Emerging Role of Biosensors for Detection of Foodborne Pathogens

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Abstract Numerous techniques are employed for the detection of various types of pathogens in different foods. Rapid detection of foodborne pathogens is very important by using biosensors. The objectives of this review are to highlight the application of the biosensors in detecting foodborne pathogens, future trends of biosensors technology in foodborne pathogens detection, and limitations of biosensors in the food industry. Biosensors are analytical devices and one of the rapid detection methods that can combat certain limitations of conventional detection techniques, such as portability, time, cost, sensitivity, and others. Biosensors have many applications in different fields. Biosensors in the food industry are used for the detection and identification of foodborne pathogens. The uses of biosensors in food are increasing from day to day due to different factors. In the future, the latest generations, which are autonomous and nanomaterial-based biosensors will emerge**.** There is also a need to develop a biosensor that is easy to use and has a short detection time.

Cite This Article: Mahendra Pal, Mati Roba Bulcha, Milsan Getu Banu, and Adugna Girma Lema, "Emerging Role of Biosensors for Detection of Foodborne Pathogens." *American Journal of Microbiological Research*, vol. 9, no. 3 (2021): 92-95. doi: 10.12691/ajmr-9-3-4.

1. Introduction

An increase in various emerging foodborne diseases had been causing great challenges and seeking significant public health concerns globally. Food or food products serve as a powerful transmitter of food-borne pathogens and the spreading of these diseases causing pathogens delivered with foods has become a life-threatening problem for millions of people around the universe [1]. There are various factors that are responsible for the emergence of foodborne illnesses. Changing food habits and food supply chain are two of these major issues. These disease outbreaks cost billions of dollars in damages and agricultural product losses. The incidence and death rate resulting due to foodborne pathogens in developing countries are highest as compared to developed nations [2].

Microorganisms exist in a number of forms and are found in a wide range of foods. Some of these bacteria in food continue to function normally and they are utilized in food (bio- processing, bio-preservation and probiotics [3]. Other bacteria, on the other hand, can contribute to food spoilage or foodborne diseases. The most common foodborne pathogens are *Salmonella, Campylobacter, Escherichia coli, Listeria, Bacillus, Clostridium, Shigella, Brucella, and Aeromonas*.

Currently, food production faces great challenges, including microbial, chemical, personal, and environmental starting from the farm to fork/plate because the presence of microorganisms in food is a natural and unavoidable event [4]. However, timely detection of foodborne pathogens is directly linked to human health and well-being. As food supply chains are growing worldwide, the need to improve food safety and monitoring systems is becoming more apparent in many countries of the world [5]. Maintaining the wholesomeness of the food with its production and/or processing industry is of great importance for our survival and to safe living. Thus, early screening or testing of the various microorganisms causing foodborne diseases and quantification of food constituents is becoming crucial for the food industries and consumers [6].

In order to detect, identify, and prevent foodborne pathogens, conventional and rapid techniques are mainly employed. Traditional or conventional methods can be highly reliable, sensitive, and provide both qualitative and quantitative information on the number and quality of the studied microorganisms [7]. However, these methods are time-consuming, ineffective, and incompatible with integration for on-site diagnosis. They also needs huge volumes of samples and well trained personnel [8]

To overcome the limitation of conventional methods, the researchers concentrate on technologies that are user-friendly, simple, reliable, combat, inexpensive, fast, and

simultaneously deliver pathogens detection results [9]. Biosensors are one of the fast-paced, revolutionary methods that have become increasingly common due to their characteristics of rapid detection of pathogens in foods. In addition to the rapid result, online biosensor technology offers the food industry a tool for internal process control to reach a high standard of quality control level [10].

Generally, the demand for improved food security has been growing steadily from day to day. Security in the food supply becomes crucial because of increased perception among the consumers and the competitive nature of food industries [11]. Food manufacturers are constantly demanding efficient methods of quality control to meet the customers and regulatory requirements to improve the production feasibility, quality sorting, automation, and reduction in production cost and time [12]. Great efforts were made on the development of various types of biosensors over the past few years. Developing biosensors with the qualities required for dependable and effective use in ordinary applications, on the other hand, is difficult. To date, there are very few commercially accessible biosensor systems available [13].The current mini review is an attempt to delineate the growing role of biosensors in the detection of pathogens in a variety of foods.

2. Biosensor in Detecting Foodborne Pathogens

The food industry is being confronted with several issues around the world now a day. The increased regulatory requirements, as well as continual improvements in traceability, sustainability, and time to market, are the examples. To overcome these challenges, attention is increasing toward biosensors technology. Biosensors are ubiquitous and have a wide range of applications [14]. The first goal of biosensors development was to fulfill the medical diagnostic requirements. However, later on, its requirement has been increasing in different disciplines, especially in the food industry. The main applications of biosensors in the food industry are the detection and identification of foodborne pathogens [15]. Besides detecting foodborne pathogens in food, biosensors can also be used to detect various chemical contaminants, such as fertilizers, heavy metals, pesticides, food additives, and antibiotics in the food industry. In addition, biosensors have been used to develop control systems to assure the food quality as well as safety [16].

All foods are not equally contaminated by foodborne pathogens due to their characteristics and compositions. The most readily contaminated food with pathogenic microorganisms is foods of animal origin including milk and milk products, meat and meat products, poultry and poultry products [17]. Unlike the food of animal origin, raw vegetables and fruits are poorly contaminated with pathogenic microorganisms. For the detection of such pathogenic microorganisms in the food; the traditional/conventional methods need more than one to two days and the developments of the biosensors have been focusing on the rapid detection and limits of detection (LOD), feasibility of operation, and economical. Therefore, the use of biosensors is the best upcoming technology to combat this problem, especially for the detection of foodborne pathogens that cause disease in the susceptible individuals [17].

In the food industry, biosensors are used mainly for two purposes. Primarily, they are used for detecting or measurement of carbohydrates from alcohol, amino acids, amines, amides, phenol, and others in the liquor and beverages industry. Secondly, biosensors are employed for the detection of microorganisms in the food [18]. There are many known types of biosensors but in the food industry, mainly enzyme-based biosensors and immune sensors are employed [19].

2.1. Optical Biosensor

These approaches are a strong alternative to traditional and most widely reported analytical techniques in detecting foodborne pathogens. It has been extensively used to identify very large numbers of bacteria and characterized by high sensitivity, simple handling, cost-effectiveness, and rapid detection [20]. Optical biosensors consist of a light source, as well as numerous optical components to generate a light beam with specific characteristics and to beeline that lights to a modulating agent, a modified sensing head along with a photo-detector [21].

There are various types of optical biosensors, such as surface plasmon resonance (SRS), Raman and Fourier transform infrared spectroscopy, fiber optics, and others. Among these optical biosensors, SRS is most widely used for the detection of foodborne pathogens due to their sensitivity. Surface plasmon resonance makes use of reflectance spectroscopy to detect food-borne pathogens, such as *Listeriamonocytogenes*, *Salmonella* spp., *Escherichia coli* O157:H7, and *Campylobacter jejuni* [1,4]. In this SPR, receptors are immobilized on the surface of thin metal, and it can directly assess the bacterial toxins that have a high molecular weight [2,5].

The electromagnetic radiation of a certain wavelength interacts with the electron cloud of the thin metal and creates a heavy strong resonance. When the pathogen binds to the metal surface, this interaction changes its refractive index, which results in the change of wavelength needed for electron resonance [3,6]. There are various commercially available optical biosensors using SPR techniques like SPREETA and BIACORE 3000 biosensors, which are currently available for the detection of foodborne pathogens. SPREETA biosensor is used to detect *E. coli* O157: H7 in milk, apple juice, and ground beef with the detection limit of around 10^2–10^3 CFU/ml [2,4,8].

2.2. Electrochemical Biosensor

An electrochemical biosensor uses an electrochemical transducer where electrochemical signals are generated during biochemical reactions and are monitored using appropriate, potentiometric, impedimetric detection, amperometric, or other analytical systems. It usually worked on the principle of enzymatic catalysis that generates or uses electrons (i.e., redox enzymes) [14,15].

Electrochemical biosensor detection methods are advanced transduction-based systems used for the identification and measurement of foodborne pathogens. It measures an electrochemical response and converting the electrical signal directly into an electronic field and allows the development of compact system designs with simple

instrumentation [16,17]. In addition; these techniques have some advantages over other analytical transduction systems. For example, comparable instrumental sensitivity the possibility to operate in turbid media and the possibility of miniaturization, which allows even to analyses small amount samples [8].

One of the electrochemical biosensors is an amperometric system and it is based on the movement of electrons that defines electrical current because of redox reactions catalyzed by enzymes [12]. Normally, a constant voltage passed between the electrodes, which can be measured. In an enzymatic reaction that occurs, the substrate or product can transfer an electron to the surface of the electrode to be oxidized or reduced. *Salmonella* with the LOD of 89 CFU/ml can be identified by this technique [17].

Potentiometric biosensors are the other electrochemical biosensor methods that use a high voltmeter to detect the difference in electrical potential between the working electrode and the reference electrode. In 2010, Zelada-Guillen, Bhosale, Riu, and Rius developed the real-time potentiometric biosensors used for *E.coli* O157: H7 to detect complex samples with detection limit as low as 10 cells/ml [13,16,19]. A major drawback linked to this biosensor is the low selectivity in certain food samples. Moreover, impedimetric electrochemical biosensors were also shown to be efficient for pathogen detection. When they are aligned with or connected to the sensing surface these biosensors measure the impedimetric signal of bacteria and pathogen capture at the electrodes will improve interface impedance [17].

2.3. Mass-based Biosensors

These biosensors work based on the detection of slight changes in mass. It involves the use of piezoelectric crystals, which vibrates at a certain frequency when induced by an electrical signal of a certain frequency. On this crystal, the bio-receptors are immobilized for the detection of pathogens [8]. Once the target antigens bind to the antibodies immobilized on the crystal, this will cause a measurable change in the vibrational frequency of the crystal, which correlates with the added mass on the crystal surface. However, in the field of foodborne pathogen detection, the application of mass-based biosensors is usually lower than electrochemical and optical biosensors [9,10].

Piezoelectric biosensors are very interesting sensors based on the concept of directly detecting bacteria without labeling [16,17]. A selective binding agent (e.g. antibodies) coats the surface of the piezoelectric sensor in which the bacteria-containing solution is placed and bacteria bind to antibodies that reduce the frequency of oscillation as the crystal mass increases. It is used for the detection of some foodborne pathogens like *S. enteritidis* with a detection limit of 1×10^5 cells/ml [21].

Magnetoelastic biosensors are also another mass-based method. They are wireless devices that can become very useful tools for remote monitoring [13,18]. Magnetoelastic biosensors are the first example of wireless biosensors and have become very helpful remote monitoring tools. These biosensors can detect microorganisms like *Staphylococcus aureus* on the surface of spinach, and *Salmonella Typhimurium* on the surface of tomatoes with different detection limits [20].

3. Future Trends of Biosensors Technology in the Food Industry

The emergence of foodborne pathogens is the main challenge in the twenty-first century and needs a special concern [7]. As the world's population rises, agricultural and livestock production intensifies and becomes more industrialized in order to fulfill the growing need for food. This provides both opportunities and challenges for food. Such rapid growth in the food production and processing industry requires biosensors to quickly detect food quality, freshness, and free of various microbial that cause foodborne diseases/illnesses to human beings [22].

Biosensors technology in food has been increasing from day to day [12]. In nature, the actual food samples are incredibly complex. The new (4th) generation biosensors will emerge to classify and detect those highly complex food samples. These fourth-generation biosensors can be autonomous data collectors that possess an internal energy supply and a wireless transmitter or sensor-actor molecules [14]. Biosensors capabilities and affinities for detecting food pathogens have improved due to the micro and nano assemblies. New nanotechnology can move the analytical micro-systems into the micro or nano biosensor area by miniaturization techniques that decrease the detection time and make them completely portable. The development of new nanomaterials that induce the performance of biosensors in terms of sensitivity, response time, and shelf life is continuously in research [3].

The present scenario demands for increased range of detectable analytes with a portable device structure. In the future, the further convergence of associated technologies, such as biochemistry, polymer chemistry, electronics, and separation technology may be going to fulfill these demands [17,18]. Additionally, excellent nanomaterial-based biosensors will emerge from the collaborative endeavors of scientists in the fields of nanotechnology and food science. There is also online use of biosensors that provides feedback control of both component and microbial levels in the future for obtaining continuous real time data [19].

For the analysis of multiple analytes using a single device, multi-functional biosensor systems are needed. At the same time, physical device size reduction and multi-array analysis are favored without losing the device's precision and sensitivity. The use of emerging nanomaterials (to improve the detection limit) will lead to the development of novel smart analytical methods and improve the existing ones. Moreover, the recent progress in microelectronics and micro-fluidics will foster the development of accurate, low-cost, and ready-to-use biosensors [21].

4. Conclusion and Recommendations

Foodborne diseases have been one of the major problems and have become a life-threatening concern for millions of people worldwide. The potent transmission agent of multiple diseases is food or food products. For the consumers, different food industries and regulatory agencies state the microbiological protection of food has become an important concern. The initial step towards

ensuring food safety lies in the prevention by raising the consciousness of industry and the consumers, and few primary daily acts can prevent foodborne diseases. A biosensor is one of the fast analytical foodborne pathogens detecting methods and the best upcoming revolutionary technology in the food industry due to its selectivity, sensibility, stability, reproducibility, linearity, cost, time, and portability. In the future, the latest or fourth generation and outstanding biosensors based on nanomaterials will arise from the joint efforts of nanotechnology and food science scientists. However, developing biosensors with the necessary properties for reliable and effective use in a routine application is challenging.

Therefore, based on the above conclusion the following recommendations are forwarded:-

- The scientists should sincerely attempt to develop an easily portable, easy utilization and simple configuration for access to the farmers who are illiterates, especially in the developing countries of the world.
- The researchers should have to raise the challenge of developing new, simple, sensitive, specific, and time saving biosensors.
- The academicians of different disciplines should work jointly to develop new and nanomaterial based biosensors.

Acknowledgements

Contribution of the Authors

All the authors contributed equally. They read the final version, and approved it for publication.

Conflict of Interest

The authors declare that they do not have conflict of interest.

Source of Financial Grant

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