Biosensors and Bioelectronics 63 (2015) 533–545

Contents lists available at ScienceDirect

Biosensors and Bioelectronics

journal homepage: www.elsevier.com/locate/bios

Advances in arsenic biosensor development – A comprehensive review

Hardeep Kaur, Rabindra Kumar, J. Nagendra Babu, Sunil Mittal *

Centre for Environmental Science and Technology, Central University of Punjab, Bathinda, Punjab 151001, India

ARTICLE INFO

Article history:
Received 28 April 2014
Received in revised form
21 July 2014
Accepted 4 August 2014
Available online 7 August 2014

Keywords:
Biosensor
Arsenic toxicity
ars Operon
Aptamer
Recombinant whole cell
Reporter proteins

ABSTRACT

Biosensors are analytical devices having high sensitivity, portability, small sample requirement and ease of use for qualitative and quantitative monitoring of various analytes of human importance. Arsenic (As), owing to its widespread presence in nature and high toxicity to living creatures, requires frequent determination in water, soil, agricultural and food samples. The present review is an effort to highlight the various advancements made so far in the development of arsenic biosensors based either on recombinant whole cells or on certain arsenic-binding oligonucleotides or proteins. The role of futuristic approaches like surface plasmon resonance (SPR) and aptamer technology has also been discussed. The biomethods employed and their general mechanisms, advantages and limitations in relevance to arsenic biosensors developed so far are intended to be discussed in this review.

Contents

1. Introduction

Arsenic (symbol As, atomic number 33) is a widespread heavy metal which has influenced human history more than any other element or toxic compound. In terms of abundance, it ranks 20th in the earth's crust, 14th in sea water and 12th in the human system (Mandal and Suzuki, 2002). The average concentration of arsenic in the earth's crust is about 3 mg/kg and in sea water is about 1–2 μg/L (Cullen and Reimer, 1989). In nature, arsenic exists in both organic and inorganic forms, having different speciations such as arsenate [As(V)] and arsenite [As(III)]. Arsenic concentration has been reported to be higher than the permissible limits in drinking

* Corresponding author. Tel.: +91 9815620186.
E-mail addresses: hardeep_kaur007@rediffmail.com (H. Kaur), rabindrabiochem@gmail.com (R. Kumar), nagendra.rd@gmail.com (J.N. Babu), sunil.cevs@gmail.com (S. Mittal).

http://dx.doi.org/10.1016/j.bios.2014.08.003
0956-5663/

water, irrigation water, variety of foodstuffs like vegetables and cereals, animal food (fish, meat, milk), etc. in many parts of the world (Chowdhury et al., 2000; Williams et al., 2006; Zhu et al., 2008; Williams et al., 2009). Arsenic contamination in the environment has aroused considerable attention due to its harmful effects on plants and animals including humans. Arsenic has been associated with mutagenic and carcinogenic potential upon prolonged exposure (IARC, 2004; Stone, 2008; Zhu et al., 2008). Due to its abundance and toxicity, monitoring arsenic in water, soil and various foodstuffs used for human consumption is becoming important. A number of techniques have been developed for this purpose in the last 5 decades and Ma et al. (2014) have reviewed these techniques very well. Most of these methods are reliable and can be used for the measurement of extremely low concentrations of arsenic. The variously approved methods used in arsenic determination along with their detection limits are listed in Table 1. However, these methods suffer from some major disadvantages like heavy and expensive instrumentation, field applicability, requirement of highly skilled technical persons, chemical processing of sample, etc. So, there is utmost need for alternate, cost- and time-efficient technologies for the real-time detection of arsenic.

Sensors are one of the alternatives, comprising two parts, namely the recognition unit and the signal transducer. The recognition unit may comprise a biocomponent or a chemical receptor. In the case of arsenic, few chemosensors for naturally occurring arsenate (Lohar et al., 2013; Sahana et al., 2013) and arsenite ions (Ezeh and Harrop, 2012) have been reported (Table 1). The major hurdles in designing a chemosensor for arsenic species are the control of selectivity particularly over phosphate, sensitivity, strong interference of other ions and the high solvation energies of anions (Dietrich, 1993; Beer and Gale, 2001; Ezeh and Harrop, 2012; Du et al., 2014). So, biosensors have earned a special niche as analytical devices and offer services in environmental monitoring (Baeumner, 2003), food safety (Mello and Kubota, 2002) and clinical diagnosis (Wang, 1999). Biosensors have the advantage of sensitivity, specificity, simplicity, low manufacturing cost, better limit of detection, fast response time, ease of use, portability, and ability to furnish continuous real-time signals. They also circumvent the need for any sample pretreatment and expert handling. Also, the extent of bioavaliable toxicity which could not be detected by conventional analytical methods can be measured by biosensors as the biocomponents used in the system are part of the living world.

Only a limited number of papers have been published in this field. A search using the PubMed central engine and Scopus database using the words “arsenic biosensors” shows 60 and 147 research publications, out of which only 50 deal with arsenic biosensors. The current review focuses on the general mechanism of biosensor working and detailed account of various types of arsenic biosensors developed in the past. The present review is an effort to highlight the various advancements so far in the development of arsenic biosensors. The study has revealed various advantages and limitations associated with recombinant bacterial, DNA- and protein-based arsenic biosensors.

2. Biosensors: a convenient detection platform

A biosensor is an analytical device that presents a synergistic combination of biotechnology and microelectronics (Singh et al., 2008). Biosensors mainly comprise three main components: a biocomponent (enzyme, whole cell, antibody, DNA, etc.), a transducer (electrochemical, optical, or thermal) and an amplification unit. Biosensors could be developed for any molecule, relevant to xenobiotics, human health or environmental protection.

Table 1
Analytical methods used for determination of arsenic with their detection limits.

Analytical technique	Analytical tools	Detection limit	Disadvantages	Reference
Spectroscopy	UV–vis spectroscopy	1.0 μg/L	Tedious sample preparation, sample preparation prone to false positive and false negative readings, significant interference of other ions like Pb, Ni, S, P, etc.	Tahir et al. (2008)
	Electrothermal Atomic Absorption Spectroscopy (ETAAS)	0.02 μg/L	Strong interference and costly matrix modifiers	Anawar (2012)
	Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP–OES/AES)	0.05 μg/L	Expensive analysis	Chen et al. (2009)
	Inductively Coupled Plasma-Mass Spectrometry (ICP–MS)	0.4 ng/L	Expensive analysis and requires trained manpower, ArCl polyatomic species interference	Petursdottir et al. (2012)
	Gas Chromatography–Mass Spectrometry (GC–MS)	5.8 ng/L	Difficult sample preparation	Richter et al. (2012)
Electrochemical voltammetry	Anodic Stripping Voltammetry (ASV)	0.8 ng/L	Expensive analysis, Cu interference, tedious analysis and requires trained manpower	Gao et al. (2013)
	Cathodic Stripping Voltammetry (CSV)	37.5 ng/L	Expensive analysis, Cu interference, tedious analysis and requires trained manpower	Gibbon-Walsh et al. (2010)
	Chronopotentiometry	7.5 ng/L	Tedious analysis and requires trained manpower	Salaun et al. (2012)
Chemical Sensors	Thiol compound based SPR sensor	3.0 ng/L	Non-specific sensing and significant redox interference	Forzani et al. (2007)
	Dosimetric Fluorescent probe	0.24 μg/L	Strong interference by Cu^{2+} and Co^{2+} ions and analysis only in Non-aqueous media	Ezeh and Harrop (2012)
	Dosimetric Fluorescent probe-ArsenoFluors	0.14 μg/L	Analysis only in Non-aqueous media	Ezeh and Harrop (2013)
	Antipyrine Based Schiff Base	225 μg/L	Poor detection limit and pH dependent fluorescence	Lohar et al. (2013)
	Ag@Fe_3O_4 SERS sensor	10 μg/L	Non-specific sensing	Du et al. (2014)