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Review

Bioassays as one of the Green Chemistry tools for assessing environmental quality: A review

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ABSTRACT

For centuries, mankind has contributed to irreversible environmental changes, but due to the modern science of recent decades, scientists are able to assess the scale of this impact. The introduction of laws and standards to ensure environmental cleanliness requires comprehensive environmental monitoring, which should also meet the requirements of Green Chemistry. The broad spectrum of Green Chemistry principle applications should also include all of the techniques and methods of pollutant analysis and environmental monitoring. The classical methods of chemical analyses do not always match the twelve principles of Green Chemistry, and they are often expensive and employ toxic and environmentally unfriendly solvents in large quantities. These solvents can generate hazardous and toxic waste while consuming large volumes of resources. Therefore, there is a need to develop reliable techniques that would not only meet the requirements of Green Analytical Chemistry, but they could also complement and sometimes provide an alternative to conventional classical analytical methods. These alternatives may be found in bioassays. Commercially available certified bioassays often come in the form of ready-to-use *toxkits*, and they are easy to use and relatively inexpensive in comparison with certain conventional analytical methods. The aim of this study is to provide evidence that bioassays can be a complementary alternative to classical methods of analysis and can fulfil Green Analytical Chemistry criteria. The test organisms discussed in this work include single-celled organisms, such as cell lines, fungi (yeast), and bacteria, and multicellular organisms, such as invertebrate and vertebrate animals and plants.

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1. Introduction

1.1. Sources and environmental fates of pollutants

The environment is a highly complex system that is split into biotic and abiotic parts, among which there is a continuous exchange of matter and energy. These processes should remain in balance, and this balance is called homeostasis. This sensitive balance may be disrupted by the release of various chemicals into the environment.

Virtually all human activities can cause environmental pollution, but some of them have important influences on the levels of anthropogenic impacts. Among these activities, the following different industrial branches can be considered: the petrochemical industry, the mining of precious metals and stones, tanneries, the lead battery industry, and industrial and/or municipal discharges. The pollution from other manifestations of human activity such as transportation, housekeeping, agriculture, sewage and municipal waste are not insignificant, either (Nadal et al., 2004; Mehlman, 1992; Kaldor et al., 1984; Cordy et al., 2011; Módenes et al., 2012; Bahadir et al., 2007; Rajaram and Das, 2008).

Environmental pollution does not respect geographic boundaries, and under favourable conditions, it may be transmitted over long distances and "travel" all over the biosphere (Oke, 2002; Walker et al., 1999; Hung et al., 2010). Pollutants may be transferred over long distances by different environmental components such as water and air (as well as particulate matter and aerosols) or by living organisms. Water and air act as a transport medium; however, transport by living organisms strongly depends on the migratory species in question (Lohmann et al., 2007).

Chemicals undergo a number of processes in the environment depending on their physicochemical properties. Hydrophilic substances remain dissolved in water, hydrophobic substances accumulate in soil or/and sediment and volatile compounds pollute the air. Chemicals may be partially bioaccumulated by living organisms (Zenker et al., 2014).

Fig. 1 shows the pathways through which xenobiotics move from the environment into the different levels of the food chain together with an indication of their bioaccumulation and biomagnification. Human beings make up the last link in the food chain, and we are particularly vulnerable to the adverse effects of accumulated xenobiotics.

1.2. Principles of Green Chemistry and Green Analytical Chemistry

To check the applicability of the analytical method, the method must be validated and optimized by determining parameters such as its accuracy, sensitivity, reproducibility, simplicity, cost effectiveness, flexibility and speed. However, none of these parameters helps to reduce the environmental burden of any specific method (Armenta et al., 2008).

At this point, it is not only "dry" validation parameters that are important but also the underlying principles, rules or guidelines are important as well. Compliance with these principles would help to reduce the burden of chemical operations on the environment, and using natural resources in a responsible and sustainable manner should be considered.

The Green Chemistry concept emerged in the 1990s and was aimed at reducing pollution by using so-called green solvents. Planning chemical processes to obtain a final product that would use the same amount of input materials (atom economy and catalysis) is essential to the Green Chemistry approach. In the late 1990s, the Green Chemistry idea began to expand slowly in Europe and across the ocean in the United States, and its first concerns were chemical synthesis and chemical engineering. In the United States, the Environmental Protection Agency played a significant role in the introduction of new "green" ideas (Anastas and Kirchhoff, 2002).

In 1998, Anastas and Warner proposed a set of twelve Green Chemistry principles that would serve as guidelines, and these guidelines would be focused on reducing the waste that was generated during chemical processes, using non-toxic solvents, applying catalysts (when possible), and designing chemical processes in accordance with the principle of atom economy (Anastas and Warner, 1998).

Over time, the concepts and principles of Green Chemistry came into effect at a smaller scale for laboratory practice. In the Handbook of Green Analytical Chemistry, de la Guardia and Garrigues (2012) state the following five Green Analytical Chemistry strategies:

- remote sensing and direct measurement of untreated samples,
- replacement of toxic reagents,
- miniaturizations of procedures and instrumentation,
- automation, and
- on-line treatment of analytical wastes De la Guardia and Garrigues, 2012).

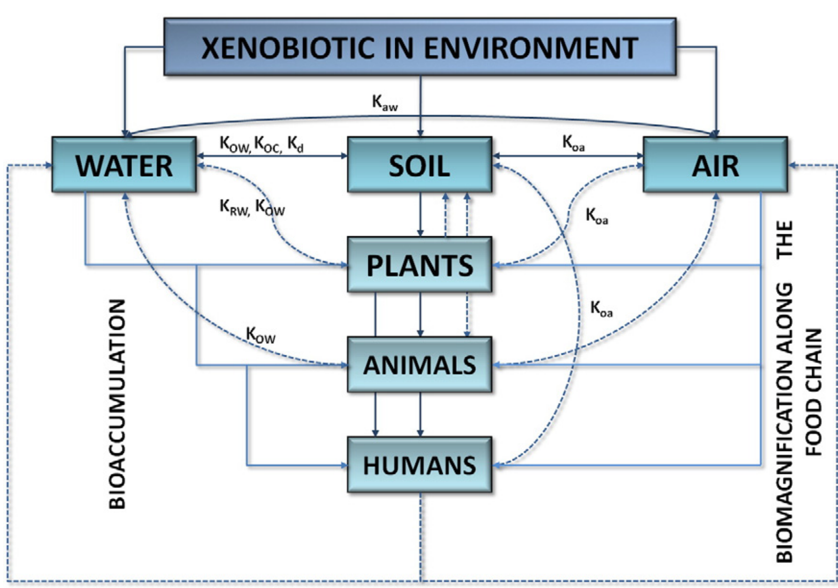

Fig. 1. Pathways of xenobiotic circulation in the environment (K_{aw} — air-water partition constant, K_{ow} — octanol-water partition coefficient, K_{oc} — organic carbon to water partition coefficient K_{RW} — root to water partition coefficient, K_{oa} — octanol-air partitions coefficient , K_d — solid/liquid partition coefficient , CR — plant/soil concentration ratio).