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Review

Yeast Biosensors for Detection of Environmental Pollutants: Current State and Limitations

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Yeast biosensors have become suitable tools for the screening and detection of environmental pollutants because of their various advantages compared to other sensing technologies. On the other hand, many limitations remain with regard to their optimal performance and applicability in several contexts, such as low-concentration samples and on-site testing. This review summarizes the current state of yeast biosensors, with special focus on screening and assessment of environmental contaminants, discusses both pros and cons, and suggests steps towards their further development and effective use in the environmental assessment.

Yeast Biosensing Principle and Applicability Domains

Numerous chemical compounds that may represent a threat in terms of both environmental risk and human health are released into the environment, contaminating vital resources including water, air, and soil. Natural populations of many species have been reported to be affected by environmental pollutants, not only in industrial areas [1–3] but also in remote ecosystems once considered as pristine [4,5]. Given the widespread use of chemicals in products and industrial processes, exposure of both humans and wild biota may result in physiological alterations and adverse effects including developmental toxicity, reduced fertility, and neurological disorders [6–8]. In addition, diverse human activities such as farming, industry, untreated waste waters, and recreation abnormally increase the concentrations of degradable organic compounds in waters, which are then metabolized by aquatic microorganisms, resulting in a dramatic depletion of oxygen levels and posing a threat for other living organisms in the ecosystem. The rapid detection of both contaminants and oxygen shortage is required to prevent health and environmental risks.

Scientists have developed various biological tools for the rapid screening of a large number of chemicals in the environment to promptly detect those that could constitute a hazard (Box 1) [9–11]. Among the available tools, *in vitro* models such as genetically modified yeast have become particularly suitable for use in biosensors because of several advantages, including time- and cost-effectiveness, sensitivity, reproducibility, and scalability to high-throughput formats. Unlike other *in vitro* sensors not based on whole-cell systems, yeast biosensors allow specific detection of compounds in their bioavailable forms and, given the less-demanding growth conditions of yeasts, they are potentially adaptable to portable devices for in-field testing [12].

Yeast biosensors are constructed by coupling yeast cells sensitive to environmental compounds with electronic transducers. Yeast can be naturally sensitive to pollutants, for example,

Trends

Yeast biosensors are *in vitro* tools used routinely for environmental monitoring.

Current yeast biosensors are still far from optimal performance.

Recent improvements in yeast biosensing include increase of sensitivity, adaptation to high-throughput formats, and immobilization of cells into/onto supporting matrices that simplify procedures and enhance cell durability.

Further improvements such as portability and combination with online applications are necessary to make yeast biosensors accessible to in-field monitoring.

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Box 1. Strategies Used for Detection of Environmental Pollutants

To help to contextualize the use of yeast biosensors for environmental monitoring purposes, Table I summarizes the advantages and disadvantages of other approaches commonly used for the detection of environmental pollutants. Given that yeasts are unicellular eukaryotic organisms, yeast-based methods combine the advantages of prokaryotic assays with being more representative of higher organisms.

Table I. Methods Used for Detection of Environmental Pollutants

Detection Method	Advantages	Disadvantages
Chemical analysis	Identification of specific compounds Low limits of detection No ethical issues	No information on biological activity Sample pre-cleaning usually needed Cost of analytical devices
Enzyme-based	Information on specific enzyme–substrate interaction Low limits of detection Results in minutes or hours Scalable to high-throughput formats No ethical issues	Low relevance for the cell or the whole-organism
Bacteria-based	Easy and inexpensive Results in hours or days Scalable to high-throughput formats Adaptable to portable devices	Low relevance for eukaryotic organisms Possible ethical issues of using genetic modifications Requires special equipment for sterile work
Yeast-based	Eukaryotic organism Easy and inexpensive Transfection with fully functioning vertebrate genes possible Results in hours or days Scalable to high-throughput formats Adaptable to portable devices	Unicellular organism Possible ethical issues of using genetic modifications Requires special equipment for sterile work
Algae-based	Easy and inexpensive Results in hours or days Scalable to high-throughput formats	Specific light requirements Nutrients in complex samples may mask effects of toxicants
Vertebrate cell *in vitro*	Specific signaling pathways can be studied separately without interference of whole-organism responses Numerous cell types available Results in hours or days Lower ethical issues compared to *in vivo* assays 3D cell cultures can mimic the responses of tissue explants	Not possible to replicate precise cellular conditions of a vertebrate organism Possible ethical issues of using genetic modifications Requires special equipment for sterile work Laborious and expensive compared to bacteria and yeast
Tissue explants	More comprehensive and complex functional information on pollutant effects than unicellular assays Possibility to use waste tissues from butchers	Ethical issues (if animals raised only for testing purposes) Laborious Duration of experiments Deterioration of tissues after a relatively short time Do not reflect systemic factors
Animals *in vivo*	Invertebrate and vertebrate models are available Reflect systemic factors The most accurate sensing system for quantifying animal-threat agents The most accurate sensing system for translation of results to human	Ethical issues Time and costs of raising and maintaining animals Duration of experiments Not suitable for use in biosensors High variability between animal species

Glossary

Amperometry: detection of analytes based on differences in the electric current after applying a potential.
Biodegradable organic compounds: organic contaminants relevant for waters, where their biodegradation by bacteria consumes oxygen. The amount of these substances is usually quantified as BOD.
Colorimetry: detection of analytes based on a chemical reaction that induces a change of color in the medium.
Cytotoxins: substances that have deleterious effects on cell function and viability.
Endocrine-disrupting compounds (EDCs): exogenous substances or mixtures that alter function(s) of the endocrine system and consequently cause adverse health effects in an intact organism, its progeny, or (sub) populations.
Fluorimetry: detection of analytes based on light emission. The light emission is triggered by light previously absorbed.
Genotoxins: chemical or other agent that directly or indirectly damages cellular DNA, resulting in mutations and consequent adverse outcomes (e.g., diseases including cancer).
Ligand: compound that interacts with a recognition biomolecule forming a complex that triggers a biological response.
Limit of detection (LoD): the lowest amount of substance that a given assay can significantly distinguish from controls (no presence of substance).
Luminometry: detection of analytes based on light emission. Unlike fluorescence, the light emission is induced by a chemical reaction and not by light.
Reporter gene: gene whose expression is easily detectable after linkage to the regulatory sequences of another gene of interest. It allows the assessment of gene expression related to that gene of interest. Reporter gene expression is typically measured as change of color, luminescence, or fluorescence signal.
Toxic metals: metals that can exert harmful effects at the levels that are relevant for polluted environment. These metals can be from the groups called biologically essential (e.g., Cu, Zn) or non-essential (e.g., Cd, Pb).