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BIOFORTIFICATION OF HORTICULTURAL CROPS WITH SELENIUM

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ABSTRACT

Selenium (Se) is a naturally occurring element, structurally resembling Sulphur, lying in group 6 of the periodic table. It is an essential micronutrient required to properly function many biological processes like hormone formation, immune system, hair growth, muscular movements, and reproduction. Se is also needed to defend against many diseases like viral infections, Keshan's diseases, and arthritis, as it is an essential component of selenoproteins and enzymes like glutathione peroxidase. Low selenium levels in the human body can lead to various diseases and disorders. A selenium-enriched diet is necessary to fulfill Se-deficiency. Plants are the main source of the human diet. Plants are fortified with selenium by adding different forms of selenium through various methods. The uptake or absorb selenium through the Sulphur assimilation pathway and store it into the tissues in either organic or inorganic form. Much research has been carried out in the production of Se-fortified crops. This review paper aims to review recent studies that have been done on biofortification of horticultural plants with selenium, like fruits and vegetables, which contribute a major portion of the human diet.

Keywords: Horticultural crops, Biofortification, Selenium

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1. INTRODUCTION

1.1. Environmental Selenium

Selenium is a non-metal element belonging to group 6 of the periodic table having 34 atomic number and 78.96 atomic mass (Fordyce 2005). It occurs in varying forms as elemental selenium (Se), selenide (Se^{-2}), selenite (SeO_3^{-2}), selenate (SeO_4^{-2}) (Chauhan et al. 2019). Naturally, selenium occurs in sedimentary rocks (White et al. 2004). Worldwide, average Se concentration in soils is $0.4mg.kg^{-1}$ while in seleniferous soils it can goes up to till $5000mg.kg^{-1}$ (Hartikainen 2005). Amount of Se vary in soils and depends upon various factors like type of soil, organic matter, and rainfall (Sors et al. 2005). Natural and anthropogenic activities are responsible for addition of selenium in environment (Winkel et al. 2012; Tan et al. 2016; Okonji et al. 2021). Natural activities like volcanic eruptions, forest fires and soil erosion and anthropogenic activities like burning of fossil fuels, plastics, rubbers, and paper etc. increase the concentration of selenium in the atmosphere (Mehdi et al. 2013). In air it is mostly present in volatile form as DMSe, DMDSe and methaneselenol. Se concentration in air is generally low, ranges from 1 to $10ng.m^{-2}$ (Mehdi et al. 2013). Selenium concentrations in plants vary depending upon specie, accumulation capacity and selenium levels in soils (Dumont et al. 2006; Pilon-Smits 2019; Ramkissoon et al. 2019; Naseem et al. 2021).

1.2. Importance of Selenium in Plants and Humans

Selenium is recognized as an essential micronutrient (El-Ramady et al. 2020; Li et al. 2021) after its discovery as an important component of enzyme glutathione peroxidase (Rotruck et al. 1973). It is crucial for proper growth and development and proper functioning of many biological functions like formation of thyroid hormones, muscle functioning, DNA synthesis, senescence, and reproduction (Hawrylak-Nowak 2013). Selenium is also involved in defense system and helps in disease prevention like cardiological disorders, viral infections, and arthritis (Shamberger 1981). Selenium is actively involved in immunity (Avery and Hoffmann 2018; Xia et al. 2021), thus preventing so many diseases. Its deficiency in human body can lead to various diseases like cystic fibrosis, Alzheimer's, heart diseases, disorders related to oxidative stress and hypothyroidism (Rayman 2012; Coppinger and Diamond 2001; Loscalzo 2014). Its optimal intake is necessary to overcome its deficiency, WHO has recommended 50-55µg/day selenium in dietary intake (World Health Organization 2011). Se enriched crops are considered ideal to increase the dietary intake of selenium (Dumont et al. 2006).

A plant growing in seleniferous soil absorbs selenium and assimilate, which varies on the capacity of plant, species, Se form and concentration in the soil (Banuelos and Meek 1990). Depending upon capacity of plant to absorb selenium, plants are classified as non-accumulators in which selenium accumulation levels are usually below 100mg.kg^{-1}, accumulators which can store up to 100-1000mg.kg^{-1} and hyper-accumulators in which selenium accumulation levels exceeds than 1000mg.kg^{-1} (Ellis and Salt 2003). At appropriate levels selenium shows various beneficial effects in plants and affects seed germination and plant growth (Xue et al. 2001). Selenium act as antioxidant and helps in defense against biotic and abiotic stresses (Schiavon and Pilon-Smits 2017). It inhibits lipid peroxidation and increases glutathione peroxidase activity which results in delay in senescence and minimal post-harvest loses (Cartes et al. 2005). The antioxidant activity of selenium is related to enzyme glutathione peroxidase which shows that selenium is integral part of glutathione peroxidase (Xue et al. 2001).

1.3. Selenium Supplementation in Plants

In order to fortify the plants with selenium, different forms of selenium are applied to the growing plants through different application methods. To produce selenium enriched foods, two types of selenium supplements are used i.e., inorganic selenium form (selenate or selenite salts) and in organic forms like selenomethionine, selenocysteine, selenium enriched yeast or addition of selinized plant into the soil to increase the selenium content of soil in which targeted crops are grown.

Commonly, selenium is applied in inorganic forms i.e., sodium selenate and sodium selenite. Both forms of selenium are toxic at higher levels but act as antioxidant at low levels. Sodium selenate is favored over selenite as it is readily absorbed by the plants and get accumulated. In 2010, Ramos et al. compared the effect of both forms by applying them on lettuce through hydroponic nutrient solution and results showed that selenate is better for fortification and increased the yield and biomass of lettuce. Different application methods are being practiced which mainly includes:

***1.3.1. Soil Addition*:** Addition of different forms of selenium supplements is most common application method to increase the soil selenium content for production of selenium fortified crops. Mostly, soil selenium content is increased by addition of selenate or selenite (Hart et al. 2011) or integration of selenium hyperaccumulator plant like *Stanleya pinnata* into the soil (Freeman and Banuelos 2011). Selenium hyperaccumulators used for phytoremediation can be used for biofortification of other plants by incorporating them into the soils. The decomposition of Se enriched plant increases the soil selenium content which is then absorbed by the growing plant and gets fortified (Bañuelos et al. 2010; Ramkissoon et al. 2019; D'Amato et al. 2020).

***1.3.2. Foliar Application*:** Foliar application of selenium is practiced on many horticultural crops but the effectiveness of this method depends upon many factors like leaf and fruit surface, presence of wax or hairs on leaves or fruits, epicarp and chemical composition of wax (Pezzarossa et al. 2014). Se accumulation in sprayed plants is found to be higher as compared to grown in hydroponics (Germ et al. 2007). It is also better than soil application because plants get fortified with minimal amount of salt and is more effective (MacLeod et al. 1998).

***1.3.3. Hydroponics*:** In this method, selenium salts are applied to the plant through nutrient solution flowing through the hydroponic system. This method is effective in controlling the selenium doses with minimal loss of salts as compared to soil and foliar application (Malorgio et al. 2009). Many horticultural crops like lettuce (Xue et al. 2001), spinach (Ferrarese et al. 2012), basil (Puccinelli et al. 2017; Hawrylak-Nowak et al. 2018), and tomatoes (Schiavon et al. 2013; Puccinelli et al. 2019) have been effectively selenium fortified through hydroponics.

***1.3.4. Seed Soaking*:** In this method seeds are soaked in different selenium concentration solutions because of which seeds absorb selenium and get fortified. This method gives better results with grain crops like wheat as compared to fruit crops. This method also induces tolerance against several stresses in the plants. In 2013, Nawaz et al. found that wheat grains soaked with selenium are drought tolerant as compared to non-treated seeds. It also induces metal (cadmium) stress tolerance in radish plants (Miao et al. 2008). Later on, lettuce seeds were investigated, and results shown that selenium-soaked lettuce seeds are tolerant towards salinity and gives good growth and yield (Shalaby and Ramadan 2017). However, selenium content in biofortified plants through seed soaking is lower than other methods.

1.4. Selenium Uptake and Accumulation by Plants

The uptake and accumulation of selenium in plants depends upon many factors like form of selenium (Organic or inorganic), plant species, growth stage of plant, soil conditions (pH, salinity) and plant translocation mechanism (Renkema et al. 2012). In soil, selenium is present in inorganic forms either as selenate or selenite. Selenate is mostly found in alkaline soils whereas selenite exist in acidic pH. Absorption rate and accumulation is different for both forms (Li et al. 2008). Both forms are absorbed by the transporters present in the root cells of the plants.

Table 1: Summary of Se- enriched horticultural crops with form, application method, dose applied, increased Se-content and effect on antioxidants and yield

Plant Species	Selenium Form	Application Method	Dose	Se Content in Edible Portion	Yield and Biomass	Antioxidants	References
Fragaria x *ananassa* Duch.	Selenium nanoparticles (Se-NPs)	Foliar application	10 and 20 $mg.L^{-1}$	-	Increased	Superoxide dismutase (SOD) and Peroxidase (POD) activity increased	Zahedi et al. (2019)
Valerianella locusta L.	Sodium selenate (Na_2SeO_4)	Foliar and soil application	$50mgdm^{-3}$	0.1-61 $mg.kg^{-1}$ DW	30-48% increased	Glutathione (GSH), Total Phenolic Content (TPC), Total Flavonoid Content (TFC), Ascorbic acid, Glutathione peroxidase (GPOX), Ascorbate peroxidase (APOX), Catalase (CAT) activity increased	Hawrylak-Nowak et al. (2018)
Lactuca sativa L. var, capitata	Sodium selenate	Hydroponic Nutrient film technique	0 – 40μM	20–140 $mg.kg^{-1}$ DW	5.7% increased	Increased total phenolic contents (TPC) and carotenoids	Pannico et al. (2019)
Malus domestica	Sodium selenate and Sodium selenite (Na_2SeO_3)	Foliar application	$0.15kg.ha^{-1}$	4.5-5.6 μg/100g FW	-	Antioxidant activity and total phenolic content increased	Groth et al. (2020)
Cichorium endivia L. var. *crispum* Hegi	Sodium selenate	Foliar and soil application	1, 2, 4 and $8\mu mol.L^{-1}$	0.71-17.61 $mg.kg^{-1}$	27.8-42.6% increased	Ascorbic acid, Total phenolic content (TPC) increased	Sabatino et al. (2019)
Brassica juncea L.	Sodium selenate	Foliar application	$50mg.L^{-1}$	8577-8922 $\mu g.kg^{-1}$ DW	Increased	Ascorbic acid, Flavonoids increased	Golubkina et al. (2018)
Lactuca sativa L.	Sodium biselenite ($HNaO_3Se$)	Foliar and soil application	50, 75 and 100ppm	200-1700 ppb	43.1% increased	Catalase, Ascorbate peroxidase, increased	Shalaby et al. (2017)
Allium cepa L. *Aggregatum*	Sodium selenate and Selenocysteine (SeCys)	Soil application	0.26mM solution	530% increased	51.6% increased	Ascorbic acid, flavonoids, phenolic content and antioxidant activity increased	Golubkina et al. (2019)
Daucus carota L. cv *Brasília*	Sodium selenate and Sodium selenite	Foliar and soil application	$1.0mgdm^{-3}$ through soil and 50 $\mu m.L^{-1}$ through foliar	$14mgkg^{-1}$	14-16% increased	7-33% carotenoid contents increased	Oliveira et al. (2018)
Lactuca sativa L. cv. *Vera*	Sodium selenate and Sodium selenite	Nutrient solution	0, 2, 4, 8, 16, 32, and $64\mu molL^{-1}$	10-22 $mg.kg^{-1}$	3.69–5.67% increased	Superoxide dismutase and catalase activity increased	Ramos et al. (2010)
Allium sativum L.	Sodium selenate and Sodium selenite	Soil application	0, 5, 10 and 15kg/ha Se	$23\mu gg^{-1}$ DW	-	-	Pérez et al. (2019)
Brassica oleracea L. var. *Marathon* and *Daucus carota* L.	Addition of hyperaccumulator *Stanleya pinnata*	Soil application	25, 50, 100, 200g	0.5 to 3.5μg Se g^{-1} DW	Increased	-	Bañuelos et al. (2015)

Selenite compound is absorbed by phosphate transport mechanism whereas selenate is transported from the soil to the plant by sulfate transporters of the root cells (Li et al. 2008).

As selenium structure resembles with that of Sulphur, it is easily absorbed by the sulfate transporters of the root cells. After entering the plants, selenate or selenite is further assimilated by the Sulphur assimilation pathway and converted into organic selenium compounds (White et al. 2004). First, by the action of enzyme ATP sulfurylase (APS) and APS reductase (APR), selenate is converted into selenite. APS hydrolyzes the ATP and convert it into adenosine phosphoselenate which is reduced by APR to selenite. Selenite is further reduced to selenide by enzyme sulfite reductase or glutathione (Wallenberg et al. 2010). In the presence of enzyme cysteine synthase, selenide is converted into selenocysteine (SeCys). SeCys is then either converted to elemental Se with the help of enzyme SeCys lyase or into selenomethionine (SeMet) by the action of series of enzymes. Two or more than two SeMet

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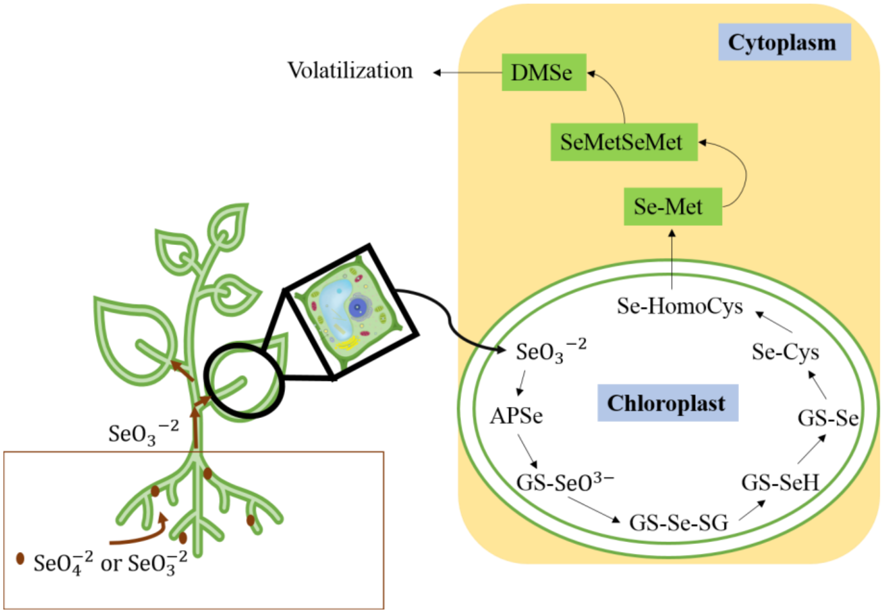

Fig. 1: Selenium uptake and assimilation pathway in plants.

compounds join to form selenoproteins or can be converted into volatile dimethylselenide, which escapes out in the atmosphere from the stomata of the plants (Pilon-Smits and Quinn 2010).

Capacity of each plant to assimilate selenium in them varies according to species. Depending upon the capacity of plant to accumulate selenium, plants are classified as accumulators, non-accumulators and hyper accumulators (Bodnar et al. 2012). Hyperaccumulators are those plants which can store more than 1000mgSe.kg^{-1} D.W and easily grows in seleniferous soils. *Stanleya,* and *Asparagalus* species are prominent examples of hyperaccumulators. Leafy vegetables are considered as accumulator plants as they can accumulate up to 100-1000 mg Se/kg dry weight. These mainly include *Lactuca sativa, Brassica juncea, Helianthus* and *Brassica napus* etc. Non accumulators are those plants which are sensitive to the selenium. Presence of high levels of selenium causes toxicity and results in retarded growth. However, they can store less than 100mgSe/kg dry weight e.g., grasses and crops (Bodnar et al. 2012).

1.5. Selenium Enrichment Effect on Horticultural Plants

Horticultural crops like vegetables and fruits contribute a major portion of human diet. To increase selenium content in human diet, many horticultural crops have been selenium fortified. Many studies have been carried out to produce se enriched horticultural crops by using different form of selenium (selenate, selenite, organic forms) through different application methods (foliar, soil, hydroponic nutrient solution). Some of the recent studies are summarized in the Table 1.

Conclusion: In conclusion, selenium has been recognized as an essential micronutrient element, required for proper functioning and health maintenance of human body. Deficiency of selenium can lead to various diseases and disorders. To overcome its deficiency, crops are fortified with selenium. Horticultural crops contribute a major portion of human diet. Se-fortified horticultural crops are efficient source of Se intake. Studies have shown that when it is applied to the plants, it also imposes positive beneficial effects on growth, nutritional profile, antioxidant composition, and induces tolerance against many stresses. However, further studies are required to explore the mechanism of action of selenium in the physiology of plants.

Author's Contributions

All authors have contributed equally and critically revised the manuscript and finalized the manuscript.

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REFERENCES

Avery JC and Hoffmann PR, 2018. Selenium, selenoproteins, and immunity. Nutrients 10: 1203. https://doi.org/10.3390/nu10091203

Banuelos GS and Meek DW, 1990. Accumulation of selenium in plants grown on selenium-treated soil. Journal of Environmental Quality 19: 772-777. https://doi.org/10.2134/jeq1990.00472425001900040023x

Bañuelos GS, Arroyo I, Pickering IJ, Yang SI and Freeman JL, 2015. Selenium biofortification of broccoli and carrots grown in soil amended with Se-enriched hyperaccumulator *Stanleya pinnata*. Food Chemistry 166: 603-608. https://doi.org/10.1016/j.foodchem.2014.06.071

Bañuelos GS, Roche JD and Robinson J, 2010. Developing selenium-enriched animal feed and biofuel from canola planted for managing Se-laden drainage waters in the Westside of Central California. International Journal of Phytoremediation 12: 243-254. https://doi.org/10.1080/15226510903563850

Bodnar M, Konieczka P and Namiesnik J, 2012. The Properties, functions, and use of selenium compounds in living organisms. Journal of Environmental Science and Health, Part C 30: 225–252. https://doi.org/10.1080/10590501.2012.705164

Cartes P, Gianfreda L and Mora ML, 2005. Uptake of selenium and its antioxidant activity in ryegrass when applied as selenate and selenite forms. Plant Soil 276: 359–367. https://doi.org/10.1007/s11104-005-5691-9

Chauhan R, Awasthi S, Srivastava S, Dwivedi S, Pilon-Smits EAH, Dhankher OP and Tripathi, RD, 2019. Understanding selenium metabolism in plants and its role as a beneficial element. Critical Reviews in Environmental Science and Technology 49: 1937-1958. https://doi.org/10.1080/10643389.2019.1598240

Coppinger RJ and Diamond AM, 2001. Selenium deficiency and human disease. In: Hatfield DL (eds) Selenium. Springer, Boston, MA. https://doi.org/10.1007/978-1-4615-1609-5_18

D'Amato R, Regni L, Falcinelli B, Mattioli S, Benincasa P, Bosco AD, Pacheco P, Proietti P, Troni E, Santi C, and Businelli D, 2020. Current knowledge on selenium biofortification to improve the nutraceutical profile of food: A comprehensive review. Journal of Agriculture and Food Chemistry 68: 4075−4097. https://doi.org/10.1021/acs.jafc.0c00172

Dumont E, Vanhaecke F and Cornelis R, 2006. Selenium speciation from food source to metabolites: A critical review. Analytical and Bioanalytical Chemistry 385: 1304–1323. https://doi.org/10.1007/s00216-006-0529-8

Ellis DR and Salt DE, 2003. Plants, selenium and human health. Current Opinion in Plant Biology 6: 273–279. https://doi.org/10.1016/s1369-5266(03)00030-x

El-Ramady H, Faizy SE-D, Abdalla N, Taha H, Domokos-Szabolcsy É, Fari M, Elsakhawy T, Omara AE-D, Shalaby T, Bayoumi Y, Shehata S, Geilfus C-M and Brevik EC, 2020. Selenium and Nano-Selenium Biofortification for Human Health: Opportunities and Challenges. Soil Systems 4: 57. https://doi.org/10.3390/soilsystems4030057

Ferrarese M, Sourestani MM, Quattrini E, Schiavi M, and Ferrante A, 2012. Biofortification of spinach plants applying selenium in the nutrient solution of floating system.Vegetable Crops Research Bulletin 76: 127-136. http://dx.doi.org/10.2478%2Fv10032-012-0009-y

Fordyce F, 2005. Selenium deficiency and toxicity in the environment. In: Selinus, O., Alloway, B.J., (eds). Essentials of medical geology: Impacts of the natural environment on public health. Academic Press, London, U.K. pp. 373-415.

Freeman JL and Banuelos GS, 2011. Selection of salt and boron tolerant selenium hyperaccumulator Stanleya pinnata genotypes and characterization of Se phytoremediation from agricultural drainage sediments. Environmental Science and Technology 45: 9703-9710. https://doi.org/10.1021/es201600f

Germ M, Stibilj V, Osvald J and Kreft I, 2007. Effect of selenium foliar application on chicory (Cichorium intybus L.). Journal of Agricultural and Food Chemistry 55: 795-798. https://doi.org/10.1021/jf0629888

Golubkina N, Kekina H and Caruso G, 2018. Yield, quality and antioxidant properties of indian mustard (*Brassica juncea* L.) in response to foliar biofortification with selenium and iodine. Plants 7: 80. https://dx.doi.org/10.3390%2Fplants7040080

Golubkina N, Zamana S, Seredin T, Poluboyarinov P, Sokolov S, Baranova H, Krivenkov L, Pietrantonio L and Caruso G, 2019. Effect of selenium biofortification and beneficial microorganism inoculation on yield, quality and antioxidant properties of shallot bulbs. Plants 8: 102. https://doi.org/10.3390/plants8040102

Groth S, Budke C, Neugart S, Ackermann S, Kappenstein FS, Daum D and Rohn S, 2020. Influence of a selenium biofortification on antioxidant properties and phenolic compounds of apples (*Malus domestica*). Antioxidants 9: 187. https://doi.org/10.3390/antiox9020187

Hart DJ, Fairweather-Tait SJ, Broadley MR, Dickinson SJ, Foot I, Knott P and Hurst R, 2011. Selenium concentration and speciation in biofortified flour and bread: Retention of selenium during grain biofortification, processing and production of Se-enriched food. Food Chemistry 126: 1771-1778. https://doi.org/10.1016/j.foodchem.2010.12.079

Hartikainen H, 2005. Biogeochemistry of selenium and its impact on food chain quality and human health. Journal of Trace Elements in Medicine and Biology 18: 309-318. https://doi.org/10.1016/j.jtemb.2005.02.009

Hawrylak-Nowak B, 2013. Comparative effects of selenite and selenate on growth and selenium accumulation in lettuce plants under hydroponic conditions. Plant Growth Regulation 70: 149–157. https://doi.org/10.1007/s10725-013-9788-5

Hawrylak-Nowak B, Dresler S, Rubinowska K, Matraszek-Gawron R, Woch W and Hasanuzzaman M, 2018. Selenium biofortification enhances the growth and alters the physiological response of lamb's lettuce grown under high temperature stress. Plant Physiology and Biochemistry 127: 446-456. https://doi.org/10.1016/j.plaphy.2018.04.018

Li HF, McGrath SP and Zhao FJ, 2008. Selenium uptake, translocation and speciation in wheat supplied with selenate or selenite. New Phytologist 178: 92-102. https://doi.org/10.1111/j.1469-8137.2007.02343.x

Li J, Otero-Gonzalez L, Parao A, Tack P, Folens K, Ferrer I, Lens PNL and Laing GD, 2021. Valorization of selenium-enriched sludge and duckweed generated from wastewater as micronutrient biofertilizer. Chemosphere 281: 130767. https://doi.org/10.1016/j.chemosphere.2021.130767

Loscalzo J, 2014. Keshan disease, selenium deficiency, and the selenoproteome. New England Journal of Medicine 370:1756-1760. https://doi.org/10.1056/NEJMcibr1402199

MacLeod JA, Gupta UC, Milburn P and Sanderson JB, 1998. Selenium concentration in plant material, drainage and surface water as influenced by Se applied to barley foliage in a barley–red clover–potato rotation. Canadian Journal of Soil Science 78: 685-688. https://doi.org/10.4141/S97-069

Malorgio F, Diaz KE, Ferrante A, Mensuali-Sodi A and Pezzarossa B, 2009. Effects of selenium addition on minimally processed leafy vegetables grown in a floating system. Journal of the Science of Food and Agriculture 89: 2243-2251. https://doi.org/10.1002/jsfa.3714

Mehdi Y, Hornick JL, Istasse L and Dufrasne I, 2013. Selenium in the environment, metabolism and involvement in body functions. Molecules 18: 3292-311. https://doi.org/10.3390/molecules18033292

Miao Y, Smykowski A and Zentgraf U, 2008. A novel upstream regulator of WRKY53 transcription during leaf senescence in Arabidopsis thaliana. Plant Biology 10: 110-120. https://doi.org/10.1111/j.1438-8677.2008.00083.x

Naseem M, Anwar-ul-Haq M, Wang X, Farooq N, Awais M, Sattar H, Malik NA, Mustafa A, Ahmad J and El-Esawi MA, 2021. Influence of selenium on growth, physiology, and antioxidant responses in maize varies in a dose-dependent manner. Journal of Food Quality 2021: Article ID 6642018. https://doi.org/10.1155/2021/6642018

Nawaz F, Ashraf MY, Ahmad R and Waraich EA, 2013. Selenium (Se) seed priming induced growth and biochemical changes in wheat under water deficit conditions. Biological Trace Element Research 151: 284-293. https://doi.org/10.1007/s12011-012-9556-9

Okonji SO, Achari G and Pernitsky D, 2021. Environmental impacts of selenium contamination: A review on current-issues and remediation strategies in an aqueous system. Water 13: 1473. https://doi.org/10.3390/w13111473

Oliveira VCD, Faquin V, Guimarães KC, Andrade FR, Pereira J and Guilherme LRG, 2018. Agronomic biofortification of carrot with selenium. Ciência e Agrotecnologia 42: 138-147.

Pannico A, El-Nakhel C, Kyriacou MC, Giordano M, Stazi SR, De Pascale S and Rouphael Y, 2019. Combating micronutrient deficiency and enhancing food functional quality through selenium fortification of select lettuce genotypes grown in a closed soilless system. Frontiers in Plant Science 10: 1495. https://doi.org/10.3389/fpls.2019.01495

Pérez MB, Lipinski VM, Filippini MF, Chacón-Madrid K, Arruda MAZ and Wuilloud RG, 2019. Selenium biofortification on garlic growth and other nutrients accumulation. Horticultura Brasileira 37: 294-301. http://dx.doi.org/10.1590/s0102-053620190307

Pezzarossa B, Rosellini I, Borghesi E, Tonutti P and Malorgio F, 2014. Effects of Se-enrichment on yield, fruit composition and ripening of tomato (*Solanum lycopersicum*) plants grown in hydroponics. Scientia Horticulturae 165: 106-110. http://dx.doi.org/10.1016/j.scienta.2013.10.029

Pilon-Smits EAH and Quinn CF, 2010. Selenium metabolism in plants. In: Cell Biology of Metals and Nutrients (pp. 225-241). Springer, Berlin, Heidelberg. http://dx.doi.org/10.1007/978-3-642-10613-2_10

Pilon-Smits EAH, 2019. On the ecology of selenium accumulation in plants. Plants 8: 197. https://doi.org/10.3390/plants8070197

Puccinelli M, Malorgio F, Rosellini I and Pezzarossa B, 2017. Uptake and partitioning of selenium in basil (*Ocimum basilicum* L.) plants grown in hydroponics. Scientia Horticulturae 225: 271-276. https://doi.org/10.1016/j.scienta.2017.07.014

Puccinelli M, Malorgio F, Terry LA, Tosetti R, Rosellini I and Pezzarossa B, 2019. Effect of selenium enrichment on metabolism of tomato (*Solanum lycopersicum*) fruit during postharvest ripening. Journal of the Science of Food and Agriculture 99: 2463-2472. https://doi.org/10.1002/jsfa.9455

Ramkissoon C, Degryse F, da Silva RC, Baird R, Young SD, Bailey EH and McLaughlin MJ, 2019. Improving the efficacy of selenium fertilizers for wheat biofortification. Scientific Reports 9: 19520 (2019). https://doi.org/10.1038/s41598-019-55914-0

Ramos SJ, Faquin V, Guilherme LRG, Castro EM, Ávila FW, Carvalho GS, Bastos CEA and Oliveira C, 2010. Selenium biofortification and antioxidant activity in lettuce plants fed with selenate and selenite. Plants, Soil and Environment 56: 584–588. https://doi.org/10.17221/113/2010-PSE

Rayman MP, 2012. Selenium and human health. The Lancet 379: 1256–1268. https://doi.org/10.1016/S0140-6736(11)61452-9

Renkema H, Koopmans A, Kersbergen L, Kikkert J, Hale B and Berkelaar E, 2012. The effect of transpiration on selenium uptake and mobility in durum wheat and spring canola. Plant and Soil 354: 239-250. http://dx.doi.org/10.1007/s11104-011-1069-3

Rotruck JT, Pope AL, Ganther HE, Swanson AB, Hafeman DG and Hoekstra WG, 1973. Selenium: Biochemical role as a component of glutathione peroxidase. Science 179: 588–590. https://doi.org/10.1126/science.179.4073.588

Sabatino L, Ntatsi G, Iapichino G, D'anna F and De Pasqual C, 2019. Effect of selenium enrichment and type of application on yield, functional quality and mineral composition of curly endive grown in a hydroponic system. Agronomy 9: 207. https://doi.org/10.3390/agronomy9040207

Schiavon M and Pilon-Smits EAH, 2017. Selenium biofortification and phytoremediation phytotechnologies: A Review. Journal of Environmental Quality 46: 10-19. https://doi.org/10.2134/jeq2016.09.0342

Schiavon M, dall'Acqua S, Mietto A, Pilon-Smits EA, Sambo P, Masi A and Malagoli M, 2013. Selenium fertilization alters the chemical composition and antioxidant constituents of tomato (*Solanum lycopersicon* L.). Journal of Agricultural and Food Chemistry 61: 10542-10554.

Shalaby O and Ramadan M, 2017. Effect of seed soaking and foliar spraying with selenium on the growth and yield of lettuce under saline stress. Egyptian Journal of Desert Research 67: 251–263. http://dx.doi.org/10.21608/ejdr.2017.7137

Shalaby T, Bayoumi Y, Alshaal T, Elhawat N, Sztrik A and El-Ramady H, 2017. Selenium fortification induces growth, antioxidant activity, yield and nutritional quality of lettuce in salt-affected soil using foliar and soil applications. Plant and Soil 421: 245-258. https://link.springer.com/article/10.1007/s11104-017-3458-8

Shamberger RJ, 1981. Selenium in Human Health and Disease. Biochemistry of Selenium. Biochemistry of the Elements, vol 2. Springer, Boston, MA.

Sors TG, Ellis DR, Gun NN, Lahner B, Lee S, Leustek T, Pickering I and Salt D, 2005. Analysis of sulfur and selenium assimilation in Astragalus plants with varying capacities to accumulate selenium. Plant Journal 42: 785-797. https://doi.org/10.1111/j.1365-313X.2005.02413.x

Tan LC, Nancharaiah YV, van Hullebusch ED and Lens PN, 2016. Selenium: Environmental significance, pollution, and biological treatment technologies. Biotechnology Advances 34: 886–907. https://doi.org/10.1016/j.biotechadv.2016.05.005

Wallenberg M, Olm E, Hebert C, Bjornstedt M and Fernandes AP, 2010. Selenium compounds are substrates for glutaredoxins: a novel pathway for selenium metabolism and a potential mechanism for selenium-mediated cytotoxicity. Biochemical Journal 429: 85-93. https://doi.org/10.1042/bj20100368

Winkel LHE, Jhonson CA, Lenz M, Grundl T, Leupin OX, Amini M and Charlet L, 2012. Environmental selenium research: From microscopic processes to global understanding. Environmental Science and Technology 46: 571-579. https://doi.org/10.1021/es203434d

White PJ, Bowen HC, Parmaguru P, Fritz M, Spracklen WP, Spiby RE and Broadley MR, 2004. Interactions between selenium and sulphur nutrition in Arabidopsis thaliana. Journal of Experimental Botany 55: 1927-1937. https://doi.org/10.1093/jxb/erh192

WHO, 2011. Selenium in Drinking-water Background. World Health Organization. WHO Press, 2,7. (WHO/HSE/WSH/10.01/14).

Xia X, Zhang X, Liu MC, Duan MY, Zhang SS, Wei XB and Liu XY, 2021. Toward improved human health: efficacy of dietary selenium on immunity at the cellular level. Food and Function **12:** 976-989. https://doi.org/10.1039/D0FO03067H

Xue T, Hartikainen H and Piironen V, 2001. Antioxidative and growth-promoting effect of selenium on senescing lettuce. Plant and Soil 237: 55–61. https://doi.org/10.1023/A:1013369804867

Zahedi SM, Abdelrahman M, Hosseini MS, Hoveizeh NF and Tran LSP, 2019. Alleviation of the effect of salinity on growth and yield of strawberry by foliar spray of selenium-nanoparticles. Environmental Pollution 253: 246-258. https://doi.org/10.1016/j.envpol.2019.04.078