

Applications of Biosensors for Safety Detection of Sea and Dairy Foods

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Abstract. Food spoilage is a complex process that can be challenging to recognize among many practical cases. Therefore, the use of biosensors in detecting food safety has become a popular trend since the growing demand for efficient auxiliary tools. In this article, the importance of food safety is discussed at first, followed by an analysis of multiple reasons of food spoilage from the variety of specific substances and the process of food chain. Subsequently, the advantages of applying biosensors are illustrated from a detailed definition and explanation of their unique working principles. Next, the application of biosensors techniques in detecting the quality of seafood and dairy food are concluded, highlighting their potential to apply in diverse fields due to its sensitivity, accuracy and portability. Finally, the trend of future development of biosensors is analyzed, suggesting that biosensors in food safety are possible to combined with artificial intelligence to improve structure design and provide services to customers directly.

Keywords: Food safety, biosensors, safety detection.

1. Introduction

Food is the basic necessity for humans, but there are numerous problems related to the food safety. Since the growing food industry and huge demand of food, food safety has become a critical issue, the debates about how to improve food safety and quality are continuously conducting in everywhere around the world. Identifying the status of food is quite complex, which is connected with a variety of factors, such as appearance, color, scent and texture. In most cases, the signal signs released from unsafe food are too weak to make it be detected by the human senses only. Apart from lack of experiences of observation to different types of food (for example teenagers), the situation also happens on many older adults, whose perception of gustation receded because of their increased ages [1].

The rottenness and spoilage of food is always caused by multiple reasons throughout food chain, depending on different categories of food. Among all factors affecting the status of food, microorganism is the most commonly dangers, because it carries many other harmful substances, including yeasts, molds and diverse bacteria. [2]. In addition, during the process of food distribution, if it is not distributed to customers in time which is under unsuitable environment (for example, high temperature), especially some raw materials (for example, seafood) it will spoil rapidly.

Traditionally, the methods of detecting spoilage are very complex, requiring high demands of precise machines and sufficient professional employees to conduct corresponding operation and gain accurate data. One of the most common ways is to identify microorganism with quantitative data or figures, selecting from a specific colony. Therefore, we can determine the number of bacteria and other toxins existed in the sample, after comparing the results with average level of growth of microorganisms, then the state of food can be gained and analyzed. However, there are many preparations are supposed to implement, making it less efficient. For example, in order to gain precise data, it should be confirmed that all the potential factors related to detection should be under control, such as temperature, moisture, the percentage of oxygen, etc. The single cell droplet microfluidic system is a specific representative way of detection, which is related to bio-analytical process. The first step of the operation is to extract one single cell as an independent object that will be analyzed. It can achieve functions of high-throughput, parallelization, and integration, and allows accesses to detect microorganism and analysis of pathogens. However, it will take a lot of time and economic

costs due to the reaction time and maintenance of machine, as well as the high requirements of staff, although it has high sensitivities [3]. In comparison, a new technology of spoilage detection called biosensor devices shows its unique advantage (convenience, low cost, high efficiency).

In this paper, the working principles and theories of biosensor will be explored firstly. Then, the application of biosensor in the field of food safety is going to be expanded with explicit evidence and details, as well as the future trend and development of biosensor.

2. Working Principles of Biosensors

Biosensors are known as their efficiency, convenience and low price, which allows the rapid detection for objects such as pathogens, toxic substances, protein and allergens, as long as it is provided by analytes. As the development of technologies, the functions and performance of biosensors have developed significantly, accounting for increasing market due to its wide range of potential implementations. These include providing service to customers with commercial values, enhancing the detection efficiency in for food safety and medical diagnosis [4]. A biosensor is a sensing device, which detects the state of various substances by measuring specific analyte known as biomarkers. The biological recognition element that binds to the target analyte is the clue to identify whether a substance is in a normal state. This element is always a molecule, such as antibodies, enzymes, DeoxyriboNucleic Acid (DNA) probe and aptamers [5].

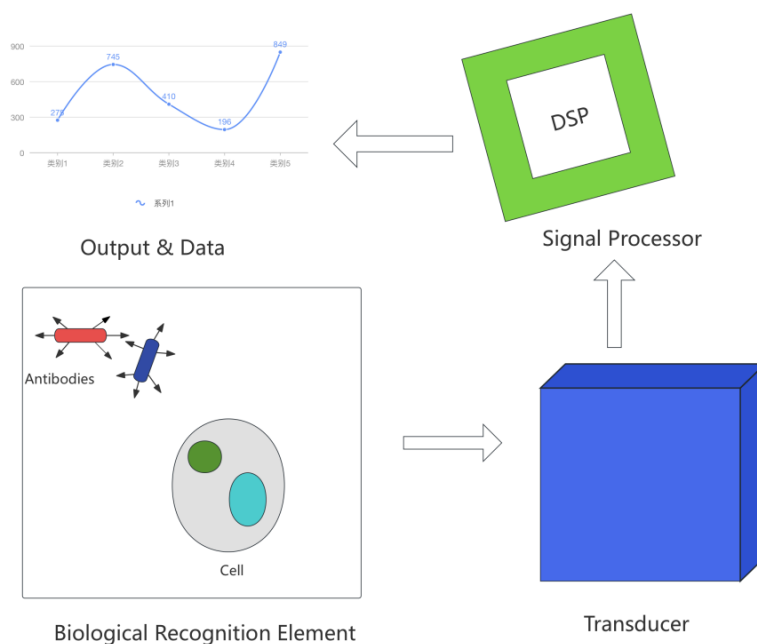


Fig. 1 General demonstration of working principle of biosensors (Picture credit: Original)

The biosensor is composed by many components that played different roles in the detection process, including detector, transducers, signal processors and readers. A generalized graph illustrating the working principle of biosensors is shown in Fig.1. The detector refers to interacting with the biological recognition element, which is mentioned above, receiving and reflecting the change of chemical substances in the target. Then the change will be converted into an electrical signal, such as voltage, current, thermal signals, optical signals, or any kind of index that can exchange information and demonstrate the concentration of different substances in the sample. The signal processor is constructed by multiple components together, physically including semiconductors (PN junctions), compute engines, thermistors, and digitally with input and output. Next, the signal processor will process the signal gained previously by amplifying and analyzing to generate the data, which can measure the specific value. Then, compared with the standard range of values in the database, the composition of biological materials can be known. Finally, combine with a reader to display results in a visual way.

Biosensors are categorized based on a variety of optional properties. Electrochemical biosensors form the basis for widely used devices such as glucose biosensors for diabetes detection and DNA biosensors for genes detection. Optical biosensors are employed in protein biosensor for medical and environmental issues. Piezoelectric biosensors operated by detecting changes in mass or viscosity has and have been applied in detecting water quality. Microelectromechanical systems (MEMS) biosensors utilize microfabrication techniques to make tiny but robust structures, and it has been applied for detecting cells [6].

Among the detection technologies mentioned above, potentiometric biosensors are the most widely used. They mainly utilize the different rates of change of potential difference change between two electrodes to scan specific molecules in food samples for multiple times in the term of triangle waves. So there will be redox (reduction and oxidation) reaction conducting, finally specific data are selected for analysis based on current peaks to derive detection conclusions [7]. There's only one special technology that related to mathematics, called metal-oxide-semiconductor field-effect (MOSFET) based biosensors. The gate electrode of this in the biosensor makes it bind to the analyte with multiple choices, which allows it to be seen in presence of electrical properties. Leveraging the measurable signal, the specific concentration of the target analyte can be analyzed and shown with high sensitivity.

Biosensors have emerged as a transformative technology in analytical detection, offering many advantages over conventional methods. Traditional detection methods typically demand high investment and complicated operation, making them nearly impossible to apply in wide ranges of industries. Instead, biosensors, benefited by their portable size and simple but fast designs, exhibit significant potential to expand application over all sectors and procedures. Apart from it, biosensor have high separation-efficiency, ease for recycling, less demand of samples, and high flexibility, which perfectly cater to the detection of food safety.

The application scope of biosensors covers multiple fields, including the detection for land security, medicine, food spoilage, gardening, environmental issues [8]. Notably, they also play a role in the detection of specific cancers, such as CA 125 in ovarian cancer, Elecsys CA 125 || Immunoassay, BRAF V600E mutation in melanoma, BRAF V600E Detection Kit, Oncomine Dx Target Test, and ExoDx Prostate IntelliScore Test [9].

Therefore, biosensors can improve the accuracy when dealing with biological and chemical practical problems with selectivity and specificity, bring more creative solutions and higher possibility of pursuing better food safety and health care.

3. The Application of Biosensors in Food Safety Detection

In contemporary society, with the dramatic growth of food production demands, the application of emerging technologies for food quality monitoring has become inevitable. Therefore, achieving complete automation of monitoring throughout the food chain becomes an important goal. Conventional detection methods, which detects the state of food by counting the number of microorganisms is almost impossible to achieve this effect. In contrast, biosensors provide a lot of advantages in detecting spoilage biomarkers, including high sensitivity and specificity. Specifically, they even can detect extremely low concentrations of rottenness in food samples with high accuracy. Furthermore, when integrated with internet connectivity, biosensors allow real-time feedback about the state of food by analyzing specific analyte. This chapter will analyze application of biosensors in seafood detection and dairy food detection.

3.1. Detection of Seafood

Seafood is considered as a high-risk food. As aquatic organisms, marine creature is inherently associated with enormous contamination, including tons of invisible microorganisms and marine toxins. These toxins—such as saxitoxins, ciguatoxins, domoic acid, brevetoxins, and tetrodotoxin—are major causative agents of food poisoning. Even worse, these toxic substances are difficult to be

destroyed by extreme temperature, whether heating or freezing. In a word, the consumption of seafood without identification leads to potential health issues and diseases.

For seafood quality assessment, the standard of identifying its state is mainly related to the changes in pH value and biogenic amines. The variation in pH value is caused by the accumulation of ammonia and other nitrogenous compounds in seafood for a period. Due to their property of volatility, their content in seafood will decrease as they are released to the air, leading to a decline in pH value. The biogenic amine, which also contain nitrogen compounds, are biologically active molecules that connect the nervous and immune systems. They include neurotransmitters such as dopamine and serotonin. The formative process of biogenic amines covers microbial activity that frequently happen in fermented products, leading to food poisoning and other toxic effects at presence of high levels.

The electrochemical biosensor is suitable to detect seafood due to its high sensitivity and selectivity toward target analytes, with especially accuracy for proteins, biotoxins, and antigens. The applicability of electrochemical biosensors has been proved by the team of Nelis. In their study, a collection of co-occurring saxitoxin and tetrodotoxin was prepared and conducted. The results illustrated that the biosensor successfully discriminate the okadaic acid and domoic acid. Another scientist, Sharma, conducted a test to enhance the analyte detection capability of electrochemical biosensors by utilizing the enzymes reactions. He attached xanthine oxidase to the surface of the electrodes of electrochemical biosensors in order to determine the existence of xanthine. The working principle is based on the reaction between enzymes and xanthine oxidase, which generates an electronic signal-- an indicator of successful detection of xanthine in fish samples.

Similarly, Munir aimed to detect toxic substances known as histamine, which will produce after fish spoils. To achieve this, molecularly imprinted polymers (MIP) was applied on the surface of electrode as an element to recognize the spoilage. Experiment data presented a linear detection range from 1 to 1000 nmol/L and a detection limit of 1.765 nmol/L [10].

Overall, biosensors used to detect the food safety of seafood provide time-efficiency due to less needs of preparation, as well as high sensitivity, accuracy and portability.

3.2. Detection of Dairy Food

Milk, a classic representation of dairy food, has become a necessary part of daily life. Renowned for its rich nutrient elements, such as proteins, minerals, fats and carbohydrates, it offers significant benefits for the human health of. However, milk also has some certain safety risks as there are many potential residues existed in the cow. For example, in order to improve the production of milk, farmers may use pesticide to the cow, which can enter the cow's body through blood. Then the milk gained from the cow might carry with the residue of pesticide, leading to damage to health effects to consumers. To avoid such risks, applying biosensor to monitor the residue in milk is a viable solution. Notably, biosensors have the ability to detect many harmful components by recognizing specific biomolecules, such as enzymes, antibodies, and nucleic acid.

Ni established a method to detect avermectins in milk samples, developing a model of monoclonal antibody in the term of ELISA. The results showed a detection limit of 0.5 to 5.4 ug/L and a recovery rate between 78.1% to 110.5%. Therefore, it suggested that biosensors can detect the harmful substances by the analysis of antibodies. Similarly, enzyme is capable for detecting specific target analytes through specific binding interactions. Unlike other biomolecules, enzyme can react with various analytes, to accelerate reaction kinetics. Therefore, a more obvious signal can be generated. A relevant research represented that if the environmental variables are well controlled, enzyme-based biosensors can achieve a linear detection range of 3.3×10^3 to 10^6 cfu/mL, with the limitation of detection reaching to 9.2×10^2 cfu/ml. In addition, nucleic acid-based biosensors demonstrated unique advantages, which can detect the target analyte accurately in complex environments. Besides, a CRISPR-Cas12a biosensor has been reported to detect estradiol and prostate-specific antigen in milk with awesome performance [11].

4. Conclusion

This paper provides an overview of the application of biosensors in detection of sea food and dairy food. Initially, the importance of food safety is discussed, along with the analysis of traditional biosensor, the fundamental concepts and theories of detection about biosensors, as well as its advantages and disadvantages. Finally, the current application of biosensor in detection of food are presented in detail.

A series of experimental findings prove that the biosensors exhibit core performance characteristics including selectivity, sensitivity, accuracy, portability, and time-efficiency. These biosensors have been applied in diverse fields of food, like the mentioned detection of seafood and dairy food, and their adoption promotes reform and innovation to food industry and replace with the conventional method. It is interesting to point out that despite these advancements, biosensors still face enormous challenges and limitations, which still require a lot of efforts to do furthermore investigations. For example, when dealing with complex environmental conditions, the result gained from biosensors might lack of accuracy due to interference.

In the future, biosensors have the potential to directly serve to customers, not restricted in food chains. Realizing this breakthrough step will require simplifying the structure design of biosensors hardware. Apart from it, biosensors are possible to combine with artificial intelligence by connecting with internet, to enhance and assist their judgement capabilities. In order to achieve this integration, sufficient datasets must be gained to train the model and improve the accuracy.

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