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Overview of commercially available bioassays for assessing chemical toxicity in aqueous samples

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ABSTRACT

Environmental monitoring is fast developing with continual evolution of novel advancements for assessing chemical toxicity. This review provides an overview of the commercially available test kits and technologies for evaluating chemical toxicity using laboratory-based tests, portable devices and on-line biomonitors. The wide application to organisms along with the possible measured endpoints offers a great variety of combinations that can be applied for measurements of acute and chronic toxicity. We also review advanced software for studying toxic effects on the behavior and locomotor activities of the organisms along with statistical packages for evaluating the results. Finally, this review concludes with a recommendation to the user to select a battery of assays and biomonitors for a complete chemical toxicity assessment of an aqueous source considering:

- the needs and the facilities of the research institute, industry, or utilities; and,
- selecting species from different trophic levels.

Contents

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1. Introduction

Environmental protection has become a worldwide issue of concern. Governments have established legislation for controlling industrial and wastewater effluents being discharged into the environment and for monitoring water quality [1,2].

A potential contamination can be caused from several factors, including environmental degradation, intentional contamination, destruction of natural resources and pathogens or biotoxins, which are potentially resistant to chlorine disinfection [3–5]. Considering the large number of new compounds entering the market and the environment every year, the need for suitable analytical techniques along with toxicity monitoring to assess the interaction effects of mixtures on the biota is very important [6]. Conventional laboratory methods are very accurate and reproducible within low limits of detection (LODs) but they are time consuming and expensive in performing target analysis and they require qualified personnel [1,7]. Furthermore, chemical analysis itself is not adequate to provide the required information for the ecological risk of contaminated waters [1,2,8]. Technological advancements in on-line, real-time and early warning toxicity biomonitors using live organisms have facilitated the continuous audit of water for protecting environmental biota and human health.

The design of techniques suitable for toxicity assessment of wastewater along with the implementation of basic ecotoxicity tests dates back to the 1940s [9]. The idea of using aquatic organisms for monitoring water quality was initially applied by Henderson et al. [10] and Jackson et al. [11]. They applied fish in flowing water or wastewater and measured the mortality or visually obvious stress signs in the fish.

Another system was implemented in Sweden in 1965 to help researchers to determine the source of toxic effects. They exposed fish to diluted waste from a cellulose plant and observed them occasionally during the day [12].

In the 1970s, biomonitors started being applied in Europe for monitoring river-water quality [2]. Drinking-water quality should be assessed real time, continuously and at different places from the source. Early warning systems (EWSs) revolutionized the market by analyzing and interpreting results in real time. According to a US Environmental Protection Agency (EPA) research report [13], an EWS is defined as “an integrated system for monitoring, analyzing, interpreting and communicating monitoring data, which can be used to make decisions that are protective for public health and minimize unnecessary concern and inconvenience to the public”.

Subsequently, biomonitors have been developed, which are able to detect the toxicity of water samples usually by analyzing the behavior of living organisms. When the behavior changes significantly, an alarm is triggered. These systems are the last word in technology and are due to the important advances in digital image processing and signal analysis, and in the revolution in fast computers. The on-line biomonitoring systems commonly use bacteria (*V. fischeri*), aquatic invertebrates, algae and fish.

In the market, there are also laboratory-based bioassays for routine analysis of the toxicity of aqueous samples and/or ecotoxicity assessment of new chemicals, pharmaceuticals, pesticides and other industrial components possibly harmful to the environment. Furthermore, there are portable devices using live organisms for toxicity assessment at the point of interest in the field. Finally, there are also some commercially available software packages that can monitor the behavior of any species using your own camera and arena. Statistical packages are also in the market for processing the results according to standards (OECD or DIN EN ISO). However, there is also a broad market for monitoring physical and microbiological toxicity using advanced equipment in the laboratory and biosensors, which are not included in this review.

This is the first attempt to present a broad overview of the available options in the market for toxicity monitoring. Consequently, this review aims to offer a complete guide to devices and assays for assessing chemical toxicity using living organisms and cells commercially available to the scientific and industrial community. It includes:

(1) laboratory bioassays;
(2) portable devices;
(3) on-line and/or real-time biomonitors that can be installed at the point of interest;
(4) software packages for behavioral and locomotion studies; and,
(5) statistical packages for processing the results according to the legislation, along with the advantages and the limitations for each category (Section 9) and each test (Table 2).

2. Categories of organisms with their potential endpoints

Laboratory-based bioassays, portable devices and on-line biomonitors are toxicity-assessment options that have revolutionized the market (Table 1). These assays usually apply a species from a wide range of organisms, including microorganisms, mammalian cells, algae, plants, and invertebrates, and higher organisms, such as fish, by measuring a specific endpoint in their life cycle or the inhibition of a chemical reaction (e.g., using enzymes). We discuss briefly the applied endpoints of the main organism categories (Section 3). Then, we describe the commercially available laboratory-based assays (Section 4), portable devices (Section 5) and on-line biomonitors (Section 6) for each category of organism (Table 1). Table 2 gives a complete list, including the company that commercializes an assay or a device, the applied organism, the endpoint, advantages and limitations or requirements, and references.

3. Organism categories

3.1. Bacteria-based bioassays

The widest applied category of organisms in toxicity assessment comprises bacteria, which belong to the trophic level of decomposers, along with fungi, since they degrade dead organisms (plants and animals). Many devices and assays have been developed using several endpoints of the life-cycle of bacteria as indicators for the presence of toxic compounds, including mortality and growth inhibition (e.g., Rotoxkit). However there are also assays measuring.

(1) microbial enzyme activity, such as adenosine tri-phosphatases and dehydrogenases (e.g., Toxi-Chromotest Kit) [91];
(2) inhibition of respiration (e.g., PolyTox) [92]; and,