Review Article

Journal of Food Safety and Hygiene

Journal homepage: http://jfsh.tums.ac.ir

Biosensor for maintaining the quality of meat and meat products: a review

Dhananjoy Dhara[1]*, Subhasish Biswas[1], Gopal Patra[1], Olipriya Biswas[2], Geetanjali Sharma[3]

[1]Department of Livestock Products Technology, West Bengal University of Animal and Fishery Sciences, Belgachia, Kolkata, West Bengal.
[2]Department of Agricultural Engineering, Visva Bharati, Shantiniketan, West Bengal.
[3]National Food Laboratory, Institute of Agriculture, Kolkata, West Bengal.

ARTICLE INFO

Article history:
Received 14 May. 2022
Received in revised form 03 Dec. 2022
Accepted 12 Jan. 2023

Keywords:
Biosensor;
Human health;
Hazard;
Meat

ABSTRACT

The meat industry has a greater responsibility to meet consumer's expectations and demands due to the industry's expansion, the state of global trade, stringent laws, and consumer awareness. The meat industry needs a tool to address the better quality and guarantee a safer product for consumers because it is linked to human health risks such as pathogens, drug residues, pesticide residues, toxins, contaminants and heavy metals. Biosensor is the latest detection technology in the fast-growing industry including food sector due to its ability to increase the detection specificity, decrease the time of analysis, apply on a large scale and reduce the resource requirement as in the molecular methods. Food quality, food component, food packaging, pathogen, food allergens, drug residues, contaminants and sensory analysis of food can be detected quickly using biosensors. Biosensor can be an important monitoring and controlling tool in food chain from farm to fork in the near future. Although the application of biosensors has advanced significantly, more research is still required, especially to make the majority of laboratory experiments already published on the commercial market.

Citation: Dhara D, Biswas S, Patra G, Biswas O, Sharma G. **Biosensor for maintaining the quality of meat and meat products: a review**. J food safe & hyg 2023; 9 (1): 1-15

1. Introduction

Food safety issues have been the top priority of consumers as well as industry for many years around the world and there are signs that these issues will persist in the near and distant future.

'New', 'emerging', re-emerging', traditional pathogens as well as potentially high pathogens, antibiotic resistance, allergens, contaminants, pesticide residues, etc. are required to control for safety of the food However, various approaches have been established to

*Corresponding author. Tel.: +91 33 25569234
E-mail address: dhananjoydhara@gmail.com

reduce the incidence of food borne diseases by maintaining excellent farm practices, hygienic standards, manufacturing standards, and food laws, hazards must still be monitored in each phase (1). In addition, food additives, chemicals, toxins, drug residues, traceability issues and other quality related issues are also found.

Other problems and obstacles include defining who is responsible for zoonotic illnesses between animal and human health, as well as issues with regulatory and inspection harmonization at the national and international levels While bacteria like *E. coli* O157:H7, Listeria, Salmonella, and Campylobacter as well as chemicals like naturally occurring toxins, persistent organic pollutants (POPs), antibiotic residues, and heavy metals will continue to pose a hazard, viruses will remain a source of worry in the food sector. Every year, 420,000 people die and 600 million people get sick from consuming contaminated food on average, resulting in the loss of 33 million healthy life years (DALYs) (2). Traditional detection methods demand trained personnel and are exceedingly laborious and time-consuming. Conventional pathogen identification techniques including colony counts and culture, for instance, can take several days. Additionally, physico-chemical approaches such as liquid chromatography–tandem mass spectrometry (LCMS/MS), for the identification of pollutants such as contaminants, toxins, heavy metals and residues of veterinary medicine are expensive, difficult to perform, and time-consuming (3).

New detection and real time techniques are anticipated for better evaluation of quality and safety of the food. The principle aim of these techniques is to increase the detection specificity, decrease the time of analysis, application on a large scale and reduce the resource requirement as in the molecular methods (4). Biosensor devices are becoming one of the most important diagnostic techniques for foods because of their speed, specificity, ease of mass production, economy and field applicability (5).

High sensitivity and accuracy of measurements, selectivity, substance determination without the need for initial sample preparation for analysis, the capability of continuous tracking, speed and convenience of measurement, safety during usage, and low cost are just a few advantages that biosensors offer (6). Their biological binding response, which results from a variety of interactions such as antigen/antibody, enzyme/substrate/cofactor, receptor/ligand, chemical interactions, and nucleic acid hybridization in combination with different transducers, is what gives them their specificity

Interest in using biosensors as measuring devices has grown since the 1970s. Biosensors and advances in their technology, including the availability of nanomaterials, have the potential to change current analytical measurements (7). Nanotechnology has changed the field of biosensors over the years. Due to their huge surface area with numerous active sites and great biocompatibility, nanomaterials offer a wide range of applications in bioanalytical research (8). Various types of nanoparticles, from metal to carbon-based materials including carbon nanotubes, graphite, and graphene, have been developed and are frequently used in biosensors(9). Nano biosensors may be essential for the detection of microbes, pesticides, contaminants, toxins, and other dangerous compounds in food in the future (10).

Despite their huge advantages, biosensors are not widely employed. They are still seen as supplementary instruments to traditional analytical procedures, and they are mostly employed in screening tests (10). Although significant progress has been made in the use of biosensors, further research is needed, especially to make the majority of already published laboratory experiments into field-portable and publicly usable. (11). Therefore, the purpose of this paper is to provide the current level of knowledge about the use of biosensors in meat and meat products.

2. Working principle of biosensor

A biosensor typically works on the principle of signal transduction as it consists of a biological receptor connected to a transducer and signal processing unit. The biological response is transformed into an electrical response that is comparable and then into a quantifiable output by the combination of these components. In a simple term, biosensor translates a molecule's biological function into a quantifiable signal to perform a quantitative examination of the molecule (12). The test sample's target molecule first attaches to or specifically interacts with the biological receptor, which causes a physiological alteration. As a result, the physicochemical characteristics of the transducer that is close to the biological receptor are further altered. Thus, it alters the optical or electronic properties of the transducer, resulting in a detectable electrical signal. (13).

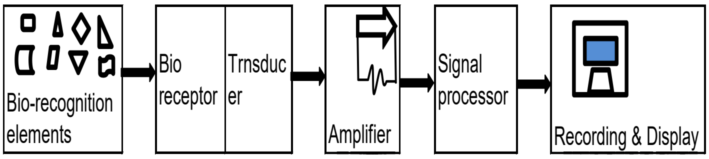

Figure 1. Schematic diagram of a biosensor (14).

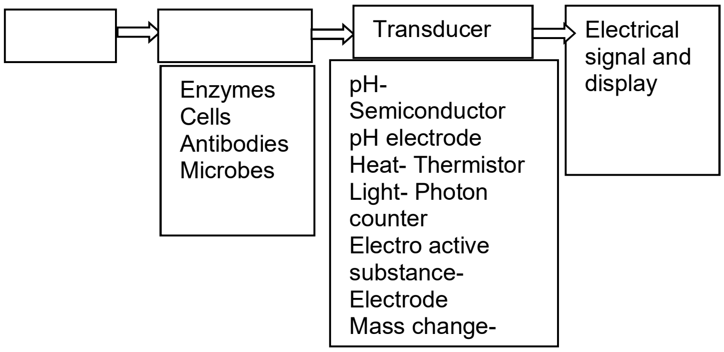

Figure 2. Working principle of biosensor (15)

3. Application of biosensor in meat and meat products

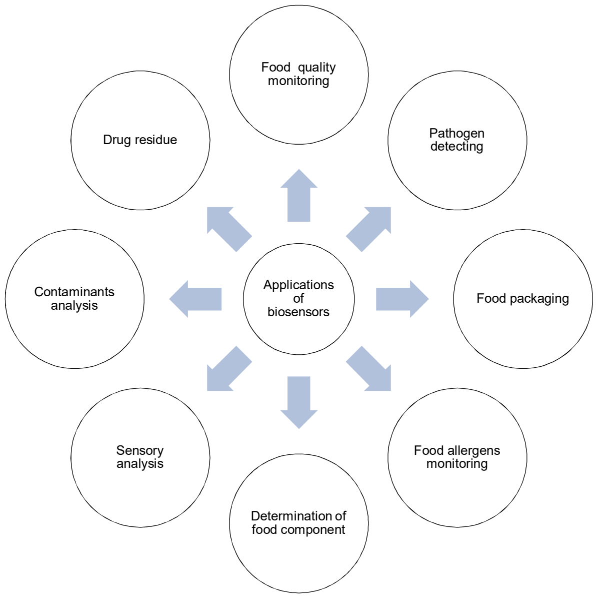

Figure 3. Application of biosensor

3.1. Determination of food component

They can be used to determine organic acids, vitamins, alcohols, phenols, and amino acids, as well as analyses carbohydrates, proteins and triglycerides found in food.

3.2. Sensory analysis

Electronic nose (E-Nose) and Electronic tongue (E-tongue) are two types of biosensors used for sensory evaluation of various foods. The purpose of the E-Nose is to mimic the human olfactory system. It works on the idea that when a sensor is exposed to scents or vapors, the resistance of the sensor changes (16). When compared to traditional measurement systems, the main advantages of using electronic noses are their lower cost, smaller size, and easier to use. They do not require prior separation of the specific components of a gaseous mixture, which significantly reduces the time required for a single analysis. As a result, the possible applications of electronic olfaction have expanded throughout time. The usage pattern of e-nose and e-tongue for meat quality is depicted in Table 1.

The e-tongue had shown superior sensitivity than the human tongue in detecting compound by their natural counterparts and had shown satisfactory correlations with the organoleptic results of human panelists (24). E-tongue is a liquid analysis multimodal system that uses chemical sensor arrays and a suitable recognition algorithm. They have generally been used to analyses food products, water samples, and pharmaceutical taste masking technology. Their uses are nearly endless in principle, as they can almost totally decrease the impact of interference and can be used to identify extremely complicated samples.

It can be used to find out a wide range of dissolved molecules, including volatile compounds that evaporate to produce aromas. Process checking (batch fermentation of starter cultures to produce cheese), foodstuff identification (to differentiate among different meats), freshness evaluation, quality control (to detect freshness of meat), and quantitative analysis (to detect microbial count in meats) are all examples of where E-tongue is used.

3.3. Freshness and tenderness of meat

The moisture content of meat is a crucial quality that assures freshness; if a sample of fresh chicken is maintained at room temperature for an extended length of time, the moisture level gradually decreases. Chicken pieces will become dry and odorous as a result of the growth of numerous organisms, resulting in chemical changes and meat decomposing. As a result, meat freshness is frequently linked to meat ageing and spoiling (25). Additionally, chemical metabolites such as biogenic amines, ammonia gas, total volatile basic nitrogen (TVB-N), trimethylamine (TMA), and xanthine that are produced during the microbiological deterioration of food goods have been used as meat freshness indicators (26).For the consumer aspect, the tenderness of meat is one of the most crucial quality characteristics of meat and meat products. More than one enzyme system is in charge of the proteolytic reactions that occur in meat after it has been slaughtered (27). Calpain and cathepsins are a collection of enzymes that have an impact on protein metabolism as well as meat tenderness. Calpastatin is a μ-calpain inhibitor that affects meat tenderness. Table 2 shows the trend of using biosensors for detecting freshness and tenderness of meat.

Table 1. Applications of e-nose and e-tongue in meat analysis.

Application of e-nose in meat analysis				
E-nose type	**Type of meat matrix**	**Storage condition**	**Purpose**	**References**
MOS (Metal oxide semiconductor sensor)	Beef and chicken	4°C	Identification of rotten meat	(17)
10 MOS (metal oxide semiconductor sensor)	Pork, beef and mutton	25˚C and 70% humidity for 7 days	Pork, beef, and mutton's freshness, including fresh, sub-fresh, and stale	(18)
Applications of e-tongue in meat analysis				
Potentiometric	Cattle meat	5°C	To distinguish different meat species (i.e. Angus, domestic buffalo, Hungarian Grey, Hungarian Spotted cattle, and Holstein beef)	(19)
Potentiometric (TS-5000Z)	Beef	After ageing at 1–4°C for 72 h	Identifying the various cattle breeds	(20)
Potentiometric Ag/AgCl reference electrode	Duck breast meat	---	Monitoring on how cooking methods affect the chemicals that give umami flavor	(21)
Applications of e-nose and e-tongue in meat analysis				
E- nose (Metal oxide sensor) and E-tongue (Ag/AgC reference electrode)	Mutton and pork	-18°C	To check for pork and minced mutton adulteration.	(22)
E- nose (10 Metal oxide sensor) and E-tongue (Ag/AgCl reference electrode)	minced beef-bone protein	-18°C	Flavor analysis of Maillard reaction products made from different enzymolysis products	(23)

Table 2. Application of freshness and tenderness in meat analysis.

Name of biosensor	**Meat matrix**	**Storage**	**Purpose**	**References**
Amperometric hypox anthine(Hx) sensor	pork	Room temperature for 7 days	Meat freshness	(28)
Piezoelectric sensor	Beef and Chicken	Room temperature	Freshness of beef and chicken	(29)
Amperometric biosensor	Chicken meat	4°C for 5 days	Meat freshness (Total volatile basic nitrogen)	(30)

3.4. Pathogen

Food and water infections caused by pathogens pose a serious threat to human health, and the identification of these pathogens in meat and meat products has recently become increasingly important due to the increased number of pathogenic diseases. Microbiological methods typically include an enrichment step (pre-enrichment and/or selective enrichment), culturing in selective or differential agar plates for isolation of cultures, and phenotypic analysis or metabolic fingerprint analysis for confirmation of the result, all of these steps take between two and ten days, making the detection system quite time-consuming (31). Furthermore, traditional pathogen detection techniques primarily depend on microbiological and biochemical analyses, which are highly accurate but time consuming, expensive, and not always feasible to integrate for on-site detection (32).

When compared to conventional methods, biosensors have demonstrated promising results for fast and accurate pathogen detection, which has piqued the interest of researchers worldwide in food quality and safety management. Biosensors can now detect more than just common pathogens like *E. coli* O157:H7, *Salmonella*, *Listeria monocytogenes*, *Clostridium perfringens*, and *Staphylococcus*, including *Campylobacter*, *Bacillus*, and *Shigella* (3). Detection of pathogens by using biosensors is presented in Table 3.

3.5. Drug residue

Large-scale animal production has resulted in veterinary medicine residues which have become a concern in the sectors of food safety and environmental ecological security. Antibiotics used to treat food-producing animals, on the other hand, pose risks to human health since these chemicals and their metabolites can be transmitted into meat, milk, egg, and fish products. It has become a severe issue for farmers and the food industry to quickly detect antibiotics in foods in order to verify their quality. Alternative approaches that are fast, cost-effective, and easy to implement should be considered as traditional analytical methods are either too slow or do not allow for quantitative identification of antibiotic or drug residues. Biosensors used to detect antibiotics, heavy metals, pesticides, toxins and food allergens are presented in Table 4.

3.6. Heavy metals

Heavy metal poses a serious hazard to human health because they are not biodegradable and are maintained by the natural system. Traditional heavy metal measurement methods (such as cold vapor atomic absorption spectrometry and inductively coupled plasma mass spectrometry) are accurate, but they are costly, require specialized personnel, and are essentially laboratory-based. The benefits of biosensor are their specificity, low cost, ease of use, portability, and ability to deliver ongoing real-time readings. Biosensor can be used to analyses heavy metal ions utilizing both protein-based (enzyme, metal-binding protein, and antibody) and whole-cell (natural and genetically created microorganism) techniques.

3.7. Pesticides residue

Food safety concerns about pesticide residues in agricultural goods have prompted the development of a pesticide residue detection tool that can detect pesticide residues quickly, sensitively, and online in a variety of commodities. Biosensor-based instruments for detecting pesticide residues have shown promise in the instrument market, with a wide range of applications.

Table 3. Detection of pathogens in foods.

Pathogens	**Food Item**	**Biosensor Type**	**References**
Listeria monocytogenes	Milk	Chemiluminescence (Optical)	(33)
Pseudomonas	Water	Surface Plasmon Resonance (SPR) (Optical)	(34)
Salmonella typhimurium	Pork Meat	localized Surface Plasmon Resonance (LSPR) (Optical)	(35)
Cronobacter sakazakii	Powdered Infant	Colorimetric (Optical)	(36)
Campylobacter jejuni	Poultry	QCM (Mechanical)	(37)
Mycobacterium tuberculosis	Buffer	Multi-Channel Series Piezoelectric Guartz Crystal (MSPQC) (Mechanical)	(38)
Staphylococcus aureus	Chicken	Colorimetric immunosensor	(39)
E.coli O157:H7	Ground beef	Electrochemical immunosensor	(40)
Streptococcus agalactiae	Fish	Amperometric (Electrochemical)	(41)
Staphylococcus aureus	Pig skin	Potentiometric (Electrochemical)	(42)
Vibrio parahaemolyticus	Seafood	ECL Immunosensor (Electrochemical)	(43)

Table 4. Antibiotics, heavy metals, pesticides, toxins and food allergens detection by biosensors.

Antibiotics	**Food Matrix**	**Biosensor Type**	**References**
Tetracyclines			
Tetracyclines	Poultry muscle,	Bioluminescent biosensor bacterial;	(44)
Phenicols			
Chloramphenicol	Pork, beef poultry, milk, honey, prawn	SPR	(45)
Aminoglycosides			
Steptomycin and dihydrostreptomycin	Pig muscle	Optical biosensor—SPR	(46)
Quinolones			
Norfloxacin	Animal derived food	Electrochemical immunosensor	(47)
Sulfonamides			
Sulfonamides(sulfamethazine, sulfisoxazole, sulfachlorpyridazine, sulfachlorpyrazine, sulfamerazine, sulfadiazine, sulfatroxazole and sulfathiazole)	Chicken serum; Porcine muscle	Optical biosensor—SPR	(48)
Benzimidazoles			
Benzimidazoles	Beef mutton	Chemiluminescence sensor	(49)
Heavy metals	Matrix/Bioreceptor	Biosensor Type	References
Hg^{2+}	Water	Amperometric	(50)
Hg^{2+}, Cd^{2+}, Pb^{2+} and Cr^{Vi}	Milk	Electrochemical biosensor	(51)
Cd, Cu, Hg, Pb, and Zn	Water	Capacitance protein-based biosensor	(52)
Ni(II) and Cr(III)	Water	MFC-based	(53)
Pb^{2+}, Ni^{2+}, and Cd^{2}	Water	Amperometric	(54)
Pesticide	Bioreceptor	Biosensor Type	References
Temephos, fenobucarb and dimethoate	Glutathione-*s*-transferase	Electrochemical	(55)
Benzamidazole, organochlorine, organothiophosphate, organocarbamate, polyphenol and pyrethroid.	Glutathione-*S*-transferase	Amperometric	(56)
Paraoxon, 2,4dichlorophenoxyacetic acid, and atrazine	butyrylcholinesterase, ALP, and tyrosinase	Electrochemical	(57)
Dichlorvos	ChOx	Electrochemical	(58)
Toxins	**Food Matrix**	**Biosensor Type**	**References**
Aflatoxins (AFB1, T2, HT-2, AFM1)	Corn, barley, grapes, milk	Electrochemical (amperometry)	(59)
Brevetoxin B	Razor clams, Mussels, cockles	Electrochemical (square wave voltammetry)	(59)
Staphylococcal enterotoxin B	Soy milk, Watermelon juice, Pork apple juice, milk	Electrochemical	(59)
Fumonisin Deoxynivalenol	Corn Cereals	Electrochemical immunosensor	(59)
Ochratoxin A	Beer and wine	Electrochemiluminescence	(60)
Zearalenone	Beer and wine	Immunosensor	(61)
Allergens	**Food Matrix**	**Biosensor Type**	**References**
Gluten	Cereals grains	Immunosensor	(62)
tropomyosin	shrimp	Immunosensor	(63)
Ara h 1; β-lactoglobulin (β LG); tropomyosin	peanuts; milk; shrimp	Genosensors	(64)
Ara h 6; Gly m Bd 28K; and 2S albumin	Peanut, soybean and sesame	Genosensors	(65)

3.8. Toxins

Staphylococcal toxin, *Bacillus* toxin, botulinum neurotoxins, listerial toxins, and enterotoxins are of great concern due to their relationship with meat and other food products. There are chromatography-based approaches available, such as high-performance liquid chromatography (HPLC) with fluorimetric detection and LCMS/MS, but they are time-consuming and expensive (66). Toxins at high levels in the diet can have negative, acute, and chronic impacts on human health as well as the health of many different animal species. Organs, such as liver, kidneys, nervous system, endocrine system, and immune system, may suffer from unwanted side effects. For the past 20 years, interest in research and development of biosensors has been piqued for making it simpler and faster analytical processes because of their ease of use and sensitivity.

3.9. Food Allergen

In general, food is safe to eat, however 2-4 percent of adults and 6-8 percent of children worldwide suffer from food allergies (67). Food allergens such as eggs, milk, peanuts, soy, fish, shellfish, mustard, gluten, sesame, and almonds, to name a few, account for 90% of all food allergies. Even a small amount of these allergens consumed unintentionally can result in life-threatening conditions. As a result of FSSAI, EU and USDA regulation, it is now required to mention the substance suspected of causing allergy on food labels. To reduce accidental exposure to undeclared or concealed allergens and to manage cross contamination during food preparation, biosensor-based instruments can be ideal for rapid and real-time detection of allergens.

4. Food quality monitoring

4.1. Meat quality checking

The meat check is a four-electrode array mounted on a knife that may be pushed into meat to monitor the glucose gradient just beneath the surface. The magnitude of the gradient is linked to microbial activity on the meat's surface and is used as a reliable measure of meat quality. What laboratory-based microbiology takes days to test is provided in seconds by the device. The bio checks approach turned a glucose sensor into a microorganism detection and quantification device in aqueous solutions. The technology transfers electrons from microorganisms' respiratory routes, and it can identify germs within a few minutes.

Sensory quality of raw meat (i.e. visual texture, color, visible fat, natural drip), cooked meat (i.e. aroma, flavor, texture), technological quality (i.e. water holding capacity, pH value, protein, lipid, connective tissue properties), and product safety (i.e. microbiological quality, food impurities including pesticides, heavy metal ions, antibiotics, hormones) are all areas where biosensors can be used.

4.2. Fish quality

Trimethylamine N-oxide (TMAO) is broken down in sea creatures to create trimethylamine (TMA), a common fish-odour component in seafood. TMA is found in extremely small amounts in fresh marine items. Mitsubayashi et al. (68) immobilized flavine containing mono oxygenase type 3 (FMO3), a drug metabolizing enzyme present in the human liver, onto a sensitive area of a dissolved oxygen electrode to construct a TMA biosensor. Flow injection analysis (FIA) was conducted to calibrate this sensor using TMA solutions. The TMA sensor with FMO3 proved to be an effective tool for assessing the freshness of seafood.

The fish vendor utilizes formaldehyde, a well-known preservative, to keep the fish fresh, despite the fact that it has carcinogenic effects on humans. The electrochemical biosensor, which is less expensive and easy to use, can detect the presence of formaldehyde in fish in real time (69).

5. Biosensor in food packaging

Sustainability and real-time monitoring of meat quality are coupled in bio-based smart packaging, ensuring safety while also giving economic and environmental benefits. The food sentinel system, a biosensor/barcode, is being created to detect disease in food packaging. When there are contaminating bacteria present, a localized black bar will emerge, making the barcode unreadable when scanned. This is caused by a specific-pathogen antibody that is connected to the membrane-forming component of the barcode. Another technology for detecting pathogens called Toxin Guard is also in development. In this process, antibodies are included into the plastic packaging films. When antibodies come into contact with a pathogen of interest, the packing material emits a distinct visual signal (70).

6. Future of biosensor

The future of biosensor is bright and exciting, but it will need a committed, cost-effective, and multi-disciplinary strategy to transfer biosensor systems from the lab to the market. The key to producing an efficient biosensor is a better connection of biosensing and bio fabrication with synthetic biological approaches that use electrochemical or bioelectronics principles or optics. Food processors can utilize biosensors to track raw materials, trace chemicals, sugars, alcohols, amino acids, vitamins, flavor additives, and contaminants including antibiotics, bacteria, and their enzymes in real time. In the future, biosensors could be used in every step of the food chain.

7. Conclusions

The use of biosensors will make it easier to fulfil the quality standards of meat and meat products of domestic and international by allowing for the efficient, safe, and accurate detection and quantification of pathogenic microorganisms that cause foodborne illnesses as well as inorganic contaminants that pose a health risk to consumers. Small amounts of chemical and biological pollutants in items for human and animal use, however, must still be detected. Because biosensor is based on the recording of events that cause physical, chemical, and/or immunological changes; their specificity, selectivity, and quick response are all dependent on the receiving and transduction systems. This type of reading is suitable for food process control because it provides for a quick response.

Despite the fact that biosensor technology is about 5 decades old, some topics are currently being researched. It is necessary to continue looking for new identification components that meet minimum requirements and are free of inhibitory chemicals that prevent analyte detection. Similarly, receptors that are more stable for the analyte are required to be researched.

Biosensor detects substances that produce unusual odors and scents in these circumstances, signaling microbial development and food safety issues. However, while biosensor created in recent years are effective, and some have been effectively employed in the industry, their usage is limited by the requirement for receiver refurbishment and calibration, as well as proper system variable control.

Conflict of interest

Authors declare that there is no conflict of interest regarding his manuscript.

Acknowledgment

The authors express their sincere gratitude to the department of Livestock Products Technology, F/O Veterinary and Animal Sciences, West Bengal University of Animal and Fishery Sciences, Kolkata for all the support provided.

References

1. Scott E. Food safety and foodborne disease in the 21st Century. Can J Infect Dis 2003; 14: 277–280.
2. WHO Fact sheet. Food Safety. Available from: https://www.who.int/news-room/fact-sheets/detail/food-safety. Accessed April 15, 2022.
3. McGrath TF, Elliott CT, Fodey TL. Biosensors for the analysis of microbiological and chemical contaminants in food. Anal Bioanal Chem 2012; 403:75–92.
4. Aggarwal S, Sehgal S, Tando AW. Biosensors-type and application in food processing industry. J Postharvest Technol 2021; 9: 1-19.
5. Thakur MS, Ragavan KV. Biosensors in food processing. J Food Sci Technol 2013; 50: 625–641.
6. Inshyna NM, Chorna I, Primova LO, et al. Biosensors: design, classification and application. J Nano-Electron Phys 2020; 12: 03033-1-03033-9.
7. Sionek B, Przybylski W, Ban´ska A, et al. Applications of biosensors for meat quality evaluations. Sensors 2021; 21: 7430. DOI: org/10.3390/s21227430.
8. Chen Y, Qian C, Liu C, et al. Nucleic acid amplification free biosensors for pathogen detection. Biosens and Bioelectron 2020; 153: 112049. DOI: 10.1016/j.bios.2020.112049.
9. Sharifi S, Vahed SZ, Ahmadian E, et al. Detection of pathogenic bacteria via nanomaterials-modified aptasensors. Biosens and Bioelectron 2020; 150: 111933. DOI: 10.1016/j.bios.2019.111933.
10. Sionek B, Przybylski W, Tambor K. Biosensors in evaluation of quality of meat and meat products – a review. Ann Anim Sci 2020; 20: 1151–1168.
11. Bankole O, Verma D, González M, et al. Recent trends and technical advancements in biosensors and their emerging applications in food and bioscience. Food Biosci 2022; 47: 101695. DOI: 10.1016/j.fbio.2022.101695.
12. Soleymani L, Li F. Mechanistic challenges and advantages of biosensor miniaturization into the nanoscale. ACS Sensors 2017; 2: 458-467.
13. Njagi JI, Kagwanja SM. The interface in biosensing: improving selectivity and sensitivity. In: Helburn R, Vitha MF (eds.). Interfaces and interphases in Analytical Chemistry. American Chemical Society 2011; p. 225-247. DOI: 10.1021/bk-2011-1062.ch011.

14. Velusamy V, Arshak K, Korostynska O, et al. An overview of food borne pathogens: In the perspective of biosensors. Biotechnol Adv 2010; 28: 232-254.
15. Shams R, Singh J, Ashraf S, et al. Application of biosensors in food quality control. J Postharvest Technol 2020; 8: 53-74.
16. Lawrence S, Masih D. Electronic nose technique for aroma analysis of food and beverages. Beverage & Food World 2011; 19-23.
17. Benabdellah N, Hachami K, Bourhaleb M, et al. Identification of two types of rotten meat using an electronic nose for food quality control. Int J Smart Sens Intell Syst 2017; 10: 673-695.
18. Chen J, Gu J, Zhang R, et al. Freshness evaluation of three kinds of meats based on the electronic nose. Sensors 2019; 19: 605. DOI: org/10.3390/s19030605.
19. Surányi J, Zaukuu J-LZ, Friedrich L, et al. Electronic tongue as a correlative technique for modeling cattle meat quality and classification of breeds. Foods 2021; 10: 2283. DOI: org/10.3390/ foods10102283.
20. Zhang X, Zhang Y, Meng Q, et al. Evaluation of beef by electronic tongue system TS-5000Z: flavor assessment, recognition and chemical compositions according to its correlation with flavor. Plos One 2015; 10: 0137807. DOI: org/10.1371/journal.pone.0137807.
21. Shuangjuan Z, Xi F, Zhicheng H, et al. Effect of cooking methods on the chemical compounds associated with umami taste in duck breast meat. J Food Sci Eng 2018; 8: 65–73.
22. Tian X, Wang J, Ma Z, et al. Combination of an e-nose and an e-tongue for adulteration detection of minced mutton mixed with pork. J Food Qual 2019; Article ID 4342509. DOI: org/10.1155/2019/4342509.
23. Fan X, Ding L, Liu H, et al. Flavor analysis of MRPS made from different enzymolysis products based on electronic nose and electronic tongue. IOP Conf Ser Earth Environ Sci 2020; 440: 022011. DOI:10.1088/1755-1315/440/2/022011.
24. Campbell GA, Charles JA, Roberts-Skilton K, et al. Evaluating the taste masking effectiveness of various flavors in a stable formulated pediatric suspension and solution using the AstreeTM electronic tongue. Powder Technol 2012; 224: 109–123.
25. Dave D, Ghaly A. Meat spoilage mechanisms and preservation techniques: a critical review. Am J Agri Biol Sci 2011; 6: 486-510.
26. Galgano F, Favati F, Bonadio M, et al. Role of biogenic amines as index of freshness in beef meat packed with different bio polymeric materials. Food Res Int 2009; 42:1147–1152.
27. Hopkins DL, Thompson JM. The relationship between tenderness, proteolysis, muscle contraction and dissociation of actomyosin. Meat Sci 2001; 57: 1–12.
28. Albelda JAV, Uzunoglu A, Santos GNC, et al. Graphene-titanium dioxide nanocomposite based hypoxanthine sensor for assessment of meat freshness. Biosens Bioelectron 2016; 89: 518-524.
29. Shahzad N, Khalid U, Iqbal A, et al. eFresh – a device to detect food freshness. Int J Soft Comput Eng 2018; 8: 1-4.
30. Tang X, Yu Z. Rapid evaluation of chicken meat freshness using gas sensor array and signal analysis considering total volatile basic nitrogen. Int J Food Prop 2020; 23(1): 297–305.
31. Bai S, Zhao J, Zhang Y, et al. Rapid and reliable detection of 11 food-borne pathogens using thin-film biosensor chips. Appl Microbiol Biotechnol 2010; 86: 983–990.

32. Singh A, Poshtiban S, Evoy S. Recent advances in bacteriophage based biosensors for food-borne pathogen detection. Sensors 2013; 13: 1763–1786.
33. Shang Q, Su Y, Liang Y, et al. Ultrasensitive cloth-based microfluidic chemiluminescence detection of *Listeria monocytogenes* hlyA gene by hemin/G-quadruplex DNAzyme and hybridization chain reaction signal amplification. Anal Bioanal Chem 2020; 412: 3787-3797.
34. Mudgal N, Yupapin P, Ali J, et al. $BaTiO_3$-graphene-affinity layer–based surface plasmon resonance (spr) biosensor for *Pseudomonas* bacterial detection. Plasmonics 2020; 15: 1221-1229.
35. Oh SY, Heo NS, Shukla S, et al. Development of gold nanoparticle-aptamer-based LSPR sensing chips for the rapid detection of *Salmonella typhimurium* in pork meat Sci Rep 2017; 7: 1–10.
36. Kim HS, Kim YJ, Chon JW, et al. Two-stage label-free aptasensing platform for rapid detection of *Cronobacter sakazakii* in powdered infant formula. Sens Actuators B Chem 2017; 239: 94–99.
37. Masdor NA, Altintas Z, Shukor MY, et al. Subtractive inhibition assay for the detection of *Campylobacter jejuni* in chicken samples using surface plasmon resonance. Sci Rep 2019; 9: 1–10.
38. He F, Xiong Y, Liu J, et al. Construction of Au-IDE/CFP10-ESAT6 aptamer/DNA-AuNPs MSPQC for rapid detection of *Mycobacterium tuberculosis*. Biosens Bioelectron 2016; 77: 799–804.
39. Alamer S, Chinnappan R, Zourob M. Development of rapid immuno-based nanosensors for the detection of pathogenic bacteria in poultry processing plants. Procedia Technol 2017; 27: 23-26.
40. Xu M, Wang R, Li Y. Rapid detection of *Escherichia coli* O157:H7 and *Salmonella Typhimurium* in foods using an electrochemical immunosensor based on screen-printed interdigitated microelectrode and immunomagnetic separation. Talanta 2016; 148: 200-208.
41. Vásquez G, Rey A, Rivera C, et al. Amperometric biosensor based on a single antibody of dual function for rapid detection of *Streptococcus agalactiae*. Biosens Bioelectron 2017; 87: 453–458.
42. Arora S, Ahmed DN, Khubber S et al. Detecting food borne pathogens using electrochemical biosensors: an overview. Int J Conserv Sci 2018; 6: 1031–1039.
43. Sha Y, Zhang X, Li W, et al. A label-free multi-functionalized graphene oxide based electrochemiluminscence immunosensor for ultrasensitive and rapid detection of *Vibrio parahaemolyticus* in seawater and seafood. Talanta 2016; 147: 220–225.
44. Pikkemaat MG, Rapallini MLBA, Karp MT, et al. Application of a luminescent bacterial biosensor for the detection of tetracyclines in routine analysis of poultry muscle samples. Food Addit Contam 2010; 27: 1112–1117.
45. Gao F, Feng S, Chen Z, et al. Detection and quantification of chloramphenicol in milk and honey using molecularly imprinted polymers: Canadian pennybased SERS nanobiosensor. J Food Sci 2014; 79: 2542–2549.
46. Ferguson JP, Baxter GA, McEvoy JDG, et al. Detection of streptomycin and dihydrostreptomycin residues in milk, honey and meat samples using an optical biosensor. Analyst 2002; 127: 951–956.

47. Liu B, Li M, Zhao Y, et al. A sensitive electrochemical immunosensor based on PAMAM dendrimer-encapsulated Au for detection of norfloxacin in animal derived foods. Sensors 2018; 18: 1946–1956.
48. Haasnoot W, Bienenmann-Ploum M, Kohen F. Biosensor immunoassay for the detection of eight sulfonamides in chicken serum. Anal Chim Acta 2003; 483: 171–180.
49. Cai Y, He X, Cui PL, et al. Preparation of a chemiluminescence sensor for multi-detection of benzimidazoles in meat based on molecularly imprinted polymer. Food Chem 2019; 280: 103–109.
50. Elsebai B, Ghica ME, Abbas MN, et al. Catalase Based Hydrogen Peroxide Biosensor for Mercury Determination by Inhibition Measurements. J Hazard Mater 2017; 340: 344–350.
51. da Silva W, Ghica ME, Brett CMA. Biotoxic trace metal ion detection by enzymatic inhibition of a glucose biosensor based on a poly (brilliant green)-deep eutectic solvent/carbon nanotube modified electrode. Talanta 2020; 208:120427. DOI: 10.1016/j.talanta.2019.120427.
52. Odobašić A, Šestan I, Begić S. 2019. Biosensors for determination of heavy metals in waters. Biosens Environment Monitor 2019; DOI: 10.5772/intechopen.84139.
53. Agostino V, Massaglia G, Gerosa M. Environmental electroactive consortia as reusable biosensing element for freshwater toxicity monitoring. New Biotechnol 2020; 55: 36–45.
54. Dalkiran B. Amperometric determination of heavy metal using an HRP inhibition biosensor based on ITO nanoparticles ruthenium (iii) hexamine trichloride composite: Central composite design optimization. Bio electrochemistry 2020; 135: 107569. DOI: org/10.1016/j.bioelechem.2020.107569.
55. Borah H, Dutta RR, Gogoi S, et al. Glutathione-S-transferase-catalyzed reaction of glutathione for electrochemical biosensing of temephos, fenobucarb and dimethoate. Anal Methods 2017; 9: 4044–4051.
56. Borah H, Gogoi S, Kalita S, et al. A broad spectrum amperometric pesticide biosensor based on glutathione s-transferase immobilized on graphene oxide-gelatin matrix. J Electroanal Chem 2018; 828: 116–123.
57. Arduini F, Cinti S, Caratelli V, et al. Origami multiple paper-based electrochemical biosensors for pesticide detection. Biosens Bioelectron 2019; 126: 346– 354.
58. da Silva W, Ghica ME, Brett CMA. Choline oxidase inhibition biosensor based on poly (brilliant cresyl blue) - deep eutectic solvent/carbon nanotube modified electrode for dichlorvos organophosphorus pesticide. Sens Actuators B 2019; 298: 126862. DOI: org/10.1016/j.snb.2019.126862.
59. Patra JK, Mahato DK, Kumar P. Biosensor technology—advanced scientific tools, with special reference to nanobiosensors and plant-and food-based biosensors. Nanomat Plants Algae Microorg 2019; 2: 287-303.
60. Wei M, Wang C, Xu E, et al. A simple and sensitive electrochemiluminescence aptasensor for determination of ochratoxin a based on a nicking endonuclease-powered DNA walking machine. Food Chem 2019; 282: 141–6.

61. Yugender Goud K, Sunil Kumar V, Hayat A, et al. A highly sensitive electrochemical immunosensor for zearalenone using screen-printed disposable electrodes. J Electroanal Chem 2019; 832: 336–42.
62. Ontiveros GPH, Ibarra IS, Dominguez JM, et al. Development of a biosensor modified with nanoparticles for sensitive detection of gluten by chronoamperometry. ECS Trans 2017; 76:103–107.
63. Zhang Y, Wu Q, Wei X, et al. DNA aptamer for use in a fluorescent assay for the shrimp allergen tropomyosin. Microchim Acta 2017; 184: 633–639.
64. Tah A, Cordero JMO, Weng X, et al. Aptamer-based biosensor for food allergen determination using graphene oxide/gold nanocomposite on a paper-assisted analytical device. bioRxiv 2018; 343368. DOI: 10.1101/343368.
65. Yuan D, Fang X, Liu Y, et al. A hybridization chain reaction coupled with gold nanoparticles for allergen gene detection in peanut, soybean and sesame DNAs. Analyst 2019; 144: 3886–3891.
66. Campas M, Prieto-Simon B, Marty JL. Biosensors to detect marine toxins: assessing seafood safety. Talanta 2007; 72: 884–89.
67. Planque M, Arnould T, Gillard N. Food allergen analysis: detection, quantification and validation by mass spectrometry. Allergen 2017; DOI: 10.5772/intechopen.69361.
68. Mitsubayashi K, Kubotera Y, Yano K, et al. Trimethylamine biosensor with flavin-containing monooxygenase type 3 (FMO3) for fish-freshness analysis. Sens Actuators B Chem 2004; 103: 463-467.
69. Aini BN, Siddiquee S, Ampon K. Development of formaldehyde biosensor for determination of formalin in fish samples; malabar red snapper (*Lutjanus malabaricus*) and longtail tuna (*Thunnus tonggol*). Biosensors (Basel) 2016; 6: 32. DOI: 10.3390/ bios6030032.
70. Otles S, Yalcin B. Smart food packing. Log Forum 2008; 4: 5-6.