Arsenic in Plants

Uptake, Consequences and Remediation Techniques

Edited by:
Prabhat Kumar Srivastava • Rachana Singh
Parul Parihar • Sheo Mohan Prasad

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Preface

Arsenic contamination in agricultural lands has become a global problem extending from Middle-East countries, South Asian countries including Afghanistan and Pakistan, India, Bangladesh, South-East Asian countries, China, Japan, Canada, USA, Mexico, Brazil, Argentina, Chile, New Zealand to European and African countries. This metalloid severely affects the plant as well as the human system by interrupting important physiological and molecular processes. The food chain is infiltrated by arsenic through arsenic-loaded groundwater and industrial and municipal wastewater contaminated with arsenic used for irrigation purposes. Arsenic also penetrates the food chain through the usage of fertilizers and herbicides (arsenicals) in agricultural fields. Arsenic severely intoxicates plants via various physiological and biochemical anomalies and reduces their growth and development. Toxicity symptoms range from biomass reduction to morphological impairments leading to the loss in fruit and grain yield that culminates into the complete death of the plants. Severe toxic effects of arsenic change the concentration, accumulation, and translocation of nutrient elements in plants, inhibit seed germination, and increase arsenic levels in the edible parts of vegetables.

This book gives an overview of arsenic, prominently covers the occurrence of arsenic in our environment, usage of arsenicals in crop fields, its chemistry, speciation, its transportation and metabolism in plants, phytotoxicity, i.e. impact on plant metabolism, alteration in different plant groups, from plants' overall structure, their physiology up to the changes at their ultrastructural level; and mechanisms involved therein and interaction/interruption with phytohormones and metabolic processes and future perspectives. The book covers the morphological, anatomical, and other quantitative and qualitative traits of plants including their physiological, biochemical, and molecular responses under arsenic stress. The impact of exogenous phytohormones and growth-regulating substances and mineral nutrients has been covered. It discusses *-omics* approaches, i.e. regulation at genomic, transcriptomic, proteomic, ionomic, and metabolomic levels adapted by plants to combat this stress condition and the models used to explain these adaptations.

This book brings forth ideas being explored by scientists and environmentalists to overcome this menace. This book emphasizes the differences in the mechanism of tolerance in hyper-accumulator and non-accumulator plants. It discusses the management of arsenic contamination in the soil-plant continuum, major arsenic remediation techniques including the removal of arsenic from soil and water through physical and biological methods.

Thus, this book is a comprehensive compilation of studies to date and is an endeavor to bridge the gap between the research from the past to the current time. This book will serve as a reference book for environmentalists, toxicologists, and risk assessors. The compilation of various studies in the form of an edited book enriches the existing knowledge about arsenic pollution and opens newer avenues to be exercised. The students and scholars would find many studies, researches, reviews of literature, views, and opinions in one book.

This book is the result of an arduous effort of many scholars working in different parts of the world along with all four editors. All the editors thankfully acknowledge their contributions. All editors also gratefully acknowledge the team at JohnWiley & Sons Ltd. that made possible the proposed book in its present form. We hope that this book will remain relevant for the upcoming many years for the students of environmental sciences, stress physiology, agronomy, life sciences, and crop sciences at the university level.

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1

An Introduction to Arsenic: Sources, Occurrence, and Speciation

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1.1 Introduction

Naturally, arsenic is present in rocks and water in the environment, and its concentration depends on geological and anthropogenic activities. Generally, the concentrations of arsenic in noncontaminated soils are usually less than 10 mg kg^{-1}. Arsenic (As) contamination has become a worldwide problem due to its toxicity and increasing contamination of soil, water, and crops around the world. It occurs as a result of geological processes and anthropogenic activities. Arsenic is a toxic metal that occurs by a natural and anthropogenic process such as the burning of fossil fuels, mining, and uses of agrochemicals (Mandal and Suzuki 2002; Bissen and Frimmel 2003). Excess arsenic in water and soil accumulates in plants and leads to food chain contamination. Arsenic causes toxic effects in plants and carcinogenic effects in human beings through water, soil, and food contamination (Zhao et al. 2010; Naujokas et al. 2013). Litter et al. (2010) reported that regular arsenic consumption through food and water causes arsenicosis, affects the central nervous system detrimentally, and causes hyperkeratosis, hepatic damage, skin cancer, hair fall, etc. Chakraborty et al. (2018) investigated the contamination of arsenic in groundwater and food materials in different regions of the Ganga River Basin (GRB), which includes Nepal, Bangladesh, and Tibet, where arsenic concentration was above the permissible limit of the World Health Organization's (WHO) standards. Anderson and Bruand (1991) reported the position of arsenic in the Group 15 of the periodic table, and it exists in the environment with the combination of oxygen, chlorine, and sulfur. Saeki et al. (2000) reported that arsenic has long been toxic and teratogenic (risk for a birth defect in a baby). In soil, dust, rocks, and air, arsenic is present in small quantities. In many industrial goods and processes, arsenic is used. Therefore, through waste and environmental pollution, arsenic becomes a major contaminant (Berg et al. 2001; Reboredo et al. 2019). The mobilization and occurrence of

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heavy metals in the environment include various procedures such as soil weathering, rock and coal, biological processes, volcanic processes, etc. Similarly, high amount of urban waste, burning of fossil fuels, mining, use of fertilizers, biocides, sewage sludge, seed desiccants, alloys, and anthropogenic activities account for the widespread dispersion of arsenic (Smedley and Kinniburgh 2002). However, this causes adverse effects such as atmospheric accumulation, especially in crops, such as increased cancer risk, teratogenicity, and mutagenicity (Farid et al. 2003). Due to high-arsenic concentrations, a cereal yield decrease of about 20% was observed. The potential to accumulate arsenic and its relative toxicity increase the threat to the ecosystem. Reducing As and other heavy metal contamination in crops, with particular emphasis on horticultural products, has been one of the key objectives of the research over the past decades (Wilson et al. 2014; Mancinelli et al. 2019). Due to overexploitation of water, more arsenic may be released into the aquifers as arsenopyrite minerals oxidized by exposure to oxygen-rich water. Therefore, due to oxidation of arsenic-containing rocks and release, more arsenic concentration is reported in the groundwater from Bangladesh (Mandal et al. 1996; Nickson et al. 1998). Chen et al. (1992) reported that arsenic is known as one of the most significant environmental contaminants due to its toxic effects on human health. Arsenic toxicity is due to the replacement of phosphate by arsenic (+5), the protein thiol groups' affinity of arsenic (+3), and the cross-linking of protein–DNA and DNA–DNA. Arsenic contamination is a regular occurrence in many countries due to its pervasiveness in the environment, and millions of people have been continuously exposed to arsenic through geological contamination of potable water (International Agency for Research on Cancer 2004). Arsenic contamination in marine habitats is primarily due to the indiscriminate disposal of effluents containing high arsenic from household and industrial discharge (Huysmans and Frankenberger 1990; Filali et al. 2000). Aquatic plants growing in contaminated water may accumulate arsenic, causing a health risk to animals and humans through the food chain. The concentration of arsenic in seafood and fish can be high due to accumulation and biomagnification (International Agency for Research on Cancer 2004). Arsenic is a notorious neurotoxin that affects the nervous system in the exposed species. Arsenic can be tolerated to a certain extent in humans because it is eliminated from the body through urine, stool, skin, hair, nails, and breathing. Arsenic is accumulated in tissues as a result of excessive exposure affecting cellular functions and metabolism (Mukhopadhyay et al. 2002). Aside from toxicity, arsenic's inhibitory effects are influenced by background concentrations and the type of organism (Birnboim and Doly 1979). In plant and animal tissues, it can be actively sequestered. Arsenicals have been used medicinally for a long time and were among the first chemotherapeutic agents to be used in the treatment of infectious diseases such as syphilis and trypanosomiasis. Salvarsan, an arsenic-based drug, was introduced by Paul Ehrlich as a "magic bullet" in syphilis treatment (Waxman and Anderson 2001).

1.2 Status of Arsenic Contamination Around the World

The geogenic and anthropogenic degradation of persistent toxic substances poses significant threats to the environment (Nordstrom 2002; Hoang et al. 2010). Arsenic contamination in groundwater is reported in various countries, including Argentina, Bangladesh, Chile,