BIOSENSORS FOR THE ANALYSIS OF BIOACTIVE COMPOUNDS IN FUNCTIONAL DRINKS: EVOLVING TECHNOLOGIES AND LONG-TERM POTENTIAL

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INTRODUCTION

- The growing consumer focus on **well-being and sustainability,** has fueled a significant surge in the global **functional drinks (FDs) market,** expected to grow at a **CAGR of 6.46% from 2025 to 2034.**

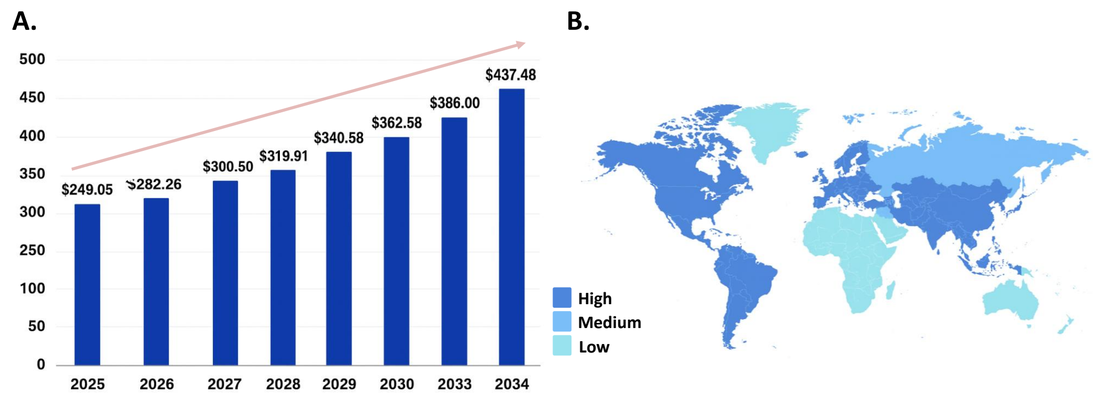

Figure 1: A) Functional drink market size. B) Global Beverage Market CAGR (%) by Region.
Source: Precedence Research. (2025); Mordor Intelligence. (2025).

- **FDs** have emerged as a **leading segment** due to their **ease of use, sensorial desirability,** and **capacity to vehicle bioactive compounds (BCs)** in relevant **physiological concentrations.**
- Today, **R&D lines** are being focused on formulations fortified with antioxidants, essential amino acids, prebiotics, and probiotics, **with synergistic benefits in the modulation of the immune system, inflammation,** or **cognitive health (Figure 2).**

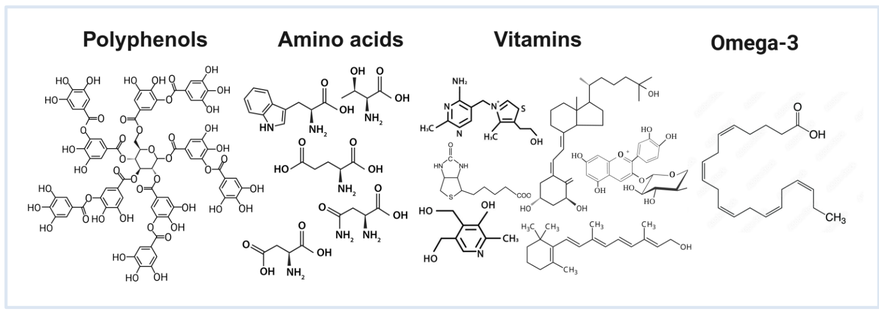

Figure 2: Chemical structure of commonly used BCs (polyphenols, amino acids, and vitamins) for FD fortification.

- Quantification of BCs is a critical stage in the **design**, **control of quality,** and **compliance of FDs.**
- Yet, their screening involves technical hurdles given the **complexity and variability of food matrices.**
- Against this backdrop, **biosensors (BSs)** are emerging as **encouraging analytical platforms.**
- In particularly, **electrochemical and optical BSs** have proven to be **effective** in targeting key **BCs** in liquid matrices.
- The latest progress in transducers based on **nanotechnology** and **biological recognition elements like aptamers.**

OBJECTIVES

This **systematic review** aims to:

a) Make available an **overview** of **biosensing approaches applied to FDs.**
b) Evaluate their **analytical performance parameters** and **technological maturity.**
c) Identify **future trends** toward **intelligent, scalable, and affordable food analysis systems**.

METHODOLOGY

Articles from **2017–2025** were retrieved from **scientific databases** using keywords such as **“biosensors”, “functional drinks”,** and **“bioactive compounds”.**

Eligible studies include those that apply biosensors to detect BCs in drinks, **excluding drink** studies.

Selected papers were categorized by **BSs type, recognition element, and analytical parameters.**

Data were **analyzed comparatively.**

BIOSENSING APPROACHES IN FUNCTIONAL DRINKS

Biosensing is an analytical field dedicated to detecting biological indicators using transducer systems. When performing biosensing, the key parameters are detection specificity and sensitivity**. Within this field, micro-analytical systems, e.g., BSs,** can respond to **external stimuli** and **translate biological interactions into quantifiable, readable signals. BSs** can be divided into **1) the biotransducer; 2) the instrumentation subsystem; and 3) the readout device (Figure 3).**
Their specificity arises from **biological interactions such as those between enzymes** and **substrates, antigens** and **antibodies, receptors and ligands, or nucleic acids.** Thus, quantitative detection of target **BCs** is possible even in complex matrices.

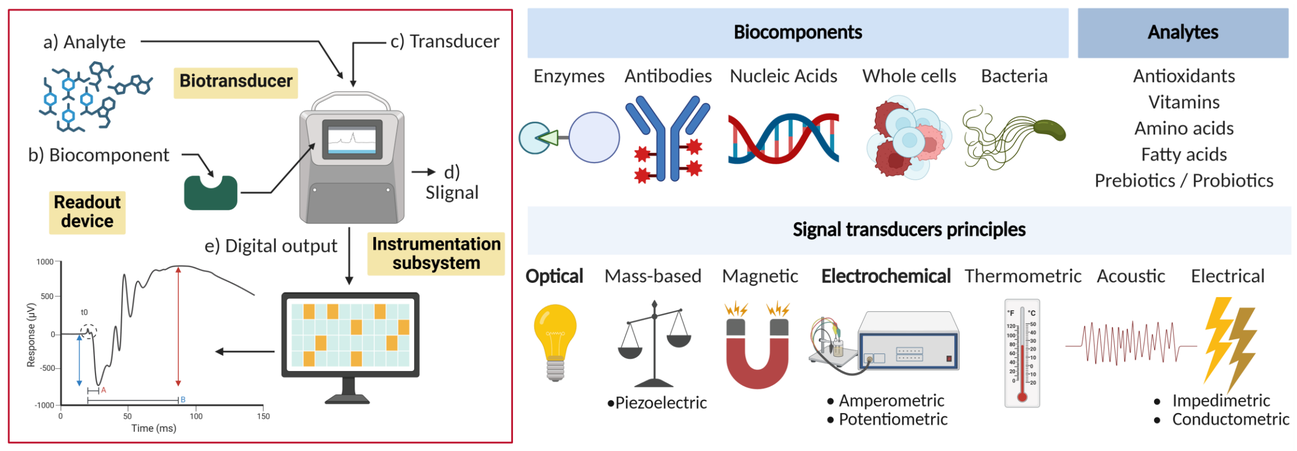

Figure 3: Overview of the architecture principles of biosensing systems for FDs.

BSs currently offer **high accuracy** by incorporating **nanomaterials (NMs), e.g., Au or Ag nanoparticles, carbon nanotubes, graphene,** and **polymers (Figure 4)**. Yet challenges remain, such as **cost, lengthy experimental times, and toxicity.** One promising approach to overcoming these limitations is the use of **electronic tongues,** which are analytical systems that consist of arrays of chemical sensors **with low selectivity** and **cross-sensitivity, coupled** with **multivariate data analysis.** When connected to BS elements, they form **bioelectronic tongues** that use **advanced algorithms** to quickly and thoroughly evaluate the **flavor profiles, BCs, and quality attributes of FD.**

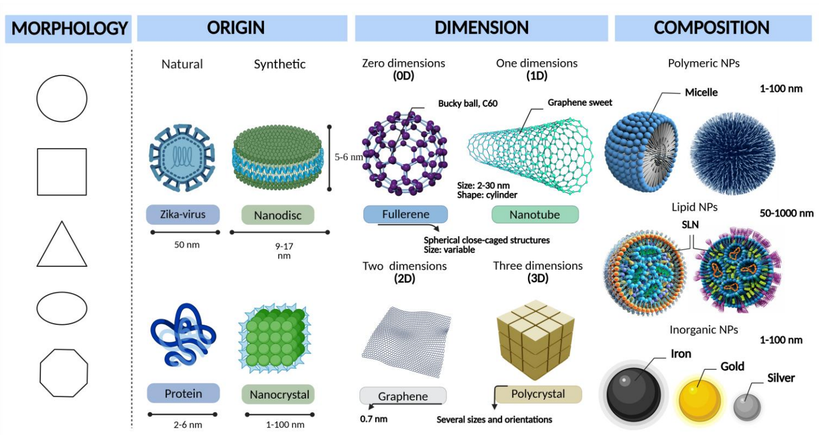

Figure 4: Characteristics and types of nanomaterials.

FUTURE TRENDS AND RESEARCH DIRECTIONS

Biosensing trends fit into the following categorizations:

- **point-of-care molecular diagnostics;**
- **noninvasive and implantable systems;**
- **lab-on-a-chip technologies;**
- **wearable sensors;**
- **health monitoring;**
- **artificial intelligence (AI);**
- **machine learning (ML).**

The integration of these tools with **NMs** and **functional nucleic acids** has resulted in reduced **testing costs** and **times, increased sensitivity** and **specificity,** and **enhanced portability.** Despite these advances, the field still faces significant challenges, including the need for **more robust, versatile, and cost-effective solutions.**

Current discussions are focus on **optimizing** these techniques for practical applications and integrating emerging methods, like **CRISPR-based diagnostics.**

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