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Agronomic biofortification of selenium

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Abstract

Selenium, mineral element has tremendous impact on human health, animals and plants. The dietary consumption by people could not satisfy the daily allowable limit of selenium for its proper function in the human system. Selenoproteins identified till now accounts for about 25 and has specific functions viz., antioxidant, thyroid hormone secretion, guard against oxidative stress, synthesis of biomolecules, phospholipid biosynthesis, anticancerous heart regulation, sperm motility and male fertility. Deficiency of selenium is profound in many countries accounting to 3 billion people deficient globally causing malnutrition resulting two endemic diseases Kaschin-Beck disease and Keshan disease and other diseases such as heart diseases, breast cancer, cardiovascular diseases, HIV viral infections, immune system impairment, etc. Agronomic biofortification acts as an effective strategy by enhancing/increasing the concentration of selenium in the agricultural staple food crops thus indirectly achieving the targeted leel of selenium in daily human dietary uptake even in rural areas. Research evidences from field investigations of research scientist proves that cereal crops on an average have 15 to 20 fold increase in grain selenium concentration during crop growth rate by selenium fertilization.

Keywords: Selenium, human health, deficiency, malnutrition, agronomic biofortification

Introduction

Selenium is an trace element and acts as an integral part for several proteins plays a crucial role in the human health. The main function is it that protects the human body from free radicals, synthesis of macromolecules especially thyroid hormones, muscular functions, fertility in males and immune system development in human body. Deficiency of selenium is noticed widespread in the world. Selenium inadequate condition was found in one billion people globally. In general, soil Se concentration determines human Se nutrition status, especially in populations dependent on local food sources. The selenium consumption in the human dietary is indirectly determined by the concentration of selenium in the soil since translocation occurs from soil to plants. Factors such as edaphic (soil physical and chemical properties), crop species and environment also influence the selenium concentration in agricultural crops. The extractable selenium which is taken up by plants mainly determines the concentration on crop that paves way to human nutrition. The aspects of biofortification in staple agricultural food crops could be an effective measure in mitigating the malnutrition of selenium. The biofortification process focuses on increasing the concentration of nutrients in the edible parts thereby the dietary intake by humans will alleviate the malnutrition in the rural livelihoods. Different approaches such as genetic biofortification, molecular approaches, microbiological interventions and agronomic biofortification are done, out of agronomic biofortification was found to be cheap, cost effective and less time consuming coping with the normal farmers cultivation aspects. The present paper gies an panoramic view of selenium on human health importance, factors governing selenium bioavailability, agronomic biofortification and results of eminent research scientist on agronomic biofortification in selenium.

Selenium

Selenium one among the mineral element requirement is generally met through soils and crop plants like rice, wheat, vegetables and maize in many countries. The concentration of selenium in soil generally ranges from 0.01-2.0 mg kg^{-1} except the seleniferous soils which normally usually has more than 5 mg kg^{-1}. The countries such as China, Ireland, India and United States of America were found to be with seleniferous soils. The selenium levels will increase in the environment through the natural process from the weathering of parent rock materials as well

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as deposition from volcanic plumes. The chemical fertilizers, farmyard manure application, combustion of coal, sludge from sewages, and mining, incineration of wastes, smelting and processing of crude oil are some of the selenium sources contributed by human activities. Selenium (Se) acts an essential micronutrient to humans, plants and animals. Selenium exists in different oxidation states, such as selenate (Se^{6+}), selenite (Se^{4+}), elemental selenium (Se^0) and selenide (Se^{2-}). In oxidized form the selenium is absorbed mainly as selenate (SeO$_4^{-2}$) and, must be reduced to the selenium ion (Se^{2-}) either enzymatically or nonenzymatically as that it occurs in sulfur for subsequent incorporation into other organic compounds like amino acids and proteins. Its deficiency is found to cause Keshan disease, Kashin-Beck disease and cancer in humans as well as it is also recognized to have associated with HIV/AIDS occurrence (Foster, 2003) [5]. The countries such as Canada, India, China, Japan, Scotland, Finland, Spain, New Zealand, and United States of America (Hartinkainen, 2005) [14]. The National Academy of Science recommends to take 55 µg of daily Se for adults. The intake level should be within the limit of 400 µg in humans and beyond that is considered as toxic to humans.

Selenium on human health

Selenium being considered as trace element plays essential role in human health. It is found to be necessary for the synthesis of the amino acid selenocysteine, which involves in 25-35 proteins formation called as called selenoproteins which plays critical role in mammal metabolism (Rayman, 2012) [13]. Selenoproteins include a) glutathione perioxidases (GPX1, GPX2, GPX3, GPX4) acts an antioxidant enzyme against oxidative damage of lipids, biomolecules and DNA, b) Sperm/ Mitochondrial capsule selenoprotein acts as an shield in protecting the developing sperm cells from the oxidative damage and enhances the motility of sperm cells, c) Iodothyronine deiodinases that produces and regulates the the thyroid hormone, d) Thioredoxin reductases that aids in nucleotide reduction in DNA, maintenance of redox state of intercellular enzymes, crucial role in viability as well as cell proliferation e) Selenophosphate synthetase SPS 2 indulging in selenoprotein synthesis as a result from biosynthesis of selenophosphate which is a precursor of selenophosphate f) Selenoprotein P that protects the endothelial cells damage from peroxynitrite, g) Selenoprotein W essential for functional activity of muscles, h) Prostrate epithelial selenoprotein that guards secretory cells against carcinoma infection, i) DNA-bound spermatid selenoprotein, especially found in nuclei of spermatozoa and stomach protecting sperm cells and j) 18 kDa selenoprotein an important protein found in kidney (Gromer *et al.*, 2005) [7].

List of human selenoproteins with their functions and related disorders

Selenoprotein Name	**Function**	**Selenium Effects and Related Disorders**
GPx1: cytoplasmic glutathione peroxidase	Oxidative stress	Sensitive to Se status from the diet Cardiovascular diseases
Px2: gastrointestinal glutathione peroxidase	Oxidative stress	Relatively resistant to Se changes Intestinal cancer
GPx3: plasma glutathione peroxidaset	Antioxidant	Sensitive to Se status Cardiovascular protection
GPx4: phospholipid hydroperoxide glutathione peroxidase	Antioxidant and structural protein in sperm	Relatively resistant to Se changes Immune disorders, HIV
GPx6: olfactory glutathione peroxidase	Unknown	Unknown
DIO1: deiodinase Type I	Thyroid hormone production and level at systemic level	Thyroid dysfunctions and Kaschin-Beck disease
DIO2: deiodinase Type II	Thyroid hormone production and level at local level	Stable expression under low Se status Thyroid dysfunctions and Kaschin-Beck disease
DIO3: deiodinase Type III	Inactivates thyroid hormone	Thyroid dysfunctions and Kaschin-Beck disease
TrxR1: thioredoxin reductase Type I	Oxidative stress, present in the cytosol Enhanced activity under high Se status	Overexpression in several cancer
TrxR2: thioredoxin reductase Type II	Oxidative stress, mitochondrial protein	Subject to dietary Se changes
TrxR3: thioredoxin reductase Type III	Oxidative stress, specific expression in testes	-
Selenoprotein H	Transcription factor, present in nucleus, important in oxidative stress	-
Selenoprotein I	Phospholipid biosynthesis	-
Selenoprotein K	Localized in the endoplasmic reticulum (ER) at transmembrane level	-
Selenoprotein M (also called Sep 15)	ER localization, oxidoreductase	
Selenoprotein N	ER localization, Calcium signaling, role in early muscle formation	Multiminicore diseases, muscular dystrophy
Selenoprotein O	ER localization, probable redox function	
Selenoprotein P	Secreted and cytoplasmic, very abundant in plasma, Se transport, oxidative stress, metal detoxification	Cancer, neurodegenerative diseases (Alzheimer's disease)
Selenoprotein R	Cytoplasmic protein, reduction of methyl sulphoxy groups	-
Selenoprotein S	ER localization, removal of misfolded proteins Inflammation responses	-
Selenoprotein T	ER localization, Calcium mobilization	-
Selenoprotein V	Expression testes-specific	-

Selenoprotein W	Oxidative stress	Highly dependent on dietary Se levels and SelP levels
SPS2: selenophosphate synthetase	Selenoproteins synthesis	Thyroid dysfunction

(Mangiapane *et al.*, 2014) [11]

Selenium deficiency in humans

Selenium deficiency in human beings assumes more importance to two endemic diseases viz., Kaschin-Beck disease and Keshan disease.

A) Kaschin-Beck disease: Kaschin-Beck disease is a chondrodystrophy affecting the epiphyseal and articular cartilage and the epiphyseal growth plates of growing bones. It is characterized by enlarged joints, shortened fingers, toes and extremities and, in severe cases, dwarfism.

B) Keshan disease: Keshan disease is a multifocal myocarditis occurring primarily in children aged 2-10 years and, to a lesser extent, in women of child-bearing age. Its main manifestations are insufficiencies of cardiac function, cardiac enlargement, arrhythmias, and electrocardiographic and radiographic abnormalities.

Lower levels of selenium in the human body can be associated with other following organism dysfunctions causings for example; friedreich's ataxia, decrease in the enzyme activity that are responsible for regulation of cellular membrane function, normal immune response impairment, cancer cell development, liver and pancreatic cirrhosis, reduction in the fertility, high risk of hypertension, thyroid functional impairment, degeneration of cardiac and hepatic cells, impairment of bone mineralization, abnormal tooth growth, high risk to viral infection and its susceptibility, ageing, prevalence and occurrence of frequent inflammatory disorders, cataract, cardiovascular disease, sudden infant deadth syndrome, phobias, erythrocyte dysfunction, depression and enmities, crohn's disease and cystic fibrosis.

Selenium deficiency in animals

Selenium deficiency in animals had the following impact on animals causing cardiomyopathy in young pigs, cattle, horses, and poultry; cataract in rats; lymphatic diathesis in hens and turkeys; and "white muscle disease" in lambs and sheep Bodnar *et al.*, (2012) [2].

Factors affecting selenium bioavailability

The bioavailability of selenium to plants from soil is influenced by soil type, pH of the soil, soil structure, organic matter content in the soil, structure of the soil, microorganism activity, redox potential, Me_2O_3 oxide quantity, climatic factors viz., bioaccumulation occurs as a result of increase in temperature, higher precipitation decreasing the selenium compound assimilation, Al and Fe complexion, soil acidity, calcium carbonate content in soil, phosphate, sulfate interaction with selenium, salinization of soil and antagonistic character over Mn, S, P, Cu, Cd, Zn and W by selenium (Mangiapane *et al.*, 2014) [11].

Biofortification – an approaches for selenium malnutrition alleviation Biofortification

Biofortification is the process by which the nutrient concentration of food crops is increased either through conventional plant breeding, and/or enhanced agronomic practices and/or latest biotechnology without deteoriating or declining any characteristic which is preferred for consumption or most important by farmers. Biofortification emphasizes on increasing the mineral nutritional qualities of crops at source, which encompasses processes that increase both mineral levels and their bioavailability in the staple crops edible tissues. This can be achieved by different approaches like agronomic intervention, genetic engineering or breeding aspects, whereas only plant breeding and genetic engineering can influence mineral bioavailability. The process of biofortification differs from other conventional fortification process by increasing the nutrient levels in crops during plant growth instead of manual means during processing of the agricultural crops.

Agronomic biofortification

Agronomic biofortification is a method wherein the mineral element content is increased in the edible tissues or economic part used for consumption purpose by supplementing mineral fertilizers or by increasing the mineralization, solubilisation of applied mineral fertilizers. Soluble inorganic form of nutrient supplying fertilizers are applied by agronomical methods viz., band placement, split application, spot application or by foliar means to deficient soils or selenium unavailability conditions owing to soil, crop or other environmental factors. Foliar application of solube inorganic fertilizers serves as an effective measure where mineral elements are not readily translocated to edible tissues.

Agronomic biofortification – Research reviews

The barley grain selenium concentration had a significant increase of 234 µg kg^{-1} while the compared treatment registered only 33 µg kg^{-1} with selenite form of selenium application at 10 g ha^{-1} in sandy loam soils (Gupta *et al.*, 1993) [6]. Foliar application of selenite increased the selenium concentration in rice grains to 35% when compared to selenite as well as control treatment (Chen *et al*., 2002) [3]. (Chilimba *et al.*, 2016) [10] carried an investigation in Malawi entitled "Agronomic biofortification of maize, soyabean and groundnut with selenium in intercropping and sole cropping system" and documented significant increase of 8 fold in maize, 9 fold in groundnut and 18 fold in soyabean selenium concentration in seeds with foliar application of 10 g Se ha^{-1} over control and stated that universal adoption of this technique could increase the average estimated dietary selenium supply in Malawi. Field experiment was conducted with different crops viz., maize, soybean, potato, cabbage, canola, wheat with the objective to increase the selenium concentration by agronomic biofortification measure with selenite and selenite form application in soil. The selenium application at 1 g ha^{-1} significantly increased the concentration of selenium by 0.2 µg kg^{-1} for maize, 1.2 µg kg^{-1} for soybean, 0.9 µg kg^{-1} for potato, and 6.5 µg kg^{-1} for cabbage, with the Se biofortification target reached at 1445, 212, 317 and 31 g ha^{-1}, respectively. In case of selenite form the selenium increment compared to the no application treatment was78 to 228 fold, and application of selenium at 1 g ha^{-1} increased the selenium concentration by 17.4 µg kg^{-1} in wheat grain, 8.6 µg kg-1 in maize grain, 17.3 µg kg^{-1} in soybean seed, 10.2 µg kg^{-1} in potato tuber, 4.1 µg kg^{-1} in canola seed, and 76.8 µg kg^{-1} in cabbage leaf, with the selenium biofortification target of 300 µg kg^{-1} DW reached at 16, 34, 15, 28, 71 and 3 g ha^{-1}, respectively. Foliar application of selenium as sodium selenite in winter wheat significantly increased the selenium concentration in wheat grain from 25 to 312 µg kg^{-1} in with application of 60 g selenium ha^{-1} against control (Mao *et al.*, 2014) [9]. (Alfthan *et al.*, 2015) [1] registered an average increase of 15 fold in cereal crop in Finland (15 mg Se/kg) with selenium addition along with NPK fertilizers and the selenium intake increased by this intervention. Selenium content in grains were 133 fold increased with application of selenium at 4 – 120 g ha and 20 fold increase found with foliar means of application in wheat was reported. Masanza *et al.*, (2016) [10] registered an significant increase in maize grain selenium content of 0.079 mg Se kg^{-1} with the application of 5 g Se ha^{-1} to the soil that which was supplied with rate of 5 t ha^{-1} of dolomitic limestone. (Petkovic *et al.*, 2019) [12] conducted an field investigation with foliar spray at two levels (5 g and 10 g Se/ha) in two splits using sodium selenate in alfalfa and recorded significantly higher assimilation of nutrients in the treatment plots supplied with 10 g Se ha^{-1} which was 149% higher compared to control treatment.

Advantages of Agronomic biofortification

1. It is an easy and cheap method.
2. The time duration is very low while compared with genetic biofortification as it takes longer period (more than 10 years) and needs more cost and higher skill.
3. Requires no technical skill and accompanies with the normal cultivation aspects.

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