https://dergipark.org.tr/tr/pub/food
OPEN ACCESS JOURNAL

ISSN 2667-5803

FHTI Journal of Food Health and Technology Innovations
December Vol 5, No 11 (2022)

DergiPark AKADEMİK

Review Article

Promising Tools for Food Safety and Quality: Biosensors

Deniz BAŞ[1] * Ebru DENİZ[2]

Abstract

Food safety is a critical concern for modern society. In order to ensure that the food sold to customers is safe, authorities around the world impose restrictions and make new legal arrangements. To protect both consumers and manufacturers, it is essential to continuously track the food production and processing, and to get fast and reliable results. Rapid test methods, including biosensors, play a vital role in this process. Biosensors, offer a range of benefits when used in food safety and quality applications. However, they also have some limitations and challenges. This review aims to explore the use of biosensors in food safety and quality, and to discuss the advantages, disadvantages, and potential of these technologies.

Keywords: biosensors, food safety, food quality, quality control

TÜBİTAK ULAKBİM

1 Department of Food Engineering, Faculty of Engineering, Çankırı Karatekin University, Çankırı, 18100, Turkiye
http://orcid.org/0000-0003-1494-681X
*Corresponding Author: denizbas@gmail.com
2 Ebru DENİZ's e-mail: denizzebru@gmail.com

Introduction

Safe food is the food that is good quality in compliance with physical, chemical and microbiological regulations, maintains its nutritional value, and does not harm the consumer when consumed. In this context, the status of being chemically and microbiologically safe has gained more importance in recent years, and methods of detection, evaluation and analysis for food safety have become more interesting.

Food safety is a process that requires consistent measures and adequate monitoring from the field to the table. This process consists of steps such as raw material procurement, food processing, obtaining the final product, and storage. In order to track the parameters that determine the food safety and quality at each stage of the process, many analyses must be carried out. This huge demand of analyses requires laboratories with high investment and operating costs and trained personnel to carry out these analyses. On the other hand, it is essential to obtain low-cost and reliable results in a short time. In recent years, legal regulations and increasing concerns related to food safety and quality have allowed for the popularity of rapid analysis methods, such as biosensors, developed through innovative and advanced technology-based interdisciplinary studies.

In the last decade, the scientific literature on the applications of biosensors for food safety and quality control grew enormously. In addition to this highly growing literature, the global food and agriculture biosensors market in year 2021 was valued at 6 billion US$ and is predicted to reach 12.40 billion US$ by the year 2030 (1). This study aims to overview the applications of biosensors for food safety and quality control, discuss their advantages and disadvantages. In addition to these, without ignoring the importance of conventional methods in food analysis, the future of biosensors and the importance of the contributions of food science and technology experts to this field tried to be emphasized.

Biosensors

Food analysis includes instrumental analysis, which encompasses conventional chromatographic and spectroscopic methods, and cultural counting methods used in microbiological analysis. These methods are reliable and quite sensitive, but they require high investment and operating costs, and are time-consuming methods that require a certain level of expertise (2). Research and quality control laboratories with high-cost investments have access to these capabilities, but it is not always possible to invest in instruments and experts in the industry. In other words, analytical methods that can be performed quickly with portable devices and do not require personal skill are desired for use in industry. At the same time, when small and medium-sized enterprises are considered, the analysis investment and operating costs may cause a financial shortage. These special circumstances and current conditions make it necessary for businesses to use fast, reliable, accessible, low-cost analysis methods that do not require expertise (2-4). Therefore, the development/improvement of fast and innovative analysis methods that will be complementary to or even alternatives to conventional analysis methods has become a necessity.

The aforementioned fast and innovative analysis methods can be examined under two underlying categories; nucleic acid and protein-based methods. Nucleic acid-based methods are based on polymerase chain reaction (PCR), loop-mediated isothermal amplification (LAMP) and CRISPR-Cas strategies. Protein-based methods include enzyme-linked immunoassays (ELISA), lateral flow systems and enzymatic/catalytic sensing systems. Biosensor and bioanalysis systems developed using the methods mentioned above, as well as miniature laboratories (lab-on-a-chip, LOC) and micro total analysis systems (µTAS), can be referred to as fast and innovative analysis systems. When these systems are considered in terms of production and measurement systematics, they can all be examined under the heading of biosensor and bioanalysis methods, and that they do not differ from each other in principle. At this point, a detailed examination of the concepts of biosensors and bioanalysis will give sufficient information about the working principles of these methods. The differences between the methods stem from the architectural structures and production technologies rather than the measurement method.

Bioanalysis is a general concept used for measurement and analysis methods that can be examined in a wide category, including imaging systems, where biological interactions or biochemical processes play a role in the analysis of the target molecule, at least one of the target or recognition molecule is a biological molecule. A biosensor, on the other hand, is defined as an analytical device that is integrated into a physicochemical transducer through an interface of any bioanalysis method and mostly has a compact architecture (5). A biosensor consists of two main parts, namely the recognition layer and the transducer. The recognition layer is the analytical interface of the biosensor, and obtained by immobilization or adsorption any biomolecule such as antibody, aptamer, nucleic acids, protein, enzyme or carbohydrate. And after the interaction of this layer with the target analyte, a signal in proportion to the target concentration is formed by the transducer (6). Although transducer with different characteristics are present, frequently used transducers are electrochemical and optical signal processing systems.

The above-mentioned analysis systems or methods, including biosensors, have been developed initially for medical diagnosis to meet the strong needs in healthcare system. Nowadays, these methods have become so practical that they have been adapted for industries such as the environment, agriculture, and food, creating a wide range of use and market. The use of these methods for food safety and quality brings important advantages for the food industry and public health. However, the complex nature of food matrix also brings various disadvantages due to the physicochemical properties of food. Despite these disadvantages, the applications of biosensors in the field of food safety and quality control are as follows.

- Chemical contaminants: pesticide residues, herbicides, veterinary drug residues, environmental contaminants (7-11),
- Microbial contaminants(12, 13),
- Allergens (14-16),
- Natural toxins: mycotoxins, seafood toxins, pathogenic toxins (17-22)
- Process contaminants: polycyclic aromatic hydrocarbons (PAHs), biogenic amines(23-27),
- Food component analysis (28-30),
- Process quality and control (31-35).

When these applications are considered in detail, it can be seen that various recognition layers can be used and measurements can be made in two different ways, either directly or indirectly. As an example for indirect sensing mechanism, the inhibition of enzymes or microorganisms that are present in the recognition layer is determined for the presence of chemical contaminants. The most significant and practical application of the indirect sensing is the inhibition of the acetylcholine esterase enzyme. Since some pesticides are the natural inhibitors of this enzyme, many pesticide biosensing methods have been developed based on this principle. Thus, in the presence of acetylcholine esterase inhibiting pesticides, the decrease in enzyme activity allows the pesticide concentration to be determined quantitatively.

In the determination of microbiological contaminants, allergens and toxins, antibodies or aptamers specific to the target analyte are used as the recognition element. While it is possible to make direct measurements with surface plasmon resonance, mass-sensitive and impedance systems, indirect sensing mechanism is prefered in electrochemical (amperometric, voltammetric) and optical systems since most of the target moelcules are either electrochemically or optically inactive. Direct measurements are performed by measuring the signal change after the interaction of the target analyte with its counterpart on the recognition layer, and a response directly proportional to the target analyte concentration is obtained. On the contrary, indirect measurements are performed by using an enzyme or fluorescent dye-labeled secondary antibody/aptamer in addition to the antibody/aptamer used in the recognition layer. Since the amount and/or presence of these secondary biomolecules will be defined by the target, quantitative analysis of the target analyte can be possible by measuring the specific signal of the label on the secondary antibody/aptamer. Direct sensing strategies are simplier and they do not require cost increasing labels or secondary recognition biomolecules and they can be performed with less operational procedures. Some food components can also be measured by catalytic methods based on the electrochemical and/or optical mesaurement systems. It is possible to perform quantitative analyses by using the enzymatic reaction specific to target component. The best-known example is the glucose biosensor, in which the amount of hydrogen peroxide formed as a result of the reaction catalyzed by the glucose oxidase enzyme is measured electrochemically (36).

Advantages and Disadvantages of Biosensors

Biosensors have several advantages over conventional methods such as chromatographic, spectroscopic, and culture-based microbiological analyses. These include low investment costs, ease of use without requiring specialized knowledge, speed, and portability. While chromatographic and spectroscopic systems (such as LC-MS-MS and GC-MS) are highly sensitive, they also have high analysis and investment costs, which limits their widespread use.
Additionally, these methods and devices require skilled, qualified personnel to be used effectively. In this regard, DNA, aptamer, and immunoaffinity-based (e.g. ELISA) rapid analysis methods and biosensor systems/methods emerge as potential alternatives to conventional food analysis methods. While rapid test/analysis methods such as ELISA and lateral flow kits are widely used, they have significant disadvantages such as limited success in their application to automation, requiring personal skill, being time-consuming, and being expensive for multiple analyses. On the other hand, biosensors have advantegeous features such as being simple, user-friendly, fast (short response time), real-time, suitable for automation, miniaturizable, and therefore portable, as part of their existential philosophy. In addition to these features, biosensors are systems with high selectivity, specificity and accuracy.

In parallel with developments in the field of nanotechnology, biosensor systems that can be miniaturized and thus made portable by the integration of nanostructures and the use of microfluidic technologies in biosensor systems allow fast and real-time analysis since they can be used anywhere because they have low power consumption. Thus, being able to perform analysis independently from the laboratory provides important conveniences in the realization of today's production and inspection processes. The potential to be miniaturized and made portable offers another important advantage. By performing analysis in small volumes, less sample and reagents are needed and this allows a significant reduction in the analysis and production costs. This economic benefit provides an increase in access and demand and is important for individuals, institutions and organizations, especially developing countries, who do not have access to expensive analytical devices.

Finally, their ease of use or adaptability to automation reduces the need for specialized personnel, reducing operational and analysis costs.

Biosensors are currently unable to provide the lower limit of detection values of methods such as LC and/or LC-MS in some analyzes. In addition, a decrease in analysis performance can be observed due to the complex structure of the food matrix and textural properties. It should be emphasized that the disadvantageous situation caused by the complex structure of the food matrix is only important for field analysis, but from the point of view of established laboratories, it should not be considered as a disadvantage in the presence of inexpensive basic equipment such as shredders and centrifuges.

Future Perspectives of Biosensors

In addition to the abovementioned advantages, many factors are effective in the increase in demand for the use of biosensors. These factors include the desire of professionals in the supply chain to improve competition conditions due to developments in regulation, and the interest of conscious consumers in food safety. Having low operating and investment costs, allows the commercial use of affordable analysis devices. The fact that the devices are easy to access and their use does not require a certain expertise enables the new generation conscious consumer to control personal food safety. At this point, it seems inevitable that biosensors that can be used for food safety, such as personal glucose meters, which are widely used in blood sugar measurement and accepted as the ancestor of biosensors, will be shaped in line with the needs of conscious consumers whose number is increasing. In addition, it is thought that food analysis applications of biosensors will gain importance with the adaptation of microfluidic technologies and micro-total analysis (µTAS) systems, which are still being developed for clinical diagnosis. It is anticipated that these systems based on microfluidic technology and miniaturized analysis platforms can be integrated into smart phones and/or tablets without the need for a power source or computer, and fast and reliable on-site analysis will be beneficial in terms of food safety and quality control. As a result, in addition to the advantages of biosensors and their high commercial potential as emphasized in market reports (12.40 billion US$ market size by the year 2030), it is thought that new technologies will be introduced and significant developments will be achieved with the increasing interest of scientists engaged in research and development in food science and technology. Besides these, combining biosensors with the smartphones (37) and the artificial intelligence (38) will enhance the accuracy, real-time monitoring capabilities, and will allow easy decision-making. So there is still room for improvements in this field and huge marketplace.

Conclusion

It is an undeniable fact that biosensors, which have features such as adaptability to automation, short analysis time and portability and do not require expertise, are an important alternative to labor-intensive and time-consuming food analysis methods.

However, since instrumental methods such as liquid chromatography and mass spectroscopy cannot provide the low limit of detection values they have, they should not be considered as an alternative but as a complement to them. Although most of the studies on biosensors are for clinical diagnosis and diagnosis, it should not be neglected that there has been an interesting increase in biosensor studies on food safety and quality in the last 10 years. It is thought that the above-mentioned disadvantages will be overcome and the performance of biosensors in food analysis will increase with the contributions of food science and technology experts to this field.

Acknowledgement

This article is based on a previous review article that have been previously published in the journal "Gıda" in 2015 (https://dergipark.org.tr/tr/download/articlefile/665583). The article has been revised, adapted and updated according to Creative Commons Attribution 4.0 CC BY-NC licence (39).

References

1. Anonymous. Global Food & Agriculture Biosensors Market Report ID : 1302 2022 [Available from: https://www.insightaceanalytic.com/report/global-food--agriculture-biosensors-market/1302.
2. Pividori MI, Alegret S. Micro and nanoparticles in biosensing systems for food safety and environmental monitoring. An example of converging technologies. Microchimica Acta. 2010;170(3-4):227-42.
3. Pérez-López B, Merkoçi A. Nanomaterials based biosensors for food analysis applications. Trends Food Sci Technol. 2011;22(11):625-39.
4. Pilolli R, Monaci L, Visconti A. Advances in biosensor development based on integrating nanotechnology and applied to food-allergen management. TrAC Trends in Analytical Chemistry. 2013;47(0):12-26.
5. Turner AP. Biosensors: sense and sensitivity. Science. 2000;290(5495):1315-7.
6. Chambers JP, Arulanandam BP, Matta LL, Weis A, Valdes JJ. Biosensor recognition elements. Curr Issues Mol Biol. 2008;10(1-2):1-12.
7. Jia M, E Z, Zhai F, Bing X. Rapid multi-residue detection methods for pesticides and veterinary drugs. Molecules. 2020;25(16):3590.
8. Xie M, Zhao F, Zhang Y, Xiong Y, Han S. Recent advances in aptamer-based optical and electrochemical biosensors for detection of pesticides and veterinary drugs. Food Control. 2022;131:108399.
9. Hua Z, Yu T, Liu D, Xianyu Y. Recent advances in gold nanoparticles-based biosensors for food safety detection. Biosensors and Bioelectronics. 2021;179:113076.
10. Rahman MM, Lee DJ, Jo A, Yun SH, Eun JB, Im MH, et al. Onsite/on-field analysis of pesticide and veterinary drug residues by a state-of-art technology: A review. Journal of Separation Science. 2021;44(11):2310-27.
11. Bhavadharini B, Kavimughil M, Malini B, Vallath A, Prajapati HK, Sunil C. Recent Advances in Biosensors for Detection of Chemical Contaminants in Food—a Review. Food Analytical Methods. 2022:1-20.
12. Xu X, Su Y, Zhang Y, Wang X, Tian H, Ma X, et al. Novel rolling circle amplification biosensors for food-borne microorganism detection. TrAC Trends in Analytical Chemistry. 2021;141:116293.
13. Jayan H, Pu H, Sun D-W. Recent development in rapid detection techniques for microorganism activities in food matrices using bio-recognition: A review. Trends in Food Science & Technology. 2020;95:233-46.
14. Aquino A, Conte-Junior CA. A systematic review of food allergy: Nanobiosensor and food allergen detection. Biosensors. 2020;10(12):194.
15. Shin JH, Reddy YVM, Park TJ, Park JP. Recent advances in analytical strategies and microsystems for food allergen detection. Food Chemistry. 2022;371:131120.
16. Vasilescu A, Polonschii C, Titoiu AM, Mishra R, Peteu S, Marty J-L. Bioassays and biosensors for food analysis: focus on allergens and food packaging. Commercial Biosensors and Their Applications: Elsevier; 2020. p. 217-58.
17. Oliveira IS, da Silva Junior AG, de Andrade CAS, Oliveira MDL. Biosensors for early detection of fungi spoilage and toxigenic and mycotoxins in food. Current opinion in food science. 2019;29:64-79.
18. Zhou Q, Tang D. Recent advances in photoelectrochemical biosensors for analysis of mycotoxins in food. TrAC Trends in Analytical Chemistry. 2020;124:115814.
19. Li R, Wen Y, Wang F, He P. Recent advances in immunoassays and biosensors for mycotoxins detection in feedstuffs and foods. Journal of Animal Science and Biotechnology. 2021;12(1):1-19.

20. Agriopoulou S, Stamatelopoulou E, Varzakas T. Advances in analysis and detection of major mycotoxins in foods. Foods. 2020;9(4):518.
21. Rovina K, Shaeera SN, Vonnie JM, Yi SX. Recent biosensors technologies for detection of mycotoxin in food products. Mycotoxins and Food Safety. 2019.
22. Shrivastava A, Sharma RK. Biosensors for the detection of mycotoxins. Toxin Reviews. 2022;41(2):618-38.
23. Ahangari H, Kurbanoglu S, Ehsani A, Uslu B. Latest trends for biogenic amines detection in foods: Enzymatic biosensors and nanozymes applications. Trends in Food Science & Technology. 2021;112:75-87.
24. Vasconcelos H, Coelho LC, Matias A, Saraiva C, Jorge PA, de Almeida JM. Biosensors for biogenic amines: A review. Biosensors. 2021;11(3):82.
25. Qin Y, Ke W, Faheem A, Ye Y, Hu Y. A rapid and naked-eye on-site monitoring of biogenic amines in foods spoilage. Food Chemistry. 2023;404:134581.
26. Koçoğlu İO, Erden PE, Kılıç E. Disposable biogenic amine biosensors for histamine determination in fish. Analytical Methods. 2020;12(30):3802-12.
27. Prossner KM, Vadas GG, Harvey E, Unger MA. A novel antibody-based biosensor method for the rapid measurement of PAH contamination in oysters. Environmental Technology & Innovation. 2022;28:102567.
28. Nanda PK, Bhattacharya D, Das JK, Bandyopadhyay S, Ekhlas D, Lorenzo JM, et al. Emerging Role of Biosensors and Chemical Indicators to Monitor the Quality and Safety of Meat and Meat Products. Chemosensors. 2022;10(8):322.
29. Bhatt P, Mukherjee M, Akshath US. Biosensors for food component analysis. Food Nanotechnology: CRC Press; 2019. p. 341-74.
30. Shao J, Wang C, Shen Y, Shi J, Ding D. Electrochemical sensors and biosensors for the analysis of tea components: a bibliometric review. Frontiers in Chemistry. 2022;9:1267.
31. Kuswandi B, Hidayat MA, Noviana E. paper Based Electrochemical Biosensors for Food Safety Analysis. Biosensors. 2022;12(12):1088.
32. Singh RP. Recent Trends, Prospects, and Challenges of Nanobiosensors in Agriculture. Biosensors in Agriculture: Recent Trends and Future Perspectives. 2021:3-13.
33. Ragavan K, Neethirajan S. Nanoparticles as biosensors for food quality and safety assessment. Nanomaterials for food applications: Elsevier; 2019. p. 147-202.
34. Balbinot S, Srivastav AM, Vidic J, Abdulhalim I, Manzano M. Plasmonic biosensors for food control. Trends in Food Science & Technology. 2021;111:128-40.
35. Di Nardo F, Anfossi L. Commercial biosensors for detection of food additives, contaminants, and pathogens. Commercial Biosensors and Their Applications: Elsevier; 2020. p. 183-215.
36. Witkowska Nery E, Kundys M, Jeleń PS, Jönsson-Niedziółka M. Electrochemical Glucose Sensing: Is T{BAŞ, 2015 #5}. Analytical Chemistry. 2016;88(23):11271-82.
37. Lu Y, Shi Z, Liu Q. Smartphone-based biosensors for portable food evaluation. Current Opinion in Food Science. 2019;28:74-81.
38. Zhang J, Huang H, Song G, Huang K, Luo Y, Liu Q, et al. Intelligent biosensing strategies for rapid detection in food safety: A review. Biosensors and Bioelectronics. 2022;202:114003.
39. BAŞ D, DENİZ E. Gıda Güvenliği ve Kalite Kontrolünde Biyosensörler. Gıda. 2015;40(4):225-32.