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Agronomic Biofortification of Iodine in Vegetables – A Review

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ABSTRACT

Iodine is a necessary component for both animals and humans. It is well known that iodine is required for thyroid hormone synthesis. One of the most common preventable human health concerns is iodine deficiency illnesses. In many areas, growing iodine-enriched foods could be an effective method to prevent epidemicity. An adequate iodine supply approach is the employment of various iodine fertilization strategies to biofortify crops. As a result, iodine biofortification is an active area of research with extremely important outcomes. However, most of what we know about this topic comes from studies involving grain crops and inorganic iodine fertilizers. Furthermore, little is known about iodine's transport, transformation, and distribution from soil to plants. This review systematically analyses the results of published research on the use of iodine in vegetables, taking into account of varied environmental condition in various species, as well as varying iodine concentrations, chemical forms, and application methods. Some studies suggest that iodine has good effects, such as improved growth and increases in stress tolerance, whereas others report that iodine has little effect or perhaps has negative effects. This review aims to provide an overview about the biofortification of iodine to vegetables (in terms of its forms, concentration applied, results and instrument used), understanding of iodine biogeochemistry and transfer behavior and stability and bioavailability of biofortified iodine in vegetables.

Keywords: Iodine, Hormone, Deficiency, Biofortification, Vegetables and Stability

I. INTRODUCTION

Baumann discovered iodine in the thyroid gland in 1895. Iodine is a trace element that may be found in some foods naturally. Despite the fact that iodine is not regarded a micronutrient by higher plants, it is necessary for animals. Iodine is required for the production of the thyroid hormones thyroxine (T4) and triiodothyronine (T3) (T3). Thyroid Stimulating Hormone (TSH), also known as thyrotropin, affects critical metabolic activities such as enzyme activity and protein synthesis. Iodine deficiency caused thyroid enlargement (goitre) (Marine and Kimball, 1917). Thyrotropin is a hormone secreted by the pituitary gland that regulates thyroid hormone production and secretion. It also guards against hypothyroidism and hyperthyroidism. TSH secretion promotes iodine absorption by thyroid hormones and boosts T3 and T4 synthesis and release. In the lack of sufficient iodine, the TSH level remains elevated, resulting in goitre, which is an expansion of the thyroid gland caused by the body's attempt to capture more iodine from the circulation and generate thyroid hormones.

In recent times, agricultural biofortification has made significant progress in improving human micronutrients such as Fe, Zn, and Se, among others (Graham et al., 1999; Poletti et al., 2004). Although it has been established that applying exogenous iodine to soil can increase iodine levels in agricultural products (Weng et al., 2003; Dai et al., 2004), most of these studies focused on grain crops and used inorganic iodine (e.g., I, IO 3) as the exogenous iodine fertilizer (Ashmore et al., 1996; Gregorio, 2000). Vegetables are basic requirements of life that are consumed in great quantities. Although studies has revealed that vegetables have a higher propensity to absorb iodine than grain crops, the translocation, transformation, and transport of iodine from soil to various vegetables are unknown.

Ecology of iodine

The earth's iodine (as iodide) is extensively spread but unevenly distributed. Because iodine is a rare element that is primarily found as a salt, it is referred to as iodide rather than iodine. Iodine is found in soils in both inorganic and organic forms [Iodate-(IO_3^-) and Iodide-(I^-)]. Iodine has several oxidation states, and its behaviour in soils is complicated by factors such as soil composition, texture, pH, and redox processes (Weng et al., 2009).

In the duodenum, iodide is entirely absorbed, whereas IO_3^- is reduced in the gastrointestinal system and absorbed as iodide. Depletion of surface soil iodide due to leaching, flooding, and erosion results in increased iodide deposition in seas. Iodine concentration in marine water is around 50μg/liter. Seawater iodide ions are converted to elemental iodine, which is subsequently volatilized into the atmosphere until rain returns it to the land. In many areas, the iodine cycle is sluggish and incomplete, resulting in iodine depletion in soils and drinking water. Crops cultivated in these soils will be lacking in iodine, and humans and animals eating food grown in these soils will be deficient in iodine.

Both coastal and inland communities are affected by iodine deficiency. Iodine deficiency remains until iodine is added into their food chain by salt iodization, biofortification of iodine in crops, or the production of foods outside of iodine-deficient areas.

Sources of Iodine

Iodine levels are extremely high in a number of crucial foods. One of the best sources of natural iodine is sea veggies. Sea vegetables help protect the glandular system from radiation sickness by providing enough iodine. Sea vegetables with high natural iodine content include kelp, nori, kombu, and sea spaghetti (Zimmermann, 2009). Iodine is found in dairy products. The quantity of iodine in dairy products, on the other hand, varies depending on whether the cows were given iodine feed supplements.

Unless the producer has employed potassium iodate or calcium iodate as a dough conditioner, most commercially produced bread has relatively little iodine (Ershow et al., 2018 and Patterson et al., 2020). Iodine is scarce in fruits and vegetables. The iodine concentration of the soil, fertilizer use and irrigation procedures all have an impact on the amount of iodine present.

The amount of iodine you need each day depends on your age. Average daily recommended amounts are listed below in micrograms (mcg)

Life Stage	Recommended Amount
Birth to 6 months	110 mcg
Infants 7–12 months	130 mcg
Children 1–8 years	90 mcg
Children 9–13 years	120 mcg
Teens 14–18 years	150 mcg
Adults	150 mcg
Pregnant teens and women	220 mcg
Breastfeeding teens and women	290 mcg

Source: https://ods.od.nih.gov/factsheets/Iodine-Consumer

Iodine deficiency disorder (IDD)

Iodine insufficiency occurs when the soil is deficient in iodine, resulting in low uptake in crops and, as a result, a population affected by insufficient iodine intake. When iodine requirements are not satisfied, the thyroid hormone will stop working. Thyroid hormone levels in the blood were low, resulting in a series of functional and developmental disorders known as IDD (Umesh kapil, 2007). The signs and symptoms of iodine deficiency disorder include swelling in the neck, sudden weight gain, weariness and weakness, hair loss, changes in heart rate, difficulty learning and remembering, and issues during pregnancy. These symptoms are comparable to hypothyroidism symptoms (Low thyroid hormones)

The universal fortification of salt with iodine is one technique to treat Iodine Deficiency Disorder (IDD). This strategy, however, will not be sufficient to treat iodine deficiency illness (de Benoist et al., 2008). This is due to the fact that the iodine in table salt is unstable and exposed to increased volatilization (Mottiar and Altosaar, 2011). In this regard, agronomic biofortification of iodine in crops may be a viable option because organic sources are more stable than inorganic sources (Weng et al., 2008a). Over the last few decades, fortification has helped to lower the prevalence of iodine deficiency around the world. The amount of iodine in the salt is determined by the quantity of iodization used by the manufacturer. As a result, there was a greater need for cooking, storage, and transportation. On the other hand, iodine volatilization was increased as a result of additional cooking, storage and transportation.

Biofortification of iodine

Agronomic biofortification of food plants with iodine has been proposed as a new technique to address human iodine insufficiency. Crops can boost the absorption and concentration of this trace element by adding iodine-containing salts or iodine-rich organic materials (e.g., seaweed) to soils. Iodine present in the foods is highly accessible (up to 99 percent) and quickly absorbed (Weng et al., 2009). When compared to inorganic forms, the organic form of iodine has improved stability and bioavailability. Iodine from the plants is absorbed into the tissue, where it is bonded to protein and more easily absorbed. Iodine deficiency can be avoided by adding iodine biofortification to commonly consumed crops. Weng et al., 2014 and Tonacchera et al., 2013 studied the efficacy of iodine prophylaxis in people by consuming various biofortified vegetables and found a significant increase in mean urine iodine excretion, which closely mirrors human iodine intake.

Stability and bioavailability of iodine

The bioavailability of iodine in biofortified vegetables is far more essential than the amount of iodine present. Iodine biofortification by foliar spray and soil application resulted in higher iodine stability during various cooking techniques, whereas iodine provided in the form of iodized salt to non biofortified vegetables resulted in significant iodine losses during the boiling process (Comandini et al., 2013 and Weng et al., 2014). The amount of iodine lost from vegetables is mostly determined by the method of cooking and the amount of salt used. 2011 (Rana and Raghuvanshi). The results of a study to determine the stability of added iodine under various Indian cooking processes revealed that iodine retention is lowest in shallow frying with oil and highest in pressure cooking. (Longvah et al., 2012).

Table1. Agronomic biofortification of iodine in different vegetables

Crop	Form of Iodine	Application	Concentration applied	Place	Results	Instrument	Author
Tomato	Algal organic iodized fertilizer and Diatomite	Soil	12,25,50,100,150 mg/m^2	China	Organic fertilizers increased the iodine content in the plant proportional to the amount applied	ICP-MS	Weng et al.,2013
Tomato	KI and KIO_3	Nutrient Solution	1mg I dm^{-3}	Europe	In combination with salicylic acid, the iodine content was increased in fruits	ICP-OES	Smolen et al.,2015
Tomato	KI, Radioactive Iodine	Nutrient Solution	0,5,10, 20 mM	Italy	Iodine was taken up better when supplied to roots using hydroponically grown plants. Tomato plants can tolerate high levels of	ICP-MS	Landini et al.,2011

					Iodine		
Tomato	KI, KIO_3	Nutrient Solution	KI- 1,2 and mM and KIO_3- 0.5, 1 and 2 mM	Italy	Concentration of iodine in biofortified fruits is proportional to the concentration in the nutrient solution	ICP-MS	Kiferle et al.,2013
Crop	**Form of Iodine**	**Application**	**Concentration applied**	**Place**	**Results**	**Instrument**	**Author**
Amaranthus	Sodium Iodide	Soil or foliage	0.5 and 10 kg/ha^{-1}	Zimbabwe	Soil and foliar application of iodine increased iodine uptake by plants	ICP-MS	Ivy et al.,2020
Lettuce	KI, KIO_3, Chitosan-KIO_3, Chitosan-KI	Nutrient Solution	0,5 and 25mg I Kg^{-1}	Mexico	Application of CS- KIO_3 increased the biomass.	ICP-OES	Rangel et al.,2020
Chinese cabbage	NaI or $NAIO_3$	Nutrient Solution	0.05-5mg/l	China	There is effective uptake of iodine when it is supplied in the form of IO_3^- (<0. mg l^{-1})	ICP-MS	Weng et al.,2008a
Tomato	KI	Nutrient Solution	1-5mM	Italy	Exogenous iodine application increased the iodine content in the flesh of the fruit	ICP-MS	Caffagni et al.,2012
Spinach	I and IO_3^-	Nutrient Solution	0-100 µM	China	The concentration of iodine in plants increased by increasing the concentration of iodine in nutrient solution	Neutron activation analysis	Zhu et al.,2003
Lettuce	KI and KIO_3	Nutrient	10-240 µM	Spain	The concentration	Atomic Absorption	Blasco et al.,2008

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		Solution			of 40 µM KI in plants resulted in accumulation of iodine	Spectroscopy	
Crop	**Form of Iodine**	**Application**	**Concentration applied**	**Place**	**Results**	**Instrument**	**Author**
Pakchoi, celery, pepper and radish	KI	Soil	10-150mg/kg	China	The iodine residue in soil was less when it was cultivated with vegetables	ICP-MS	Hong et al.,2009
Cucumber, aubergine and radish	Kelp and diatomite fertilizer	Soil	10-150mg/kg	China	The iodine content in leaf, fruit and rhizome tissue increased by addition of iodine fertilizers	Photometer	Weng et al.,2008b
Spinach	KI and KIO_3	Fertilization and Fertigation	1.0-1.1 mg I dm^{-3}	Poland	Fertigation method of biofortification is more effective than fertilization in spinach	ICP-MS	Smolen et al.,2012
Chinese cabbage, lettuce, tomato and carrot	KI and Sea weed composite iodine	Soil	10-150mg/kg	China	The level of iodine content in vegetables increased with increased addition of iodine	Photometer	Hong et al.,2008
Lettuce, kohlrabi and radish	KI and KIO_3	Soil and Foliar spray	Soil: 1-15kg/ha Leaf: 0.5-2kg/ha	Germany	Soil applied iodine was phyto available only for a shorter period of time when compared to foliar applied.	ICP-MS	Lawson et al.,2015

ICP- Inductively Coupled Plasma and MS- Mass Spectroscopy

Table2. Bioavailability and stability of iodine

Crop	Experiment	Results	Author
Carrot, potato and tomato	Boiling and Baking	In biofortified crops, the typical home cooking method boiling and baking are suitable to preserve iodine. The loss of iodine during cooking process (boiling and baking) is less for potato and tomato when compared to carrot	Comandini et al., 2013
Celery	Soaking, cooking and digestion	The bioavailability of iodine in biofortified celery is higher under cooking (80%) and digestion (74%). The loss of iodine during soaking is also minimum (3.5-10.4%).	Rui Li et al., 2018
Carrot	Boiling	There is about 56% loss of iodine in biofortified carrot during cooking. This is due to the fact that the carrot is having low starch content	Piątkowska et al., 2015
Brassica	Boiling and steaming	Depending on the brassica genotypes, boiling decreased	Gonnella et al., 2019

		iodine content and steaming increased or unchanged the iodine content	

II. CONCLUSION

The agronomic technique is particularly practical in leafy vegetables (such as lettuce and spinach) as well as several tuber and fruit vegetables (such as potato and tomato). Because the iodine level drops from root to leaf, stem, and grain, it is not practicable in crops whose grains are the edible product. The efficacy of iodine biofortification in vegetables is largely determined by the technology chosen, as well as dosages and application timing. As a result, biofortification of crops was encouraged in order to ensure appropriate iodine intake as a substitute for inorganic iodine in table salt.

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