# Chapter 1
# Phytoremediation and Biofortification: Two Sides of One Coin

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**Abstract** Phytoremediation is a biotechnology to clean the contaminated sites by toxic elements (e.g. Cd, Cu, Zn, As, Se, Fe) via plant breeding, plant extracting, and plant volatilizing. Biofortification is an agricultural process that increases the uptake and accumulation of trace mineral nutrients (Fe, I, Cu, Zn, Mn, Co, Cr, Se, Mo, F, Sn, Si, and V) in staple crops through plant breeding, genetic engineering, or manipulation of agricultural practices. However, these two biotechnologies could be connected closely just like two sides of one coin. Actually, plant materials produced from phytoremediation could be used as supplementary sources for foods, animal feedstuff for fortified meat, or green fertilizers for fortified agricultural products. Furthermore, the transgenic technology will substantially increase their accumulation of micronutrient elements in plants or staple crops, which could be used for phytoremediation and biofortification, respectively. Future work will be needed to phytoremediate and biofortify multiple micronutrients, and then integrate both.

**Keywords** Phytoremediation · Biofortification · Integration · Micronutrition

Phytoremediation is the use of plants and their associated microbes for environmental cleanup, which has gained public acceptance in the past 15 years as a cost-

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competitive and nondestructive green technology. Phytoremediation provides an alternative for engineering-based physical and chemical remediation methods. Meanwhile, biofortification is an agricultural process that increases the uptake and accumulation of mineral nutrients in agricultural products through plant breeding, genetic engineering, or manipulation of agricultural practices. The development and uses of biofortified agricultural products have recently become a promising strategy to increase the dietary nutrient intake for humans. Indeed, both phytoremediation and biofortification technologies are based on the phytoextraction process that involves plant uptake, accumulation, and transformation of nutrient elements from soil (Zhao and McGrath 2009). Although phytoremediation and biofortification have different goals, these two processes sometimes can be closely connected. This chapter discusses the applicability of different mineral nutrients (e.g., selenium, iron, and zinc) and toxic metals (such as cadmium and copper) in several suitable plant species. Both phytoextraction and biofortification have focused on enhancing the efficiency of elemental uptake and accumulation in plants. There is a strong need for better understanding the processes that affect element bioavailability, rhizosphere processes, plant uptake, translocation, distribution, and transformation in soil–plant systems. All these processes are essentially important for successful implementation of phytoremediation and biofortification strategies. In the future, phytoremediation of contaminated agricultural water and soil and biofortification of nutritionally important trace elements shall be integrated to meet the different goals of the phytotechnologies. Indeed, in some cases, phytoremediation and biofortification processes are the two sides of one coin. In this chapter, we will address this emerging concept and discuss some of the environmental and human health concerns associated with the processes of phytoremediation and biofortification.

## 1.1 Essential Micronutrient Elements for Humans

There are 20 mineral elements that are essential for human health (Vander et al. 2001), including 7 major mineral elements (Ca, P, K, S, Na, Cl, and Mg) and 13 trace elements (Fe, I, Cu, Zn, Mn, Co, Cr, Se, Mo, F, Sn, Si, and V). These elements cannot be synthesized by the body and must be continuously supplied from foods. The main physiological functions and recommended nutritional intake (RNI) and upper limit (UL) of the essential mineral trace elements are shown in Table 1.1. Because concentrations of these essential elements in soil vary substantially, plant-derived foods contain different contents of those 13 essential trace elements. When foods are lacking in one of the essential mineral nutrients in a region, local residents will suffer from malnutrition which will result in health problems. The international micronutrient organization reported that malnutrition or so-called “hidden hungry” affected one in three people worldwide. For example, approximately 2/3 Chinese dietary selenium intake is about 40 microgram per day, which is significantly lower than the recommended selenium intake value of 55 μg per day according to the World Health Organization (WHO); about one half of the Chinese population has dietary iron

**Table 1.1** Main functions, RNI, and UL of 13 mineral trace elements essential for humans

| Elements | Main functions | RNI [a] (mg/ day) | UL [a] (mg/ day) |
|---|---|---|---|
| Iron | a. Important part of hemoglobin<br>b. Participates in the nitrogen body exchange and breathing process<br>c. Catalyzes $\beta$, carotene into vitamin A<br>d. Induces antibodies synthesis and enhances immunity | 15 | 50 |
| Iodine | a. An essential constituent of the thyroid hormones thyroxine<br>b. Promoting growth and development of humans | 0.15 | 1.0 |
| Zinc | a. Participates in the synthesis and degradation of carbohydrates, lipids, proteins, and nucleic acids.<br>b. Promotes children's intellectual development<br>c. Accelerates teenagers' growth<br>d. Affects the palate and appetite<br>e. Affects male fertility | 15 | 45 |
| Selenium | a. Enhances immunity<br>b. Anti-aging<br>c. Inhibit cancer<br>d. Protects the heart<br>e. Antagonist heavy metal | 0.05 | 0.4 |
| Copper | a. An important component of proteins and enzymes<br>b. Closely related to human body hematopoiesis<br>c. Affects antioxidant ability of body | 2.0 | 8.0 |
| Molybdenum | a. An important component of xanthine oxidase and aldehydes oxidase<br>b. Takes part in the electronic transmission of cell<br>c. Restrains the breeding of virus in cell | 60 | 280 |
| Chromium | a. Promotes protein metabolism and body growth<br>b. Influences lipid metabolism<br>c. An important part of glucose tolerance factor | 0.05 | 0.5 |
| Silicon | a. Plays an essential role in the development of bone<br>b. Participates in the metabolism of the polysaccharide | – | – |
| Nickel | a. Is a component of hydrogenated enzyme<br>b. Promotes the formation of insulin<br>c. Lowers blood glucose | 0.1 | 0.6 |
| Cobalt | a. Is a component of Vitamin B12<br>b. Participates in hemoglobin synthesis | – | – |
| Vanadium | a. Maintains normal metabolism of fat<br>b. Is a constituent of nucleic acid<br>c. Promotes the growth of bones and teeth | 0.03 | 10 |
| Fluoride | a. Plays an important part in the growth of bones and teeth | 1.5 | 3.0 |
| Tin | a. Has a function in the tertiary structure of proteins or other biosubstances<br>b. Is used as catalyst for polymerization, transesterification, and olefin condensation reactions | 15 | – |

*Note* [a] Means male adult (ages: 18–50) intake of about 3 microgram per day, which is also lower than the recommended value of 15 microgram by WHO. Globally, there are 80 % children with zinc deficiency for their rapid growth. To increase dietary intake of essential micronutrient elements, biofortification was proposed and regarded as an economic and promising approach for developing countries. Scientists worldwide have published many research papers in the past two decades (http://apps.webofknowledge.com). These studies help with better understanding on the biofortification technology, potential health effects, and food safety regulations.

While the 13 trace elements are considered essential for human health, they can also become environmental pollutants due to their excessive levels in soils. To protect the environment and to minimize local environmental risk, the polluted sites need to be remediated. In the past decades, phytoremediation was introduced as a successful green biotechnology (Terry and Bañuelos 2000). However, one of the difficulties that we are facing in phytoremediation management is to deal with the large volume of polluted plant waste materials harvested from phytoremediation sites. Different management options have been discussed by researchers regarding the disposal of plant waste materials, including landfill and incineration. But, none of them are sustainable or environmental-friendly. Generally, the phytoremediation plant waste materials contained high concentrations of the pollutant trace elements, and were potentially toxic to humans and wildlifes via direct consumption exposure. One may hypothesize that those polluted plant materials can be used to produce agricultural crops that are enriched with the essential micronutrients. For example, selenium, zinc, and iron-laden plant materials can be used as valuable sources of nutrients in agricultural production systems. However, the plant materials should not contain high levels of other toxic heavy metals, such as cadmium, arsenic, and mercury. All these will be further discussed in this book.

## 1.2 Can Phytoremediation Plants Become Sources of Human Micronutrient Elements?

Some plants are able to concentrate large amounts of specific trace elements in their leaves or stems (Robinson Brett et al. 2009; Schwitzguebel et al. 2009). This natural process has been applied to remediate the metal-polluted soil and water. As a result, the plant materials produced from phytoremediation can be further used as supplementary sources of mineral nutrients to produce food or feedstuff or functional biofortified agricultural products. Micronutrient-laden plant materials can be used as green fertilizers to increase concentrations and bioavailability of micronutrient trace elements in agricultural soils, or used as animal feed to increase dietary intake of micronutrients by animals which further enhances the accumulation of micronutrients in animal originated food products. Therefore, to integrate phytoremediation and biofortification processes, the chemical composition of phytoremediation plant materials is of utmost concern. The contents of toxic metals accumulated in plant materials will essentially jeopardize the use of phytoremediation plant materials for biofortification. It is critically important to screen and select the right plant species and acceptable phytoremediation field sites to implement the integration of phytoremediation and biofortification strategies. In general, there are two very basic requirements to meet this goal: first, the selected plants should be edible; second, the edible part of the plant should accumulate more micronutrients, but very less toxic trace elements. For example, Indian mustard was used for phytoremediation of selenium-contaminated water and soil in agricultural lands of the San Joaquin Valley, Central California. The selenium-laden mustard plant materials have also been used as biofortified selenium supplement for animals and humans (Bañuelos et al. 2007, 2009, 2011; Turan and Bringue 2007; Hamlin and Barker 2008). Additionally, researchers have also applied genetic engineering technology to substantially increase plant accumulation of micronutrient elements (Bañuelos and Lin 2009; Manohar et al. 2011).

Phytoremediation commonly selects the plant species that accumulate more pollutants in shoots, and focuses on the phytoextraction or remediation efficiency, while biofortification focuses on increasing micronutrient contents in crops. If the biofortified materials are directly utilized as food supplements to increase human mineral dietary intake, the phytoremediation plant should be edible.

## 1.3 Managing Toxic Metals in Plant Tissues

When phytoremediation plant materials can be used as sources of nutrient trace elements for biofortification, the connection between phytoremediation and biofortification could be still problematic. Since the contaminated sites are often contaminated with multi-pollutants, including toxic cadmium, mercury, and arsenic, the use of phytoremediation plant materials for biofortification becomes more difficult.

Previous studies indicated that the manipulation of soil physicochemical properties, including soil pH, total organic carbon (TOC), fulvic acid (such as citrate), and chelate can change the uptake and accumulation of various nutrient elements by plants. Some organic acids produced in the rhizosphere may play important roles in determining bioavailability of mineral trace elements in the soil and affect nutrient uptake efficiency via roots.

## 1.4 Future Research Needs

Recent studies on phytoextraction have been partially focused on the development of biofortified agricultural products. New efforts have been made to integrate the phytoremediation with biofortification processes. There are still many scientific questions that have not been answered. The future research shall investigate the feasibility of biofortification of multiple micronutrients, such as increasing accumulation of both selenium and zinc in crops or vegetables (Srivastava et al. 2009; Zhu et al. 2009) For example, *Thlaspi caerulescens* is zinc hyperaccumulator and *Stanleya pinnata* is selenium hyperaccumulator. The application of these two plant materials as green manures in agricultural soils could significantly increase the total content and bioavailability of both zinc and selenium in the soil, and therefore, enhance the accumulation of zinc and selenium in the edible portion of crops.

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