Environment, Biodiversity & Soil Security

http://jenvbs.journals.ekb.eg/

Biofortification of Vegetables under Stress Conditions Using Biological Nano-Selenium: A Mini-Review

Hassan El-Ramady[1,4],Shaymaa I. Shedeed[2], Zakaria F. Fawzy[3], Abd El- Mohsin M. El-Bassiony[3], Sameh M. El-Sawy[3], Sami H. Mahmoud [1], andJózsef Prokisch [4]

[1] Soil and Water Dept., Faculty of Agriculture, Kafrelsheikh University, 33516 Kafr El-Sheikh, Egypt.
[2]Plant Nutrition Department, Agricultural and Biological Research Institute, National Research Centre, Egypt
[3]Vegetable Research Dept., Agriculture and Biological Research Institute, National Research Centre, 33 El Behouth St., Dokki, 12622 Giza, Egypt
[4]Institute of Animal Science, Biotechnology and Nature Conservation, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, 138 Böszörményi Street, 4032 Debrecen, Hungary

VEGETABLE crops are importantsources of vitamins, and minerals for human, and provides him with several bioactive compounds. Producing safe and healthy vegetables for human diet is of a great global issue. Thisneeds to exploit all available resources, particularly soils understressful conditions such as saline, saline-sodic, waterlogged and low fertile soils), climatic stress (drought, flooding, saltwater intrusion, and heat stress), and along with normal conditions. Nano-biofortification can support the vegetable productivity especiallyunder such conditions by using the biological nano-nutrients. Bio-nanonutrients exhibitsmany distinguishableproperties than mineral forms such as higher biological activity, lower toxicity, and better bioavailability. Bio-nanonutrients also promote the vegetable growth, productivity and enhance planttolerance towards different stresses by reinforcing the function of antioxidant enzymes. Thus, production of biofortified vegetables under stressful conditions might be an optimum and sustainable solution particularly by using the biological nanonutrients like selenium. The controlling factors that are needed for a successful nano-biofortification program of vegetables are correlated with growing media, plant species, and method application of nanonutrients. The over dose of nanonutrients maycause a nanotoxicity for cultivated plants, and then human health after consumption. This problem can be managed by following the 4R Nutrient Stewardship concept, which focuses on the right rate, right source, right time, and right place. This program will be discussed in more details in this review article.

Keywords: Soil fertility, Bio-nanofertilizer, Nano-biofortification, Malnutrition, Nanotoxicity.

1. Introduction

Deficiency of nutrients and vitamins (i.e., hidden hunger or malnutrition), are major problems facing several countries all over the world including the Caribbean, sub-Saharan Africa, Mediterranean countries, and Southeast/Western Asia (Morelli et al. 2023). Several approaches have been adapted for biofortification and food supplementation to incorporate required nutrients or vitamins during food processing or crop cultivation (Monika et al. 2023). The main approaches of biofortification include fertilization or agronomic strategies, conventional crop breeding, and genetic engineering or biotechnology methods (Kaur et al. 2020; Lal et al. 2020; Mir et al. 2020). Several materials on biofortification were published which focus on the targeted nutrients such as calcium (Pessoa et al. 2021), copper (Saffan et al. 2022), iodine (Izydorczyk et al. 2021), iron (Buturi et al. 2023), lithium (Naeem e al. 2021), magnesium (Mg), selenium (Cheng et al. 2023), and zinc (Buturi et al. 2023). Some vitamins and bioactive components were also reported in biofortified plants such as vitamins (De Lepeleire et al. 2018; Fitzpatrick and Chapman 2020; Jiang et al. 2021), and carotenoids (Yan et al. 2020; Morelli et al. 2023).

Production of vegetables is a crucial global issue for human health, which can supply the human with many essential minerals, vitamins and bioactives. Vegetables biofortification is a common practice nowadays, which started in many countries several years ago and was applied successfully on production

*Corresponding author e-mail: ramady2000@gmail.com
Received: 08/02/2023; Accepted: 20/02/2023
DOI: 10.21608/JENVBS.2023.192780.1210

of some vegetables like sweet potato to enrich or supply vitamin A (China and Uganda in 2004), vitamin A on cauliflower (India in 2016), iodine on lettuce (Poland in 2011), iodine on tomato (Italy in 2011), selenium on onion (Norway in 2012), anthocyanin on eggplant (India in 2016), as reported by Kiran (2020). There are other crops already applied in the biofortification program in different countries all over the world like cereals including rice (Barman and Kundu 2023), maize (Msungu et al. 2022), wheat (Chen et al. 2022), and sorghum (Cipriano et al. 2022); oil seeds like soybean (Dai et al. 2020), rapeseed (Praus et al. 2019), and safflower (Rani et al. 2018) and fruit crops like apple (Groth et al. 2021), apricot (Yan et al. 2020), banana (Sperança et al. 2021), and peach (Sun et al. 2020).

Nano selenium (nano-Se) is well known with distinguished characteristics as antistressor, bio-stimulant, nano-insecticide, and nanofertilizer (El-Ramady et al. 2020, 2022a, b; Kang et al. 2022; Medrano-Macías et al. 2022). This product can promote cultivated plants under different stresses such as heat stress (Seliem et al. 2020), drought and heat stress (El-Saadony et al. 2021), drought and heat stress (Shalaby et al. 2021), salinity (El-Badri et al. 2022), organic pollutants (Liu et al. 2022), heavy metals stress (Zhu et al. 2022), and nano-toxicity (Kamali-Andani et al. 2023). Many benefits were reported for nano-Se on several agro-cultivation practices such as improving the rate of germination under salinity stress (Ghazi et al. 2022), reducing the hazards of irrigation with low water quality (Saffan et al. 2022), acclimatization of banana Seedlings (Shalaby et al. 2022a), and enhance rooting of strawberry seedlings (El-Bialy et al. 2023). Nano-Se can also improve lettuce growth, nutrient availability, and photosynthesis (Cheng et al. 2023), protect melon plants from insect infestations and pathogens by enhancing their resistance to biotic stress (Kang et al. 2022), enhance cowpea photosynthesis process and/or photosynthetic pigments, and antioxidant capacity (Lanza et al. 2021), and improve tomato by promoting plant enzyme activities especially phenylalanine ammonia-lyase, β-1,3-glucanase, superoxide dismutase (Joshi et al. 2021).

Therefore, this review was designed to highlight the impacts of bio fortification for alleviating stress conditions of vegetables using biological nano-selenium. Biofortification and malnutrition, vegetables and human health, and the biofortification of vegetables under stress are the main issues in this study.

2. Biofortification and malnutrition

The global agriculture has a great challenge that needs to follow the mission of "Farm to Fork to Gut". The humanity already encountered a series of huge challenges starting from the global COVID-19 pandemic (coronavirus disease) in 2020, droughts, and floods in Europe, North America, and Asia extreme snow disasters, and unprecedented locust attacks in Africa (Jiang et al. 2021). These series ofchallenges have had devastating impacts on food security, human health, and the entire environment (Jiang et al. 2021). Due to the previous global crises, human health suffers from many troubles especially the malnutrition and / or hidden hunger because of micronutrient deficiencies. Malnutrition is considered a global challenge facing the world in order to develop a think-tank to alleviate and provide the right access to food globally and also secure them nutritionally (Shukla et al. 2022). Several nutrients have been confirmed their deficient in the human diet in many developing countries (mainly African and Asian Continent) such as calcium (Ca), iron (Fe), iodine (I), magnesium (Mg), selenium (Se), and zinc (Zn). Although, the proper solution for the malnutrition is the biofortification, there are many options to improve dietary foods with essential micronutrients including food supplementation, fortification, and dietary diversification (Shukla et al. 2022). Biofortification is "*a revolutionary technique for improving plant nutrition and alleviating human micronutrient deficiency*" (Monika et al. 2023). The main approaches of biofortification, the targeted crops, and nutrients that can be applied to the program of biofortification are presented in **Figure 1**. Among, biofortification with essential micronutrients in the targeted crop could be achieved through agronomic practices, conventional breeding, genetic engineering, and microorganism approaches. These approaches can be employed in the pulse crops (e.g., chickpea, pigeon pea, and lentils), which showed great potential to overcome micronutrient deficiencies prevalent among the vulnerable group (Shukla et al. 2022).

Many published articles reported about the strong relationship between biofortification and malnutrition with focus on different topics such as:

1- The suggested interactions among malnutrition and possible strategies for vitamin biofortification (Jiang et al. 2021),

2- Studying recent strategies for pulse biofortification to combat malnutrition (Shukla et al. 2022), 3- Carotenoids biofortification in plant with focus on their post-harvest stability and assessing bioaccessibility of the biofortified products (Morelli et al. 2023),

4- The strongrelation between both biofortification and phytoremediation with focus on sulphur amendments for long-term field studies using different S-doses to maximize the food safety and ecosystem health (Cao et al. 2023),

5- Studying biofortification as a long-term solution to improve global health (Monika et al. 2023),

6- Benefits of biofortification strategies in the field using chelated forms of both Fe and Zn minerals as preferable toots for biofortification programs of carrots (Buturi et al. 2023),

7- Field-scale studies quantify limitations for wheat grain zinc biofortification in dryland areas with reducing P-fertilizer use (Li et al. 2023), and

8- Exploring the complementarity of dietary diversification and fortification to combat micronutrient deficiencies to establish evidence of effectiveness of combined strategies to foster policy adoption (Bechoff et al. 2023).

3. Vegetables and human health

Vegetables are important edible plants of high nutritional value for human health. More than 1000 vegetable crops are recognized, whereas globally at least 402 vegetables are cultivated and commercialized (Dias 2019). The main classification of vegetables is based on either being leafy and stalk vegetable (53% of the total), fruit and flower vegetables (15%) and belowground or root, bulb, and tuber vegetables (17%), as reported by Dias (2019). Concerning the group of leafy and stalk vegetables, it includes lettuce, head cabbages, chicory, coriander, kales, collards, Chinese cabbage, Swiss chard, Brussels sprouts, pak-choi, mustards, rocket, watercress, spinach, purslane, spinach, celery, asparagus, chives, fennel, and parsley (**Figure 1**). Regarding the group of fruit and flower vegetables, it includes cauliflower, cucumber, tomato, eggplant, pepper, watermelon, melon, pumpkin, squash, zucchini, bitter gourd, green pea, beans, lentil, okra, sweet maize, broccoli, artichoke, etc. The third group (i.e., root, bulb, and tuber vegetables) includes carrot, garden beet, turnip, radish, rutabaga, parsnip potato, sweet potato, cassava, onion, celeriac, garlic, leek, shallot, (Dias 2019).

There are several human health benefits of vegetables including the antioxidants, natural colorants (e.g., carotenoids), vitamins, and minerals, as confirmed by several researchers (e.g., Ramya and Patel 2019; Dias 2019; Kumar et al. 2020). As essential source for human nutrition, vegetables should include the adequate and proper nutrients and vitamins for human diets, and production of biofortified vegetables sometimes is needed (**Figure 2**). Vegetables may have several phytochemicals, which are important for human health such as vitamin A, vitamin C (ascorbic acid), vitamin E (tocopherols), vitamin K, vitamin B9 (folate or folic acid), α-carotene, β-carotene, lycopene, xanthophylls, dietary fiber, flavonoids (anthocyanidin), and phenolic acids (**Table 1**).

4. Nano-biofortification of vegetables under stress

Nano-biofortification is a new biotechnological approach that has been used in enriching different crops with many essential nutrients in a nano-form to supply human diet with balanced diet (El-Ramady et al. 2021a). Nano biofortification can be achieved by applying essential nutrients (mainly Cu, Fe, Se and Zn) as nano-fertilizers using foliar or soil or hydroponics application (El-Ramady et al. 2021a, b). Vegetable crops are well-known with their short duration period of growth, which sometimes needs for 2-3 months. This very short growing period makes the biofortification process is more critical than other crops, which their growth may extend to one year or more. Therefore, the biofortification programs of vegetables are very critical and special case due to the short growth periods, the expected toxicity after applying higher doses of nutrient candidates, and growing under stress conditions (El-Ramady et al. 2021a). the following sub-sections will include some stress conditions like nutrient deficiency stress, and other stresses.

4.1 Under soil nutrient deficiency conditions

During the last years, some selected vegetable crops (i.e., broccoli, onion, pepper and eggplant) were grown successfullyunder the alkaline sandy soil conditions, which suffer from deficiency inavailable soil nutrient. At the same time, biological nano Se and its bulk form under different doses were foliar applied on these selectedprevious vegetable crops for biofortification program (**Tables 2-4**). The positive outcomes of these nano-applications ondifferent vegetables were identifiedi.e.,broccoli (Fawzy et al. 2023a), onion (Fawzy et al. 2023b), eggplant (Mahmoud et al. 2023), and pepper (unpublished data). The production of these vegetables significantly increased by increasing the applied doses of both bulk and nano-Se, with priority to bulk

Se (sodium selenate). The reason may back to the lower applied doses of nano-Se, whereas the higher doses (up to 100 ppm or more) were the best as reported by other crops such as banana (Shalaby et al. 2022a), tomato (Saffan et al. 2022), strawberry (El-Baily et al. 2023).

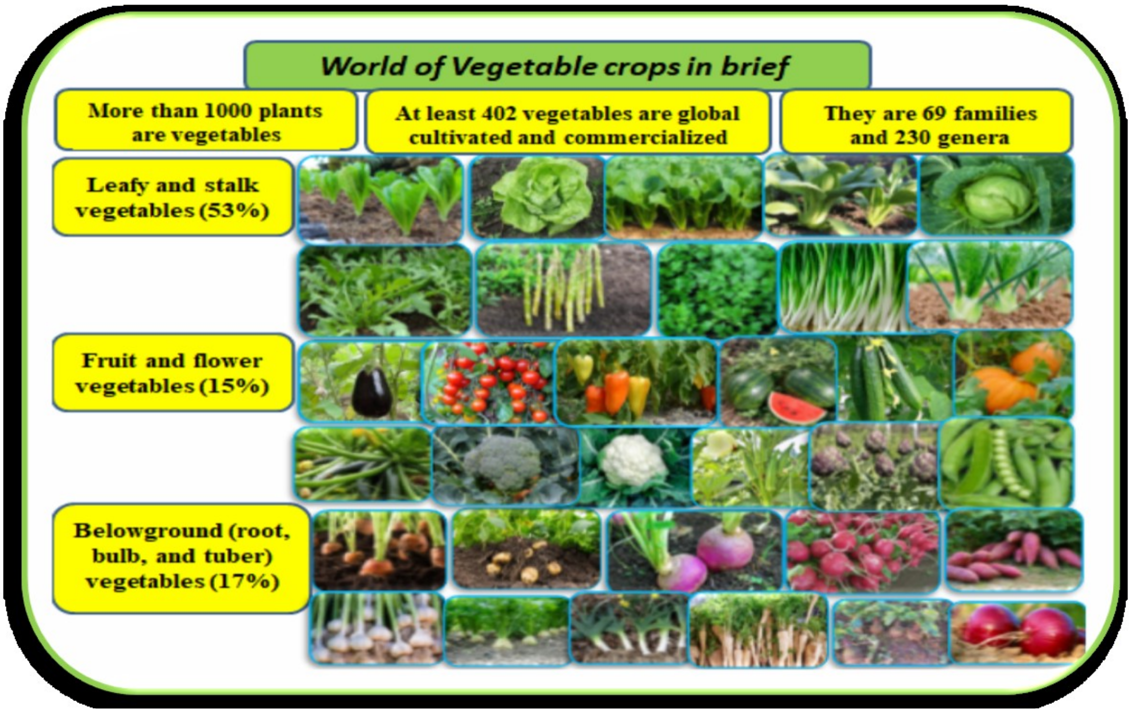

Fig. 1. A brief of the most common vegetables including the commercial and cultivated number, and the main classification of vegetable crops with some photos.

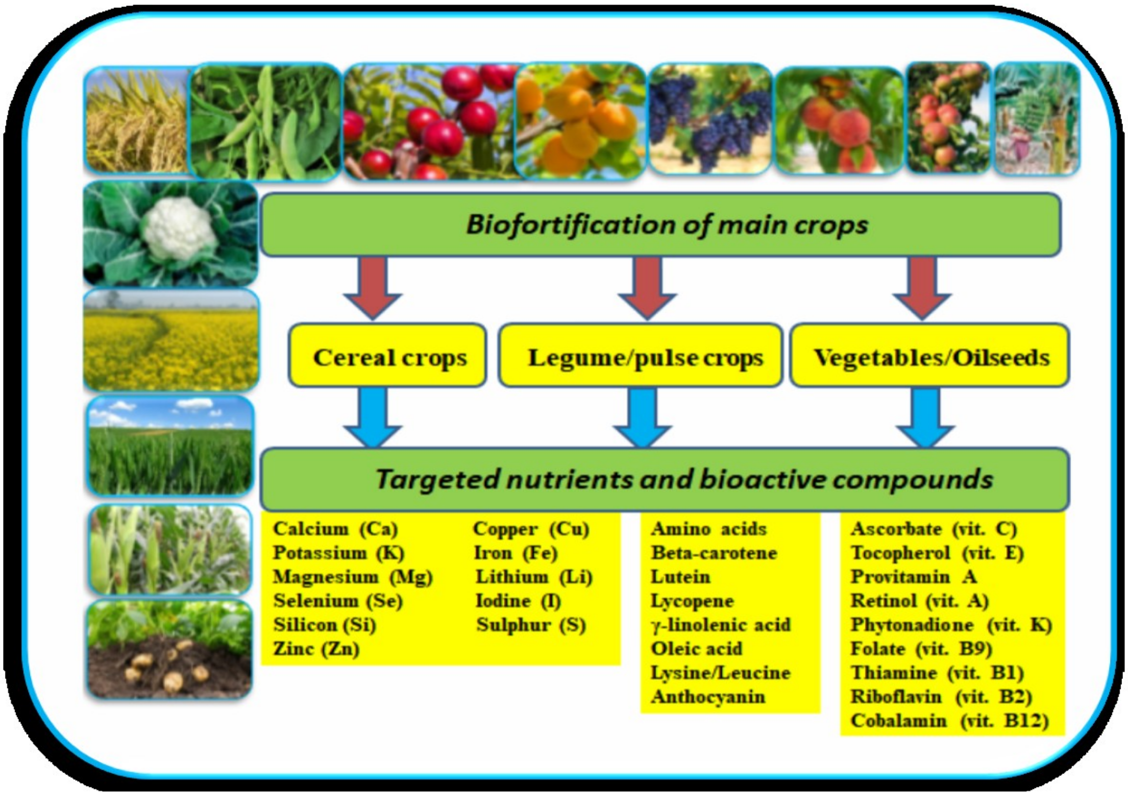

Fig. 2. The main targeted nutrients for biofortification, which could be applied in the biofortified crops (sources: Kaur et al. 2020; Lal et al. 2020; Mir et al. 2020).

Table 1. The main constituents of vegetables that have a positive impact on human health and their sources (adapted from Ramya and Patel 2019; Yahia et al. 2019; Kumar et al. 2020).

Phytochemicals	Function in human body	Sources of vegetables	Impacted human diseases
Vitamin A	Promotes growth, essential for vision, skin and human immune system	Pumpkin, carrot, sweet potato, pepper, and spinach	Heart diseases, cancer, and stroke
Vitamin C (ascorbic acid)	Improveswound and bone healing, strengthens blood vessels, and increases the absorption of iron	Broccoli, cabbage, pepper, pineapples, potato, strawberry, tomato, watermelon	Cardiovascular disease, healthy immune system, scurvy prevention, and wound healing
Vitamin E (tocopherols)	Acts as antioxidant to protect cells from the damage caused by free radicals	Lentil, chickpea, green leafy vegetables	Heartdisease, cancer, diabetes, and healthy immune system
Vitamin K	Helpsto make 4 of 13 proteins needed for blood clotting to stop wounds from continuously bleeding	Broccoli, Brussels sprouts, cabbage, green onions, lentil, and leafy greens	Osteoporosis, blood coagulation problem
VitaminB9 (folateor folic acid)	Importantin red blood cell formation and for healthy cell growth and function	Spinach, mustard greens, lettuce, okra, broccoli, Brussels sprouts	Birth defects, cancer, heart disease
α-Carotene	Acts as antioxidants, and enhances immune function	Broccoli, cabbage, carrot, green bean, kale, lettuce, spinach, squash, sweet potato	Cardiovasculardiseases and cancers, ischemic, stroke, tumor growth
β-Carotene	Acts as an antioxidantto protect the body from damaging free radicals; Beta carotene can convert into vitamin A	Broccoli, spinach, turnip greens; orange vegetables such as carrots, pumpkins, sweet potato	Cancer, cataracts, coronary artery disease, heart disease, night blindness prevention, provitamin A activity, psoriasis
Lycopene	Antioxidant can improve heart health and a lower risk of certain types of cancer	Tomato, watermelon, carrot, strawberry	Atherosclerosis, breast andprostate cancer, heart disease,male infertility
Xanthophylls	Protects human against phototoxic damage	Okra, spinach, summer squash, turnip greens, sweet corn	Atherosclerosis, cancer, macular degeneration
Dietary fiber	Important to maintain digestive health, as well as reduce blood cholesterol	Pea, Brusselssprouts, parsnips, broccoli	Diabetes, heart disease, colorectal cancer
Flavonoids (anthocyanidin)	Anticancer, antioxidant, anti-inflammatory, antiviral properties, neuroprotective and cardio-protective effects	Parsley, strawberry, red onion, celery, hot pepper, lettuce, garlic	Heart disease, cancer initiation, diabetes, cataracts, blood pressure, allergies
Phenolic acids	Antioxidants can avert the damage of cells resulted from free-radicals	Carrot, green chicory, mushrooms, eggplant, strawberry, potato	Endothelial dysfunction, cancer, anti-microbial, anti-inflammatory

Table 2. Response of the yield (ton fed^{-1}) of some vegetables to applied doses of Se-fertilizers cultivated in sandy soil (pH=8.25, EC= 0.85 dS m^{-1}, available N, P and K were 12, 4 and 35 mg kg^{-1} soil, respectively).

Applied doses of Se-fertilizers	Broccoli	Onion	Pepper	Eggplant
	(ton fed^{-1})			
Mineral Se-fertilizer (sodium selenite: Na_2SeO_3)				
Control	6.36 d	16.77c	7.42c	6.07c
10 ppm	7.82 c	28.04b	8.18b	7.04b
20 ppm	8.91 b	28.97b	8.99a	7.48b
30 ppm	10.00 a	34.62a	8.46b	8.46a
40 ppm	7.32 c	35.57a	8.17b	8.17a
Biological Nano Se-fertilizer				
Control	6.41 c	17.89c	5.92c	5.96b
10 ppm	7.47 b	26.85b	7.28b	6.65b
20 ppm	9.27 a	26.50b	8.09a	7.49a
30 ppm	9.45 a	33.01a	8.12a	8.12a
40 ppm	8.00 b	32.98a	7.49b	7.65a

The size of selenium nanoparticles was 87.7 nm using *Bacillus cereus* TAH as reported by Ghazi et al. (2022); fed = 4200 m^2 = acre.

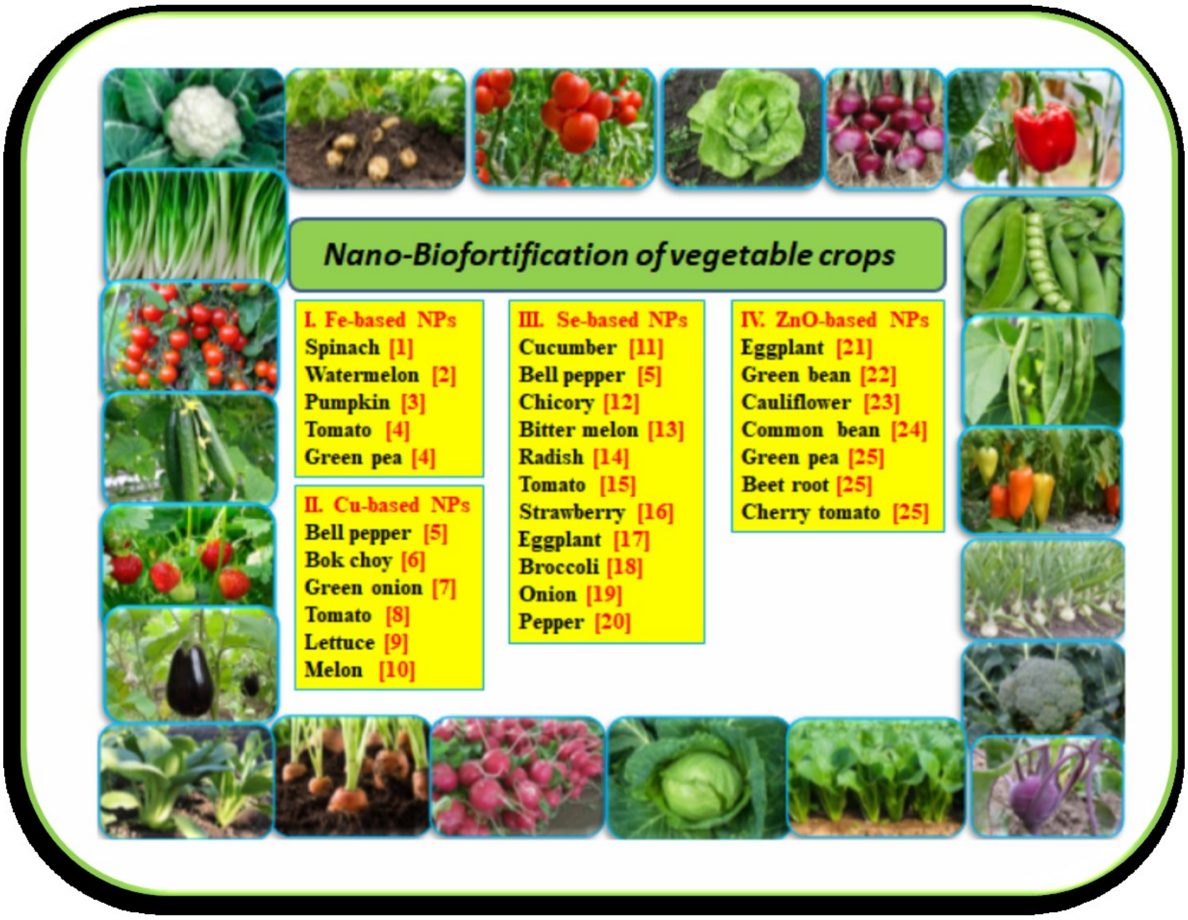

Fig. 3. List of some published studied on nano-biofortification on vegetable crops, where the list of refs. [1] Hossain and Bezbaruah (2021), [2] Li et al. (2013), [3] Zhu et al. (2008), [4] Cifuentes et al. (2010), [5] Gonzalez-García et al. (2021), [6] Deng et al. (2020), [7] Wang et al. (2020), [8] Hernandez-Hernandez et al. (2019), [9] Wang et al. (2019), [10] Fortis-Hernández et al. (2022), [11] Shalaby et al. (2021), [12] Abedi et al. (2021), [13] RajaeeBehbahani et al. (2020), [14] Huang et al. (2023), [15] Quiterio-Gutierrez et al. (2019), [16] El-Bialy et al. (2023), [17] Mahmoud et al. (2023), [18] Fawzy et al. (2023a), [19] Fawzy et al. (2023b), [20] Li et al. (2021), [21] Semida et al. (2021), [22] Skiba et al. (2020), [23] Raza et al. (2022), [24] Salama et al. (2019), [25] Obrador et al. (2022).

Table 3. Content of nutrients in edible parts of vegetables as response to applied Se-fertilizers cultivated in sandy soil (pH=8.25, EC= 0.85 dS m^{-1}, available N, P and K were 12, 4 and 35 mg kg^{-1} soil, respectively).

Applied doses of Se-fertilizers	Broccoli (heads)				Onion (bulbs)			
	N (%)	P (%)	K (%)	Se (ppm)	N (%)	P (%)	K (%)	Se (ppm)
Mineral Se-fertilizer (sodium selenite: Na_2SeO_3)								
Control	3.23 e	0.41 c	2.00 d	0.0000 e	0.67d	0.12	1.35d	0.0000d
10 ppm	3.50 d	0.61 b	2.18 cd	0.0013 d	0.71d	0.18	1.72c	0.0021c
20 ppm	3.84 c	0.73 a	2.34 c	0.0031 c	0.79c	0.26	1.78c	0.0040b
30 ppm	4.42 b	0.74 a	2.54 b	0.0078 b	1.05b	0.29	2.03b	0.0096a
40 ppm	5.02 a	0.81 a	2.77 a	0.0094 a	1.45a	0.36	2.29a	0.0109a
Biological nano Se-fertilizer								
Control	3.10 d	0.38 c	1.91 c	0.0000 d	0.56e	0.10	1.17c	0.0000d
10 ppm	3.53 c	0.55 b	2.15 b	0.0015 c	0.70d	0.15	1.38b	0.0022c
20 ppm	3.78 b	0.62 b	2.25 b	0.0017 c	0.79c	0.23	1.58b	0.0036c
30 ppm	3.99 b	0.71 a	2.42 ab	0.0043 b	0.87b	0.27	1.78ab	0.0052b
40 ppm	4.24 a	0.75 a	2.47 a	0.0061 a	1.05a	0.32	1.92a	0.0080a

The size of selenium nanoparticles was 87.7 nm using *Bacillus cereus* TAH as reported by Ghazi et al. (2022); fed = 4200 m^2 = acre.

Table 4. Content of nutrients in edible parts of vegetables as response to applied Se-fertilizers cultivated in sandy soil (pH=8.25, EC= 0.85 dS m^{-1}, available N, P and K were 12, 4 and 35 mg kg^{-1} soil, respectively).

Applied doses of Se-fertilizers	Pepper (fruits)				Eggplant (fruits)			
	N (%)	P (%)	K (%)	Se (ppm)	N (%)	P (%)	K (%)	Se (ppm)
Mineral Se-fertilizer (sodium selenite: Na_2SeO_3)								
Control	1.56d	0.34	1.25c	0.0000e	1.32d	0.41	0.94d	0.0000e
10 ppm	1.69c	0.40	1.52b	0.0039d	1.42c	0.51	1.09c	0.0029d
20 ppm	1.73c	0.45	1.58b	0.0049c	1.48c	0.59	1.14c	0.0043c
30 ppm	2.04b	0.51	1.75a	0.0066b	1.61b	0.63	1.39b	0.0069b
40 ppm	2.25a	0.71	1.85a	0.0098a	1.73a	0.74	1.70a	0.0101a
Biological nano Se-fertilizer								
Control	1.47c	0.29	1.19c	0.0000d	1.12c	0.38	0.72d	0.0000d
10 ppm	1.58c	0.37	1.28c	0.0021c	1.19bc	0.47	0.91c	0.0018c
20 ppm	1.65bc	0.39	1.48b	0.0044b	1.25b	0.59	1.03c	0.0032b
30 ppm	1.75b	0.43	1.55ab	0.0051b	1.38a	0.63	1.20b	0.0054a
40 ppm	1.92a	0.48	1.59a	0.0073a	1.39a	0.68	1.39a	0.0066a

The size of selenium nanoparticles was 87.7 nm using *Bacillus cereus* TAH as reported by Ghazi et al. (2022); fed = 4200 m^2 = acre.

4.2 Under salinity stress

In general, the main factors controlling the effectiveness of any biofortification program may include all information related to plant species (genotypes, and phenotypes), soil characteristics (mainly pH, salinity or EC, fertility or CEC, and texture), types of application (foliar, soil, hydroponics, seed priming), and forms/doses of applied nutrients and climatic conditions (Szerement et al. 2022). Salinity stress is considered one of the major environmental stresses, which decrease theproductivity of cultivate by more than 50%. Applying nano-Se, mitigates and enhances the production under suchstressful conditions (**Table 5**). The role of applied nano-Se for producing biofortified crops under salinity stress may depend on its applied dose, method of preparation, and plant species. It is found that, applied nano-Se can alleviate salt stress in plants by improving the plant growth, and photosynthesis, as well as reducing the oxidative stress in plants under salt stress. This effect mainly depends on the nano-size, doses, types, exposure time, and plants species (Etesami et al. 2021).

Table 5. Production of vegetables under salinity stress and applied nano-Se.

Biofortified vegetable	Applied nano-Se	Method of preparing	Salinity level	Growth media	Recommended applied dose	Reference
Cucumber	25 mg L^{-1}	Biological (41-87 nm)	Soil EC 4.49 dS m^{-1}	Saline soil	25 ppm	Shalaby et al. (2021)
Bell pepper	10 and 50 mg L^{-1}	Chemical (2–20 nm)	Solution 25 and 50 mM NaCl	Peat and perlite (1:1)	25 ppm	Gonzalez-García et al. (2021)
Tomato	From 1 to 20 mg L^{-1}	Chemical (2–20 nm)	Solution 50 mM NaCl	Peat and perlite (1:1)	20 ppm	Morales-Espinoza et al. (2019)
Strawberry	10 and 20 mg L^{-1}	Chemical (10–45 nm)	Saline soil (25, 50, 75 mM NaCl	Perlite, coco peat and sand (5:7:23)	20 ppm	Zahedi et al. (2019)

4.3 Nanotoxicity and biofortification

The program of biofortification should be very critical and precise because it may increasenutrient accumulationin cultivated plants when applied at higherdoses than the allowable onesof these nutrients. These phenomena are noticed after applying intensive nanomaterials or nanoparticles which induce phytotoxicity *via* producing excess reactive oxygen species and oxidative stress, and this in turnlead to imbalanced metabolic and biological processes in plants (Sharma et al. 2022). Therefore, there is an urgent need for the understanding of various biochemical and physiological responses of plants to nanotoxicity, evaluating phytotoxicity, and developing mitigation strategies for cultivated vegetable crops. Recently, a great concern on nanotoxicity can be noticed on different crops and nanomaterials/nanoparticles such as nanotoxicity of nano-applications in agriculture (Ali et al. 2021; Muthukrishnan 2022), graphite-derived nanomaterials (Wu et al. 2023), and the biomagnification and bioaccumulation of NPs in vegetables and their phytotoxicity, which may cause serious effects on human health (Sharma et al. 2022). The successful biofortification should depend on the following items:

(1) The applied recommended doses of nanonutrients can achieve positive impacts on plant growth of biofortified and edible plants (Gil-Díaz et al. 2022),
(2) The successful biofortification program could be also applied to reduce the uptake of toxic heavy metals (e.g., Cd, Pb, Hg) by cultivated plants when some nutrients applied like selenium (Sardar R, et al. 2022a, b; Shalaby et al. 2022b),
(3) Under higher applied doses of nanonutrients, toxic impacts on cultivated plants are expected and the toxic effects on plants may include different physiological, morphological, and genotoxic changes (Kumar et al. 2023). The toxic level differs from plant to other and may stimulate the regeneration of the oxidative stress (i.e., excess of free radicals or ROS), which disturbs the functions and stability of plant cells by affecting biomolecules including DNA, carbohydrates, protein, and membrane lipids (Sharma et al. 2022),
(4) The growing media are very important in this program whose characterization are crucial such as pH, salinity, available nutrients and application method (Almendros et al. 2022), as well as the forms, types of nanonutrients and the methods of their transmission into cultivated plants (Salama et al. 2021), and
(5) The main strategies to mitigate the nano-toxicity may represent in effective antioxidants, which are considered the better means to minimize this oxidative stress and reduce free radicals induced nanotoxicity (Sharma et al. 2022). Before this approach, the **4R Nutrient Stewardship** can be considered as a sustainable solution, which means "*apply the right source of nutrients at the right rate, at the right time, and in the right place*".

5. Conclusions

Biofortification is a promising tool for producing biofortified vegetable crops, especially nano selenium, which is essential for human health. Unlikely, not all essential nutrients for human nutrition can be biofortified in the nano-form using all edible plants but there are several obstacles that prevent this approach. Production of biofortified vegetables is a great mission, which is needed in different regions all over the world. This production can depend on the nano-forms of many nutrients, but the acceptable recommendation for different nano-nutrients and plant species still is an unattainable dream. The reason is simply back to the unknown recommendation applied dose of many needed nano-nutrients for vegetable production. This may cause application of higher doses, which can lead to nanotoxicity on cultivated plants, and their consumption humans is a serious for human health. On the other hand, nano-biofortification program for vegetable production can be applied under stressful conditions, but with a more concern on the production requirements. Therefore, mitigation strategies should be kept in mind to avoid the nano-phytotoxicity and associated negative impacts on human health. Several studies are needed concerning the nano-biofortification of vegetables under both stressful and non-stressful conditions.

Ethics approval and consent to participate: This article does not contain any studies with human participants or animals performed by any of the authors.
Consent for publication: All authors declare their consent for publication.
Funding: Authors would like to thank Science and technology assistance project to developing countries. Research and demonstration of key technologies about green and intelligent water-saving irrigation in arid area of Egypt, KY201904010. Furthermore, the Experimental Station for Research and Production of National Research Centre.
Conflicts of Interest: The author declares no conflict of interest.
Contribution of Authors: All authors shared in writing, editing and revising the MS and agree to its publication.
Acknowledgments: Authors would like to thank the Experimental Station for Research and Production of National Research Centre.

6. References

Abedi S., Iranbakhsh, A., Ardebili, Z.O., Ebadi M (2021). Nitric oxide and selenium nanoparticles confer changes in growth, metabolism, antioxidant machinery, gene expression, and flowering in chicory (*Cichorium intybus* L.): potential benefits and risk assessment. Environ. Sci. Pollut. Res. 28, 3136–3148. https://doi.org/10.1007/s11356-020-10706-2.

Ali SS, Al-Tohamy R, Koutra E, Moawad MS, Kornaros M, Mustafa AM, Mahmoud YAG, Badr A, Osman MEH, Elsamahy T, Jiao H, Sun J (2021). Nanobiotechnological advancements in agriculture and food industry: Applications, nanotoxicity, and future perspectives. Science of The Total Environment, 792, 148359.https://doi.org/10.1016/j.scitotenv.2021.148359.

Almendros P, González D, Fernández MD, García-Gomez C, Obrador A (2022). Both Zn biofortification and nutrient distribution pattern in cherry tomato plants are influenced by the application of ZnO nanofertilizer. Heliyon, 8, Issue 3, e09130. https://doi.org/10.10 16/j.heliyon.2022.e09130.

Barman F, Kundu R (2023). Foliar application of selenium affecting pollen viability, grain chalkiness, and transporter genes in cadmium accumulating rice cultivar: A pot study. Chemosphere, 313, 137538. https://doi.org/10.1016/j.chemosphere.2022.137538.

Bechoff A, de Bruyn J, Alpha A, Wieringa F, Greffeuille V (2023). Exploring the complementarity of fortification and dietary diversification to combat micronutrient deficiencies: A scoping review. Current Developments in Nutrition, 100033. https://doi.org/10.1016/j.cdnut.2023.100033.

ButuriCV, Mauro RP, Fogliano V, Leonardi C, Giuffrida F (2023). Iron and zinc biofortification and bioaccessibility in carrot 'Dordogne': Comparison between foliar applications of chelate and sulphate forms. Scientia Horticulturae, 312, 111851. https://doi.org/10.1016/j.scienta.2023.111851.

Cao Y, Ma C, Yu H, Tan Q, Dhankher OP, White JC, Xing B (2023). The role of sulfur nutrition in plant response to metal(loid) stress: Facilitating biofortification and phytoremediation. Journal of Hazardous Materials, 443, Part B, 130283. https://doi.org/10.1016/j.jhazmat.2022.130283.

Chen Y, Mi H, Zhang Y, Zhang G, Li C, Ye Y, Zhang R, Shi J, Li Z, Tian X, Wang Y (2022). Impact of $ZnSO_4$ and ZnEDTA applications on wheat Zn biofortification, soil Zn fractions and bacterial community: Significance for public health and agroecological environment. Applied Soil Ecology, 176, 104484. https://doi.org/10.1016/j.apsoil.2022.104484.

Cheng B, Wang C, Yue L, Chen F, Cao X, Lan Q, Liu T, Wang Z (2023). Selenium nanomaterials improve the quality of lettuce (*Lactuca sativa* L.) by modulating root growth, nutrient availability, and photosynthesis. NanoImpact, 29, 100449. https://doi.org/10.1016/j.impact.2022.100449.

Cifuentes Z, Custardoy L, de la Fuente JM, Marquina C, Ibarra MR, Rubiales D, Pérez-de-Luque A (2010) Absorption and translocation to the aerial part of magnetic carbon-coated nanoparticles through the root of different crop plants. Journal of Nanobiotechnology 8, 26. doi:10.1186/1477-3155-8-26.

Cipriano PE, da Silva RF, de Lima FRD, de Oliveira C, de Lima AB, Celante G, Dos Santos AA, Archilha MVLR, Pinatto-Botelho MF, Faquin V, Guilherme LRG (2022). Selenium biofortification via soil and its effect on plant metabolism and mineral content of sorghum plants. Journal of Food Composition and Analysis, 109, 104505. https://doi.org/10.1016/j.jfca.2022.104505.

Dai H, Wei S, Twardowska I (2020). Biofortification of soybean (*Glycine max* L.) with Se and Zn, and enhancing its physiological functions by spiking these elements to soil during flowering phase. Science of The Total Environment, 740, 139648. https://doi.org/10.1016/j.scitotenv.2020.139648.

De Lepeleire J, Strobbe S, Verstraete J, Blancquaert D, Ambach L, Visser RGF, Stove C, Van Der Straeten D (2018). Folate Biofortification of Potato by Tuber-Specific Expression of Four Folate Biosynthesis Genes. Molecular Plant, 11 (1), 175-188. https://doi.org/10.1016/j.molp.2017.12.008.

Deng, C., Wang, Y., Cota-Ruiz, K., Reyes, A., Sun, Y., Peralta-Videa, J., HernandezViezcas, J.A., Turley, R.S., Niu, G., Li, C., Gardea-Torresdey, J (2020). Bok choy (*Brassica rapa*) grown in copper oxide nanoparticles-amended soils exhibits toxicity in a phenotype-dependent manner: translocation, biodistribution and nutritional disturbance. J. Hazard. Mater. 398, 122978. https://doi.org/10.1016/j. jhazmat.2020.122978.

Dias JS (2019). Nutritional Quality and Effect on Disease Prevention of Vegetables. In: IntechOpen, pp: 1 – 30. DOI: http://dx.doi.org/10.5772/intechopen.85038.

El-Badri AM, Batool M, Mohamed IAA, Wang Z, Wang C, Tabl KM, Khatab A, Kuai J, Wang J, Wang B, Zhou G (2022). Mitigation of the salinity stress in rapeseed(*Brassica napus* L.) productivity by exogenous applications of bio-selenium nanoparticles during the early seedling stage. Environmental Pollution, 310, 119815. https://doi.org/10.1016/j.envpol.2022.119815.

El-Bialy, S.M.; El-Mahrouk, M.E.; Elesawy, T.; Omara, A.E.-D.; Elbehiry, F.; El-Ramady, H.; Áron, B.; Prokisch, J.; Brevik, E.C.; Solberg, S.Ø (2023). Biological Nanofertilizers to Enhance Growth Potential of Strawberry Seedlings by Boosting Photosynthetic Pigments, Plant Enzymatic Antioxidants, and Nutritional Status. Plants, 12, 302. https://doi.org/10.3390/plants12020302.

El-Ramady H, Abdalla N, Heba Elbasiouny, Fathy Elbehiry, Tamer Elsakhawy, Alaa El-Dein Omara, Megahed Amer, YousryBayoumi, Tarek A. Shalaby, Yahya Eid, Muhammad Zia-ur- Rehman M (2021a). Nano-biofortification of different crops to immune against COVID-19: A review. Ecotoxicology and Environmental Safety, 222, 112500. https://doi.org/10.1016/j.ecoenv.2021.112500.

El-Ramady H, El-Mahdy S, Awad A, Nassar S, Osman O, Metwally E, Aly E, Fares E, El-Henawy A (2021b). Is Nano-Biofortification the Right Approach for Malnutrition in the Era of COVID-19 and Climate change? Egypt. J. Soil. Sci. 61 (2), 161-173. DOI: 10.21608/ejss.2021.75653.1445.

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, Brevik EC (2020). Selenium and nano-selenium biofortification for human health: opportunities and challenges. Soil Systems 4:57. https://doi.org/10.3390/soilsystems4030057

El-Ramady H, Omara AED, El-Sakhawy T, Prokisch J, Brevik EC (2022a). Sources of Selenium and Nano-Selenium in Soils and Plants. In: M. A. Hossain et al. (eds.), Selenium and Nano-Selenium in Environmental Stress Management and Crop Quality Improvement, Sustainable Plant Nutrition in a Changing World, https://doi.org/10.1007/978-3-031-07063-1_1, pp: 1 – 24. Springer Nature Switzerland AG.

El-Ramady H, Omara AED, El-Sakhawy T, Prokisch J, Brevik EC (2022b). Selenium and Nano-Selenium for Plant Nutrition and Crop Quality. In: M. A. Hossain et al. (eds.), Selenium and Nano-Selenium in

Environmental Stress Management and Crop Quality Improvement, Sustainable Plant Nutrition in a Changing World, World, https://doi.org/10.1007/978-3-031-07063-1_4, pp: 55 – 78. Springer Nature Switzerland AG.

El-Saadony MT, Saad AM, Najjar AA, Alzahrani SO, Alkhatib FM, Shafi ME, Selem E, Desoky EM, Fouda SEE, El-Tahan AM, Hassan MAA (2021). The use of biological selenium nanoparticles to suppress *Triticum aestivum* L. crown and root rot diseases induced by *Fusarium* species and improve yield under drought and heat stress. Saudi Journal of Biological Sciences, 28, 8, 4461-4471. https://doi.org/10.1016/j.sjbs.2021.04.043.

Etesami H, Fatemi H, Rizwan M (2021). Interactions of nanoparticles and salinity stress at physiological, biochemical and molecular levels in plants: A review. Ecotoxicology and Environmental Safety, 225, 112769. https://doi.org/10.1016/j.ecoenv.2021.112769.

Fawzy ZF, El-Bassiony AM, El-Ramady H, El-Sawy SM, Shedeed SI, Mahmoud SH (2023b). Onion Biofortification Using Selenium Bionanofertilizer and its Bulk Source under Sandy Soil Conditions.

FawzyZF, El-Bassiony AM, El-Ramady H, El-Sawy SM, Shedeed SI, Sami H. Mahmoud SH (2023a). Broccoli Biofortification Using Biological Nano- and Mineral Fertilizers of Selenium: A Comparative Study under Soil Nutrient Deficiency Stress. Egypt. J. Soil Sci. Vol. 63, No. 1, 57 – 66. DOI: 10.21608/EJSS.2022.176648.1553

Fitzpatrick TB, Chapman LM (2020). The importance of thiamine (vitamin B1) in plant health: From crop yield to biofortification. Journal of Biological Chemistry, 295, (34), 12002-12013. https://doi.org/10.1074/jbc.REV120.010918.

Fortis-Hernández M, Jaime O, Pablo P, Radames T, Erika L, Alfonso A, Edgar O (2022). Biofortification with copper nanoparticles (Nps Cu) and its effect on the physical and nutraceutical quality of hydroponic melon fruits. NotulaeBotanicae Horti Agrobotanici Cluj-Napoca 50 (1), 12568. DOI:10.15835/nbha50112568

Ghazi AA, El-Nahrawy S, El-Ramady H, Ling W (2022). Biosynthesis of Nano-Selenium and Its Impact on Germination of Wheat under Salt Stress for Sustainable Production. Sustainability, 14, 1784. https://doi.org/10.3390/su14031784

Gil-Díaz M, García-Gonzalo P, Mancho C, Hernández LE, Alonso J, Lobo MC (2022). Response of spinach plants to different doses of two commercial nanofertilizers. Scientia Horticulturae, 301, 111143. https://doi.org/10.1016/j.scienta.2022.111143.

Gonzalez-García, Y., Cardenas- ´ Alvarez, ´ C., Cadenas-Pliego, G., Benavides-Mendoza, A., Cabrera-de-la-Fuente, M., Sandoval-Rangel, A., Vald´es-Reyna, J, Juarez-Maldonado A (2021). Effect of three nanoparticles (Se, Si and Cu) on the bioactive compounds of bell pepper fruits under saline stress. Plants 10 (2), 217. https://doi.org/10.3390/plants10020217.

Groth S, Budke C, Weber T, Oest M, Brockmann S, Holz M, Daum D, Sascha Rohn S (2021). Selenium biofortification of different varieties of apples (*Malus domestica*) – Influence on protein content and the allergenic proteins Mal d 1 and Mal d 3. Food Chemistry, 362, 130134. https://doi.org/10.1016/j.foodchem.2021.130134.

Hernandez-Hernandez, H., Quiterio-Gutierrez, T., Cadenas-Pliego, G., Ortega-Ortiz, H., Hernandez-Fuentes, ´ A.D., de la Fuente, M.C., Valdes-Reyna, J., Ju´ arezMaldonado, A., (2019). Impact of selenium and copper nanoparticles on yield, antioxidant system, and fruit quality of tomato plants. Plants 8, 355.

Hossain ME, Bezbaruah AN (2021). Nano- and microscale iron for Fe fortification in *Spinacia oleracea*. Nanotechnol. Environ. Engin. 6, 61 https://doi.org/10.1007/s41204-021-00132-1.

Huang S, Yu K, Xiao Q, Song B, Yuan W, Long X, Cai D, Xiong X, Wei Zheng W (2023). Effect of bio-nano-selenium on yield, nutritional quality and selenium content of radish. Journal of Food Composition and Analysis, 115, 104927. https://doi.org/10.1016/j.jfca.2022.104927.

Izydorczyk G, Ligas B, Mikula K, Witek-Krowiak A, Moustakas K, Chojnacka K (2021). Biofortification of edible plants with selenium and iodine – A systematic literature review. Sci Total Environ, 754, 141983. https://doi.org/10.1016/j.scitotenv.2020.141983.

Jiang L, Strobbe S, Van Der Straeten D, Zhang C (2021). Regulation of Plant Vitamin Metabolism: Backbone of Biofortification for the Alleviation of Hidden Hunger. Molecular Plant, 14 (1), 40-60. https://doi.org/10.1016/j.molp.2020.11.019.

Joshi S.M., De Britto S., Jogaiah S (2021). Myco-engineered selenium nanoparticles elicit resistance against tomato late blight disease by regulating differential expression of cellular, biochemical and defense responsive genes. J. Biotechnol., 325, 196-206, DOI: 10.1016/j.jbiotec.2020.10.023

Kamali-Andani N, Fallah S, Peralta-Videa JR, Golkar P (2023). Selenium nanoparticles reduce Ce accumulation in grains and ameliorate yield attributes in mung bean (*Vigna radiata*) exposed to CeO_2. Environmental Pollution, 316, Part 2, 120638. https://doi.org/10.1016/j.envpol.2022.120638.

Kang L, Wu Y, Zhang J, An Q, Zhou C, Li D, Pan C (2022). Nano-selenium enhances the antioxidant capacity, organic acids and cucurbitacin B in melon (*Cucumis melo* L.) plants. Ecotoxicology and Environmental Safety, 241, 113777. https://doi.org/10.1016/j.ecoenv.2022.113777.

Kaur S, Kumari A, Singh P, Kaur L, Sharma N, Garg M (2020). Biofortification in Pulses. In: Sharma et al. (eds.), Advances in Agri-Food Biotechnology, https://doi.org/10.1007/978-981-15-2874-3_4, pp: 58 – 104. Springer Nature Singapore Pte Ltd.

Kiran K (2020). Advanced Approaches for Biofortification. In: Sharma et al. (eds.), Advances in Agri-Food Biotechnology, https://doi.org/10.1007/978-981-15-2874-3_2, pp: 29 – 55. Springer Nature Singapore Pte Ltd.

Kumar D, Kumar S, Bhadana NK, Singh B, Shekhar C (2020). Vegetables: Source of adequate health benefits. Annals of Horticulture 13 (2), 124-130. DOI: 10.5958/0976-4623.2020.00023.7.

Kumar N, Samota SR, Venkatesh K, Tripathi SC (2023). Global trends in use of nano-fertilizers for crop production: Advantages and constraints – A review. Soil and Tillage Research, 228, 105645. https://doi.org/10.1016/j.still.2023.105645.

Lal MK, Kumar A, Kardile HB, Raigond P, Changan SS, Thakur N, Dutt S, Tiwari RK, Chourasia KN, Kumar D, Singh B (2020). Biofortification of Vegetables. In: Sharma et al. (eds.), Advances in Agri-Food Biotechnology, https://doi.org/10.1007/978-981-15-2874-3_5, pp: 105 – 129. Springer Nature Singapore Pte Ltd.

Lanza M., Silva V.M., Montanha G.S., Lavres J., Pereira de Carvalho H.W., Reis A.R.D (2021). Assessment of selenium spatial distribution using mu-XFR in cowpea (*Vigna unguiculata* (L.) Walp.) plants: Integration of physiological and biochemical responses. Ecotoxicol. Environ. Saf., 207. DOI: 10.1016/j.ecoenv.2020.111216.

Li C, Guo Z, Wang X, Ma Y, Liu J, Shi M, Zhang D, Malhi SS, Siddique KHM, Zhaohui Wang Z (2023). Field-scale studies quantify limitations for wheat grain zinc biofortification in dryland areas. European Journal of Agronomy, 142, 126687. https://doi.org/10.1016/j.eja.2022.126687.

Li D, Zhou C, Ma J, Wu Y, Kang L, An Q, Zhang J, Deng K, Li JQ, Pan C (2021). Nanoselenium transformation and inhibition of cadmium accumulation by regulating the lignin biosynthetic pathway and plant hormone signal transduction in pepper plants. l. J Nanobiotechnol 19, 316. https://doi.org/10.1186/s12951-021-01061-6

Li J, Chang PR, Huang J, Wang Y, Yuan H, Ren H (2013). Physiological effects of magnetic iron oxide nanoparticles towards watermelon. Journal of Nanoscience and Nanotechnology 13, 5561–5567. doi:10.1166/jnn.2013.7533

Liu R, Deng Y, Zheng M, Liu Y, Wang Z, Yu S, Nie Y, Zhu W, Zhou Z, Diao J (2022). Nano selenium repairs the fruit growth and flavor quality of tomato under the stress of penthiopyrad. Plant Physiology and Biochemistry, 184, 126-136. https://doi.org/10.1016/j.plaphy.2022.05.026.

Mahmoud S, et al. (2023). Biological Nano-Selenium for Eggplant Biofortification under Soil Nutrient Deficiency. Egypt. J. Soil Sci. Vol. 63, No. 2, pp: 83 - 100 .

Medrano-MacíasJ, Narvaéz-Ortiz WA (2022). Selenium and Nano-Selenium as a New Frontier of Plant Biostimulant. In: M. A. Hossain et al. (eds.), Selenium and Nano-Selenium in Environmental Stress Management and Crop Quality Improvement, Sustainable Plant Nutrition in a Changing World, World, https://doi.org/10.1007/978-3-031-07063-1_3, pp: 41 – 54. Springer Nature Switzerland AG

Mir ZA, Yadav P, Ali S, Sanand S, Mushtaq M, Bhat JA, Tyagi A, Upadhyay D, Singh A, Grover A (2020). Transgenic Biofortified Crops: Applicability and Challenges. In: Sharma et al. (eds.), Advances in Agri-Food Biotechnology, https://doi.org/10.1007/978-981-15-2874-3_7, pp: 153 – 172. Springer Nature Singapore Pte Ltd.

Monika G, Kim SRM, Kumar PS, Gayathri KV, Rangasamy G, Saravanan A (2023). Biofortification: A long-term solution to improve global health- a review. Chemosphere, 314, 137713. https://doi.org/10.1016/j.chemosphere.2022.137713.

Morales-Espinoza, M.C., Cadenas-Pliego, G., Perez-Alvarez, M., Hernandez-Fuentes, A.D., de la Fuente, M.C., Benavides-Mendoza, A., Valdes-Reyna, J., Juarez-Maldonado A (2019). Se nanoparticles induce changes in the growth, antioxidant responses, and fruit quality of tomato developed under NaCl stress. Molecules 24, 3030.

Morelli L, Rodriguez-Concepcion M (2023). Open avenues for carotenoid biofortification of plant tissues. Plant Communications, 4 (1), 100466. https://doi.org/10.1016/j.xplc.2022.100466.

Msungu SD, Mushongi AA, Venkataramana PB, Mbega ER (2022). A review on the trends of maize biofortification in alleviating hidden hunger in sub-Sahara Africa. Scientia Horticulturae, 299, 111029. https://doi.org/10.1016/j.scienta.2022.111029.

Muthukrishnan L (2022). An overview on the nanotechnological expansion, toxicity assessment and remediating approaches in Agriculture and Food industry. Environmental Technology & Innovation, 25, 102136. https://doi.org/10.1016/j.eti.2021.102136.

Naeem A, Aslam M, Saifullah, Mühling KH (2021). Lithium: Perspectives of nutritional beneficence, dietary intake, biogeochemistry, and biofortification of vegetables and mushrooms. Sci Total Environ, 798, 149249. https://doi.org/10.1016/j.scitotenv.2021.149249.

Obrador A, González D, Almendros P, García- Gómez C, Dolores Fernández M (2022). Assessment of Phytotoxicity and Behavior of 1-Year-Aged Zn in Soil from ZnO Nanoparticles, Bulk ZnO, and Zn Sulfate in Different Soil Plant Cropping Systems: from

Biofortification to Toxicity. Journal of Soil Science and Plant Nutrition 22, 150–164.

Pessoa CC, Lidon FC, Coelho ARF, Caleiro JC, Marques AC, Luís IC, Kullberg, et al. (2021). Calcium biofortification of Rocha pears, tissues accumulation and physicochemical implications in fresh and heat-treated fruits. Scientia Horticulturae, 277, 109834. https://doi.org/10.1016/j.scienta.2020.109834.

Praus L, Száková J, Steiner O, Goessler W (2019). Rapeseed (*Brassica napus* L.) biofortification with selenium: How do sulphate and phosphate influence the efficiency of selenate application into soil? Archives of Agronomy and Soil Science, 65:14, 2059-2072. DOI: 10.1080/03650340.2019.1592163

Quiterio-Gutierrez T., Ortega-Ortiz, H., Cadenas-Pliego, G., Hernandez-Fuentes, A.D., Sandoval-Rangel, A., Benavides-Mendoza, A., la Fuente, M., Juarez-Maldonado, A (2019). The application of selenium and copper nanoparticles modifies the biochemical responses of tomato plants under stress by *Alternaria solani*. Int. J. Mol. Sci. 20, 1950.

RajaeeBehbahaniS, Iranbakhsh, A., Ebadi, M., Majd, A., Ardebili, ZO (2020). Red elemental selenium nanoparticles mediated substantial variations in growth, tissue differentiation, metabolism, gene transcription, epigenetic cytosine DNA methylation, and callogenesis in bitter melon (*Momordica charantia*); an *in vitro* experiment. PLOS One 15 (7), e0235556. https://doi.org/10.1371/journal.pone.0235556.

Ramya V and Patel P (2019). Health benefits of vegetables. International Journal of Chemical Studies 7(2), 82-87.

Rani A, Panwar A, Sathe M, Chandrashekhara KA, Kush A (2018). Biofortification of safflower: an oil seed crop engineered for ALA-targeting better sustainability and plant-based omega-3 fatty acids. Transgenic Res. 27(3), 253-263. Doi: 10.1007/s11248-018-0070-5.

Raza, S.H., Shahzadi, A., Iqbal, M. et al. (2022). Foliar application of nano-zinc oxide crystals improved zinc biofortification in cauliflower (*Brassica oleracea* L. var. botrytis). Appl Nanosci 12, 1803–1813 https://doi.org/10.1007/s13204-022-02455-0

Saffan, M.M.; Koriem, M.A.; El-Henawy, A.; El-Mahdy, S.; El-Ramady, H.; Elbehiry, F.; Omara, A.E.-D.; Bayoumi, Y.; Badgar, K.; Prokisch, J. Sustainable Production of Tomato Plants (*Solanum lycopersicum* L.) under Low-Quality Irrigation Water as Affected by Bio-Nanofertilizers of Selenium and Copper. Sustainability 2022, 14, 3236.

Salama DM, Abd El-Aziz ME, Rizk FA, Abd Elwahed MSA (2021). Applications of nanotechnology on vegetable crops. Chemosphere, 266, 129026. https://doi.org/10.1016/j.chemosphere.2020.129026.

Salama DM, Osman, S.A., Abd El-Aziz, M.E., Abd Elwahed, M.S.A., Shaaban EA (2019). Effect of zinc oxide nanoparticles on the growth, genomic DNA, production and the quality of common dry bean (*Phaseolus vulgaris*). Biocatal. Agric. Biotechnol. 11, 101083.

Sardar R, Ahmed S, Shah AA, Yasin NA (2022a). Selenium nanoparticles reduced cadmium uptake, regulated nutritional homeostasis and antioxidative system in *Coriandrum sativum* grown in cadmium toxic conditions. Chemosphere, 287, Part 3, 132332. https://doi.org/10.1016/j.chemosphere.2021.132332.

Sardar R, Shakil Ahmed, Nasim Ahmad Yasin NA (2022b). Titanium dioxide nanoparticles mitigate cadmium toxicity in *Coriandrum sativum* L. through modulating antioxidant system, stress markers and reducing cadmium uptake. Environmental Pollution, 292, Part A, 118373. https://doi.org/10.1016/j.envpol.2021.118373.

SeliemMK, Hafez YM, El-Ramady HR (2020). Using Nano—Selenium in Reducing the Negative Effects of High Temperature Stress on *Chrysanthemum morifolium*Ramat. J. Sustain. Agric. Sci., 46, 47–59.

SemidaW.M., Abdelkhalik, A., Mohamed, G.F., Abd El-Mageed, T.A., Abd El-Mageed, S. A., Rady, M.M., Ali EF (2021). Foliar application of zinc oxide nanoparticles promotes drought stress tolerance in eggplant (*Solanum melongena* L.). Plants 10 (2), 421. https://doi.org/10.3390/plants10020421.

Shalaby TA, Abd-Alkarim E, El-Aidy F, Hamed E, Sharaf-Eldin M, Taha N, El-Ramady H, Bayoumi Y, André Rodrigues dos Reis AR (2021). Nano-selenium, silicon and H_2O_2 boost growth and productivity of cucumber under combined salinity and heat stress. Ecotoxicology and Environmental Safety, 212, 111962. https://doi.org/10.1016/j.ecoenv.2021.111962.

Shalaby TA, El-Bialy SM, El-Mahrouk ME, Omara AE-D, El-Beltagi HS, El-Ramady H (2022a). Acclimatization of *In Vitro* Banana Seedlings Using Root-Applied Bio-Nanofertilizer of Copper and Selenium. Agronomy 12, 539. https://doi.org/10.3390/agronomy12020539

Shalaby, T.A.; Bayoumi, Y.; Eid, Y.; Elbasiouny, H.; Elbehiry, F.; Prokisch, J.; El-Ramady, H.; Ling, W (2022b). Can Nanofertilizers Mitigate Multiple Environmental Stresses for Higher Crop Productivity? Sustainability, 14, 3480.

Sharma S, Shree B, Aditika, Sharma A, Irfan M, Kumar P (2022). Nanoparticle-based toxicity in perishable vegetable crops: Molecular insights, impact on human health and mitigation strategies for sustainable cultivation. Environmental Research, 212, Part A, 113168. https://doi.org/10.1016/j.envres.2022.113168.

Shukla UN, Mishra ML, Meena RS, Kumar S, Sheoran S, Bedwal S, Jangir CK, Khan N, Sheoran S (2022). Recent strategies for pulse biofortification to combat malnutrition. In: Ram Swaroop Meena, Sandeep

Kumar (Eds.), Advances in Legumes for Sustainable Intensification, Academic Press, Pp: 179-204. https://doi.org/10.1016/B978-0-323-85797-0.00023-9.

Skiba E., Michlewska, S., Pietrzak, M., Wolf WM (2020). Additive interactions of nanoparticulate ZnO with copper, manganese and iron in *Pisum sativum* L., a hydroponic study. Sci. Rep. 10, 13574. https://doi.org/10.1038/s41598-020-70303-8.

SperançaMA, Mayorquín-Guevara JE, da Cruz MCP, Teixeira GHA, FabíolaManhasVerbi Pereira FMV (2021). Biofortification quality in bananas monitored by energy-dispersive X-ray fluorescence and chemometrics. Food Chemistry, 362, 130172. https://doi.org/10.1016/j.foodchem.2021.130172.

Sun X, Wang Y, Han G, Ye S, Zhou X (2020). Effects of different selenium forms on selenium accumulation, plant growth, and physiological parameters of wild peach. South African Journal of Botany, 131, 437-442. https://doi.org/10.1016/j.sajb.2020.03.038.

Szerement J, Szatanik- Kloc A, Mokrzycki J, Mierzwa- Hersztek M (2022). Agronomic Biofortifcation with Se, Zn, and Fe: An Efective Strategy to Enhance Crop Nutritional Quality and Stress Defense—A Review. Journal of Soil Science and Plant Nutrition 22, 1129–1159.

Wang M, Wang Y, Ge C, Wu H, Jing F, Wu S, Li H, Zhou D (2023). Foliar Selenium Nanoparticles Application Promotes the Growth of Maize (*Zea mays* L.) Seedlings by Regulating Carbon, Nitrogen and Oxidative Stress Metabolism. Scientia Horticulturae, 311,

Wang, Y., Lin, Y., Xu, Y., Yin, Y., Guo, H., Du, W (2019). Divergence in response of lettuce (var. ramosa Hort.) to copper oxide nanoparticles/microparticles as potential agricultural fertilizer. Environ. Pollut. Bioavailab. 31, 80–84. https://doi.org/10.1080/26395940.2019.1578187.

Wu Q, Fan C, Wang H, Han Y, Tai F, Wu J, Li H, He R (2023). Biphasic impacts of graphite-derived engineering carbon-based nanomaterials on plant performance: Effectiveness vs. nanotoxicity. Advanced Agrochem, https://doi.org/10.1016/j.aac.2023.01.001.

Yahia EM, García-Solís P, Celis MEM (2019). Contribution of Fruits and Vegetables to Human Nutrition and Health. In: Yahia (Ed.), Postharvest Physiology and Biochemistry of Fruits and Vegetables, pp: 19–45. Doi:10.1016/b978-0-12-813278-4.00002-6

Yan H, Pengfei W, Brennan H, Ping Q, Bingxiang L, Feiyan Z, Hongbo C, Haijiang C (2020). Diversity of carotenoid composition, sequestering structures and gene transcription in mature fruits of four *Prunus* species. Plant Physiology and Biochemistry, 151, 113-123. https://doi.org/10.1016/j.plaphy.2020.03.015.

Zahedi SM, Abdelrahman M, Hosseini MS, Hoveizeh NF, Tran LP (2019). Alleviation of the effect of salinity on growth and yield of strawberry by foliar spray of selenium-nanoparticles. Environ. Pollut. 253, 246–258.

Zhu H, Han J, Xiao JQ, Jin Y (2008). Uptake, translocation, and accumulation of manufactured iron oxide nanoparticles by pumpkin plants. J Environ Monit. 10(6), 713-7. Doi: 10.1039/b805998e.

Zhu Y, Dong Y, Zhu N, Jin H (2022). Foliar application of biosynthetic nano-selenium alleviates the toxicity of Cd, Pb, and Hg in *Brassica chinensis* by inhibiting heavy metal adsorption and improving antioxidant system in plant. Ecotoxicology and Environmental Safety, 240, 113681. https://doi.org/10.1016/j.ecoenv.2022.113681.