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Review

Uses of Selenium Nanoparticles in the Plant Production

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Abstract: Plant production today depends on the ability of agriculturists to transport and recycle minerals, particularly those minerals which are nutritionally important to animals and human beings, through various agriculture products. It is important to note that the attenuation of these mineral deposits by green plants, as well as their subsequent role in the production of organic compounds, is fundamental to almost all known forms of life. Selenium (Se) is among those trace mineral which are crucial for the maintenance of plant physiology. The significance, production, and biological effects of this element, as well as its application in sustainable development, are remaining an interesting topic of discussion. Moreover, there has been a huge rise in the potential applications of nanotechnology in the food and agriculture industries. Several studies have been conducted on the various biological activities of selenium nanoparticles (SeNPs) and their biosynthesis. There is plenty of research performed on the effects of Se in plant nutrition and physiology, but there is a lack of information about the effects of SeNPs in SeNPs toxicity, and other aspects of using SeNPs in agriculture. The current review is focused on recent information related to the effects and fate of SeNPs in agronomy. We also aimed attention at the primary sources and behavior of Se in different environments, such as soil, water, air, and plants. All the data provides an extremely fertile domain for future investigation and research.

Keywords: selenium; nanoparticles; plant nutrition; agriculture

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1. Introduction

Selenium (Se) is a common trace metalloid found in the Earth's crust. In 1817, chemist Jacob Berzelius isolated it for the first time, and since then, it has been known for its properties [1]. However, its relevance was identified in 1957. Se is also associated with the sulfur (S) element due to their similar ionic radius and physicochemical properties. Therefore, they are both members of the same group of the periodic table.

Recent research has shown that treatment with Se at low concentrations has a beneficial influence on plant development and yield. Se may work as an essential factor by interfering with a several of physiological processes [2]. It is a remarkable antioxidant and pro-oxidant agent of plants that helps to cope with a variety of abiotic stresses, such as salinity, drought, intense temperature fluctuations, toxic metals/metalloids, and other environmental pollutants and toxins [3]. Its protective mechanism entails the stimulation of photosynthetic pigment formation, net photosynthetic ratio, gas exchange, the accumulation of osmoprotectants, and the formation of secondary metabolites during the events of photosynthesis. As an antioxidant, Se helps to reduce an accumulation of free radicals or reactive oxygen species (ROS) and prevents an oxidative stress. It induces and modulates the expression of stress-responsive proteins and genes [4]. At high concentrations, it can be toxic and thus can contribute to pro-oxidative reactions.

From a plant source, Se is transferred to the food chain, however, the deficiency of Se in soils where the bioavailability of Se is low results in health risks for both animals and humans [5]. Even though Se is not an indispensable mineral for higher plants, it must be applied to soil to arrange sufficient nutritional needs for animals and humans. Therefore, the safety margin of Se concentrations should be stressed as relatively narrow [6]. Furthermore, plants have the potential to play significant roles in alleviating Se deficiency and toxicity in a variety of regions around the world; therefore, understanding the wide-ranging mechanism of Se metabolism is essential for effective Se biofortification strategies [7].

Recently, there has been a huge rise in the potential applications of nanotechnology in the food and agriculture industries. Nanotechnology enabled the characterization of huge product lines as materials called nanoparticles (NPs), having a size ranging from 1 to 100 nanometers. Several implementations of nanotechnology have been developed and commercialized in the food and agriculture sectors, with variety of targets varying from enhanced food security, handling, and nutrition to agriculture products and enhanced packaging, as well as the possibilities to encourage sustainable agriculture and delivering of better foods on a global scale [8]. Because there is limited available information about the risks associated with handling NPs, such as selenium nanoparticles (SeNPs), they have obtained a heightened interest in their uses in agriculture and in-plant nutrition via ultra-small scales. Additional research should be conducted, including ensuring the continued growth of the nano-food industry, bridging knowledge gaps, and avoiding any unexpected toxic consequences on the environment and plants [9]. The current review is based on the fate of SeNPs in the plant-production agronomic sector with respect to environment, plant nutrition, and agronomy.

2. Sources of Selenium in the Environment

Se is found in all sources in agricultural systems. Individual concentrations depend on the specific area. In the following chapter, we describe an occurrence and life cycle of Se in the environment.

2.1. Selenium in Air

Due to a variety of sources, the ratio of Se in the atmosphere is extremely variable. These sources include volcanic eruptions, industrial emissions, and evaporation from the oceans and sea surfaces. There is a concentration of 0.06 ng m^{-3} of Se in the air just above the South Pole, and the estimated value for global air from remote areas is 0.2 ng m^{-3}, although the median concentration in polluted cities is 4.0 ng m^{-3} [10]. The ocean may be a noteworthy source of Se for coastal communities. Se enrichment in marine aerosols is thought to be caused by the formation of volatile organo-Se compounds, particularly dimethyl selenide, $(CH_3)_2Se$. Se is then finally released into the atmosphere as hydrogen selenide, which is metabolically transformed via plants, as well as elemental Se^0, selenites, and selenates as fine particles [11,12].

2.2. Selenium in Water

In marine ecosystems and underneath the most redox environments, the two oxyanions (Se^4 and Se^6) are crucial, with several forms of selenide. In water, Se can be traced back to ambient deposits or its emissions because of the soil irrigation. Its concentration varies, but it never exceeds 9 mg L^{-1} [13]. Moreover, the World Health Organization (WHO) recommends that the amount of Se present in drinking water should not exceed 10 µg L^{-1} of water. Elevated levels of Se have been found in surface water, ranging from 0.06 µg L^{-1} to approximately 400 µg L^{-1}. Concentrations rise in consequence to pH of water because of the conversion of compounds with higher solubility in water to more insoluble compounds. Se concentrations in groundwater samples from water supply across the world are typically less than 10 µg L^{-1}, but they can sometimes exceed 50 µg L^{-1} [12]. According to some reports from China, it has been determined that the drinking water from an area with increased Se concentration in the soil was found to contain 50–160 µg L^{-1} of Se. The surface waters contain the most Se and sodium selenite, while freshwater contains the most selenite. In contaminated aquifers there may be present a high level of biological activity, as well as a regionally oxidative environment. As a result, under these environmental conditions, Se is oxidized and solubilized, and then can easily enter to the food chain [10].

2.3. Selenium in Soils

Se occurs naturally in soils where it is commonly introduced through deterioration of rocks containing selenides and selenite associated with sulfide minerals in mass fractions of only about 1 mg/kg. Within the soil, it is present either in organic form or as elemental Se as selenite salts and ferric selenite [14]. The anionic forms of Se are usually present in the soils, such as selenite and selenate, which are highly soluble and potentially toxic, whereas organic Se is primarily derived from the decomposition of plants [15]. Hence, the amount of Se present in the soil varies based on the level of organic matter, the texture of the soil, and the amount of rainfall received. It is also determined by the physicochemical parameters of the soil, including microbial activity, pH, and redox status, which affect the rate of Se assimilation. The intensity of Se in land and resources varies from 0.1 to 0.7 mg kg^{-1}, depending on the region. Moreover, Se levels in granites, as well as volcanic soils, are typically low, whereas its level in soils around the mountains is very high [16]. The quantity of Se in crops is determined by the rate at which soil acidity increases; more Se is discharged in alkaline soils than in acidic soils. Selenite is transformed into a soluble form that is more readily assimilable by plants when grown in alkaline soils. In acidic soils, on the other hand, selenite combines with iron hydroxide, causing it all to be permanently fixed by the soil structure [16].

3. Selenium in Plants

Se is abundant, thus the amount of Se present in plants is proportional to the amount in the surrounding soil [17]. Many plants accumulate Se to the point where it becomes poisonous if consumed by livestock. Plants that accumulate massive volumes of Se are frequently found in areas with high Se concentration in the soil. The summarization of the main classes of Se utilizing plants is given in Figure 1. The plants which can accumulate larger quantities of Se are called indicator plants. Some Astragalus species, as well as prince's plume and some woody asters, are considered as indicator plants (Figure 1A). The indicator plants can accumulate up to 3000 parts per million (ppm) of Se in their different parts including roots, shoots, and leaves. Some plants they can accumulate up to 50 ppm Se [18]. The secondary Se accumulators are some native ranges of plants and crop plants, including wheat, barley, alfalfa, and western wheatgrass, respectively (Figure 1B). The physiological conditions of the plant, as well as the species of the plant, influence how the Se is taken up and dispersed by its root [19]. Aerial silks are typically composed of approximately 80% selenite and 65% selenate by weight [17]. Forages contain Se in concentrations ranging from 0.2 to 0.6 ppm, putting livestock at threat of Se poisoning. Se in wheat plants' seeds is normally stored as selenomethionine (SeMet), with varying levels of Se stored depending on the environment [20]. Compared to other minerals, plants mostly absorb selenite in higher concentrations. Considering that selenate and selenite have chemical characteristics, they both undergo the same metabolic pathway [17]. There is a strong correlation between Se deficiency in soil and the appearance of disease symptoms associated with low Se intake in humans and other mammals. For example, soil's Se concentrations range from 8000 mg kg^{-1} in soils of Russia to 0.005 mg kg^{1} in soils of China and Finland. As a result, various efforts have been made to enhance agricultural food production with Se through fertilization, genetic breeding, or in biofortification strategy [21].

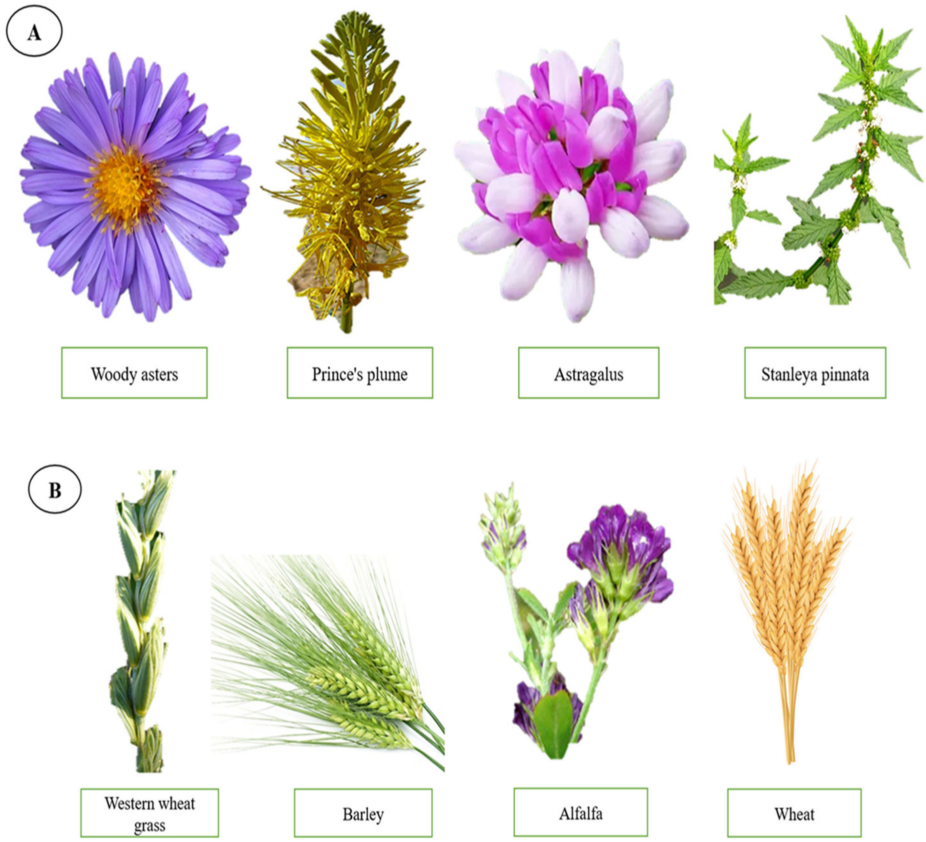

Figure 1. Images of plants containing Se: (**A**) indicator plants and (**B**) facultative Se-absorbing plants.

3.1. Effects of Selenium in Plants

Many studies have been conducted to determine the role of Se in plants. The issue of Se utilization of higher plants is still up in the air and this question has not been resolved. There are, however, some answers [22]. Some positive and negative effects of Se are discussed below and summarized in Figure 2.

3.1.1. Beneficial Effects of Selenium in Plants

Many studies have shown that Se, even at low concentrations, can stimulate plant growth. It was found that 5 µg of Se boosted a root growth and increased relative water content in hot pepper plants by 13% when compared to control plants [23]. Furthermore, both 3 and 5 µM concentration of Se triggered a 25% spike in leaf area, which resulted in an increase in the plant's overall growth and biomass. Moreover, the growth of rice was reported to be stimulated by using a low dose of Se. In 2019, Hemmati et al. suggested that soil Se fertilization can be an accurate and efficient technique for improving the overall performance of plants [10]. Last year, Rady et al. (2020) confirmed that tomatoes treated with 40 M of Se established increased drought tolerance, which was accompanied by actions of several antioxidant enzymes, including ascorbate peroxidase (APX) by 44%, superoxide dismutase (SOD) by 56%, and catalase (CAT) by 57%, respectively [24]. The application of Se also increased accumulation of carbohydrates in the young leaf surfaces of potatoes.

Salinity harms agricultural production because it inhibits plants growth and yield. There have been many experiments conducted to investigate the crucial role of Se in protecting plants against salt-induced stress. Another study investigated the role of 1–25 mM of sodium selenite (Na_2SeO_3) in regulating salinity tolerance in maize by measuring its concentration in the plant [25]. Under salinity, their findings revealed that 1 mM Se increased plant growth and development, photosynthetic rate, and K^+ content, while the ratio of Na^+ was deceased. Moreover, the Se supplementation (20 mg L^{-1}) improved the growth and chlorophyll content of maize by reducing oxidative damage because of high malondialdehyde (MDA) and hydrogen peroxide (H_2O_2) levels under high-salinity stress [26]. A significant finding was that supplementation of Se enhanced the salinity tolerance of maize at the reproductive phase more than at the vegetative stage. Several experiments were conducted to determine the significant function of Se for enhancing plant drought tolerance and drought resistance [27]. Abiotic stress is a significant constraint on the productivity of modern agriculture. Therefore, researchers are attempting to develop modern tactics that will be effective in dealing with plant stress. Exogenous stress protectants are becoming increasingly popular as a means of increasing stress tolerance [27]. Besides improving the photosynthetic activity, increasing the direct quenching of ROS, and upregulating both the enzymatic and nonenzymatic parts of the antioxidant defense system, Se can helps to decrease plant cell membrane damage. Noticeably, at significant amounts, Se tends to increase lipid peroxidation and α-tocopherol levels, but also, in particular, glutathione peroxidase (GPx) activity, which ultimately results in cell death. This contributes to the systemic defense against the tissue-damaging effects of ROS [28].

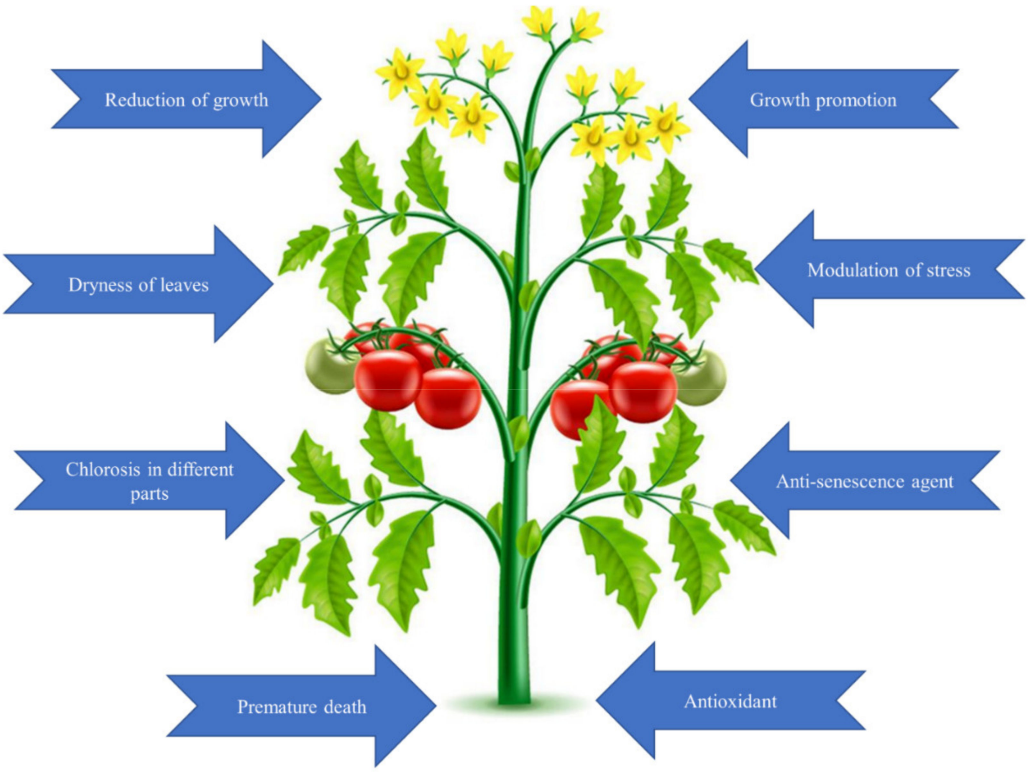

Figure 2. Demonstration of useful and harmful effects of Se on plant physiology.

3.1.2. Harmful Effects of Selenium in Plants

Although Se has a biofortifying effect on plants, when given to them in high concentrations, it could have also toxic effects on plant growth. It was found that a plant growth is negatively impacted by the alteration of S for Se in cysteine and methionine amino acids, which results in alteration of disulfide bonds in proteins, altering the structure and behavior of proteins, and having a devastating effect on overall growth [29,30]. Besides that, another damaging effect of Se during its incorporation into organic compounds is the depletion of glutathione, a nonenzymatic antioxidant that protects plants against ROS. Because of this asymmetry between detoxification and the creation of ROS, a significant oxidative burst occurs, with a resulting reduction in plant growth. It has been revealed by previous studies that plants' mineral balance is disrupted by a surplus of Se, which causes adverse changes in the quantifiable composition of essential nutrients [21]. Se affects a variety of biochemical processes and physiological processes, including development, photosynthesis, respiration, gas exchange, water holding capacity, phloem unloading, and initiation of protease inhibitor genes, by altering the uptake, aggregation, and transit of mineral nutrients. For example, Na^+ interferes with nutrients in plant tissues, which causes disturbance of various physiological events controlled by Se [25]. It is the quantitative proportions of Se and essential elements that determine the interaction between them, resulting in antagonistic and synergistic effects. Se ions can also alter the permeability coefficients of several ions in biomembranes, affecting the transport of those ions through the membrane [31]. Molnár et al. (2018) demonstrated that selenite-induced cell wall alterations and stomatal regulations in Arabidopsis were associated with lower stomatal density and that selenite sensitivity resulted in the stomatal opening, callose aggregation, serious oxidative stress, and moderate nitrosative modifications in plants. The Se-induced photosynthesis dysfunction is widely regarded as the most important cause of increased accumulation of ROS and oxidative stress, and it is widely recognized as one of the most important mechanisms of Se phytotoxicity [32].

The plant proteomes are targeted by Se toxicity, as was recently shown by Kolbert et al. (2019). An excess of Se in plants harms a variety of physiological and biochemical processes. One of the most significant negative consequence is a reduction in chlorophyll biosynthesis, which results in chlorosis. Maize handled with selenite (5–100 M) has shown enhanced levels of phosphorus (P) and calcium (Ca^+) content, but decreased potassium (K) content. Tall fescue and white clover that had been treated with hydrogen selenate showed increased Ca^+ bioconcentration and a decrease in P concentration in the opposite direction [6]. Se toxicity is unquestionably a result of the accumulation of excess Se within the plant cell and the competition among Se and S for the addition of structural components or involvement in biochemical reactions due to the chemical structural similarity between them. Because of Se toxicity, not only are seleno- and oxyproteins formed, but it has been discovered that nitroproteins have also been created. Using specific plants, Se-induced proteomic damage can be reduced by diverting protein synthesis into other pathways [31]. Furthermore, proteasomes can remove nitroproteins, selenoproteins, and oxyproteins that have been damaged or malformed. Another researcher showed that lettuce growth was stimulated when the hydrogen selenate content was low [33]. A significant reduction in lettuce yield was observed when the Se concentration in the shoots exceeded 20 mg kg^{-1} dry weight. Furthermore, Se exposure had a variety of effects on the morphology of the roots [31], which could be harmful for the plant. In a separate study, the effect of Se on lettuce was investigated, and the results revealed increased Se concentrations in the shoots, but decreased macronutrient accumulation in the leaves of lettuce, as well as growth reduction symptoms.

4. Selenium Nanoformulation

Agriculture and technology are the heart of human efforts, and the process of generating new tools and goods has been hastened by reaching the nanoscale's fundamental building blocks. It was the USDA that was first to claim nanotechnology in the agricultural and food industries. It is regarded as a field that is emerging and developing fast and has the potential to change agriculture and food arrangements along the whole agricultural worth chain.

The importance of Se in plant nutrition has been known for a long time. There are becoming many ways to use SeNPs in the field of agriculture, such as the addition of Se to the soil, hydroponic and aeroponic cultivation of plants in the nutritive medium containing SeNPs, soaking seeds in the SeNPs solution before sowing, or foliar application of plants with Se solution [34].

Plants can benefit from the use of SeNPs in a variety of applications, including (1) the controlled release of agrochemicals and their distribution to increase the effectiveness of the products used, (2) the handle of pests and illnesses triggered by infectious microbes such as bacteria and fungi, (3) as quasi-essential trace nutrients, via promoting plant biochemical pathways, and so refining crop progress, yield, and nutritional worth, (4) biofortifying harvests using Se to upsurge their content, (5) alleviating abiotic stress, and (6) increasing the nutraceutical quality of consumable foods [35].

The use of SeNPs has become more widespread with the discovery of new synthetic methods that allow large-scale production. SeNPs may be synthesized via a variety of techniques, including physical, chemical, and biological synthesis.

The techniques for producing SeNPs on a large scale, such as pulse laser ablation, electrokinetic approach, hydrothermal treatment, and vapor deposition, all need either specialized equipment or particular chemicals [36]. Such methods frequently make use of toxic chemicals, as well as high temperatures and high pressures, which contribute to further pollution of the environment. A common approach to synthetize SeNPs is via sodium selenite reduction with glutathione at room temperature in an aqueous solution [37].

The biological synthesis of SeNPs includes the use of microorganisms, enzymes, and fungi, as well as plant extracts, according to the researchers [38]. Aside from that, they show biological activity as a result of their interaction with proteins and some other biomolecules present in bacterial cells, as well as plant extracts that include functional groups including NH, C=O (carbonyl), COO (carbonyl oxygen), and C–N (carbonyl nitrogen) [33]. For example, the bacteria *Capsicum annum*, *Escherichia coli*, and *Bacillus subtilis* have all been utilized to generate NPs in recent years [33]. The SeNPs synthesis using bacteria and actinomycetes involves the intracellular synthesis method in which the bacterial cell is treated with metal salt solution and then kept in a shaker machine at ambient temperature and pressure in a dark environment [39]. Moreover, compared to other methods, the biogenic method is economically friendly and less time-consuming as well.

Uptake of SeNPs by Plants

Related to the phyto-uptake of SeNPs and its translocation, determining the security and toxicity of SeNPs causes a thorough understanding of their uptake by different plants. Here, understanding the phyto-uptake of SeNPs and their translocation is essential. Several avenues have been proposed to explore the absorption and entry of SeNPs into plant systems [40], even though this phenomenon is still not fully understood. SeNPs pass through a cell wall and penetrate the plasma membrane. Only NPs aggregates with diameters smaller than pore diameter could pass through the cell wall successfully [41]. The cell wall of the plant acts as a barrier, preventing easy entry of any external influences, including SeNPs, into the plant's cell walls. These sieving properties are determined by the pore size of the cell wall, which can range from 5 to 20 nm [42]. It was shown that SeNPs could abide by plant roots and could influence a chemical and physical uptake in plants [41]. The most widely accepted explanation for the translocation of engineered nanomaterials is that such nanomaterials can start moving intracellularly and extracellularly among the plant tissues until they reach the xylem [43]. Once SeNPs are inside the plant's vascular system, designed NPs could be transported to the aerial parts along with the plant's water perspiration and nutritional flow in the transmission of nutrients.

5. Agricultural Use of Nano SeNPs

5.1. Fertilizer for Crops

In terms of the application of SeNPs in the Se fertilization sector, fertilizers are one of the most important factors in increasing crop yields and agricultural productivity, as well as ensuring food security in developing countries [31]. With the progress of innovative, cutting-edge, and developing technologies such as nanotechnology, the implementation of SeNPs as an adjunct to standard Se fertilizers to improve crops has emerged as a viable option to conventional Se fertilizers.

The soil is a biodegradable material, and SeNPs are used to stimulate the soil organic matter. It has been shown that the humic substance, which is delivered synchronously with SeNPs and other NPs, handles the stimulation effect as well [44]. Microbial communities control organic matter degradation, which has a significant impact on soil fertility. Within specific environments, bacteria are not a faceless mixture of once-gained participants, but a structured, strictly-ordered polymicrobial community in which each participant has a specific functional role. As a bioreactor, the soil speeds up a wide range of biodegradation processes [45]. In terms of biological processes and yield in the soil and plants, the application of Se in standard fertilizer form is deemed less efficient than the application of SeNPs in standard fertilizer form [46]. Specifically, it has been found that Se can ease stress in plants because it causes the manufacture of secondary metabolites and increases the activities of antioxidant enzymes according to the literature [32]. To mitigate multiple kinds of abiotic stress, including extremely high temperatures, droughts, heavy metal accumulation, and salt, the usage of SeNPs is increasingly popular and is becoming increasingly important. The bean plant is used for soil fertility analysis, which enhances plant development. The plant has been evaluated and analyzed for chlorophyll and protein content. Plants showed effective growth at high concentrations of SeNPs [47]. A study by Hebat-Allah et al. (2019) showed that SeNPs impacted the growth of groundnut cultivars by altering photosynthetic pigments, lipid peroxidation, antioxidant enzymes (ascorbic acid peroxidase, catalase, peroxidase), total soluble sugars, phenol content, and total flavonoids in the plants. Tolerance to sandy soil conditions was improved when SeNPs were used as a stimulant and/or a stressor [48]. As an example, handling with SeNPs at a ratio of 100 mg/L in barley (*Hordeum vulgare*) crops cultivated under saline stress led to a direct accumulation of Se in leaves, an improvement in the amount of aggregate phenolic composites, and a decrease in the content of ROS-mediated cellular membrane harm markers, including such MDA, which may affect metabolism and be responsible for nutrient deficiencies [35]. In the study conducted on tobacco plants it was shown that SeNPs had no positive effect on the number of tobacco shoots, whereas 50 mg L^{-1} selenate completely inhibited the expansion of tobacco shoots. Increasing the concentrations of SeNPs significantly increased the rate of roots regeneration. With the use of 50–100 mg L^{-1} SeNPs, the roots were far more extensive and densely packed, and the fresh weight increased significantly as well. On the contrary, selenate completely inhibited the formation of roots at concentrations ranging from 50 to 100 mg L^{-1} [48]. In plant tissue culture, the biological activities of SeNPs were distinct from those of the selenate ion (SeO_3^{2-}). It was showed that SeNPs concentrations ranging from 50 to 100 mg kg^{-1} significantly increased organogenesis and root system growth (>40%), whereas selenate had no such effects at any intensity. SeNPs concentration ranging from 50 to 100 mg kg^{-1} strongly prevented both callus development and root regeneration. This previous concentration was effective in stimulating not only roots initiation or roots elongation, but biomass production as well [48].

Another point worth mentioning is that SeNPs have been shown to reduce the concentrations of heavy metals throughout plant tissues, which are extremely toxic to the organism. It was discovered in most of the studies that Se is more of an adversary of noxious elements than lead (Pb) as well as cadmium (Cd); as a result, implementing SeNPs has been shown to significantly lower the concentrations of both elements in the environment, dropping the negative effects of these toxic substances on the plant's environment. After the usage of SeNPs in female spinach plants, it was discovered that the Cd and Pb concentrations decreased by 66% and 19%, respectively. The protective effect of female spinach plants against Cd increases as the oxidation state of the plant decreases [49]. To date, the nanofertilizers are manufactured using metal ions such as silicone and Se. SeNPs are a potent low-dose stimulant with a noticeable effect.

5.2. Biofortification

The potential for gradual Se release from SeNPs for biofortification of plant foods has piqued the curiosity of researchers interested in using them in agroecosystems to minimize potential losses that can occur when commercial fertilizers are used. Therefore, SeNPs may be employed in biofortification, which aims to raise the Se content of comestible parts of plants to prevent Se insufficiency in humans and livestock because of this. SeNPs have also been proven to be less harmful to plants than ionic Se salts (SeO_4^{-2} and SeO_3^{-2}), as shown in investigations of *Nicotiana tabacum* and *Allium sativum* [50]. It was described that the uptake of SeNPs was 1.7 times more decreased than the uptake ratio of SeO_4^{-2} and SeO_3^{-2} and that SeNPs were then absorbed into organic forms, including SeMet, which accumulated mostly in the root cell walls of the plants [51]. Furthermore, SeNPs generated by chemical means were more capably absorbed than SeNPs manufactured via biological approaches. For example, it has been published that wheat roots handled with 40 nm SeNPs, attained through chemical synthesis, absorbed 1.8 and 2.2 times more Se than wheat roots preserved to 140 and 240 nm SeNPs, respectively. This shows the importance of particulate type and amount of NP synthesis in this type of application [41]. Recently, there has been amplified attention in the practice of SeNPs for the biofortification of crops, owing to their ability to improve the quality, nutritional characteristics, and amount of Se available in the edible sections of plants. When compared to other regularly used Se sources, the consumption of plant foodstuffs biofortified with SeNPs may have an entirely different effect on the human body, depending on parameters such as the diameter of the NPs, the processing methods, and the surface makeup of the NPs [41]. As a result, a great number of in vivo experiments must be carried out to determine whether there are any harmful effects associated with the utilization of plant foods biofortified with SeNPs. Because of this, it is impossible to make a broad generalization about the recommended doses for the intake of foods biofortified using SeNPs [35].

5.3. Effect of SeNPs on Germination

Because of their ability to influence seed growth and sowing characteristics, SeNPs are an asset in agriculture. Plants grow more resilient to drought, disease, and pests when they are exposed to their effects [52]. It has been shown in studies that SeNPs have a substantial impact on seedling germination and development early in the ontogenesis process. There may be a dose–response relationship between NPs and plant development [53]. A higher concentration of NPs, for example, has been found to slow down seedling development when compared to controls. The impact of SeNPs on the germination characteristics of *Hordeum vulgare* L. seeds was investigated. Researchers found that SeNPs increased the length of shoots and roots, as well as the germination rate [54]. The sample treated with SeNPs preparation at a dosage of 4.65 g mL^{-1} had the greatest seed germination percentage [52]. The study's findings suggest that SeNPs may serve as a seed-based supply of the microelement Se. There is less toxicity in the production of SeNPs in this research compared to Se in ionic form; thus, it may be utilized to repair biochemical processes and replenish Se in germinating seeds [54]. It is essential to investigate the effects of SeNPs preparation and to investigate the effects of SeNPs on the germination characteristics of other common crops such as maize, rice, and soybeans [52]. SeNPs also promote root development and organogenesis. In lettuce, ryegrass, *Brassica oleracea*, and potato plants, trace quantities of Se have been shown to increase growth [55].

6. Conclusions

Several agricultural and horticultural uses exist for Se; some of these include using it in the form of SeNPs and sodium selenite, as well as selenate. Plants can benefit from the use of SeNPs in a variety of applications, including the controlled release of agrochemicals and their distribution to increase the effectiveness of the products used, the handle of pests and illnesses triggered by infectious microbes such as bacteria and fungi, biofortification, and increasing the nutraceutical quality of consumable foods. Crops fortified with Se, such as rice and maize, can be used in the future as a sustainable Se supplement in regions where Se is deficient. Along with supplying sufficient amounts and types of Se, a successful fertilization method must be designed for the safety of the environment and its inhabitants. There is plenty of research performed on the effects of Se in plant nutrition and physiology, but there is still a lack of information about the effects of SeNPs in plants nutrition, toxicity, and future aspects of using SeNPs in agriculture.

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