Recent Trends and Advancements in Biosensor Research for Food Safety

5

Sunny Dhiman and Gunjan Mukherjee

Abstract

A vast majority of food safety concerns are caused by the consumption of contaminated food.

Thus, there is an increasing demand of improved methods for detecting the foodborne pathogens. Traditional microbiological detection and identification methods for foodborne pathogens are well known to be time-consuming and laborious as they are increasingly being perceived as insufficient to meet the demands of rapid food testing. Biosensing technologies have put forward themselves as an alternative for rapid and effective detection of foodborne pathogens. A vast range of signal transducers have been developed in the recent time to detect foodborne pathogens. Their sensitivity and results vary significantly based upon the features of the transducers and the biological materials being used as analytes. However, the development of highly sensitive biosensors for rapid, effective detection and identification of foodborne pathogens for ensuring food safety still remains a challenging task in front of global food safety organizations due to one or other technical obstacles. The present chapter highlights various biosensing technologies available for quick, on-site, and efficient detection of major foodborne pathogens.

Keywords

Biosensor · Obstacles · Transducer · Analyte · Foodborne pathogens · Food safety

S. Dhiman · G. Mukherjee (✉)
University Institute of Biotechnology, Chandigarh University, Mohali, Punjab, India

R. Prasad et al. (eds.), *Recent Developments in Microbial Technologies*,
Environmental and Microbial Biotechnology,
https://doi.org/10.1007/978-981-15-4439-2_5

5.1 Introduction

One of the major healthcare concerns for mankind in the modern era is foodborne pathogens causing severe illness and deaths worldwide. There is an increased awareness among people worldwide about food safety. Food safety has become a major health concern globally as foodborne diseases have outspread in both developing and developed countries to alarming levels (Zhao et al. 2014). The increased globalization of food supplies due to cross-country trades has made food safety as the most vital concern (Lan et al. 2017). Unhealthy and unhygienic food can cause various dreadful diseases eventually leading to deaths (Sharma et al. 2015). The current worldwide situation from a health perspective is dire. Currently, the most significant food safety concerns are caused by the consumption of contaminated food. Foodborne pathogens affect food safety at various stages including food manufacturing, handling, food distribution, and finally the consumption by the customers. Thus, monitoring and real-time detection of food contaminants hold utmost importance to ensure the availability of risk-free and contaminant-free foods. The current global situation in the twenty-first century from a food safety perspective is dire. Over the years, foodborne pathogens have become a major factor contributing to society's ill health, thus increasing the morbidity and mortality rate to alarming levels in both developed and developing countries. Foodborne pathogens are basically the microbes such as bacteria, fungi, viruses, and several other parasites that have capabilities to infect humans consuming contaminated foods. Major foodborne pathogens responsible for illness and deaths worldwide include foodborne bacteria such as *Escherichia coli* O157:H7, *Staphylococcus aureus*, *Clostridium perfringens*, *Salmonella enterica*, *Campylobacter jejuni*, *Toxoplasma gondii*, *Listeria monocytogenes*, other Shiga toxin-producing *E. coli* strains (non-O157 STEC), *Norovirus* and *Vibrio* spp., etc. (Velusamy et al. 2010; Zhao et al. 2014). Foodborne illnesses have been exacerbated by these contaminants resulting in a number of dreadful diseases and disorders such as recurring intestinal inflammation, reactive arthritis, blindness, mental disability, chronic kidney diseases, and even deaths. Yasmin et al. 2016 documented that an estimated two million deaths happen every year due to around 200 diseases and disorders like diarrhea, cancer, etc. caused due to consumption of contaminated foods. Thus, the World Health Organization has endorsed food safety as "from farm to plate (and everywhere in between) make food safe" on World Health Day, 2015. The US Centers for Disease Control and Prevention in their reports documented that in the United States, 1 among 6 people get ill per year and approximately 3000 people die because of foodborne diseases (CDC 2011). The US Department of Agriculture in their reports documented an approximate cost of $15.6 billion attributed to illnesses caused due to foodborne pathogens (CDC 2016). Foodborne pathogens are the root cause of severe health issues associated with the consumption of contaminated foods globally. Thus, the effective, accurate, and real-time detection of these contaminants is the only possible measure to ensure global food safety from a public health perspective (Arora et al. 2013). It should be taken care of to maintain proper hygiene and aseptic environment during the production, processing, and packaging of foods

so as to minimize the outbreaks of diseases and disorders as a consequence of consumption of contaminated foods (Arora et al. 2013). Thus, looking at the current global food safety and health concerns, there is a desperate need for developing much efficient methods of foodborne pathogen detection besides improving the existing methods. Biosensing technologies have put forward themselves as an alternative for rapid and effective detection of foodborne pathogens. A vast range of signal transducers have been developed in the recent time to detect foodborne pathogens. Their sensitivity and results vary significantly based upon the features of the transducers and the biological materials being used as analytes. However, the development of highly sensitive biosensors for rapid, effective detection and identification of foodborne pathogens for ensuring food safety still remains a challenging task in front of global food safety organizations due to one or other technical obstacles. The purpose of this chapter is to review the biosensing methods available for quick, on-site, and efficient detection of major foodborne pathogens along with various challenges that need to be addressed as well as improvements that are required to make biosensing devices a real utility in the upcoming future for ensuring global food safety.

5.2 Current Public Health Situational Analysis in Developed and Developing Countries

The current global situation in the twenty-first century from food safety and public health perspective is dire. The world's population explosion and the insatiable quest for advancement by mankind have brought about very grave consequences on man's livelihood. A continuous surge in the world population has led to a huge strain on the available societal food resources. This has been exacerbated by the rapidly increasing populations especially in developing countries. In developing countries, the emergence of slum areas in the periphery of major urban cities has led to an increase in the levels of poverty, poor living conditions, illiteracy, unemployment, crime, violence, alcoholism, substance and drug abuse, prostitution, and smoking, thus contributing to society's ill health. The excessive pervasiveness and recurrence of foodborne diseases worldwide especially in developing countries clearly suggest that food safety concerns need to be addressed. Thus it becomes imperative to ensure quick, effective, and on-site detection of foodborne pathogens so as to minimize their prevalence (Zhao et al. 2014). Thus, in this context, there has been a continuous demand for the development of efficient and quick detection methods for the detection of foodborne pathogens from a global public health perspective. A significant number of microorganisms have been reported with the ability to generate toxins responsible for causing foodborne illnesses. These include microorganisms such as *E. coli* O157, *S. aureus*, *Bacillus cereus*, *Clostridium botulinum*, *C. perfringens*, *Vibrio cholera*, etc. (Fusco et al. 2011). Communicable diseases and mental health issues may rank high among the illnesses. It is not uncommon to confront cases of diarrheal diseases, malaria, respiratory infections such as tuberculosis, HIV/AIDS, psychosis, depression, and suicide. On the extreme end of the

continuum, in the developed countries, are the noncommunicable diseases such as diabetes, cardiovascular diseases, and cancer. These usually come about due to consumption of contaminated foods and contaminated water. The same diseases are also gaining prominence and recognition in developing countries especially among the middle and upper classes.

The current dilemma is to strike a balance between feeding the majority of the increasing population on available food sources and worrying about the possible after effects of consuming the foods if they are having one or the other forms of foodborne pathogens.

5.3 Technologies Available for Detection of Foodborne Pathogens

The extremity and recurrence of foodborne diseases occurring as an after effect of consuming contaminated foods have made it inevitable for the scientific communities worldwide to develop the technologies for quick, efficient, accurate, and on-site detection of major foodborne contaminants even at extremely low levels. Foods contaminated with pathogens have become a major concern worldwide as food safety has a direct interrelationship with economy and society. Some of the available technologies that can be employed for the detection of foodborne pathogens are enzyme-linked immunosorbent assays, microarray-based techniques, and methods based on polymerase chain reactions along with conventional methods of detection. These technologies can be an answer to the food safety issues faced by most of the developing countries which are currently struggling to feed the majority of their population in the wake of limited food availability, changing weather patterns, erratic rains, and land degradation and limitation. However, majority of these methods are time-consuming. The duration of time taken varies from hours to several days to give an output in the form of result. Thus, to overcome these shortcomings, detection based on biosensors plays a pivotal role in quick and effective detection of food contaminants. Biosensing technologies have emerged as an effective and rapid detection method and have extended their utility in a wide range of areas that include food safety, environmental monitoring, and clinical studies. Biosensing devices are reckoned as highly efficient detection methods due to properties like high sensitivity, specificity, quickness, applicability in various fields, and cost-effectiveness (Thakur and Ragavan 2013; Singh et al. 2020). Advances and developments in biosensing technologies have significantly improved the quality of life as they have the abilities to detect even minute levels of analytes under question (Arora et al. 2013). Foodborne pathogen detection using biosensing technologies has attained significant importance in the food sector for ensuring food safety. Biosensors possess the ability to detect low levels of pathogens and toxins making the foods highly contaminated. Biosensing methods possess certain properties like real-time detection, on-site detection, high sensitivity, selectivity, etc. which makes this technology advantageous over conventional methods of foodborne pathogen detection. These salient features give an indication of

biosensing technology being used as stand-alone devices for foodborne pathogen detection in the near future (Zhao et al. 2014).

5.4 Biosensors for Detection of Foodborne Pathogens

Biosensor devices for foodborne pathogen detection in general possess as minimum as three elements which include a biological capture molecule, a measure for converting the interaction between capture molecule and target into a detectable signal, and a readout (output) system (Lazcka et al. 2007; Velusamy et al. 2010). Methods such as enzyme-linked immunosorbent assays and those based on polymerase chain reaction are considered as quick detection methods. However, these methods take several hours to days for reaching at some kind of interpretations and results (Velusamy et al. 2010). The urgency for development of highly sensitive, quick, proficient, and accurate detection methods has paved a way for the development of biosensing technology. Biosensors are basically the sensing devices which can be utilized for analyzing and detecting the substances (analytes) in question by translating a biological response to a detectable signal (Velusamy et al. 2010). Biosensing devices comprise of a biological sensing element coupled to a transducer which translates the biological response to a measurable signal. Biosensors fulfill the requirements of desired features of high sensitivity, rapidness, real-time detection, and economic analysis of analyte under investigation. Biosensor devices are portable, offer on-site detection, and possess the ability for both on-site and in laboratory detection of multiple pathogenic organisms. These characteristics make biosensors highly advantageous over other available technologies of foodborne pathogen detection which otherwise would take several hours for their detection. The abovementioned advantages of biosensing technology have made it possible to ensure correct and on the spot detection of foodborne pathogens present (if any) before consuming the food (Rasooly and Herold 2006). Different biosensors work on different fundaments of analyte detection. Overall sensitivity of a biosensor device relies upon the characteristics of transducer and upon the types of biological materials utilized as biorecognition element for analysis (Palchetti and Mascini 2008). Different biological substances which are used as biorecognition elements in biosensor devices include antibodies, peptides, nucleic acids, bacteriophages, aptamers, etc. Some biosensors utilize labeled probes or reagents for analyte detection (Bhunia et al. 2010). The performance of a biosensor device is evaluated by assessment of parameters like sensitivity, specificity, selectivity, rapidness in detection, size of device, ability to manufacture on large scale, and cost factor (Arugula and Simonian 2014). An ideal biosensor device must possess the ability to analyze undefined samples within seconds and must have the capability of simultaneous detection of multiple analytes. Biosensors have been developed and applied for the detection of various foodborne pathogens (Table 5.1) including *Escherichia coli* O157:H7, *Staphylococcus aureus*, *Bacillus*, *Salmonella*, *Listeria monocytogenes*, and *Cryptosporidium* as well as various microbial toxins such as staphylococcal enterotoxins and mycotoxins (Asiello and Baeumner 2011).

Table 5.1 Foodborne pathogen detection using different biosensors

Biosensor type	Analyte detected	Reference
Optical biosensors	*Salmonella typhimurium*	Seo et al. 1999
Optical biosensors	*Salmonella enterica*	Koubova et al. 2001; Silbert et al. 2006
Optical biosensors	*Escherichia coli* O157:H7	DeMarco and Lim 2002; Waswa et al. 2007
Optical biosensors	Tobacco mosaic virus	Boltovets et al. 2004
Optical biosensors	*Listeria monocytogenes*	Leonard et al. 2004; Hamon et al. 2006; Bierne et al. 2007; Ohk et al. 2010
Optical biosensors	*E. coli*	Su et al. 2005
Optical biosensors	*Cryptosporidium parvum*	Kang et al. 2006
Optical biosensors	*V. cholera*	Jyoung et al. 2006
Electrochemical biosensors	*Bacillus cereus*	Ertl and Mikkelsen 2001
Electrochemical biosensors	*Salmonella typhi*	Rao et al. 2005
Electrochemical biosensors	Rat IgG, HBsAg, HBeAg	Yu et al. 2006
Electrochemical biosensors	*Escherichia coli*	Elsholz et al. 2006
Electrochemical biosensors	*Bacillus anthracis*	Ghindilis et al. 2007; Liu et al. 2008
Electrochemical biosensors	*Bordetella pertussis*	Lodes et al. 2007
Electrochemical biosensors	*Clostridium piliforme*	Goto et al. 2007
Electrochemical biosensors	*E. coli* O157:H7	LaGier et al. 2007; Lin et al. 2008
Electrochemical biosensors	*Bacillus cereus*	Pal et al. 2008; Elsholz et al. 2009
Electrochemical biosensors	*Escherichia coli*	Pohlman et al. 2009
Piezoelectric biosensors	*Escherichia coli* O157:H7	Wu et al. 2007
Piezoelectric biosensors	*Bacillus anthracis*	Bolton et al. 2000
Immunosensors	*Salmonella typhi*	Singh et al. 2005
Immunosensors	*Salmonella* spp.	McEgan et al. 2009
Immunosensors	*E. coli* O157:H7	Li et al. 2012

5.4.1 Optical Biosensors

Optical biosensors present themselves as a sturdy alternate to conventional methods of analysis on the basis of characteristics like high specificity, high sensitivity, relatively small size, and economic feasibility (Luo et al. 2004). Biosensing of analytes using biosensor device basically depends upon an enzymatic system, whereby the enzyme transforms the analyte in question to a product which can be either oxidized or reduced at a working electrode and maintained at a specific potential. An optical biosensor is a compact analytical device containing a biological sensing element coupled to an optical transducer which translates the biological response to a detectable signal (Dongyou 2010). Analyte detection through optical transducers offers advantages like economic feasibility and utilization of electrodes which are biodegradable. Optical biosensing technology can be further classified into various subclasses on the basis of a number of phenomena like fluorescence, phosphorescence, chemiluminescence, refraction, absorption, reflection, dispersion, etc. Over the past few years, several types of optical biosensors have been developed for quick, efficient, accurate, and real-time detection of various foodborne pathogens and toxins in foods before their consumption (Velusamy et al. 2010).

5.4.2 Electrochemical Biosensors

The underlying basic principle in the operation of electrochemical biosensors is concerned with their abilities of detecting distinct molecules. Electrochemical biosensors are specifically utilized for detecting biomolecules like glucose, hybridized DNA, DNA-binding drugs, etc. The electrochemical biosensing technique involves production or suppression of detectable electrons or ions by distinct chemical reaction types (Kovacs 1998). The electrochemical biosensing method of pathogen detection is transduction-based systems which have been utilized for identification and quantification of various foodborne pathogens. These biosensors can be further classified into potentiometric, conductometric, amperometric, and impedimetric types on the basis of the phenomenon in observation such as potential, conductance, current, and impedance, respectively (Velusamy et al. 2010). Electrochemical biosensors can be classified into amperometric, potentiometric, impedimetric, and conductometric responses, based on observed parameters such as current, potential, impedance, and conductance, respectively (Velusamy et al. 2010). Pedrero et al. 2009 reported that electrochemical biosensors principally utilize electrochemical impedance spectroscopy as a method of transduction for simultaneous detection of multiple foodborne pathogens. Biosensors based upon impedance spectroscopy measure the deviations in the electrical attributes of bacterial cells (coupled to or attached to the electrodes) for detecting foodborne pathogens (Yang and Bashir 2008).

5.4.3 Piezoelectric Biosensors

Piezoelectric biosensors utilize immensely sensitive piezoelectric crystals which possess the abilities of detecting even minor deviations in mass. There are two main types of mass-sensitive biosensors: bulk wave devices and surface acoustic wave devices. Piezoelectric crystals start vibrating at a particular frequency upon applying an alternating current with a fixed frequency. This specific frequency at which piezoelectric crystals vibrates depends upon the mass of the crystals along with the fixed electrical frequency. Piezoelectric biosensors have been extensively utilized for pathogen detection, and their performances in studying the affine interactions have been immensely referred.

5.4.4 Immunosensors

Immuno-biosensors basically rely on antibody-antigen-specific interactions. Their work involves detection of antigen binding to antibody by reaction onto the surface of a transducer which in turn translates changes in the surface parameters to a measurable electric signal (Gomez et al. 2010). The real-time measurement of immunological reactions is rather arduous due to the difficulty in the diffusion of antigen onto immobilized antibodies especially in cases of extremely low level of contaminants. However, a majority of immune biosensors generate results within 20–90 min range which is closer to real-time detection as compared to other conventional methods of pathogen detection.

5.5 Future Prospects

The conventional methods of foodborne pathogen detection although have good sensitivity are time-consuming when it comes to practical applicability. This time taken for giving output in the form of results varies from hours to days. The need of the hour is the development of a technology that fulfills the requirements of an ideal pathogen detection method. Thus to overcome these limitation, new technologies are required in terms of efficiency, accuracy, ability to perform on-site detection in real time, and economic feasibility. Biosensor technology is one such method that has overcome the limitations of conventional methods to significant extents. A vast range of signal transducers have been developed for the detection of foodborne pathogens. Even though biosensing technology holds enormous potential for foodborne pathogen detection, several challenges still need to be addressed to make the biosensor technology a real utility in ensuring global food safety. These challenges include factors like being able to perform in the long run, ease in use, cost-effectiveness, access to common people, increasing the sensitivity, increasing the pathogen detection limit, and development of transducers able to detect multiple pathogens in one food sample in real time. The future of biosensing technology will depend upon the applicability and suitability of the biosensors in the long run and the

ability to provide quick and accurate results for on-site and real-time detection and identification of foodborne pathogens so as to meet the consumer demand for safe foods as well as for ensuring global food safety. However, despite the broader applicability and the great potential of biosensing technologies, there is still a great chance for further developments in the near future.

References

Arora P, Sindhu A, Kaur H, Dilbaghi N, Chaudhury A (2013) An overview of transducers as platform for the rapid detection of foodborne pathogens. Appl Microbiol Biotechnol 97:1829–1840

Arugula MA, Simonian A (2014) Novel trends in affinity biosensors: current challenges and perspectives. Meas Sci Technol 25(3):032001–032022

Asiello PJ, Baeumner AJ (2011) Miniaturized isothermal nucleic acid amplification, a review. Lab Chip 11:14201430

Bhunia AK, Nanduri V, Bae E, Hirleman ED (2010) Biosensors, foodborne pathogen detection. Encyclopedia of Industrial Biotechnology: Bioprocess, Bioseparation, and Cell Technology doi: https://doi.org/10.1002/9780470054581.eib158

Bierne H, Sabet C, Personnic N, Cossart P (2007) Internalins: a complex family of leucine-rich repeat containing proteins in Listeria monocytogenes. Microb Inf 9:1156–1166

Bolton FJ, Fritz E, Poynton S, Jensen T (2000) Rapid enzyme-linked immunoassay for detection of Salmonella in food and feed products: performance testing program. J AOAC Int 83:299–303

Boltovets PM, Snopok BA, Boyko VR, Shevchenko TP, Dyachenko NS, Shirshov YM (2004) Detection of plant viruses using a surface plasmon resonance via complexing with specific antibodies. J Virol Meth 121(1):101–106

CDC (2011) CDC Estimates of Foodborne Illness in the United States. http://www.cdc.gov/foodborneburden/2011-foodborne-estimates.html

CDC (2016) Food Safety Report. USA, IL: Centers for Disease Control and Prevention. www.cdc.gov/foodnet/index.html

DeMarco DR, Lim DV (2002) Detection of *Escherichia coli* O157:H7 in 10- and 25-gram ground beef samples with an evanescent-wave biosensor with silica and polystyrene waveguides. J Food Prot 65:596–602

Dongyou L (2010) Molecular detection of foodborne pathogens. CRC Press, Boca Raton

Elsholz B, Wörl R, Blohm L, Albers J, Feucht H, Grunwald T, Jürgen B, Schweder T, Hintsche R (2006) Automated detection and quantitation of bacterial RNA by using electrical microarrays. Anal Chem 78:4794–4802

Elsholz B, Nitsche A, Achenbach J, Ellerbrok H, Blohm L, Albers J, Pauli G, Hintsche R, Wörl R (2009) Electrical microarrays for highly sensitive detection of multiplex PCR products from biological agents. Biosens Bioelectron 24:1737–1743

Ertl P, Mikkelsen SR (2001) Electrochemical biosensor array for the identification of microorganisms based on lectin-lipopolysaccharide recognition. Anal Chem 73:4241–4248

Fusco V, Quero GM, Morea M, Blaiotta G, Visconti A (2011) Rapid and reliable identification of Staphylococcus aureus harbouring the enterotoxin gene cluster (egc) and quantitative detection in raw milk by real time PCR. Int J Food Microbiol 144:528–537

Ghindilis AL, Smith MW, Schwarzkopf KR, Roth KM, Peyvan K, Munro SB, Lodes MJ, Stöver AG, Bernards K, Dill K, McShea A (2007) CombiMatrix oligonucleotide arrays: genotyping and gene expression assays employing electrochemical detection. Biosens Bioelectron 22:1853–1860

Gomez P, Pagnon M, Egea-Cortines M, Artes F, Weiss J (2010) A fast molecular non-destructive protocol for evaluating aerobic bacterial load on fresh-cut lettuce. Food Sci Technol Int 16:409–415

Goto K, Horiuchi H, Shinohara H, Motegi K, Hashimoto K, Hongo S, Gemma N, Hayashimoto N, Itoh T, Takakura A (2007) Specific and quantitative detection of PCR products from *Clostridium piliforme, Helicobacter bilis, H. hepaticus*, and mouse hepatitis virus infected mouse samples using a newly developed electrochemical DNA chip. J Microbiol Methods 69:93–99

Hamon M, Bierne H, Cossart P (2006) *Listeria monocytogenes*: a multifaceted model. Nat Rev Microbiol 4:423–434

Jyoung JY, Hong S, Lee W, Choi JW (2006) Immunosensor for the detection of *Vibrio cholerae* O1 using surface plasmon resonance. Biosens Bioelectron 21(12):2315–2319

Kang CD, Lee SW, Park TH, Sim SJ (2006) Performance enhancement of real-time detection of protozoan parasite, *Cryptosporidium* oocyst by a modified surface plasmon resonance (SPR) biosensor. Enzym Microb Technol 39(3):387–390

Koubova V, Brynda E, Karasova L, Skvor J, Homola J, Dostalek J, Tobiska P, Rosicky J (2001) Detection of food-borne pathogens using surface plasmon resonance biosensors. Sens Act B Chem 74(1–3):100–105

Kovacs G (1998) Micromachined transducers: sourcebook. WCB/McGraw Hill, Inc, Pennsylvania

LaGier M, Fell J, Goddwin KD (2007) Electrochemical detection of harmful algae and other microbial contaminants in coastal waters using hand-held biosensors. Mar Pollut Bull 54:757–770

Lan L, Yao Y, Ping J, Ying Y (2017) Recent progress in nanomaterial-based optical aptamer assay for the detection of food chemical contaminants. ACS Appl Mater Interfaces 9 (28):23287–23301

Lazcka O, Del Campo FJ, Munoz FX (2007) Pathogen detection: a perspective of traditional methods and biosensors. Biosens Bioelectron 22:1205–1217

Leonard P, Hearty S, Quinn J, O'Kennedy R (2004) A generic approach for the detection of whole *Listeria monocytogenes* cells in contaminated samples using surface plasmon resonance. Biosens Bioelectron 19:1331–1335

Li Y, Cheng P, Gong JH, Fang LC, Deng J, Liang WB, Zheng JS (2012) Amperometric immunosensor for the detection of *Escherichia coli* O157:H7 in food specimens. Anal Biochem 421:227–233

Lin YH, Chen SH, Chuang YC, Lu YC, Shen TY, Chang CA, Lin CS (2008) Disposable amperometric immunosensing strips fabricated by Au nanoparticles-modified screen-printed carbon electrodes for the detection of foodborne pathogen *Escherichia coli* O157:H7. Biosens Bioelectron 23:1832–1837

Liu Y, Elsholz B, Enfors SO, Gabig-Ciminska M (2008) Critical factors for the performance of chip array-based electrical detection of DNA for analysis of pathogenic bacteria. Anal Biochem 382:77–86

Lodes MJ, Suciu D, Wilmoth JL, Ross M, Munro S, Dix K et al (2007) Identification of upper respiratory tract pathogens using electrochemical detection on an oligonucleotide microarray. PLoS One 2(9):e924. https://doi.org/10.1371/journal.pone.0000924

Luo XL, Xu JJ, Zhao W, Chen HY (2004) Glucose biosensor based on ENFET doped with SiO2 nanoparticles. Sens Actuat B Chem 97:249–255

McEgan R, Fu TJ, Warriner K (2009) Concentration and detection of Salmonella in mung bean sprout spent irrigation water by use of tangential flow filtration coupled with an amperometric flowthrough enzyme-linked immunosorbent assay. J Food Prot 72:591–600

Ohk SH, Koo OK, Sen T, Yamamoto CM, Bhunia AK (2010) Antibody–aptamer functionalized fibre-optic biosensor for specific detection of *Listeria monocytogenes* from food. J Appl Microbiol 109(3):808–817

Pal S, Ying W, Alocilja EC, Downes FP (2008) Sensitivity and specificity performance of a direct-charge transfer biosensor for detecting *Bacillus cereus* in selected food matrices. Biosyst Eng 99:461–468

Palchetti I, Mascini M (2008) Electroanalytical biosensors and their potential for food pathogen and toxin detection. Anal Bioanal Chem 391:455–471

Pedrero M, Campuzano S, Pingarron JM (2009) Electroanalytical sensors and devices for multiplexed detection of foodborne pathogen microorganisms. Sensors 9:5503–5520

Pohlman C, Wang Y, Humenik M, Heidenreich B, Gareis M, Sprinzl M (2009) Rapid, specific and sensitive electrochemical detection of foodborne bacteria. Biosens Bioelectron 24:2766–2771

Rao VK, Rai GP, Agarwal GS, Suresh S (2005) Amperometric immunosensor for detection of antibodies of *Salmonella Typhi* in patient serum. Anal Chim Acta 531:173–177

Rasooly A, Herold KE (2006) Biosensors for the analysis of food- and waterborne pathogens and their toxins. J AOAC Int 89:873–883

Seo KH, Brackett RE, Hartman NF, Campbell DP (1999) Development of a rapid response biosensor for detection of Salmonella typhimurium. J Food Prot 62:431–437

Sharma R, Ragavan KV, Thakur MS, Raghavarao K (2015) Recent advances in nanoparticle based aptasensors for food contaminants. Biosens Bioelectron 74:612–627

Silbert L, Shlush IB, Israel E, Porgador A, Kolusheva S, Jelinek R (2006) Rapid chromatic detection of bacteria by use of a new biomimetic polymer sensor. Appl Environ Microbiol 72 (11):7339–7344

Singh C, Agarwal GS, Rai GP, Singh L, Rao VK (2005) Specific detection of *Salmonella Typhi* using renewable amperometric immunosensor. Electroanalysis 17:2062–2067

Singh S, Kumar V, Dhanjal DS, Datta S, Prasad R, Singh J (2020) Biological biosensors for monitoring and diagnosis. In: Singh J, Vyas A, Wang S, Prasad R (eds) Microbial biotechnology: basic research and applications. Springer Nature Singapore, Singapore, pp 317–336

Su YL, Li RJ, Jiang L, Cao J (2005) Biosensor signal amplification of vesicles functionalized with glycolipid for colorimetric detection of *Escherichia coli*. J Colloid Interface Sci 284(1):114–119

Thakur MS, Ragavan KV (2013) Biosensors in food processing. J Food Sci Technol 50(4):625–641

Velusamy V, Arshak K, Korostynska O, Oliwa K, Adley C (2010) An overview of foodborne pathogen detection: in the perspective of biosensors. Biotechnol Adv 28(2):232–254

Waswa J, Irudayaraj J, DebRoy C (2007) Direct detection of *E. coli* O157:H7 in selected food systems by a surface plasmon resonance biosensor. LWT-Food Part Sci Technol 40(2):187–192

Wu VCH, Chen SH, Lin CS (2007) Real-time detection of *Escherichia coli* O157:H7 sequences using a circulating-flow system of quartz crystal microbalance. Biosens Bioelectron 22:2967–2975

Yang L, Bashir R (2008) Electrical/electrochemical impedance for rapid detection of foodborne pathogenic bacteria. Biotechnol Adv 26:135–150

Yasmin J, Ahmed MR, Cho BK (2016) Biosensors and their applications in food safety: a review. J Biosyst Eng 41(3):240–254. https://doi.org/10.5307/JBE.2016.41.3.240

Yu X, Lv R, Ma Z, Liu Z, Hao Y, Li Q, Xu D (2006) An impedance array biosensor for detection of multiple antibody–antigen interactions. Analyst 131:745–750

Zhao X, Lin CW, Wang J, Oh DH (2014) Advances in rapid detection methods for foodborne pathogens. J Microbiol Biotechnol 24(3):297–312