital importance to the people and economy of any country. Innovations in production led to the appearance of new different types of food and methods of processing. Excessive population growth and overconsumption have led to a demand for modern methods of rapid production with modernised intelligent equipment and processing through the methods of artificial intelligence.

The leading trends in food and beverage production are sustainability, innovation, clean and quality production, health care, ecology and environmental protection from over-exploitation. Addressing these and other similar issues sparks discussions on topics such as responsible sourcing of materials, food safety, waste reduction, use of biodegradable packaging, global warming, economic imbalance, overpopulation, demand-supply chain, and more. To overcome them, it is necessary to invent and implement technologically innovative techniques and automation of work processes, which in turn lead to high productivity, sustainable business models, production speed, efficiency of processes and quality of manufactured products, and to optimise planning and reduce production losses.

The article examines AI and its application in the food industry. Developed and implemented solutions based on machine learning algorithms in sustainable industrial applications are presented. Automation of business processes, assessment of product quality, prevention in terms of detection of problems and disruption of the production process are leading in shaping the requirements for industrial AI.

Artificial Intelligence in the Food Industry

With the development of automation, computer-aided design, integration and management, the food industry is reaching a peak and exponential progress. More and more machines are performing tasks with minimal human intervention with greater accuracy, while simultaneously saving time and costs, managing production processes and food supply more efficiently, and thus improving the overall operational performance (Lee et al. 2019).

Artificial intelligence in collaboration with data science can improve the quality of work and service in restaurants, hotels, cafes, and online delivery food chains by increasing production using various appropriate sales forecasting algorithms. AI can greatly improve packaging, increase shelf life, ensure food safety, reduce the cost of reporting food properties, enhance the use of perishable raw materials with variable composition, and create a more transparent supply chain management system.

The role of AI in the food industry can also be considered in the processing, storage and delivery of food products, sensory properties of the developed food products, and the management of security, quality and safety of food. AI-based systems use computer vision and deep learning algorithms to analyse the data received from AI-based agents, tracking the development of different types of crops, predicting their progress, identifying defective plants and monitoring soil conditions.

Conceptually, the food industry is a relatively mature and slow-growing industry with a low level of investment in research and development, compared to other business sectors (Kakani et al. 2020). In agriculture, as a primary source of raw materials, AI-based computerised systems are also used to help select the best seeds, testing and inventions, satellite observations and research, analyse and monitor various soils, crops and processes in real-time, wireless communications, etc. All this undoubtedly has a positive impact on the economy, capital investments and the movement of goods. Still, it harms the environment by the way of increasing surface average temperature, the amount of greenhouse gases and carbon dioxide increases, soils becoming decertified, etc.

Industrial Artificial Intelligence

Industrial AI is a discipline focused on the development, validation and deployment of various machine learning algorithms in sustainable industrial applications. Combined with modern sensing and communication platforms for big data analysis, the systematic methodology for industrial AI enables the integration of physical systems with computational models. In terms of predictive maintenance, industrial AI can detect initial system changes predict residual useful life and further optimize maintenance tasks to avoid disruption of

operations (Lee 2020). Industrial artificial intelligence can realize intelligent and sustainable industrial systems through four enabling technologies: data technology, analytics technology, platform technology and operation technology.

- **Analytics technologies:** Many companies are making significant investments in data collection hardware and sensors to store vast amounts of process data. Analytics refers to the application of statistics and other mathematical tools to these data streams to evaluate and improve practices. Analytics can enable manufacturers to investigate even the smallest changes in production processes (Raviya and Chavda 2021). Data visualization tools are also essential to analytics technologies (Lee et al. 2019).

- **Platform technologies:** Platform refers to both hardware and software that takes care of installation, device connection and data processing (visualization, collection, retrieval and storage). This type of technology helps to coordinate, integrate, implement and support technologies (digital twins, data storage, connectivity across the shop floor, edge intelligence, robotics integration, etc.) (Lee et al. 2019).

- **Operational technologies:** Based on the information obtained from the analysis, operational technologies aim to achieve control and optimization of the enterprise through product life cycle management systems, resource planning, production execution systems, relationship management with customers and supply chain management (Lee et al. 2019). Operational technologies enable features such as self-configuration, self-tuning and self-optimization of the manufacturing ecosystem, which ultimately improves flexibility and resilience throughout the manufacturing system and leads to higher efficiency and economic impact.

Modern Applications of AI in the Food Industry

Digitalization configures food production and trade in all their aspects, defining the nature and types of exchange, communication, participants, conditions and offers. At the beginning of the digital transformation, companies mainly focused on identifying production elements, assigning IDs to

them and improving their connectivity through the use of information and communication tools (Lee et al. 2019).

Product identifiers. Applications built to identify and differentiate individual products or assets help manufacturers, retailers, and other businesses track, manage, and locate products at various stages of their supply chain. They are called product identifiers. They identify the product and track its entire life cycle, ensure proper maintenance and efficient use of raw materials/resources, and streamline production processes. Product type identifiers are barcodes, radio frequency tags, QR codes, serial and standard numbers, storage units, inventory, registration, etc.

Barcodes are machine-readable data representations that identify products by product or item code. They find applications in retail trade. To solve specific problems with food quality and safety, (Kong et al. 2013) present a system for the traceability of the quality of bee products. The authors use state-of-the-art technologies, such as ASP.NET, CDMA, GPS, XML, and barcode data collection technology. The system created by the authors, the so-called beekeeper's diary, stores the collected data from an Android terminal and saves them in an Access database, respectively, on a server. The web client displays the analysis results for review and feedback to enterprise management. To achieve quality traceability, the system enables tracking of raw material sources, assists with beekeeping technologies and gives feedback on the quality of bee products (Kong et al. 2013).

Radiofrequency identification (RFID) tags use electromagnetic fields and are used in product tracking. With RFID, a chip is used, which transmits information locked in it, the so-called tag, upon a certain radio signal. Each tag is unique and cannot be modified or copied. RFID chips are miniaturized in size and successfully embedded in cards, bracelets, etc. Reading the information from the RFID chip is a contactless reader, which makes it convenient to use (Mironov 2013). The tag functionality depends on the amount of memory on the chip, the range of the reader and the availability of a power source in the tag chip. Tags can be smart and can both read and write information (Imankul 2019).

Scannable two-dimensional (QR) codes contain a large amount of information. After scanning, they lead to a specific web page for a product or service. Serial and standard numbers are alphanumeric codes intended to record, maintain, trace or guarantee a particular provenance, and compliance with certain regulatory requirements. They all find application in asset management information systems, e-commerce, equipment organisation, sales tracking, subsequently in the formation of marketing strategies, supply chain management, compliance with legal regulations, monitoring of defective products, guarantee provision, anti-counterfeiting, etc.

Electronic nose. Aroma is one of the main characteristics for determining the quality of food and beverages and one of the first things customers evaluate when testing a product. Traditional techniques for evaluating the aromas of manufactured food products are time-consuming and require special training, expensive equipment and trained personnel. A modern technology that replaces experts and can recognize smells is the e-nose technology. The E-nose technology consists of a set of sensors to collect signals for various volatile organic compounds, and a data storage system in which analysis and processing are performed, as shown in Fig. 1.

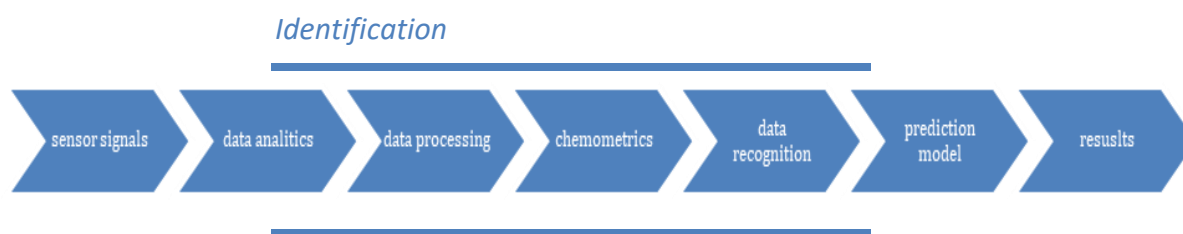


Figure 1. Electronic nose technology, from gas to data recognition

In the E-nose, the set of sensors corresponds to the olfactory receptors in humans, which detect aromatic traces of substances in the air. The electronic nose was developed as a device that does not separate the individual components that create the smell but reacts to their totality. The device is designed to test the air through sensors, which later process their signals. [Gonzalez Viejo et al. \(2020\)](#) have developed a low-cost, portable electronic nose (e-nose) that integrates 9 different gas sensors that effectively discriminate between different gases in beer samples. The scientists also developed two artificial neural network (ANN) models, one to predict aromas in beer and another to predict sensory characteristics. In conclusion, the scientists claim that their combined method using the developed e-nose and ANN models is cost-effective, fast, reliable accurate, and applicable to other foods ([Gonzalez Viejo et al. 2020](#)). ANN, including the spiking neural network (SNN), is used to recognise different types of gases ([Chen et al. 2022](#)). The authors find that each classical gas recognition method has a relatively fixed framework and a few parameters, which makes it

easy to design and perform well with limited gas samples, but weak in multi-gas recognition under noise. In contrast, ANN-based methods obtain better recognition accuracy with flexible architectures and lots of parameters ([Chen et al. 2022](#)).

E-nose technology is also used in research to assess freshness, taste, and quality control of food products. The authors in ([Wang and Chen 2024](#)) monitor the process, authenticity, and can trace the origin and detect pesticide residues in food. In their study, Loutfi team reviews the latest developments in the field of electronic noses and focuses on monitoring the quality of foods such as meat, milk, fish, tea, coffee and wines ([Loutfi et al. 2015](#)). The scientists studied the concentration of mixtures of volatile organic compounds contained in cow's milk. These vary due to various factors such as bacterial metabolism, aging, photooxidation and the presence of pro-oxidant metals such as copper, iron and nickel. They also tracked bacterial growth, which leads to milk spoilage and the appearance of an unpleasant taste upon consumption. An electronic nose is also used in wine classification.

With the help of sensors, both the taste and aroma of the wine can be monitored, as well as the transformation of organic acids during the fermentation of the must. According to the authors, the high content of some acids has a bad effect on the taste of the wine. The e-nose is also used in distinguishing different wines according to grape variety and geographical location, aging techniques, in detecting defects and preventing spoilage (Loutfi et al. 2015). An electronic nose can also be used to identify hazardous flammable/noxious gases and their concentration levels (Attallah and Morsi 2022). In their research scientists introduce an intelligent E-Nose called GasCon-Enose to identify both the gas type and its concentration level using artificial intelligence. The system GasCon-Enose utilized three machine learning classifiers (KNN, SVM, and RF) and extracts features from time, fuses them and investigates their impact on identification performance. Its application has a vital effect on providing a liveable environment and preventing hazards affecting people's safety (Attallah and Morsi 2022). Electronic nose systems can differentiate the aroma of freshly roasted coffee from different production regions (Lee et al. 2022). The authors in the research developed a method to create an aromatic digital fingerprint of a specific coffee bean to identify its origin.

Another application of electronic nose technology is in healthcare (Ma et al. 2024). The authors (Ma et al. 2024) use e-nose to detect diseases of the

gastrointestinal tract, which are characterized by a long course of symptoms and are associated with difficulties in treatment. Diagnosis requires a comprehensive review of volatile organic compounds. The e-nose technology is applied in many fields, including environmental monitoring; food safety; determination of dangerous substances such as explosives, toxic gases and chemical leaks, pharmaceutical products; biomedicine; and several other areas in applied science. It can also detect chemical fingerprints to identify different diseases (Ma et al. 2024).

In 2023 group of scientists made research (Ali et al. 2023) and found several review articles have been published on the mechanism and principles of e-nose sensors and their application in fruit identification, ripeness and quality assessment (Baietto and Wilson 2015), food safety assessment (Ali et al. 2020), food authenticity (Gliszczyńska-Swigło and Chmielewski 2017) and early detection of crop diseases (Mohammad-Razdari et al. 2022).

Electronic tongue. The monitoring of food products in terms of quality and the control of production processes are performed by physicochemical measurements. The electronic tongue is a sensory technology that is used to assess the taste qualities of food and beverages (sour, salty, sweet, and bitter). These analytical devices are mainly used to identify and classify the flavours and their mode of operation "mimics" the human sense of taste as presented in Fig. 2.

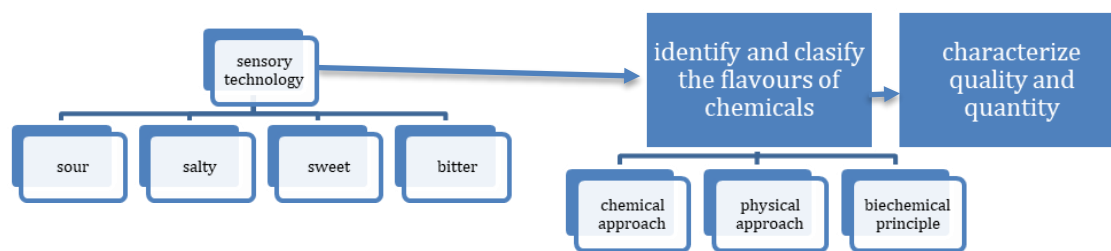


Figure 2. Electronic tongue technology, from food to data recognition

Electronic tongues can be used to characterize multicomponent mixtures for both qualitative and quantitative purposes (Peris et al. 2016). Detection techniques may include the application of both chemical and physical approaches as well as

methods based on biochemical principles (Momtaz et al. 2023).

Group of scientists lead from Martinez-Manez in 2005 use an electronic tongue for qualitative analysis of different natural waters. Their research

includes seven mineral waters, tap water and osmotised water. They performed qualitative analysis of different waters using fuzzy neural networks (Martínez-Máñez et al. 2005). In their

study Peris and his team using electronic tongues, scientists evaluate the authenticity and adulteration of foods (Peris et al. 2016). The author Sobrino-Gregorio and his team in 2018 applied an electronic tongue based on potential multistep pulse voltammetry in combination with multivariate statistical techniques to detect and quantify syrup in honey. Their methodology can distinguish between pure honey and syrups and can differentiate between different levels of spice. The measurement system proposed by the authors claims to be a fast and effective screening of the product (honey) to prevent adulteration in its production (Sobrino-Gregorio et al. 2018).

In his research Li et al. (2023) predict the freshness of horse mackerel using an e-nose, e-tongue and colorimeter based on biochemical indices analyzed during frozen storage of whole fish). The freshness in their study is monitored with an electronic sensor and biochemical indices. Group of scientists lead from Wang proposed a method to identify the origin of black pepper by synergistically applying e-tongue, e-nose, and e-eye in combination with a deep learning algorithm. They collected the taste and smell fingerprints from e-nose and e-tongue instruments, respectively, and the colour, shape and texture information of various samples was collected from e-eye instruments (Wang et al. 2023). Scientists lead from Mahanti combined data generated by e-nose and e-tongue technology with chemometric techniques to investigate food safety and authentication in the food industry (Mahanti et al. 2024).

Electronic tongue technology also finds application in healthcare. In their study, Maryam et al. investigated the role of artificial intelligence and e-tongue technology in the early detection of oral cancer. AI-driven models, particularly those utilizing deep learning algorithms, demonstrated high sensitivity (>85%) and specificity (>80%) in detecting oral cancer biomarkers (Maryam et al. 2024). Other scientists (Zniber et al. 2023) applied the e-tongue technique to urine analysis and cancer diagnosis, using machine learning and supervised

and unsupervised learning algorithms to analyse the extracted chemical data.

Computer vision. In food production, much information about the material or the finished product is obtained through visual assessments made by employees. However, this is often an inaccurate subjective assessment. Computer vision systems have been used to eliminate human error (Chmiel et al. 2011).

Computer vision is a science that develops a theoretical and algorithmic basis for automatically extracting and analysing useful information about physical objects from images (Di Rosa and Leone 2018). Scientists from (Amugongo et al. 2023) found that 90.9% of mobile applications in the food storage sector do not distinguish between food and non-food. However, the visual presentation of food has a great influence on people's eating behavior and perception (Allegra et al. 2020). In the agricultural sector, computer vision systems are applied to automate or obtain information from many agricultural tasks such as planting, cultivation, farm management, disease control, weed control or robotic harvesting.

Chmiel and his team evaluated the fat content of poultry meat using computer vision (Chmiel et al. 2011). They randomly select meat from thigh muscles (from chickens and turkeys) and from chicken breast muscles. They do a correlation analysis between the content of white spots in the images and the fat content. According to the obtained results, they conclude that the computer vision system for images of turkey thigh muscles can be used to estimate their fatness (Chmiel et al. 2011).

The scientists Fracarolli and Sharif used a citrus disease classification technique (Fracarolli et al. 2020). After segmentation, colour, textural and geometric features were used to analyse images of oranges with different peel defects. Colour and texture features were also used by Zhang in 2020 to segment images of apple orchards with similar leaf colours (Fracarolli et al. 2020). Another author has developed a method for segmenting diseased tomato leaves (Tian 2019). In his study Liu designed a computer vision-based classifier to classify tomatoes based on their colour (Liu 2019), diameter and shape using different image processing algorithms (Fracarolli et al. 2020).

A team of scientists characterized different types of olive oil and estimated its shelf life using the electronic eye, a technology that is based on computer vision systems or colorimetric techniques (Buratti et al. 2018). Electronic nose, electronic tongue and electronic eye in combination with chemometric methods were applied for quality identification and prediction of tea quality (Xu et al. 2019). The main chemical components in the study, such as amino acids, catechins, polyphenols and caffeine, were measured using traditional methods. The authors' results show 100% accuracy in quality identification of tea quality grades based on fusion signals by support vector machine and random forest (Xu et al. 2019).

The final products in the food industry are multi-component and for assessment of their quality and analysis, often only the data from one sensor is not enough. Modern technologies such as electronic noses, electronic tongues and computer vision systems designed to artificially perceived taste and appearance are increasingly used in the food industry as fast and reliable quality assessment tools (Di Rosa and Leone 2018). In this regard, current trends are towards multivariate analysis methods, together with different electronic senses, combined with the joining of multiple data and results from different sources.

Internet of Things (IoT). The IoT is a network of physical devices, means and objects that interact with each other and/or with the environment through embedded electronic systems and devices. IoT is a relatively new approach and as such provides new opportunities for the development and application of AI in various areas of the technology sector. IoT architecture includes several layers:

- i) device layer,
- ii) network layer,
- iii) service support layer,
- iv) application layer, and
- v) management and security (Ibrahim et al. 2022).

The device layer includes all devices, receivers, sensors, devices embedded in the environment that transmit and receive data directly or through ports, power supply devices with energy (batteries, solar panels) and all communication technologies, wired and/or wireless.

Impact of IoT on supply chain. In their paper (Aung et al. 2014), the authors describe the process of creating an efficient and cost-effective platform for real-time management and tracking of the prepackaged food supply chain based on Internet of Things (IoT) technology, which provides good quality and food that is safe to eat. Their platform has a service-based multi-layered architecture. They use QR codes, RFID tags, and Extensible Markup Language (XML) to facilitate information sharing between used applications and stakeholders (Aung et al. 2014). The authors implement fine-grained tracking of pre-packaged foods throughout the supply chain, collect real-time data, and demonstrate that their method is flexible and effective for sharing information throughout the entire process, and applicable to other application areas.

Impact of IoT on food safety. Through IoT technology, it is also possible to detect potential threats and take quick responses to deal with food safety incidents. The authors (Li et al. 2017) aim to minimize the production and distribution of unsafe or substandard products. Their food labelling and tracking system is based on a system of computers, mobile phones, sensors and readers and provides real-time information to consumers about the status of quality and safety of products and could also support a quick recall decision, when quality and safety standards are violated (Li et al. 2017).

Also, with the help of IoT technology, the food supply can become more transparent and safer than before, as well as increase the confidence of customers to buy certain foods (Liu et al. 2016). The authors present an AIoT pilot project that integrates state-of-the-art technologies to provide a method to easily track and trace food delivery processes and address food safety issues. In (Reddy and Babu 2017), improved technologies of service-oriented architecture, global identification, parsing, and electronic genealogy (business data generated from heterogeneous sources) are used. The AIoT architecture is a decentralized and heterogeneous ecosystem that involves the integration of disparate inputs. It consists of 3 layers – sensor, network and application (Liu et al. 2016). In particular, their system aggregates real and predicted data from fresh vegetable supply chains to display an intuitive view for users, including end customers. These findings can help consumers make better decisions

when buying food or controlling the food supply (Reddy and Babu 2017).

Impact of IoT on food quality. Gupta and Rakesh (2018) designed an IoT system to monitor impurities in food products. According to (Bouzembrak et al. 2019) another IoT food fraud system was developed by Rajakumar et al. (2018), focused on detecting impurities in milk using several sensors such as gas, temperature, viscosity, salinity, and RFID readers. Nirenjena et al. (2018) developed an IoT system to prevent food contamination and degradation, which can be used to monitor food quality in general, but can also be adapted to specific food products. They use several sensors to detect food degradation, such as temperature, moisture and GPS location. In his study, Bouzembrak et al. (2019) examined and described a cloud-based SmartWine system for monitoring the wine supply chain. The system aims to manage resource consumption (water and pesticides), disease prevention and quality improvement. They integrate several sensors to collect data on air temperature, air humidity, atmospheric pressure, solar radiation, ultraviolet radiation, wind speed, wind direction, leaf wetness, soil temperature and soil water tension (Bouzembrak et al. 2019).

Use of drones. The use of drones in agriculture began as early as the 1980s in Japan for pesticide spraying and crop pollination (Dutta and Goswami 2020). The drones can fly with special software that allows the preparation of a direction plan and deployment of the system with GPS and power in various parameters such as region, speed, altitude, geo-fencing and safety modes. They provide real-time aerial imagery of higher quality than satellite imagery over agricultural land, allowing farmers to learn more about their fields (Dutta and Goswami 2020). Users pre-program the drone's route and then integrate it with the device (Kumar et al. 2021). Computer vision records several pictures that are used for research purposes. Drones are preferred due to their high spatial resolution and fast turnaround capabilities, along with low operating costs and ease of operation. They are equipped with cameras and sensors to monitor crops and sprayers to spray pesticides. Their applicability in precision agriculture helps in crop monitoring, crop height estimation, pesticide spraying, soil analysis, monitoring conditions throughout the crop season,

plant disease surveillance, weed control, pest attacks, drought (so-called water stress), evaporation levels, etc. (Dutta and Goswami 2020).

Smart farming, which views the farm as a collection of small units and identifies irregularities in production, is also used to minimize farming costs to increase profits (Kassanuk and Phasinam 2023). This study explores how data mining and machine learning are used in agriculture, offering AI methods to optimize agricultural productivity and food quality. The research is valuable because it shows AI application in agriculture as a source of raw materials for the food industry. With the development of communication information technologies, various limitations in agriculture are being overcome, such as growing different crops and subcultures, classifying seed varieties, controlling weeds, pests, harmful emissions, lack of motivation in using technologies due to the uneducated population, etc. The authors of the study (Kassanuk and Phasinam 2022) claim that the introduction of the technologies described above in the article contributes to the overall development of agriculture and rural areas.

Conclusions

In conclusion, the integration of advanced technologies such as artificial intelligence, machine learning and innovative automation in the food industry is leading to significant progress, transformation and increased productivity, even under adverse environmental conditions.

This review highlights the practical applications of these advanced technologies, demonstrating their ability to improve product quality, identify items, optimize operations and improve consumer satisfaction and health, while addressing challenges such as product counterfeiting. By using intelligent systems such as electronic noses, electronic tongues, computer vision and IoT solutions, the food industry is not only achieving greater efficiency and productivity, but also contributing to sustainable practices. As a positive aspect, the connectivity between the food industry and rapidly evolving technologies can also be added.

With the help of the described technologies, processes such as tracking quality changes throughout the entire life cycle of food production, detecting dangerous, flammable harmful gases,

managing and locating products in the supply chain, ensuring proper control and maintenance, predicting and distinguishing aromas, assessing freshness, taste, authenticity, colour, shape, texture and maturity in foods and beverages, detecting traces of pesticides, bacteria, in diagnosing and detecting diseases, in environmental monitoring, in biomedicine, agriculture, etc. are now possible. The findings highlight the potential of these technological advances to revolutionize the food sector, ensuring a future marked by improved quality and safety for consumers

References

- Ali A., Mansol A.S., Khan A.A., Muthoosamy K., Siddiqui Y. Electronic nose as a tool for early detection of diseases and quality monitoring in fresh postharvest produce: A comprehensive review. *Comprehensive Reviews in Food Science and Food Safety*, 2023, 22(3): 2408-2432. <https://doi.org/10.1111/1541-4337.13151>
- Ali M.M., Hashim N., Aziz S.A., Lasekan O. Principles and recent advances in electronic nose for quality inspection of agricultural and food products. *Trends in Food Science & Technology*, 2020, 99(5): 1-10. <https://doi.org/10.1016/j.tifs.2020.02.028>
- Allegra D., Battiato S., Ortis A., Urso S., Polosa R. A review on food recognition technology for health applications. *Health Psychology Research*, 2020, 8(3): 9297. <https://doi.org/10.4081/hpr.2020.9297>
- Amugongo L.M., Kriebitz A., Boch A., Lütge C. Mobile computer vision-based applications for food recognition and volume and calorific estimation: A systematic review. *Healthcare*, 2023, 11(1): 59. <https://doi.org/10.3390/healthcare11010059>
- Attallah O., Morsi I. An electronic nose for identifying multiple combustible/harmful gases and their concentration levels via artificial intelligence. *Measurement*, 2022, 199(8): 111458. <https://doi.org/10.1016/j.measurement.2022.111458>
- Aung M.M., Chang Y.S. Traceability in a food supply chain: Safety and quality perspectives. *Food Control*, 2014, 39(5): 172-184. <https://doi.org/10.1016/j.foodcont.2013.11.007>
- Baietto M., Wilson A.D. Electronic-nose applications for fruit identification, ripeness and quality grading. *Sensors*, 2015, 15(1): 899-931. <https://doi.org/10.3390/s150100899>
- Bouzembrak Y., Klüche M., Gavai A., Marvin H.J.P. Internet of Things in food safety: Literature review and a bibliometric analysis. *Trends in Food Science & Technology*, 2019, 94(12): 54-64. <https://doi.org/10.1016/j.tifs.2019.11.002>
- Buratti S., Malegori C., Benedetti S., Oliveri P., Giovanelli G. E-nose, e-tongue and e-eye for edible olive oil characterization and shelf life assessment: A powerful data fusion approach. *Talanta*, 2018, 182(5): 131-141. <https://doi.org/10.1016/j.talanta.2018.01.096>
- Chen H., Huo D., Zhang J. Gas recognition in e-nose system: A review. *IEEE Transactions on Biomedical Circuits and Systems*, 2022, 16(2): 169-184. <https://doi.org/10.1109/TBCAS.2022.3166530>
- Chmiel M., Słowiński M., Dasiewicz K., Application of computer vision systems for estimation of fat content in poultry meat. *Food Control*, 2011, 22(8): 1424-1427. <https://doi.org/10.1016/j.foodcont.2011.03.002>
- Di Rosa A.R., Leone F. Application of Electronic Nose Systems on Animal-Source Food: An Overview. In: *Electronic Nose Technologies and Advances in Machine Olfaction*, (Y.Albastaki, F. Albaloooshi Eds.), IGI Global, 2018, pp. 151-174. ISBN 13: 978-1522-53862-2; ISBN 10: 152-253-862-3; EISBN 13: 978-15225-3863-9 <https://doi.org/10.4018/978-1-5225-3862-2.ch008>
- Dutta G. and Goswami P. Application of drone in agriculture: A review. *International Journal of Chemical Studies*, 2020, 8(5): 181-187. <https://doi.org/10.22271/chemi.2020.v8.i5d.10529>
- Fracarolli J.A., Pavarin F.F.A., Castro W., Blasco J. Computer vision applied to food and agricultural products. *Revista Ciência Agronômica*, 2021, 51(1): e20207749. <https://doi.org/10.5935/1806-6690.20200087>
- Gonzalez Viejo C., Fuentes S., Godbole A.M., Widdicombe B., Unnithan R.R. Development of a low-cost e-nose to assess aroma profiles: An artificial intelligence application to assess beer quality. *Sensors and Actuators B-Chemical*, 2020, 308(4): 127688. <https://doi.org/10.1016/j.snb.2020.127688>
- Gupta K., Rakesh N. IoT-based Solution for Food Adulteration. In: *Proceedings of First International Conference on Smart System, Innovations and Computing* (A.K. Somani, S. Srivastava, A. Mundra, S.Rawat Eds.). Springer Singapore, SSIC 2017, Jaipur, India. 2018, pp. 9-18, Print Hardcover ISBN: 978-981-10-5827-1; Softcover ISBN: 978-981-13-5502-8; eBook ISBN: 978-981-10-5828-8, Series Title: Smart Innovation, Systems and Technologies Series. E-ISSN: 2190-3026, <https://doi.org/10.1007/978-981-10-5828-8>
- Ibrahim S., Deb S.R., Ahmed M.F., Ahmed F. Impact of Using Electricity for Rural Warehouse Moisture Control System, *Proc. 6th International Conference on Computing Methodologies and Communication (ICCMC)*, Erode, India, 2022, pp. 495-500. <https://doi.org/10.1109/ICCMC53470.2022.9753736>

- Imankul M.N. (2019). RFID Systems Applications: Current Issues and Trends. In *Innovative Development of Science and Education* (G.Y. Gulyaev Ed.). Science and Education, Ural Federal University, Penza. 2019, pp. 158-166, Print ISBN: 978-5-907160-55-2 [in Russian]
- Kakani V., Nguyen V.H., Kumar B.P., Kim H., Pasupuleti V.R. A critical review on computer vision and artificial intelligence in food industry. *Journal of Agriculture and Food Research*, 2020, 2(12): 100033. <https://doi.org/10.1016/j.jafr.2020.100033>
- Kassanuk T., Phasinam K. A comprehensive review on the implementation of technological systems, standards, and interfaces used in the food and agriculture industries. *Materials Today: Proceedings*, 2022, 51(8): 2268-2271. <https://doi.org/10.1016/j.matpr.2021.11.396>
- Kassanuk T., Phasinam K. Application of data mining and machine learning in food and agriculture industry towards precision agriculture. *AIP Conference Proceedings*, 2023, 2587(1): 050013. <https://doi.org/10.1063/5.0150472>
- Kong Y.G., Hu X.F., Chen T.J., You Z.T. Research and development of quality traceability system based on intelligent services for bee products. *Applied Mechanics and Materials*, 2013, 302(2): 694-699. <https://doi.org/10.4028/www.scientific.net/AMM.302.694>
- Kumar I., Rawat J., Mohd N., Husain S. Opportunities of artificial intelligence and machine learning in the food industry. *Journal of Food Quality*, 2021(7). <https://doi.org/10.1155/2021%2F4535567>
- Lee C.H., Chen I.T., Yang H.C., Chen Y.J. An AI-powered electronic nose system with fingerprint extraction for aroma recognition of coffee beans. *Micromachines*, 2022, 13(8): 1313. <https://doi.org/10.3390/mi13081313>
- Lee J. How to Establish Industrial AI Technology and Capability. In: *Industrial AI. Applications with Sustainable Performance* (J. Lee Ed.). Springer Singapore, Shanghai Jiao Tong University Press, 2020, pp. 119-159. eBook ISBN: 978-981-15-2144-7. <https://doi.org/10.1007/978-981-15-2144-7>
- Lee J., Singh J., Azamfar M. Industrial artificial intelligence, *Cornell University arXiv:1908.02150 Computer Science - Computers and Society*, 2019, [v3] Tue, 22 Oct: 2150. <https://doi.org/10.48550/arXiv.1908.02150>
- Li H., Wang Y., Zhang J., Li X., Wang J., Yi S., Zhu W., Xu Y., Li J. Prediction of the freshness of horse mackerel (*Trachurus japonicus*) using E-nose, E-tongue, and colorimeter based on biochemical indexes analyzed during frozen storage of whole fish. *Food Chemistry*, 2023, 402(2): 134325. <https://doi.org/10.1016/j.foodchem.2022.134325>
- Li Z., Liu G., Liu L., Lai X., Xu G. IoT-based tracking and tracing platform for prepackaged food supply chain. *Industrial Management & Data Systems*, 2017, 117(9): 1906-1916. <https://doi.org/10.1108/IMDS-11-2016-0489>
- Liu Y., Han W., Zhang Y., Li L., Wang J., Zheng L. An Internet-of-Things solution for food safety and quality control: A pilot project in China. *Journal of Industrial Information Integration*, 2016, 3(9): 1-7. <https://doi.org/10.1016/j.jii.2016.06.001>
- Loutfi A., Coradeschi S., Kumar G., Shankar P., Bosco J., Rayappan B. Electronic noses for food quality: A review. *Journal of Food Engineering*, 2015, 144(1): 103-111. <https://doi.org/10.1016/j.jfoodeng.2014.07.019>
- Ma T., Chang Z., Zhang N. Application of electronic nose technology in the diagnosis of gastrointestinal diseases: a review. *Journal of Cancer Research and Clinical Oncology*, 2024, 150(8): 401. <https://doi.org/10.1007/s00432-024-05925-w>
- Mahanti N.K., Shivashankar S., Chhetri K.B., Kumar A., Rao B.B., Aravind J., Swami D. Enhancing food authentication through e-nose and e-tongue technologies: Current trends and future directions. *Trends in Food Science & Technology*, 2024, 150(8): 104574. <https://doi.org/10.1016/j.tifs.2024.104574>
- Martínez-Máñez R., Soto J., García-Breijo E., Gil L., Ibáñez J., Llobet E. An “electronic tongue” design for the qualitative analysis of natural waters. *Sensors and Actuators B: Chemical*, 2005, 104(2): 302-307. <https://doi.org/10.1016/j.snb.2004.05.022>
- Maryam, Khoro R., Ali I., Zareef U., Haque A., Faizan A. A systematic review on the early detection of oral cancer using artificial intelligence and electronic tongue technology. *International Annals of Health Sciences*, 2024, 1(2): 28-33. <https://doi.org/10.69491/1gc2xx82>
- Mironov K. Certify your identity in two steps for Web applications via RFID and SMS, *Scientific Work at Ruse University*, 2013, 52(6.1): 98-102. Available at: <https://conf.uni-ruse.bg/bg/docs/cp13/6.1/6.1-17.pdf> [in Bulgarian]
- Mohammad-Razdari A., Rousseau D., Bakhshipour A., Taylor S., Poveda J., Kiani H. Recent advances in E-monitoring of plant diseases. *Biosensors and Bioelectronics*, 2022, 201(4): 113953. <https://doi.org/10.1016/j.bios.2021.113953>
- Momtaz M., Bubli S.Y., Khan M.S. Mechanisms and health aspects of food adulteration: A comprehensive review. *Foods*, 2023, 12(1): 199. <https://doi.org/10.3390/foods12010199>
- Nirenjena S., BalaSubramanian D.L., Monisha M. Advancement in monitoring the food supply chain management using IoT. *International Journal of Pure and Applied Mathematics*, 2018, 119(15b):

- 3123-3131. Available at:
<https://acadpubl.eu/hub/2018-119-15/2/331.pdf>
- Peris M., Escuder-Gilabert L., Electronic noses and tongues to assess food authenticity and adulteration. *Trends in Food Science & Technology*, 2016, 58(12): 40-54.
<https://doi.org/10.1016/j.tifs.2016.10.014>
- Rajakumar G., Kumar T.A., Samuel T.A., Kumaran E.M. IoT based milk monitoring system for detection of milk adulteration. *International Journal of Pure and Applied Mathematics*, 2018, 118(9), 21-32. Available at: <https://acadpubl.eu/jsi/2018-118-7-9/articles/9/4.pdf>
- Raviya K.H., Chavda M.K. Importance of artificial intelligence in industry. *Turkish Online Journal of Qualitative Inquiry (TOJQI)*, 2021, 12(7): 14113-14118. Available at:
<https://www.tojqi.net/index.php/journal/article/view/8061/5731>
- Reddy P., Babu M. Energy efficient cluster head selection for internet of things. *New Review of Information Networking*, 2017, 22(1): 54-70.
<https://doi.org/10.1080/13614576.2017.1297734>
- Sobrino-Gregorio L., Bataller R., Soto J., Escriche I. Monitoring honey adulteration with sugar syrups using an automatic pulse voltametric electronic tongue. *Food Control*, 2018, 91(9): 254-260.
<https://doi.org/10.1016/j.foodcont.2018.04.003>
- Wang M., Chen Y. Electronic nose and its application in the food industry: a review. *European Food Research and Technology*, 2024, 250(10): 21-67.
<https://doi.org/10.1007/s00217-023-04381-z>
- Wang S., Zhang Q., Liu C., Wang Z., Gao J., Yang X., Lan Y. Synergetic application of an E-tongue, E-nose and E-eye combined with CNN models and an attention mechanism to detect the origin of black pepper. *Sensors and Actuators A: Physical*, 2023, 357(8): 114417.
<https://doi.org/10.1016/j.sna.2023.114417>
- Xu M., Wang J., Zhu L. The qualitative and quantitative assessment of tea quality based on E-nose, E-tongue and E-eye combined with chemometrics. *Food Chemistry*, 2019, 289(8): 482-489.
<https://doi.org/10.1016/j.foodchem.2019.03.080>
- Zniber M., Vahdatiyekta P., Huynh T.P. Analysis of urine using electronic tongue towards non-invasive cancer diagnosis. *Biosensors and Bioelectronics*, 2023, 219(1): 114810.
<https://doi.org/10.1016/j.bios.2022.114810>