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# Biosensing technology for sustainable food safety

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A B S T R A C T

Food and diet are closely linked to human health, and new emerging research fields are attempting to guarantee improvements in food quality and safety. Biosensor technology represents a cutting-edge frontier in environmental and biomedical diagnosis and is at the forefront in the agrifood sector. Smart monitoring of nutrients and fast screening of biological and chemical contaminants are some of the key evolving issues challenging the assessment of food quality and safety. Advances in materials science and nanotechnology, electromechanical and microfluidic systems, protein engineering and biomimetics design are boosting sensing technology from bench to market. This review highlights current and future trends in analytical diagnostic tools focused on the food industry and target analytes to support healthier nutrition.



**Contents**



## 1. Introduction

Nowadays, several research efforts are devoted to developing control systems ensuring food quality and safety [1]. Awareness of food control also increased recently, due to estimations suggesting significant global population growth in the next 30 years ("World Population to 2300", Department of Economic and Social Affairs, United Nations). This global increase poses marked challenges to the agrifood sector, since intensive agriculture and animal farming, food handling, processing and distribution may hamper food safety and quality and, as a consequence, human health. Innovation and development in the agrifood sector and the recent globalization of agro-industrial markets point to fundamental belief in the need for food safety and quality, which have become of great concern for human and environmental health, so that various efforts have been committed to guarantee food safety and quality [2].

The term food quality relates to appearance, taste, smell, nutritional value content, functional ingredients, freshness, flavor, texture and chemicals. The analysis of food composition allows us to characterize food and prove if it contains all the desired constituents, including natural components (e.g., sugars, amino acids and alcohols) and additives (e.g. vitamins and minerals). Furthermore, the evaluation of food composition enables comprehensive estimation of freshness, revealing the presence and/or the concentration of microorganisms and toxins produced as a result of damage. The

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food-safety concept entails the production and the commercialization of food which do not represent a risk to the consumer, so it must be free from allergens, pesticides, fertilizers, heavy metals, organic compounds, pathogens and toxins. These contaminants could seriously affect human health and well-being, giving rise to foodborne diseases with serious consequences for the health-care system and economic productivity (Appendix S1, Supplementary material). It is necessary to identify and to set up an ensemble of procedures, inspections, and control systems to minimize threats that cause unsafe or off-quality end products.

The diagnostics industry is key to the development of analytical methodologies endowed with high sensitivity, speed and portability. Among diagnostics, biosensors combine a high functional performance (in terms of specificity, sensitivity and short response time) with ease in building technical capacity (including modularity, integration, and automation) (Appendix S2, Supplementary material). Hazard analysis and critical control point (HACCP), generally accepted as the most effective system to ensure food safety, can utilize biosensors for process control.

Biosensing R&D had an estimated a market of US$8.5 billion in 2012 and is projected to reach US$16.8 billion by 2018. However, this market comprises mainly devices for medical diagnosis, and there is no quantitative analysis of the agrifood market [3–5].

This review provides a global overview on recent advances in biosensor technology for the agrifood field, enabling the development of reliable, robust and selective biosensors. In this context, we propose a selection of biosensing configurations with improved performance in terms of sensitivity, stability, reliability, multiplex analyses and time response compared with older generation biosensors or conventional analytical devices. Nevertheless, although a huge assortment of biosensors have been reported in the literature, only a few prototypes reached the market, dealing mainly with glucose, lactose and microorganism detection. We aim to stimulate research activity in developing innovative, tailor-made biosensors for agrifood diagnosis and to move this technology from bench to market to reduce the gap between research and industries.

## 2. Discussion

Conventional methodologies for food analysis provide high reliability and very low limits of detection (LODs). Among them chromatography, spectrophotometry, electrophoresis, immunoassays, polymerase chain reaction (PCR) assays and ATP detection methods promise results within 24 h, but they are expensive and time consuming, and need samples to be sent to laboratories, and most of them require the use of highly trained personnel.

For these reasons, there is increasing demand for robust, rapid, cost-effective alternative technologies for *in-situ*, real-time monitoring. Several biosensors have been designed and realized for the detection of food components [5] and chemical species in food and water products [6], in order to satisfy all the requirements of the diagnostic industry.

The following sections provide an overview of biosensor technology in the past 10 years, which was intended for application in the agrifood to address control of food quality and safety (Table 1).

### *2.1. Glucose*

Food content and composition change during storage, especially the main carbohydrate constituents, such as glucose and fructose, which could be responsible for food-browning processes. For this reason, glucose monitoring is important as it is an indicator of food freshness [57]. Biosensors started in the 1960s with the pioneering work of Clark and Lyons and the first enzyme-based glucose sensor reported by Updike and Hicks in 1967 [58]. Since then, widespread investigation of biosensors was done for the production of novel systems for glucose monitoring. Most electrochemical biosensors (amperometric, potentiometric, impedimetric or conductometric) are based on glucose oxidase (GO) enzyme that catalyzes the oxidation of glucose to produce gluconic acid, as shown in Fig. 1. Glucose monitoring by glucose oxidase was performed with different LODs by:

- Goriushkina et al. [7] for wine analysis in the linear range 0.04–2.5 mM;
- Shan et al. [8] with a polyvinylpyrrolidone-protected graphene/polyethylenimine-functionalized ionic liquid/GO for detection up to 14 mM; and,
- Xu et al. [9] with PPy-nanowire GO arrays showing an LOD of 50 μM.

A novel trend in glucose sensing is the use of receptors as an alternative to enzymes. In this context, research efforts were dedicated to the development of non-consuming biosensors, based on the use of inactive apo-enzymes or binding proteins for reversible, implantable and/or in-line sensing systems. Scognamiglio et al. [10], reported the use of an inactive form of glucose oxidase from *Aspergillus niger* (Fig. 2), in which the *flavin adenine dinucleotide (FAD)* cofactor, required for glucose oxidation, was removed. Fluorescence measurements showed that the apo-glucose oxidase obtained was still able to bind glucose without consuming it, so it was suitable for a reversible sensor.

Similarly, several binding proteins and receptors were exploited for the development of affinity biosensors. Among them, a D-glucose/D-galactose binding protein (GGBP) from *Escherichia coli* was produced by different research groups, extensively characterized by spectroscopic techniques and exploited for the realization of optical biosensors [59–61].

Subsequently, several genetic variants were obtained with different affinity for glucose to enhance sensor sensitivity [62–64]. In the same research field, Staiano et al. [11] employed a thermostable sugar-binding protein (Ph-SBP) from archaeon *Pyrococcus horikoshii* as a more stable variant protein to increase robustness.

In recent years, many biosensors for glucose monitoring were based on the latest research on nanotechnologies and biocomposite materials, which provided devices with better performance in term of stability and sensitivity. German et al. [12] studied the electrochemistry of glucose oxidase immobilized on a graphite-rod electrode modified by gold nanoparticles (AuNPs), in comparison with similar electrodes not containing AuNPs (GOx/graphite). They demonstrated that the application of AuNPs could increase the rate of mediated electron transfer, providing an improved sensitivity with an LOD within 0.1 mmol/L and 0.08 mmol/L, suitable for determination of glucose in beverages and/or food.

Although a large number of articles report the development of biosensors conceived for the food industry [65], very few of them have been applied to the detection of glucose in real samples, with limited exceptions, including analysis of wine [66], fruit juices [13] and soft drinks [14].

### *2.2. Glutamine*

Glutamine is an essential amino acid that plays key roles in several metabolic pathways and accomplishes crucial functions (e.g., signaling, transport and precursor in the biosynthesis of nucleic acids, amino sugars and proteins). It represents a nitrogen source in mammals' diet, since they are unable to synthesize nitrogen-containing organic compounds from inorganic salts. Glutamine supplementation in patients affected by critical pathologies such as malabsorptive disorders or immunodepression seems to be