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Selenorhizobacteria: As biofortification tool in sustainable agriculture

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ABSTRACT

Selenium biofortification in crops aims to either increase the accumulation of selenium in edible plants or to increase their bioavailability. It is one of the solutions for globally increasing hidden hunger for essential micronutrients. Plant growth promoting rhizobacteria are advantageous soil bacteria that inhabit plant roots and increase plant growth through various mechanisms in different ways. The motion of selenium across soil, crop and environment interfaces is thus of crucial importance for gain in human selenium status. This review gives an overview of microbial enhancement of selenium as beneficial element for plants, significance of selenium to human health, selenium response in soil crop system, selenium as plant protector against abiotic stresses and the possible approaches to enhancing selenium concentration through use of microorganisms (*selenorhizobacteria*) as biotechnological tools for increasing plant nutrition and quality.

1. Introduction

Biofortification is the process by which the nutritional quality of food crops is improved through agronomic practices, modern biotechnology and conventional plant breeding. Fortification is the practice of significantly increasing the content of an essential micronutrient, i.e. vitamins and trace minerals in a food. Microorganisms play an important role in the transformations and selenium availability, representing an interesting biotechnological alternative to selenium biofortification. Fertilization of crops with selenium may not only benefit plant productivity but may have the additional benefit of enhancing its nutritional value. Use of traditional agronomic selenium biofortification appears to have eminent potential for fight against hidden hunger (Haug et al., 2007).

Selenium is an essential element for humans and animals, has also been found to be beneficial to crops. Selenium offers plant growth increase and protect crops against certain biotic and abiotic stresses such as, drought, salinity, heavy metals, etc. labeling it as beneficial element. Because of the chemical analogy of Se and S, the biochemistry of these two elements are identical. Plants may take up both inorganic and organic selenium via active membrane transport while the role of simple diffusion is limited. Selenate is transported across the root cell membrane through sulfate permeases and channels, whereas selenite is transported via phosphate transport mechanisms (Oancea et al., 2014) and other ion channels as result of root metabolism. Variations in the activity of these transporters in different plant species may cause alterations in uptake of selenium (Zhang et al., 2003). Role of selenium in functioning is mainly resultant from its presence in the selenium containing amino acids such as, selenomethionine (SeMet) and selenocysteine (SeCys). The total selenium content of food sources, like chemical forms (speciation), is very important, as it affects the bioavailability and nutritional value of selenium (Kikkert et al., 2013). Beneficial effects of biofortification with micronutrients in crops, which include antioxidant properties that can stimulate plant growth and protect plants against different types of abiotic stress.

2. Selenium as beneficial element

Elements that enhance plant growth and may be essential to particular taxa but are not required by all plants are called beneficial elements. Selenium (Se), aluminum (Al), sodium (Na), cobalt (Co), silicon (Si) etc. are considered as beneficial elements for crops (Pilon-Smits et al., 2009). Essential elements are required to complete an organism's life cycle. These beneficial elements have been reported to develop resistance against abiotic stresses viz., drought, salinity, and nutrient deficiency or toxicity and biotic stresses such as pathogens. Better conception of the effects of selenium as a beneficial element is crucial to improve crop productivity and enhance plant nutritional value for a growing world population (Pilon-Smits et al., 2009). Most dietary Se is derived from crops (Yasin et al., 2015). Among higher plants, the major beneficial effects of selenium on growth have been seen in the selenium hyperaccumulator plants and selenium has been proposed to be essential for these species. Trace amounts of selenium also stimulated growth in a variety of non-hyperaccumulator sp. including ryegrass,

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lettuce, potato, etc. (White et al., 2009).

3. Significance of selenium to human health

Selenium is an essential trace element with fundamental importance to human health. Selenium is a significant micronutrient with antioxidant properties for human and animal (Jezek et al., 2012). Selenium is present in trace amounts in both organic and inorganic forms in soil and environment, which can be uptaken and translocate in various parts of plants (Kikkert et al., 2013). some organic forms viz., methylselenocysteine (MeSeCys) and selenocysteine (SeCys) appear to be very potent sources of dietary selenium, which are involved in major metabolic pathways, such as antioxidant defence and immune function (Rayman, 2012). Currently, 25 selenoproteins have been reported in human metabolism, corresponding to selenoproteins in which the selenium works as an enzymatic cofactor (Dodig et al., 2004). Selenium is an essential constituent of selenoproteins playing an important role in many biological functions with antioxidant properties, such as antioxidant defence, formation of thyroid hormones, DNA synthesis, fertility and reproduction, HIV treatment, free radical induced diseases and protection from toxic heavy metals (Fairweather-Tait et al., 2011). The predictable importance is due to the fact that this metalloid is a component of selenoenzymes such as glutathione peroxidase, thioredoxin reductases and proteins with unknown functions that are involved in maintaining the cell redox potential (Ramos et al., 2010), as well as other structural and metabolic functions in human body. Low intake of selenium in the diet can seriously affect human health by leading a number of diseases including heart diseases, hypothyroidism, reduced male fertility, weakened immune system and enhanced sensitivity to infections and cancers (Hatfield et al., 2014). Several studies have revealed the benefits of selenium compounds in the human diet like SeMet on the risk of breast, prostate, lung, bladder and liver cancers (Fairweather-Tait et al., 2011). Thus, increasing selenium concentration in food crops offers an effective approach to reduce the selenium deficiency problem in humans and animals.

Favourable range of dietary selenium intake for humans is relatively narrow and has been conferred as the Recommended Dietary Allowances (RDAs) indicates that 55 µg/day selenium is an adequate dose for adult men and women (RDAs, 2017). For human beings, an approximate adequate selenium intake is 50–60 µg/day, while toxic levels of selenium intake are 350–700 µg/day (Table 1) (Dodig et al., 2004; Badmaev et al., 2018). In different microorganisms, inorganic selenite can be converted into organic forms, which are considered safer and more effectual dietary sources of selenium. Selenium may also be complexed, through binding, with various polysaccharides and proteins. For human beings, selenium consumption or supplementation with low doses has significant health benefits, among which the prevention of cardiovascular disease and cancer is of main importance. Selenium enhancement in grains involve significant increases in the amount of reducing sugars, starch, sulphur containing amino acids etc.

Table 1
Recommended Dietary Allowances (RDAs) of Selenium (Dodig et al., 2004; Badmaev et al., 2018).

Age	Adequate intake (µg/day)	Tolerable upper levels (µg/day)
Birth to 6 months	15 µg	45 µg
7–12 months	20 µg	60 µg
1–3 years	20 µg	90 µg
4–8 years	30 µg	150 µg
9–13 years	40 µg	280 µg
14–18 years	55 µg	400 µg
19–50 years	55 µg	400 µg
51 to more than 51 years	55 µg	400 µg
Pregnancy	60 µg	400 µg
Lactation	70 µg	400 µg

4. Selenium in soil – Crop system

The efficiency for improvement of crops with selenium strongly depends on the physical, chemical and biological properties of the soil (Zhao et al., 2005). Bioavailability of selenium content of most soils is very low at 0.01–2 mg/kg, with a mean of ∼0.4 mg/kg; but higher concentrations of up to 1200 mg/kg have been observed in some seleniferous areas (Fordyce et al., 2005). Vegetation on most soils contain less than 1 mg/kg selenium concentration. On seleniferous soils most plant species contain 1–10 mg/kg selenium, whereas selenium hyperaccumulator plants (e.g. Astragalus and Stanleya genus) can accumulate 1000–15000 mg/kg selenium, even from low level of soil concentrations. Selenium status of Gujarat soil is very poor and it is considered as selenium deficient soil, total selenium in soil is 0.142–0.678 mg/kg with an average of 0.375 mg/kg (Patel et al., 1970). Selenium in the agroecosystems is found in both inorganic and organic forms. Inorganic selenium forms are present in four oxidation states, such as elemental selenium, selenide, selenite and selenate. Selenium deficiency may be observed due to uneven distribution of selenium in the soil. The moderate uptake of selenium by crops means low concentrations of plant available forms of selenium in soil can decrease the dietary intake of selenium (Winkel et al., 2015). Regions such as mountainous countries viz., Finland, Sweden and Scotland are generally deficient in soil selenium content whereas fine-grained soils and dried regions of the world are rich in soil selenium content. Countries like India, UK, Gerrmany, France, Netherlands, Nepal and Saudi Arabia are reported to have selenium deficient areas (Zhu et al., 2009) whereas, selenium rich regions are north-east region of Punjab in India (Yadav et al., 2005), Enshi district in Hubei province region in China, USA, Canada, Japan and Greenland (Yin et al., 2012). Trace amounts of selenium can enhance growth in various selenium accumulator and non-accumulator crops (Terry et al., 2000). Moreover, a significant modification has been made in understanding Se behavior in higher plants like uptake, assimilation and its metabolism (Pilon-Smits et al., 2010; Pilon-Smits, 2015). Cultivation of selenium fortified crops on seleniferous soil will improve the quality of soil and also produces crops that can be used as a diet in selenium deficient areas.

Selenium content in food sources depends upon soil selenium content, selenium accumulating capacity and uptake by crops, which alter according to geographical regions and presence of other elements in soil (Mehdi et al., 2013). Complexity of selenium behavior in plants and soils with specifically selenium deficient soils can minimize by possible approaches to improving selenium content through use of microorganisms which are capable of metabolizing the inorganic selenium and thus be used as seed inoculants as biotechnological tools for crop nutrition and quality. Biofortification and bioremediation could be combined and might be considered as a new biotechnological alternative for responding to the selenium deficiency and toxicity in certain agroecosystems (Fig. 1) (Acuna et al., 2013). In agroecosystems, bacteria play a significant role in selenium cycle by reduction, oxidation and methylation processes (Pendias, 2010). Selenium speciation, mobility and their bioavailability in soils are extremely affected by the presence of microorganisms in the environment. Relative proportions of selenium oxidation states and selenium compounds in atmosphere also depend on the bioprocesses involved in the bacterial metabolism. Bacteria have potential to reduce inorganic selenium to elemental selenium forms for bioremediation of contaminated soils, sediments, industrial effluents, and agricultural drainage waters (Dungan et al., 2003).

5. *Selenorhizobacteria* as plant growth enhancing bacteria

The new area of research involves the use of crop – microorganism interactions to enhance selenium biofortification. Plant growth