*Review Article*

Agronomic Biofortification of Vegetable Crops with Selenium and Iodine: A Review

**ABSTRACT**

Currently, there is a widespread deficiency of certain trace elements, which leads to an array of disorders/diseases in plants, animals and humans. Finding novel solutions to this problem is critical for the agro-chemical approach to food production. Numerous studies have been conducted on the fertilisation of plants with micronutrients; however, a systematic review summarising the most recent findings on the agronomic biofortification of vegetable crops with trace elements is still lacking. This work is a systematic review which compares the results of different doses and formulations of fertilisers with the yield performance and micronutrient content of edible parts of vegetable crops, with a focus on their enrichment with selenium and iodine in particular. These elements constitute a distinct group of micronutrients as, in contrast to other micronutrients like iron, zinc, manganese, copper etc., they are administered to plants in anionic form: selenium as selenite (SeO32-) and selenate (SeO42-), and iodine as iodide (I-) and iodate (IO3-). This review examines the importance of optimised fertilisation in the biofortification of Se and I, with a special emphasis on effectively mitigating hidden hunger. It may be argued that using an integrated biofortification strategy for Se and I is preferrable, but future perspectives with respect to research and development are required.

***Keywords:*** *Agronomic biofortification; micronutrients; fortification; hidden hunger; trace elements*

**1. INTRODUCTION**

“Micronutrients, or trace elements, play an important role in various biological processes and are considered essential for the proper growth of plants, animals and humans. On the other hand, if applied in higher doses, they can contaminate the soil, water and food chains. For humans, micronutrient deficiency is linked with diet quality and intensified by micronutrient-deficient soils. While the production and availability of carbohydrate-rich staple crops, especially cereals, have increased over the past few years, there has been no significant growth in the production of micronutrient-rich vegetables” [1,2]. “Intervention strategies focus on reducing micronutrient deficiencies and include dietary diversification, medicinal supplementation, or industrial food fortification. Social acceptance of biofortified food is constantly growing, displacing the belief that organoleptic characteristics (taste, smell, colour) can be modified as a result of the addition of micronutrients” [3]. “Biofortification differs from the above-mentioned strategies because it relies on increasing the nutritional content in the edible parts of plants/animals” [4]. “The goal of micronutrient biofortification of human food is to increase microelement concentration and their bioavailability in food, which seems to be the most sustainable and economic way to prevent micronutrient deficiency in human diet” [5].

Vegetables are perfect foods–they are high in nutrients, low in calories and fats, cholesterol-free, and packed with dietary fibre, antioxidants, vitamins and essential minerals. Including vegetables in the diet is strongly correlated with improved digestive and visual health, reduced risk of heart disease, diabetes, anaemia, cancer and other chronic diseases, and overall health. The consumption of vegetables is projected to increase in the upcoming years due to increased concerns about health and sustainability, and a higher demand for sustainable food sources will arise to feed the growing global population. Concurrent deficiencies of selenium and iodine are widespread in both developing and industrialised nations [6]. Agronomic biofortification of locally grown and consumed food crops, particularly vegetables, may be an effective strategy to reduce selenium and iodine deficiencies.

Selenium (Se) is an indispensable trace element for humans, and is a constituent of the selenoenzymes and selenoproteins responsible for important enzymatic functions. It is involved in the protection of DNA against damage and aging of cells, as well as from carcinogenic effects by combating the reactive oxygen species [7]. Selenium is also involved in brain functions, thyroid and cardiovascular health, metabolism, immunity, hormonal (mainly thyroid) balance, male fertility, resistance to viral infections and cancer prevention in humans [8,9,10]. “Therefore, a diet deficient in Se increases the risk of developing hypothyroidism, rheumatoid arthritis, tumours and heart failure, among other diseases [11]. The recommended dietary allowance (RDA) for Se is 55 μg day-1, while the upper limit (UL) for adults is 400 μg day-1” [12].

“Iodine (I) is required in the synthesis of the thyroid hormones, thyroxine and triiodothyronine, which regulate the growth and development of most organs, including the brain, besides maintaining the basal metabolic rate. Insufficient supply of iodine can cause enlargement of thyroid (goitre), its abnormal functioning (hyperthyroidism/hypothyroidism), miscarriage in the case of women, as well as mental impairment” [13]. “The RDA for iodine is 150-200 μg day‑1 for adults and 230-260 μg day‑1 for lactating/pregnant women” [14], with a tolerable UL of 1100 μg day‑1 [15]. “Although iodination of table salt is a typical way to prevent iodine deficiency, its excessive use can lead to hypertension or heart disease. This calls for new solution(s), and biofortification of plants can be an alternate method to alleviate iodine deficiency in humans and animals” [16].



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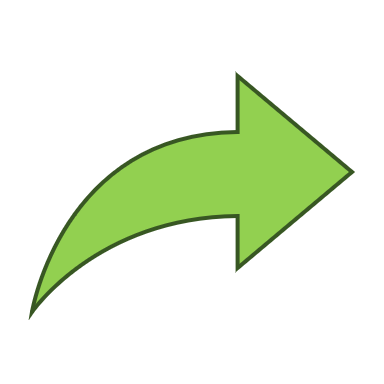
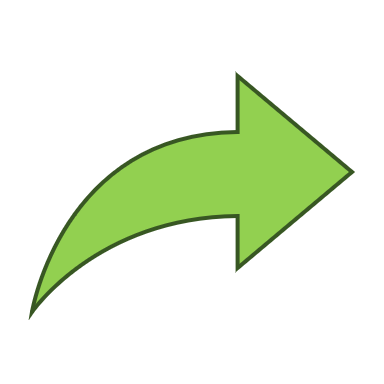
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**Agronomic biofortification of vegetable crops with selenium and/or iodine**

**Consumption of biofortified vegetables**

**Improvement in selenium and/or iodine status**

**Fig. 1 Agronomic biofortification practices in vegetable crops can improve selenium and/or iodine status in people**

Both Se and I are essential for humans and animals [17,18], and “generally make their way up the food chain through plant uptake and accumulation in the edible parts. They are considered beneficial plant elements; however, they are not classified as essential for metabolic processes. There is a worldwide deficit of Se and I in the diets of humans and animals, especially in regions where soils are also deficient in these micronutrients. This is due to their poor transit in plant tissues and low accumulation rates owing to limited bioavailability from soils. Consequently, agronomic biofortification is an effective crop-based strategy that effectively addresses the issue of mineral malnutrition, also known as “hidden hunger”, by enriching crops and food products with bioavailable micronutrients (Fig. 1). Increasing the average daily intake of Se and I can be achieved effectively and practically by supplementing vegetable crops with fertilisers (agronomic biofortification) containing these elements. Understanding the mechanism of the soil-plant nutrient system is essential to ensure the success of biofortification practices. Prior to agronomic biofortification, we must identify the form(s) or species of these micronutrients that are available in the soil, as well as the form(s) that plants can readily uptake. Although minerals are unevenly distributed among different plant parts, in order for a biofortification process to be successful, plants must accumulate minerals in their edible parts” [19].

Based on the literature reports indicating a high variability of the results and the complexity of the topic, this systematic review aims to propose an integrated approach to the planning of agronomic biofortification strategies for Se and I in vegetable crops, combining the best aspects of work presented in the publication.

**2. SELENIUM**

**2.1 Uptake, transportation and assimilation of selenium in plants**

Selenium is not an essential nutrient for higher plants [20], but its appropriated use in plant nutrition can promote seed germination, boost growth and contribute to pest and disease resistance in several crops [21]. Soil concentration of Se is normally modest, ranging from 0.01 to 7 mg kg-1, with an average of 0.4 mg kg-1 worldwide [22]; however, seleniferous soils can hold as much as 1200 mg Se kg-1 [23]. Plants absorb Se inorganically as selenite (SeO32-), selenate (SeO42-) and elemental Se, and in organic form as Se-amino acids, but not as selenides [24,25,26] or colloidal elemental Se [27]. Additionally, compared to inorganic species, they have a relatively higher affinity for organic Se [28]. Since Se is the chemical analogue of sulphur (S), selenate [Se(VI)] is absorbed along the same pathway as sulphate (SO42-) [29]. However, selenite [Se(IV)] movement is partially mediated by phosphorus (P) and silicon (Si) transporters [30]. While Se(VI) is primarily assimilated in the shoots, Se(IV) is mostly assimilated in the roots [31].

Most plant species have a tolerable Se level of 10-100 mg kg-1 DW [32]. Excessive Se can have phytotoxic effects that can damage the photosynthetic apparatus, inhibit photosynthesis and cause over-production of starch, thereby hindering plant growth [33]. On the other hand, secondary accumulators, also called Se-indicators, such as some vegetables of the Brassicaceae family, including broccoli, radish and Chinese cabbage, can accumulate high concentrations of organic Se species, especially selenomethionine (SeMet) and/or methylselenocysteine (MeSeCys), and as such, are a good target for Se biofortification [34,35,36]. Conversely, leafy vegetables like lettuce, basil and chicory, accumulate only inorganic Se [37,38].

**2.2 Type of application**

“It has been estimated that only 12% of soil-applied Se fertilisers is taken up by plants on an average, since most of the Se is fixed and retained in the soil and thus, is not bioavailable” [39]. “In contrast, foliar fertilisation of Se is up to 8 times more effective than soil supplementation” [40]. Shafiq et al. [41] compared the effects of foliar application and water flooding of Se on garlic in a field trial, and recorded an increase in Se and total phenolic content in bulbs and leaves after foliar fertilisation. Similarly, in a pot trial, de Oliveira et al. [42] found that foliar fertilisation of Se produced superior results in carrot compared to soil fertilisation. Although foliar application resulted in higher growth of fresh and dry matter, a higher degree of Se biofortification was achieved in pot-grown lettuce for soil application of Se [43]. Meanwhile, da Silva et al. [44] observed that when radish plants were treated with a low dose of sodium selenate, fertigation outperformed foliar application. They obtained roots with about 50 mg Se kg-1 DW, while foliar spray of the same chemical recorded about 15 mg Se kg-1 DW.

**2.3 Form of fertiliser**

Numerous studies have shown that Se(VI) is more bioavailable than Se(IV). An investigation revealed that Se(VI) was 33 times more effective than Se(IV) [40]. Application of Se(VI) increased the concentration of Se in potato tuber as well as improved enzymatic activity of peroxidase [42]. Conversely, a greater proline concentration was noted with Se(IV). In turnip, Li et al. [45] reported that, with the same dose of fertiliser, application of Se(IV) recorded higher weight gain of leaves and roots, whereas Se(VI) resulted in a higher accumulation of Se in leaves and roots. Golubkina et al. [46] also obtained similar results with spinach.

**2.4 Effect of specialty fertilisers**

Several attempts have been made to deliver Se in an unconventional form in order to increase its bioavailability. For instance, it has been documented that salicylic acid (SA), a plant growth regulator that protects plants against biotic and abiotic stresses, affects Se uptake. Application of the lowest SA dose resulted in an approximately 7% increase in the Se content of lettuce [47]. Biofortification of Se was also conceivable using selenium chitosan-polyacrylic acid (Cs PAA) complexes as an alternative form of fertilisation in which the usage of complexed form of Se resulted in a higher enrichment of lettuce compared to selenium oxide (SeO2) fertilisation [48]. Some studies show enrichment of edible parts of carrot roots and broccoli florets with powdered biomass of the selenium hyperaccumulator, *Stanleya pinnata* [49]. Table 1 depicts the effects of using special fertilisers on vegetable crops for Se biofortification.

**Table 1. Effect of specialty fertilisers on biofortification of vegetable crops with selenium**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Crop** | **Type of trial** | **Specialty fertiliser** | **Effect** | **Reference** |
| Lettuce | Greenhouse hydroponic | Se + SA | No significant effect of SA on the fresh weight (FW) of lettuce. Slight increase in Se, ascorbic acid, flavonoids and anthocyanin content of leaves, and large increase in proline content | [47] |
| Lettuce | Greenhouse hydroponic | Se + SA | No significant effect of SA on the FW. Slight effect on the Se content of leaves (+ or -) depending on the species of lettuce and dose of SA | [50] |
| Lettuce | Greenhouse trays | SeO2 + Cs PAA | Increase in enzyme activity as well as Se content. Cs PAA favoured Se uptake | [48] |
| Carrot and broccoli | Field | Se-enriched hyperaccumulator *Stanleya pinnata* (powder, dried plant) | The highest Se concentration in carrot roots as well as broccoli florets was obtained for the highest dose of hyperaccumulator | [49] |
| Cabbage | Pot | Se + Betaine | Non-significant decrease in Se content compared to the control group fertilised with sodium selenate without betaine | [51] |

**2.5 Influence of other elements on Se biofortification**

The presence of other elements in soil or those introduced during fertilisation, is another factor that restricts the uptake of Se by plants. These elements may favour or inhibit the uptake of this trace element (Table 2). For example, nitrogen plays a significant role in the process of enriching plants with Se, and must be administered (in form of fertilisers) in order to enhance the yield and promote greater uptake of Se [52]. In contrast, because selenium and sulphur are similar to each other in terms of uptake and assimilation, or the synthesis of related compounds like selenocysteine and cysteine, sulphur and sulphates inhibit the uptake of Se and vice-versa [29]. Mobini et al. [53] demonstrated such type of interaction in onion.

**Table 2. Impact of presence of some elements on Se biofortification of vegetable crops**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Crop** | **Type of trial** | **Type of application** | **Influencing element** | **Type of impact#** | **Effect** | **Reference** |
| Carrot | Field | Soil | I (Iodine) | + | Slight enrichment of Se in the carrot roots was achieved assuming that in the (Se + I) combination, selenium was present in the form of Se(VI) and iodine, in the form of I(V) | [16] |
| Onion | Pot | Irrigation | S (Sulphur) | – | With an increase in dose, SO42- content of bulbs increased, but however, the Se content decreased | [53] |
| Lettuce | Pot | Soil | Hg (Mercury) | + | The presence of Hg improved Se assimilation, which increased its content in the stem | [54] |

# ‘+’ denotes synergism/positive influence; ‘–’ denotes antagonism/negative influence.

Many vegetable crops have benefited from the successful application of selenium biofortification using sodium selenate or sodium selenite. In addition, the potential antioxidant and antisenescence effects of Se can improve the shelf life during post-harvest storage [55]. Naturally fermented Se-enriched sauerkraut was shown to have higher antioxidant activity than naturally fermented non-Se-enriched sauerkraut [56], which could be due to the biotransformation of Se(IV) into organic Se species, making them more available to attract free radicals. Se biofortification is beneficial to plant growth while simultaneously yielding vegetables with health benefits serving as functional foods; however, due to the high toxicity of Se, particularly in the form of Se(VI), care must be taken to ensure that the final product has a Se content that is within the safe maximum dietary intake.

**3. IODINE**

**3.1 Uptake, transportation and assimilation of iodine in plants**

“The typical iodine concentration of soils in most regions ranges between 0.5 and 20 mg kg‑1, which is insufficient to produce crops with adequate iodine content to meet the daily intake recommendations. Despite not being essential for plant growth, iodine can be taken up by plants and translocated within the tissues. Generally, iodine is toxic to plants; however, it can be beneficial at low concentrations” [57]. “Its detrimental effects (on specific plants) are contingent upon the form/species (iodide or iodate) applied, the plant’s mechanism of its uptake and transport, and the properties of the substrate employed” [58].

“Plant leaves absorb iodine through stomata (60%) and leaf surface (40%), although it can be lost as a result of tissue decay, wind and precipitation” [59]. According to Smoleń et al. [60], “leaf absorption occurs due to the organophilic nature of I and its interaction with cuticular waxes, or the oxidation of I- (iodide) to I2 (iodine), which facilitates its penetration into the cuticle. Iodide is reported to be absorbed more efficiently than elemental I or iodate, especially in hydroponically grown plants. This I is primarily stored in the roots, but in nutrient solutions with concentrations higher than 0.01-10 μM, it can also be translocated to the shoots” [61]. “In fact, iodine is efficiently transported into the xylem, I- uptake being catalysed by H+/anion symporters and released into the xylem by anion channels” [62]. “Plants can have negligible or very low I concentrations, about 30-100 μg kg‑1 FW” [63]. Depending on the plant species, a nutrient solution with concentration greater than 10-100 μM can be phytotoxic and inhibit plant growth [59]. In general, the different chemical forms of I present the following order of phytotoxicity: (I2) > iodide (I‑) > iodate (IO3-) [64]. I‑ is more detrimental to plant growth compared to IO3- due to higher uptake and due to the fact that IO3- is reduced to I- [65].

Several methods have been proposed to enrich plants with iodine, but none of them can be considered optimal, and each species needs to be carefully and precisely assessed. Leafy vegetables such as lettuce [14,66,67], spinach [68,69] and Chinese cabbage [70] have high translocation rates due to their larger surface area and thus, accumulate substantial amounts of I in their leaves. This makes them ideal candidates for I biofortification. Nevertheless, some tuber vegetables, such as potato, can also store high amounts of I [71]. Several studies have shown that tomato can accrue up to 10 mg I kg-1 FW, making them a good target plant for I biofortification [65]. In hydroponic trials, biofortification was also successfully implemented on the fruits of pepper plants, where up to 1330 μg I kg‑1 was accumulated from iodide solution [72]. “However, leafy vegetables are more convenient for dietary intake of I because they are consumed raw, which eliminates the loss of I during cooking. Also, they are easy to fortify through foliar application” [67].

**3.2 Type of application and form of fertiliser**

Biofortification of iodine has been successfully performed in carrot through repeated foliar application [73]. Instead of adding the element to the nutrient solution, Smolèn et al. [60] observed higher efficacy of I biofortification in lettuce after foliar spray. Conversely, Caffagni et al. [74] confirmed that, although foliar spray of potassium iodate (KIO3) can increase the I content of tomato fruits, fertigation with a 5 mM solution of potassium iodide (KI) yielded better results (249-fold increase in I). Hydroponic lettuce plants treated with 90 μg I L‑1 as KI produced 30 times more I in their leaves than untreated plants, demonstrating superior biofortification results compared to plants treated with the same amount of I as KIO3 [67]. Nevertheless, the I content in carrot increased to levels toxic for humans (9 mg kg‑1 FW) at high concentrations of I (50 mg L‑1) in the nutrient solution, indicating phytotoxic effects on plants [73]. Table 3 shows the impact of iodine form and type of application on vegetable crop biofortification.

**Table 3. List of studies on I biofortification of vegetable crops and their respective bioaccumulation efficiency per 100 g of fresh weight (FW)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Crop** | **Iodine dosage** | **Applied form of I** | **Type of application** | **I content per 100 g FW (μg)** | **References** |
| Carrot | 10-150 mg kg-1 | KI | Soil pot | 0-5000 | [70] |
| Celery | 10-150 mg kg-1 | KI | Soil pot | 500-16,000 | [75] |
| Cucumber | 12-150 mg m-2 | Kelp fertiliser | Soil | 30-120 | [76] |
| Lettuce | 0.5-2 kg ha-1 | KIO3 | Foliar | 45-300 | [14] |
| Pepper | 10-150 mg kg-1 | KI | Soil pot | 100-500 | [75] |
| Potato | 0.05-0.5% | KIO3 | Irrigation water | 1870-3400 | [71] |
| Radish | 10-150 mg kg-1 | Kelp fertiliser | Soil pot | 100-1300 | [69] |
| Spinach | 0.5-2 mg kg-1 | KIO3 | Soil pot | 6-824 | [68] |
| Tomato | 12-64 mg dm-3 | KI | Soil pot | 200-1000 | [65] |

**3.3 Effect of specialty fertilisers**

“In case of iodine, special fertilisers are either sophisticated forms of iodine, or its combination with additives. Salicylic acid (SA) is the most commonly used additive. Its combination with iodine does not enhance yield, but when taken at the appropriate dose (usually 0.1 mg L-1), it promotes I uptake and enriches edible plant parts [50,77]. Humic acid (HA) and fulvic acid (FA) have similar effects” [78,79]. Several forms of iodine other than KI and KIO3 have also been studied: 2-Iodobenzoic acid (2-IBeA); 4-Iodobenzoic acid (4-IBeA); 2,3,5-Triiodobenzoic acid (2,3,5-triIBeA); 5-Iodosalicylic acid (5-ISA); 3,5-Diiodosalicylic acid (3,5-diISA) etc. Table 4 summarises a comprehensive study of the impact of different non-traditional I fertilisers on vegetable crops.

**Table 4. Effect of specialty fertilisers on biofortification of vegetable crops with iodine**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Crop** | **Type of trial** | **Type of fertilisation** | **Specialty fertiliser** | **Effect** | **Reference** |
| Tomato | Greenhouse hydroponic | Hydroponic | I + SA | Significant effect on I uptake from both I- and IO3-; higher I content in fruits was observed on application of KI + SA | [80] |
| Tomato | Pot | Hydroponic | KI vs. 5-ISA vs. 3,5-diISA vs. 2-IBeA vs. 4-IBeA vs. 2,3,5-triIBeA | Significant effect (of 2-IBeA) on I content in leaves, roots and petioles, but not in fruits | [81] |
| Potato | Greenhouse hydroponic | Hydroponic | I + SA | SA positively influenced the amount of I in different parts of the potato plant | [77] |
| Lettuce | Greenhouse hydroponic | Hydroponic | I + SA | No significant effect on yield, but significant increase in I content in the group fertilised with 0.1 mg L-1 SA | [47] |
| Lettuce | Greenhouse hydroponic | Hydroponic | I + SA | The lowest dose of SA (0.1 mg L-1) resulted in highest I content in leaves | [50] |
| Spinach | Pot | Soil | I + HA/FA | HA/FA significantly influenced I content in leaves; however, there was no significant effect on yield | [78] |
| Spinach | Field | Soil fertigation | I + HA | The highest level of I enrichment was obtained with the highest dose of HA | [79] |

**3.4 Influence of other elements on I biofortification**

The effect of joint application of iodine and selenium on carrot was examined by Smoleń et al. [82], who concluded that the effect on yield varied depending on the variety; however, enrichment of carrot roots with iodine was observed in each case. In lettuce, Puccinelli et al. [83] reported that the simultaneous application of I with Zn, Se and Cu induced a greater accumulation in the leaves compared to application of I alone.

**4. COMBINED BIOFORTIFICATION WITH SELENIUM AND IODINE**

“Agronomic biofortification of vegetables with multiple mineral elements is particularly an attractive endeavour as biofortified plants can exhibit simple or combinatorial effects of the supplied elements. Specifically, farmers may benefit from the combined application of Se and I” [6]. In this regard, Golob et al. [84], who investigated the combined effects of Se and I biofortification in pumpkin, found that adding these elements to the biofortification process improved seed germination and increased Se content in seedlings. Similarly, combined application of Se and I significantly improved the I content in carrot [82]. Table 5 presents the most recent findings regarding the combined biofortification of vegetable crops with Se and I.

**Table 5. Examples of combined biofortification of vegetable crops with Se and I**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Crop** | **Applied form of Se and I** | **Dosage** | **Effect** | **Reference** |
| ***Sprouts*** | | | | |
| Pea | KI, KIO3, Na2SeO3, Na2SeO4 | 100 mg I L-1,  10 mg Se L-1 | No effect on chlorophyll accumulation; slight decrease of biomass (3.9-14.1 μg Se g-1 DW; 152-247 μg I g-1 DW) | [85] |
| ***Hydroponics*** | | | | |
| Lettuce | KIO3, Na2SeO4, Salicylic acid (SA) | 30 mg I m-3,  8.5 mg Se dm-3 | Increase in SeMet and sugar; no effect on biomass; root Р increase and Mg decrease; the effect is dose-dependent (7.8-10.4 mg Se kg-1 DW; about 250 mg I kg-1 DW) | [47] |
| Potato | KIO3, Na2SeO3, SA | 39.4 μM I,  6.3 μM Se | No effect on tuber yield; 1 mg SA L-1 + (Se + I) resulted in the highest I tuber content; 100 g of fresh tubers provide 444-489% RDA Se and 47-71% RDA I | [77] |
| ***Soil application*** | | | | |
| Carrot | KI, Na2SeO4 | 4 kg I ha-1,  0.25 kg Se ha-1 | Low effect of (Se + I) on biochemical characteristics of roots; I and Se contents in roots increased by 7.7 and 4.9 times, respectively; 100 g of biofortified carrots substantially covered the RDA for I and Se | [82] |
| Carrot | KI, Na2SeO4 | 4 kg I ha-1,  0.25 kg Se ha-1 | No effect on yield (7.24 mg Se kg-1 DW; 1.47 mg I kg-1 DW juice) | [86] |
| Lettuce | KI, KIO3, Na2SeO3, Na2SeO4 | 2.5 kg I ha-1,  0.5 kg Se ha-1 | Increase in SeMet and SeCys2; higher biofortification level for I- and Se(VI)  (9.4-86.7 mg Se kg-1; 4.2-4.7 mg I kg-1) | [16] |
| ***Foliar application*** | | | | |
| Pea | KI, KIO3, Na2SeO3, Na2SeO4 | 1000 mg I L-1 (KI or KIO3),  10 mg Se L-1 (Na2SeO3 or Na2SeO4) | No growth depression (up to 0.18-0.19 μg Se kg-1 DW; >2% RDA for I) | [87] |
| Kohlrabi | KI, KIO3, Na2SeO3, Na2SeO4 | 1 g I L-1,  10 mg Se L-1 | Se increased chlorophyll and carotene content; I increased anthocyanins; 100 g of fresh tubers provide 1.38-8.5% RDA Se and 0.79-2.01% RDA I | [84] |

**5. FUTURE PROSPECTS AND STRATEGIES**

The aforementioned evidences demonstrate that agronomic biofortification is a viable strategy to supplement vegetables with selenium and iodine, and address their deficiencies. Nevertheless, there are certain issues with the biofortification of Se and I. It is difficult, and sometimes impossible, to assess the efficacy of different strategies due to the inconsistent mass/volume units of fertilisers employed in studies. The effect of various forms of fertilisers, such as granules, liquid form, or encapsulated fertilisers, on the uptake of the micronutrients is not well understood [88-90]. The uptake standards for certain ions are sufficiently low, e.g., under soil conditions, Se(IV) is readily absorbed by humic acid and is reduced to a state that cannot be absorbed by plants, whereas Se(VI) is more mobile and gets easily absorbed by plants. Thus, from an economic point of view, the availability of an ion rather than its concentration serves as the limiting factor. Therefore, research efforts should focus on activating the ions in the soil and increasing their solubility.

The data from the literature were analysed in order to develop an effective biofortification strategy for selenium and iodine. The key points are outlined below:

* First and foremost, it is important to ascertain the essential parameters of soil, or nutrient solution (in case of hydroponic culture), e.g., pH (which affects the assimilation of Se and I), oxidative conditions (which control the uptake of ions by the plant), and the form and concentration of the micronutrients.
* Secondly, when pursuing biofortification, it is worthwhile to select the vegetables and species according to local cultivation conditions. It is also necessary to examine the dietary preferences of the target consumer group.
* Selection of the right form of ion and method of fertilisation is the final step. The majority of research show that foliar fertilisation is a more effective method of biofortifying vegetables with Se and I than soil application, and that the forms I‑ (iodide) and Se(VI) (selenate) are better assimilated.
* Ultimately, additional factors which could shave a substantial impact on the efficiency of fertilisation and uptake of Se and I include the use of other micro- and macronutrients or plant growth regulators.

This integrated approach to the biofortification strategy can result in the formulation of an optimal course of action to address Se and I deficiency issues under local conditions.

**6. CONCLUSION**

Biofortification is an effective crop-based approach to address the issue of mineral malnutrition by enriching vegetable crops and products with bioavailable nutrients using plant breeding, agronomic practices, or transgenic techniques. Among these strategies, the easiest and quickest method to increase concentration of trace elements like selenium and iodine in plant tissues is agronomic biofortification. Understanding the mechanisms underlying the bioavailability of Se and I allows determining the best strategy to alleviate their deficiencies in the soil-plant-human chain. While the development and application of biofortified vegetables (and their products) is still in its early, preliminary stages, the field of biofortified crops needs improvement. International health agencies should develop biofortification standards that can be incorporated into legislation to ensure fair trade practices, intellectual property rights, and the preservation of human health and environmental. However, adoption of biofortified vegetable crops by farmers will largely depend on factors such as yield, resistance/tolerance to biotic and abiotic stresses, marketability and consumer acceptance of expensive Se- and I-enriched vegetables.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT etc.) and text-to-image generators have been used during writing or editing of the manuscript.

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