Original Article
ISSN (Online): 2350-0530
ISSN (Print): 2394-3629

International Journal of Research - GRANTHAALAYAH
August 2025 13(8), 39–53

IODINE, SEAWEED AND FORTIFICATION

Smitha Sadan [1]

[1] Assistant Professor, Department of Chemistry, Sree Narayana Arts and Science College, Kumarakom, Kerala, India

Received 14 April 2025
Accepted 15 May 2025
Published 31 August 2025

Corresponding Author
Smitha Sadan, smithaanish2@gmail.com

DOI
10.29121/granthaalayah.v13.i8.2025.6305

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

The advancement of human health is still concerned with science. Many allopathic drugs are produced from substances that are derived from natural products. The capacity of natural products containing compounds considered equal to the medications present in the current scenario has been shown by ancient and conventional medicines in India and abroad. The main sources of natural products are fungi, algae, plants and animals. The current research aims to produce a food that is fortified with seaweed rich in iodine. Seaweeds are recognized to be used in many industries for their useful phycocolloids such as agar- agar, algin, etc. In many countries, including Japan, they are often used as food. Therefore, surveys of seaweed and its chemical composition, ecological cultivation and the method of extraction of essential components are very significant. Most seaweeds are known to absorb iodine, such as brown algae Laminaria, Fucus vesicullosus, Sargassum, etc. If incorporated into foods, these marine algae may contribute to a permanent and natural solution to iodine deficiency disorders. The aims were to research seaweed screening, availability, palatability and other biochemical aspects of available seaweed along the Indian coast. Fortification of seaweed food can lead to a product that is high in iodine other than fortified salt and without any side effects as well.

Keywords: Goiter, Iodine, Thyroid, Marine Algae, Nutrient Fortification

1. INTRODUCTION

Iodine is a simple element which is widely distributed in soils and food in nature, but most abundantly found in marine creatures and seaweeds in the ocean Eastman and Jooste (2012). Iodine was discovered in the thyroid by Baumann (1896). The thyroid hormones thyroxine (T4) and tri-iodothyronine (T3) formed by the thyroid gland are important components for human growth and development Rousset et al. (2000). Many important biochemical reactions, including protein synthesis and enzymatic activity, are regulated by thyroid hormones and are essential determinants of metabolic activity Institute of Medicine, Food and Nutrition Board (2001), which can lead to a variety of adverse effects through impairment of synthesis, identified in the 1980s as iodine deficiency disorders (IDD)

Hetzel (1983). The main issue for the health and development of populations globally is iodine deficiency disorders. Hypothyroidism, endemic goiter and cretinism, endemic mental retardation, reduced fertility, increased prenatal death and infant mortality result from extreme IDD FAO/WHO (2005). According to the latest global report, iodine deficiency is at risk for 1.88 billion people and 241 million children (~30 percent) have an insufficient intake of iodine and more than half of them live in South/Southeast Asia (76 million) and Africa (58 million) Andersson et al. (2012). Over 200 million individuals are estimated to be at risk of iodine deficiency disorders in India while the number of people with goiter and other disorders of iodine deficiency is above 71 million World Health Organization. (2007).

The substance of iodine in food depends on the quality of iodine in the soil. Low iodine concentrations in soil and water result in plants and animals deficient in iodine Rohner et al. (2014). Bad iodine content is found in the mountainous regions of Europe, the Northern Indian Subcontinent, the vast mountain ranges of China, the Andean zone of South America and the smaller ranges of Africa. In India, because of iodine deficiency in the soil of the subcontinent and hence the food extracted from it, the entire population is vulnerable to IDD Dav et al. (2013). Since communities rely on food sources grown in areas where iodine may be deficient, only by adding this nutrient to nutrient delivery (food fortification) interventions will iodine reach the food supply (e.g. iodization of salt), and the most common staple has been edible food-grade salt, a crystalline substance consisting mainly of sodium chloride Codex Alimentarius (1985).

Fortifying regular foods with vitamin A, iodine, iron and various micronutrients is one of the world's most sustainable and cost-effective ways of enhancing nutrition for large populations WHO (2006). For developed countries where micronutrient malnutrition remains a public health issue, similar fortification technology represents an underutilized potential. India's history of fortification began in 1953 when vitamin A and D Sridhar (n.d.) fortification of hydrogenated vegetable oil (vanaspati) was mandated.

Reducing iodine deficiency conditions WHO (2014) has steadily benefited from salt iodization around the world and is being introduced in more than 120 countries around the world. It was first proposed at the beginning of the 19th century that the use of salt fortified with iodine would contribute to good health for people living in mountainous regions Boussingault (1831). At 20 mg/kg, approximately 94 percent of household salt and 50-70 percent of commercial food salt is iodized. In India, however, compulsory salt iodization started in 1998 and only 51 percent of households used sufficiently iodized salt between 2005 and 2006 Ministry of Health and Family Welfare, Government of India & International Institute of Population Sciences (2007). The potential side effects of iodine excess include iodine-induced hyperthyroidism (IIH) as the key complication of public health importance of iodine excess Stanbury et al. (1998). Insufficient and excessive ingestion of iodine can lead to thyroid disease Zimmermann (2009).

Salt iodization, an expensive process requires special packaging and the presence of national commercial networks that are currently inadequate Pan American Health Organization (1986). It is noted that, under controlled production, atmosphere, packaging and storage conditions, iodine losses from iodized salt are extremely variable and have an effect on the recommended daily intake (RDI) ranging from 150 to 200 mg/day. The prescribed amount of iodine cannot be derived from a single food intake and can be obtained from various foods and beverages containing iodine. In treating deficiency disorders in children, pregnant women and those with high blood pressure, iodized salts are not effective. Supplementary iodine should also be strictly restricted and regulated by producers and government bodies. The additional quantity of iodine should therefore be added at normal as well as factory level as dietary sources.

Milk products, primarily milk, aquatic animals (sea foods) Risher and Keith (2009), and marine plants such as some marine algae (seaweeds) are the major dietary sources of iodine Kylin (1929), Mæhre et al. (2014), Saenko et al. (1978). However, due to different life style diseases, fish consumption varies with territory and milk consumption decreases. In Europe, macro algae are a possible new source of dietary iodine and are often considered to be a particularly nutritious food or even a superfood Food and Agriculture Organization (2018). In Asian cultures, seaweed is commonly used as a food Zava and Zava (2011), especially in soups, sushi, salads, and snacks, as well as in other dishes. The natural variability found in the content of macro algal iodine indicates that it may be appropriate to re-evaluate the intake level of 'seaweed' (as raw food material) containing the recommended quantity of 150 mg/day for adults Delange (2002), World Health Organization. (2007) considering (groups of) species and type of product. In brown seaweed with dry laminaria with 1500 to 8000 ppm and Fucus with 500 to 1000 ppm, the highest iodine content is contained Dharmananda (2002). While iodine has potential beneficial health effects for humans Aceves et al. (2005), some health problems could also be caused by excess ingestion. Also, as the ingestion of significant amounts of algae-derived iodine can have health consequences, the amount of unprocessed natural (dried) macro algae ingested should not exceed a few hundred milligrams per day Müssig (2009). However, through food processing, such as soaking in water, cooking etc., the initial iodine levels in seaweeds will significantly decrease. The results of the survey of iodine levels in products containing seaweed and seaweed suggest that while most seaweed and seaweed products have levels of iodine that are considered safe for consumption, some seaweed have very high levels of iodine that may be unsafe for human consumption. Food Standards Australia New Zealand (2007).

The origins of iodine nutrition, the function of iodine in thyroid hormone production, and the clinical effects of iodine excess and deficiency on thyroid physiology and disease, the role of seaweed-containing iodine as an iodine-fortified food, are outlined in this study. No studies have been reported to fortify foods with natural seaweed iodine rather than artificial potassium iodide and to attempt to evaluate the highest iodine content present in various seaweed species, especially Kelp, Kombu, Wakame, Laminaria and Ssargassum, etc.

2. THYROID COMPREHENSION

Thyroid is a butterfly-shaped endocrine gland that wraps around the windpipe, usually located in the lower front of the body. Thyroid function is to generate thyroid hormones that are vital to virtually all tissue metabolisms and are essential for the growth of the fetus and children's central nervous system Escobar et al. (2007). Thyroid hormones are hormone containing iodine, thyroxine or tetra-iodothyronine (T4) and tri-iodothyronine (T3), which helps to control a broad range of physiological processes, including calorigenesis, thermoregulation, metabolic rate, development and growth of most organs, and protein synthesis Keating and Albert (1949). Bauman—Bauman.). The discovery of the trace element iodine inside the thyroid gland Merke (1984), which is an essential constituent of thyroid hormones, was stated by Baumann (1896). The thyroid gland is able to improve or restrict the use of iodine for thyroid hormone development, depending on the availability of iodine. It has been stated that auto-regulatory intra-thyroidal mechanisms increase the activity of several processes involved in the use of iodine for the development of thyroid hormones when the supply of iodine is below a certain limit Gärtner (2009).

Iodine exists predominantly as inorganic iodide in foods, and can be completely absorbed from the gastrointestinal tract Keating and Albert (1949). The iodide that enters the body is first oxidized into iodine and then absorbed into the Thyroglobulin tyrosine residues Brody (1994). Such tyrosine residues are then covalently cross-linked to form iodinated DIT tyrosine dimmers. The reactions are catalyzed by the Haem protein thyroperoxidase. Then iodized thyroglobulin enters the thyroid cells and the iodized tyrosine dimmers are released primarily as T4 by proteolysis, which enters the bloodstream leading to the de-iodination of T4 in the liver to produce T3. Usually, urinary iodine is 85-90% of the daily intake and is a good example of adequate iodine intake in the body Lamberg (1993). Underwood (1977) proposed that the thyroid must capture approximately 60 micrograms each day to ensure a sufficient supply of thyroid hormones. A daily allowance of 90 micrograms per day is permissible for infants in order to provide a safety margin, and 150 micrograms per day is recommended for teenagers and adults. Council of National Science (1989). Thyroid secretion by TSH is under the influence of the pituitary gland. TSH secretion is increased when plasma T4 falls and thyroid function, including the uptake of iodine, increases.

3. GOITER, RELATION OF THYROID AND IODINE

Ingestion of iodine contributes to a decrease in plasma levels of T4 and T3, thereby increasing the secretion of TSH. The sum of iodine boosts the thyroid cells at a reduced level of TSH. TSH increases the size of the thyroid cell and the number of cells and the gland enlarges to form a goiter when the atmosphere has a small amount of iodine Hurrell (1997). The French nutritional chemist Jean Baptiste Boussingault (1830) found that in areas where naturally occurring iodized salt was commonly consumed, the incidence of goiter increased and suggested that natural iodized salt be distributed for public consumption. The French chemist Adolphe Chatin (1852) was the first to publish the theory that goiter induces iodine deficiency. If the goiter prevalence exceeds 10%, it is referred to as endemic goiter. It was discovered in the early 20th century that iodine supplementation could prevent this endemic goiter Marine and Kimball (1990).

Iodine is mainly present in coastal soil and water and has been classified as an ingredient of iodine Kurtois (1811). The content of iodine in food also depends on the level of iodine in the soil and groundwater. Accumulation of iodine is mainly found in coastal areas, and seaweed and other marine life are the most common sources of dietary idine Koutras et al. (1985) treated with Sulfuric acid developed a purple color that later condensed into purple crystals Rosenfeld (2000). Other sources of dietary iodine include iodized salt (as a public health measure due to the addition of iodine to table salt), milk foods (as a result of iodophore cleansers for milk cans and teats) and bread dough (as a bread conditioner due to the usage of iodate), Koutras et al. (1985).

The nutrition of iodine in an infant is determined by the concentration of iodine in breast milk. Although the iodine content of breast milk varies greatly depending on the maternal diet and supplements used during pregnancy by women Andersson et al. (2007), Untoro et al. (2007). Complementary food (CF) should be added at the age of around 4-6 months Agostoni et al. (2008), as the contribution of milk to the diet decreases. A variety of functional and developmental defects aise when the physiological criteria for iodine are not fulfilled, including thyroid dysfunction, goiter, neurocognitive impairments, and hypothyroidism resulting in cretinism in extreme deficiency. Growing clinical and public health research has shown that the symptoms of iodine deficiency are well beyond those of Goiter and Thyroid disease Zimmermann et al. (2008). Children in the Iodine deficient region are also found to have impaired motor development, lower IQ and poor school results Vermiglio et al. (1990), Bleichrodt et al. (1987).

4. DISORDERS OF IODINE DEFICIENCY (IDD)

Thyroid hormone synthesis is disrupted when requirements for iodine are not met, leading to a series of functional and developmental defects collectively referred to as iodine deficiency disorders (IDDs) Hetzel (1983) and the term IDDs was coined to emphasize that iodine deficiency can affect humans at all stages of the life cycle and have a wide range of adverse effects, including Iodine Deficiency Disorders affect fetuses, neonates, children and adults in various ways. Hetzel et al. (1990). Endemic cretinism, mainly due to brain growth failure, occurs when the consumption of iodine falls below 25 micrograms per day. 200 million people worldwide have goiter and nearly 6 million suffer from cretinism's mental and neurological consequences World Health Organization (1990). Endemic goiter affects nearly all areas of the world. Marine and Kimball (1920) stated that goiter is the result of a lack of iodine in the diet. There is a high prevalence of Goiter and Cretinism in wide areas of Africa (Zaire, Cameroon, Burundi), Asia (India, Nepal), South America (Ecuador, Peru, Bolivia). Lamberg (1993).

The worldwide reduction of IDD is a significant concern for international health and nutrition Hetzel (1993), Delange et al. (1993). In India, the entire population is vulnerable to IDD due to iodine deficiency in the soil of the subcontinent, which is the product of frequent floods and erosion, resulting in food extracted from it Pandav et al. (2013).

5. IDD AND SALT FORTIFICATION WITH IODINE

Salt enrichment with iodine has been regarded as the proper food fortification technique and it is technically feasible since the stability of iodized salt intake is preserved by the citizens themselves. Salt iodization is the favored iodine deficiency condition prevention technique and is introduced in more than 120 countries worldwide World Health Organization (2014). Many countries worldwide have successfully removed or made considerable improvement in their management of iodine deficiency disorders, primarily as a result of salt iodization. India was the first country in the world to initiate a public health program focused on salt iodization to treat iodine deficiency disorders.

Iodine intake itself, which depends on the level in the soil, access to sea foods and access to fortified foods such as salt, is the key factor that regulates the amount of bio available iodine in the diet Delange and Bürgi (1989). In iodine-deficient nations, iodine supplementation during pregnancy is important to avoid mental deficiencies that can arise in the unborn child Berbel et al. (2007). During the primary stages of development, the use of iodized table salt is unfavorable; infants from 4 to 6 months onwards are at high risk of inadequate ingestion of iodine residing in iodine-deficient soil where iodine-poor plant foods and crops are present. It is recommended that children between the ages of 7 and 24 months should receive either an iodine fortified food supplement Untoro et al. (2007). Pregnant and lactating women are at high risk of IDD, and 250 μg/day of iodine intake is recommended Trumbo et al. (2001), World Health Organization (2007). International organizations recommend a regular intake of iodine for children of 120 micrograms per day for children aged 6 to 12 years and 150 micrograms per day for teenagers from 13 years of age to adulthood.

The most favorable method of salt fortification is to iodize salt with sodium iodide. Iodate is quickly reduced to iodide and completely absorbed, which is commonly used for fortification Institute of Medicine (2000). Research is on various effective salt fortification programs which correct the IDDD Dunn et al. (1986). Iodine deficiency is almost rectified by the proven methods of iodized salt and iodized oil by adding iodine to dietary media such as salt, oil, water, sauces etc. Salt iodination is very cheap, nearly less than USD 0.01 per day Zimmermann et al. (2008). The salt is consumed by all parts of the population globally and in regular quantities, which makes it efficient in regulating the IDDD Dhaar and Robbani (2008), Hetzel (1983). Despite significant national and international initiatives to increase iodine intake, mainly through voluntary or mandatory iodization of salt, 2 billion people worldwide, including 285 million school-age children, still have iodine deficiency World Health Organization (2012). The key feature of the National Goiter Control Program (NIDDCP) in India is the fortification of potassium iodate common salt as a medium for iodine fortification in India Hetzel (1983).

6. FORTIFICATION OF FOODS OTHER THAN SALT WITH IODINE

Food fortification refers to adding micronutrients at a very affordable cost to processed foods. As part of a food-based approach, fortification of food with micronutrients is a relevant technology to minimize micronutrient malnutrition when and where current food sources and restricted access fail to provide sufficient amounts of the respective nutrients in the diet WHO/FAO (2006).

The iodine fortification of salt should be based on the estimated daily salt intake. In various countries, and even within a country, salt consumption typically varies. For example, some Brazilian indigenous populations have salt intakes of less than 1 g/day, while some countries such as Korea or Japan have recorded consumption of nearly 20 g/day Elliott and Brown (2007). Currently, WHO (2013) recommends a reduction to 2 g/day sodium (5 g/day salt) in adults, and the suggested daily consumption level in children should be modified downwards based on children's energy needs relative to adults. Hypertension, cardiovascular disease and stroke have been associated with high sodium salt intake, and decreasing sodium levels can decrease blood pressure and the risk of associated non-communicable diseases. It has been accepted that salt iodization policies to avoid iodine deficiency should be consistent with the recommendation to restrict the intake of salt (sodium) from all sources World Health Organization (2007).

The introduction of salt iodization systems in all countries may not be feasible and increased intake of iodine-fortified foods other than salt is noted to ensure adequate nutrition of iodine in the specific classes. While food-grade salt fortification is a relatively inexpensive intervention that is likely to be well received by various stakeholders, difficulties in terms of implementation are likely to arise WHO (2014). A recent trend in high-income and low middle-income families/countries has been noted that individuals ingest the majority of their salt through refined foods, in which iodized salt is normally not used, rather than through iodized salt. Therefore, countries relying on table salt iodization alone cannot achieve adequate iodine nutrition for their population Ohlhorst et al. (2012).

Fortification of other food vehicles with iodine has been recommended and checked WHO/FAO (2006), taking into account pregnant mothers, lactating women, hypertensive patients and infants under 6 years of age who are at risk of IDD only because they are unable to eat salt. In a study conducted in Norway by Dahl et al. (2004), fish, especially marine fish, have the highest natural concentration of iodine and are thus an excellent source of iodine. If cattle are fed with iodine-enriched feed, milk and milk products are also a good source of iodine, and it is important to prevent iodine deficiency disorders as part of the promotion of dietary diversification. Dairy foods, indicated during pregnancy, also remained a major contributor to iodine Charlton et al. (2013). In nations such as Switzerland and the USA, iodine containing milk is a major source. Rather than purposely inserting the iodine, they apply their iodophores.

Land et al. (2013) examined food other than salt fortification, such as edible oils, edible fats, wheat flour, maize flour, milk and milk products, condiments and seasonings, fruit juices and nectar, etc. There are 12 staple food vehicles for iodine fortification in public health programs that have been evaluated with varying degrees of success in public health programs, according to WHO/FAO (2006), including: refined water, refined sugar, fish sauce, fish oil, edible vegetable oils and fats, cereal grains such as processed rice, plus wheat and maize flours, seasonings and seasonings, and powdered or liquid milk. There are also bouillon cubes and bread made with iodized salt as an ingredient DeLong et al. (1997), Elnagar et al. (1997). The pre-and post-intervention surveys indicate that the transition to iodized bread led to a substantial increase in Tasmania's iodine status Seal et al. (2007). Eltom et al. (1995) indicated that in attempts to eradicate iodine deficiency related disorders in endemic areas, fortification of sugar with iodine may serve as a new alternative approach. Several experimental studies have been performed to understand the impact of water fortification with iodine in Thai schools, milk fortification in the United States, the United Kingdom and Northern Europe, and pig animal fodder has been fortified in Finland WHO/FAO (2006). Despite such compelling evidence in favor of salt iodization, 54 countries were estimated to still have insufficient nutrition of iodine (i.e. median urinary iodine $< 100 \mu g/l$) as recently as 2003 Benoist et al. (2004).

7. SEAWEEDS-A REPLACEMENT FOR FORTIFIED IODINE SALT

The presence of iodide/iodate in the food during the iodine fortification process may result in redox reactions and may affect the characteristics, shelf life and stability of the food. With regard to the reactions of iodine and its salts in food matrices, very little research has been undertaken. Less research has been performed on the side effects of global iodization programs Winger et al. (2008). Therefore, the effect of fortifying processed foods with iodine salts is uncertain and the need to substitute iodine fortified salt for any natural material is established.

Seaweeds have been continuously used for at least 13000 years as medicine and food. Seaweed is used as a food grown on many countries' coastlines. Macroalgae has entered the world food market in recent years, and has become increasingly popular in the western part of the world Bouga and Combet (2015). Seaweed can be used as fertilizer, animal fodder, medicine, cosmetics and even mythology, considering high availability, low cost and historical use in particular regions Kenicer et al. (2000). Seaweed, however, is commonly present in the Asian diet and, according to observational studies in South East Asia, has been found to have health benefits and potential benefits against chronic diseases such as cardiovascular disease, cancer and diabetes Brown et al. (2014), Brownlee et al.

(2011). Seaweed has the ability to serve as a functional food and ingredient Mendis and Kim (2011) and has contributed to a renaissance in the health and food industry by addressing dietary iodine properly, rather than high nutritional value. Seaweed, eaten as a whole or mixed into other foods, has the potential to increase the availability of iodine in the food chain as a functional component Combet et al. (2014) as long as the seaweed's micronutrient content is carefully evaluated to prevent unintended exposure to (too) high doses of iodine.

For approximately 2 billion years, seaweeds have been part of the world's ecosphere Gury (2003) and are considered the main source of iodine and the cheapest food to carry out the human iodine requirement. Seaweed contains a unique wealth of mineral components, macro components, and marine trace elements. Sodium, chlorine, sulfur and phosphorus, calcium, magnesium, potassium are exceptional riches of mineral macronutrients; iodine, manganese, boron, nickel and cobalt, iron, zinc, copper, selenium, molybdenum, fluoride, etc. Madhusudan et al. (2011). Following the discovery of mineral iodine from mines, seaweed was no longer used as an iodine source Chapman (1970). As their protective mechanism against enemies, the marine algae absorb iodine more than in sea water. Seaweed iodine is readily available, often soluble in water and superior to mineral iodine obtained from mineral deposits. Seaweed studies in 1978 and 2006 indicate that marine algae have an intrinsic capacity to bio-accumulate iodine Leblanc et al. (2006), Saenko et al. (1978). The ability to absorb iodine is present in red and brown algae Chennubhotla et al. (1987). Japanese people should not take iodized salt because their diet includes large amounts of seaweed rich in iodine. Iodine is derived in small amounts from brown seaweeds in Japan, Norway and France. Red seaweeds such as Phyllophora nervosa in Russia are also produced in Russia Thivy (1958). Due to the instability of iodine, Yeh et al. (2013) announced that iodine was extracted as iodo-ketone from marine algae.

The medical uses of seaweed vary from topical burn therapy to goiter therapy to softening of tumours (Schwimmer & Schwimmer et al., 1995). In countries where marine algae are part of their diet, Goiter disease caused by iodine due to deficiency is rare because seaweed is a good source of dietary iodine. Traditionally, the brown seaweeds were used to treat Thyroid goiter Suzuki et al. (1965). Seaweeds rich with iodine such as Asparagopsis taxonomis and Sarconema sp can be used for controlling goiter diseases Rao (1970). The ingestion of iodized rich seaweeds such as Asparagopsis and Sarconema spp. can regulate and cure hypothyroidism. Kaliaperumal and Ramalingam (2000). Japan's average urinary excretion ranges from 700 to 3200 μg/d and Japan's thyroid health is excellent; there is no excess occurrence of autoimmune thyroid that is expected to arise from excess intake of iodine Yeh et al. (2013).

According to Chung et al. (2009), the iodine content in breast milk among Korean and Korean-American women who regularly consumed Undaria pinnatifida seaweed soup during the early postpartum period showed the strongest association with the frequency and quantity of consumption of seaweed soup. There is an enormous amount of iodine in seaweed such as Asparagopsis deleilimontagne found in the Hanumandi Reef, Okha coast and various Mandapam Islands Vasuki et al. (2000). The seaweed varieties from which iodine is extracted in Japan, Britain and other countries are Laminaria, Phyllophora and Ecklonia Chennubhotla et al. (1987). The brown seaweed Fucus vesiculosus grows on the northern coasts of the Atlantic and Pacific Oceans and the North and Baltic Seas. The common name bladder wrack and rich source of iodine is also considered to be bioavailable Yan et al. (1999) and also includes minerals such as calcium, potassium, comparatively smaller quantities of phosphorus, selenium, and magnesium and vitamins, has a beneficial impact on thyroid function Rafieian-Kopaei (2018) and also helps to suppress trans-sialidase activity (cholest-associated enzyme). A research was conducted with Fucus vesiculosus algae extracts on rabbits with antioxidant supplementation such as vitamin C (to alleviate oxidative stress) to control thyroid hormone levels and enhance thyroid gland function in animal hypothyroidism serums Hameed et al. (2014).

Brown seaweed species such as Sargassum and Turbinaria are widely found and cultivated on the Indian coast, such as Gujarat, Tamil Nadu and Kerala Rao et al. (2008). The iodine levels in the green algae were highest in the Caulerparacemosa species at approximately 66 to 80 mg/100g of dry algae and lowest in the Enteromorpha flexuosa species at approximately 3026 Mairh et al. (1989). Among the brown algae, the levels were highest in Levringia boergensenii at 188.94 to 246.89 and lowest in Padinate trastromatica. The amounts were highest in the red algae, with 91 g in Asparagopsis taxiformis and lowest in Sarconema filiformis, respectively. Levringia boergensenii, which was developed in sea water enriched with potassium iodide, has also been found to absorb 17.2 percent more iodine than the controls Mairh et al. (1989). In brown algae, particularly Fucus species, the highest iodine content is found, with dry kelp ranging from 1500-8000 ppm (parts per million) and dry rockweed (Fucus) from 500-1000 ppm Madhusudhan et al. (2010). Red and green algae are found to have a lower content than brown algae species in most cases, around 100-300 ppm in dried seaweeds, but are comparatively large compared to any land plant. Korhonen and Pihlanto (2003). I, 66 percent in (Sargassum) and 88 percent in kelp (Laminaria) were mainly the chemical species of iodine in common seaweeds. Organic iodine ranged from 10 percent in kelp to 29 percent in Sargassum, and iodate (I03-) from 1.4 percent in kelp to 4.5 percent in Sargassum Hou et al. (2000).

8. CONCLUSION

An increasing concern in both developed and developing countries is the insufficient availability of iodine. It affects wellbeing, socio-economic development and productivity directly. If the current trend of iodine deficiency remains stable, potential growth will be at risk in a few years due to the population's intellectual disability. While iodine-fortified salt is available and almost all individuals eat it, its side effects are still unknown. A natural alternative for the reinforced salt is easier to follow. Seaweeds with many trace elements in them and even iodine can prove to be a millennium wonder plant. Several marine algae such as Fucus vesiculosus, sargassum marginatum, Sargassum vulgare, Lminaria etc. have an appreciable amount of iodine in them from the above analysis. Turbinaria and Sargassum species also have a high level of iodine on the Indian coast. Recently, iodine used for iodization has also been identified as probable for other cancer types. Breast cancer epidemiology may tend to be linked to the consumption of iodine, which is recommended for further research in the future. It is high time that an alternative source must be considered to tackle the IDD problems that exist in India and the world. Seaweeds containing iodine and other trace elements can be a natural replacement for addressing IDD prevalence.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

None.

REFERENCES

Aceves, C., Anguiano, B., & Delgado, G. (). Is Iodine a Gatekeeper of the Integrity of the Mammary Gland? Journal of Mammary Gland Biology and Neoplasia, 10(3), 189–196. https://doi.org/10.1007/s10911-005-5401-5

Agostoni, C., Decsi, T., Fewtrell, M., Goulet, O., Kolacek, S., Koletzko, B., et al. (2008). Complementary Feeding: A Commentary by the ESPGHAN Committee on Nutrition. Journal of Pediatric Gastroenterology and Nutrition, 46(1), 99–110. https://doi.org/10.1007/s10911-005-5401-5

Andersson, M., De Benoist, B., Delange, F., & Zupan, J. (2007). Prevention and Control of Iodine Deficiency in Pregnant and Lactating Women and in Children Less Than 2-years old: Conclusions and Recommendations of the Technical Consultation. Public Health Nutrition, 10(12), 1606–1611.

Andersson, M., Karumbunathan, V., & Zimmermann, M. B. (2012). Global Iodine Status in 2011 and Trends Over the Past Decade. Journal of Nutrition, 142(4), 744–750. https://doi.org/10.3945/jn.111.149393

Baumann, F. (1896). Ueber Das Normale Vorkommen Von Jod im Thierkörper. Zeitschrift Für Physiologische Chemie, 21(4), 319–330. https://doi.org/10.1515/bchm2.1896.21.4.319

Berbel, P., Obregón, M. J., Bernal, J., Escobar del Rey, F., & Morreale De Escobar, G. (2007). Iodine Supplementation During Pregnancy: A Public Health Challenge. Trends in Endocrinology and Metabolism, 18(8), 338–343. https://doi.org/10.1016/j.tem.2007.08.009

Bleichrodt, N., et al. (1987). Development Disorders Associated with Severe Iodine Deficiency. In The Prevention and Control of Iodine Deficiency Disorders (pp. 65–84). Elsevier.

Bouga, M., & Combet, E. (2015). Emergence of Seaweed and Seaweed-Containing Foods in the UK: Focus on Labeling, Iodine Content, Toxicity and Nutrition. Foods, 4(2), 240–253. https://doi.org/10.3390/foods4020240

Boussingault, J. B. (1831). Recherche Sur La Cause Qui Produit Le Goître Dans La Cordillère De La Nouvelle Grenade. Annales De Chimie Et De Physique, 48, 41–69.

Brody, T. (1994). Nutritional Biochemistry (pp. 519–527). Academic Press.

Brown, E. M., Allsopp, P. J., Magee, P. J., Gill, C. I. R., Nitecki, S., Strain, C. R., & McSorley, E. M. (2014). Seaweed and Human Health. Nutrition Reviews, 72(3), 205–216. https://doi.org/10.1111/nure.12091

Brownlee, I., Fairclough, A., Hall, A., & Paxman, J. (2011). Dietary Seaweed and Human Health. Culinary Arts and Sciences, VII, 82–88. https://doi.org/10.1111/nure.12091

Chapman, V. J., & Chapman, D. J. (1980). Seaweeds and Their Uses (pp. 62–67). Chapman and Hall. https://doi.org/10.1007/978-94-009-5806-7

Charlton, K. E., Yeatman, H., Brock, E., Lucas, C., Gemming, L., Goodfellow, A., & Ma, G. (2013). Improvement in Iodine Status of Pregnant Australian Women 3 Years After Introduction of a Mandatory Iodine Fortification Programme. Preventive Medicine, 57(1), 26–30.

Chatin, A. (1852). Recherches Sur l'Iode Des Eaux Douces; De La Présence De Ce Corps Dans Les Plantes Et Les Animaux Terrestres. Comptes Rendus De l'Académie Des Sciences De Paris, 35, 505–517.

Chennubhotla, V. S. K., Kaliaperumal, N., & Kaliamuthu, S. (1987). Economically Important Seaweeds. CMFRI Bulletin, 41, 3–19.

Chung, H. R., Shin, C. H., Yang, S. W., Choi, C. W., & Kim, B. J. (2009). Subclinical Hypothyroidism in Korean Preterm Infants Associated with High Levels of Iodine in Breast Milk. Journal of Clinical Endocrinology & Metabolism, 94(11), 4444–4447. https://doi.org/10.1210/jc.2009-0632

Codex Alimentarius. (1985). Codex Standard for Food Grade Salt (CODEX STAN 150-1985). Revised 1997, 2012; Amended 1999, 2001, 2006.

Combet, E., Ma, Z. F., Cousin, F., Thompson, B., & Lean, M. E. J. (2014). Bioavailability and Impact on Thyroid Function of Iodine from Seaweed in Iodine-Insufficient Women. British Journal of Nutrition, 112(5), 753–761. https://doi.org/10.1017/S0007114514001573

Dahl, L., Johansson, L., Julshamn, K., & Meltzer, H. M. (2004). The Iodine Content of Norwegian Foods and Diets. Public Health Nutrition, 7(4), 569–576. https://doi.org/10.1079/PHN2003554

De Escobar, G. M., Obregón, M. J., & del Rey, F. E. (2007). Iodine Deficiency and Brain Development in the First Half of Pregnancy. Public Health Nutrition, 10(12A), 1554–1570.

De Benoist, B., et al. (Eds.). (2004). Iodine Status Worldwide: WHO Global Database on Iodine Deficiency. World Health Organization. https://doi.org/10.1017/S1368980007360928

DeLong, G. R., Leslie, P. W., Wang, S. H., Jiang, X. M., Zhang, M. L., Rakeman, M., et al. (1997). Effect on Infant Mortality of Iodination of Irrigation Water in a Severely Iodine-Deficient Area of China. The Lancet, 350(9080), 771–773.

Delange, F. (2002). Iodine Deficiency in Europe and its Consequences: An Update. European Journal of Nuclear Medicine and Molecular Imaging, 29(S2), S404–S416. https://doi.org/10.1007/s00259-002-0812-7

Delange, F., & Bürgi, H. (1989). Iodine Deficiency Disorders in Europe. Bulletin of the World Health Organization, 67, 317–325.

Delange, F., Dunn, J. T., & Glinoer, D. (1993). General Comments, Conclusions and Final Recommendations. In Iodine Deficiency in Europe: A Continuing Concern (pp. 473–478). Springer. https://doi.org/10.1007/978-1-4899-1245-9_59

Dhaar, G. M., & Robbani, I. (2008). Nutritional Problems of Mothers and Children. In Foundations of Community Medicine (pp. 272–280). Reed Elsevier.

Dharmananda, S. (2002). The Nutritional and Medicinal Value of Seaweeds used in Chinese Medicine.

Dunn, J. T., Pretell, E. A., Daza, C. H., & Viteri, F. E. (Eds.). (1986). Towards the Eradication of Endemic Goitre, Cretinism and Iodine Deficiency (Scientific Publication No. 502). Pan American Health Organization.

Eastman, C. J., & Jooste, P. (2012). Current Challenges in Meeting Global Iodine Requirements. Nestlé Nutrition Institute Workshop Series, 70, 147–160. https://doi.org/10.1159/000337679

Elliott, P., & Brown, I. (2007). Sodium Intakes Around the World: Background Document Prepared for the Forum and Technical Meeting on Reducing Salt Intake in Populations (Paris, 5–7 October 2006). World Health Organization.

Elnagar, B., Gebre-Medhin, M., Larsson, A., & Karlsson, F. A. (1997). Iodine Nutrition in Sudan: Determination of Thyroid-Stimulating Hormone in Filter Paper Blood Samples. Scandinavian Journal of Clinical and Laboratory Investigation, 57(2), 175–181. https://doi.org/10.1080/00365519709056386

Eltom, M., Elnagar, B., Sulieman, E. A., Karlsson, F. A., Van Thi, H. V., Bourdoux, P., & Gebre-Medhin, M. (1995). The Use of Sugar as a Vehicle for Iodine Fortification in Endemic Iodine Deficiency. International Journal of Food Sciences and Nutrition, 46(3), 281–289. https://doi.org/10.3109/09637489509012560

FAO/WHO. (2005). Vitamin and Mineral Requirements in Human Nutrition (2nd ed.). World Health Organization.

Food Standards Australia New Zealand. (2007). Survey of Iodine Levels in Seaweed and Seaweed-Containing Products in Australia.

Food and Agriculture Organization. (2018). The Global Status of Seaweed Production, Trade and Utilization. Globefish Research Programme.

Gury, M. D. (2003). What are Algae? Seaweed Site. National University of Galway.

Gärtner, R. (2009). Autoregulation of Thyroid Growth and Function by Iodine: Independent Regulation of the Thyroid Gland by Iodocompounds. In V. R. Preedy, G. N. Burrow, & R. W. Watson (Eds.), Comprehensive Handbook of Iodine: Nutritional, Biochemical and Therapeutic Aspects (pp. 243–247). Elsevier. https://doi.org/10.1016/B978-0-12-374135-6.00025-X

Hameed, R. R., Atya, K. F., & Mohameed, M. A. (2014). Role of Fucus Vesiculosus L Extract in the Regulation of Thyroid Hormones Status in Adult Male Rabbits. Karbala Journal of Pharmaceutical Sciences, 7, 67–84.

Hetzel, B. S. (1983). Iodine Deficiency Disorders (IDD) and Their Eradication. The Lancet, 8359, 1126–1129. https://doi.org/10.1016/S0140-6736(83)90636-0

Hetzel, B. S. (1993). Iodine Deficiency Disorders. In Human Nutrition and Dietetics (pp. 534–555). https://doi.org/10.1007/978-1-4899-1245-9_3

Hetzel, B. S., Potter, B. J., & Dulberg, E. M. (1990). The Iodine Deficiency Disorders: Nature, Pathogenesis and Epidemiology. World Review of Nutrition and Dietetics, 62, 59–119. https://doi.org/10.1159/000417535

Hou, X., Hansen, V., Aldahan, A., Possnert, G., Lind, O. C., & Lujaniene, G. (2009). A Review on Speciation of Iodine-129 in Environmental and Biological Samples. Analytica Chimica Acta, 632, 181–196. https://doi.org/10.1016/j.aca.2008.11.013

Hurrell, R. F. (1997). Bioavailability of Iodine. European Journal of Clinical Nutrition, 51(Suppl. 1), S9–S12.

Institute of Medicine, Food and Nutrition Board. (2001). Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc. National Academy Press.

Kaliaperumal, N., & Ramalingam, J. R. (2000). Post-Harvest and Extraction of Phycocolloids. In Training Manual on Seaweed Culture, Processing and Utilisation (pp. 14–19). CMFRI.

Kaliaperumal, N., Chennubhotla, V. S. K., Kalimuthu, S., Ramalingam, J. R., Selvaraj, M., & Najmuddin, M. (1987). Chemical Composition of seaweeds. CMFRI Bulletin, 41, 31–51.

Keating, F. R. Jr., & Albert, A. (1949). The Metabolism of Iodine in Man as Disclosed with Use of Radioiodine. Recent Progress in Hormone Research, 4, 429–481. https://doi.org/10.1016/B978-1-4831-9893-4.50018-6

Kenicer, G., Bridgewater, S., & Milliken, W. (2000). The Ebb and Flow of Scottish Seaweed Use. Botanical Journal of Scotland, 52, 119–148. https://doi.org/10.1080/13594860009441750

Korhonen, H., & Pihlanto, A. (2003). Food-Derived Bioactive Peptides: Opportunities for Designing Future Foods. Current Pharmaceutical Design, 9(16), 1297–1308. https://doi.org/10.2174/1381612033454892

Koutras, D. A., Matovinovic, J., & Vought, R. (1985). The Ecology of Iodine. In J. B. Stanbury & B. S. Hetzel (Eds.), Endemic Goiter and Endemic Cretinism: Iodine Nutrition in Health and Disease (pp. 185–195). Wiley Eastern Limited.

Kylin, H. (1929). Über Das Vorkommen Von Jodiden, Bromiden und Jodidoxidasen Bei Den Meeresalgen. Hoppe-Seyler's Zeitschrift Für Physiologische Chemie, 186, 50–84. https://doi.org/10.1515/bchm2.1930.186.1-2.50

Lamberg, B. A. (1993). Iodine Deficiency Disorders and Endemic Goiter. European Journal of Clinical Nutrition, 47(Suppl. 2), S1–S8.

Land, M. A., Christoforou, A., Downs, S., Webster, J., Billot, L., Li, M., & Neal, B. (2013). Iodine Fortification of Foods and Condiments, Other than Salt, for Preventing Iodine Deficiency Disorders. Cochrane Database of Systematic Reviews, 2013(9), Article CD010734. https://doi.org/10.1002/14651858.CD010734

Leblanc, C., Colin, C., Delage, L., La Barre, S., Morin, P., & Fiévet, B. (2006). Iodine Transfer in the Coastal Marine Environment: The Key Role of Brown Algae and Their Vanadium-Dependent Haloperoxidases. Biochimie, 88(11), 1773–1785. https://doi.org/10.1016/j.biochi.2006.09.001

Madhusudan, C., Manoj, S., Rahul, K., & Rishi, C. M. (2011). Seaweeds: A Diet with Nutritional, Medicinal and Industrial value. Research Journal of Medicinal Plant, 5(2), 153–157. https://doi.org/10.3923/rjmp.2011.153.157

Mairh, O. P., Ramavat, B. K., Tewari, A., Oza, R. M., & Joshi, H. V. (1989). Seasonal Variation, Bioaccumulation and Prevention of Loss of Iodine in Seaweeds. Phytochemistry, 28(12), 3307–3310. https://doi.org/10.1016/0031-9422(89)80336-X

Marine, D., & Kimball, O. P. (1920). The Prevention of Simple Goiter in Man: Fourth Paper. Archives of Internal Medicine, 25(5), 661–672. https://doi.org/10.1001/archinte.1920.00090350088005

Mendis, E., & Kim, S. K. (2011). Present and Future Prospects of Seaweeds in Developing Functional Foods. Advances in Food and Nutrition Research, 64, 1–15. https://doi.org/10.1016/B978-0-12-387669-0.00001-6

Merke, F. (1984). History of Endemic Cretinism. In F. Merke (Ed.), History and Iconography of Endemic Goiter and Cretinism (pp. 195–233). Hans Huber Publishers.

Ministry of Health and Family Welfare, Government of India & International Institute of Population Sciences. (2007). National Family Health Survey-3 National Report (2005–06).

Mæhre, H. K., Malde, M. K., Eilertsen, K.-E., & Elvevoll, E. O. (2014). Characterization of Protein, Lipid and Mineral Contents in Common Norwegian Seaweeds and Evaluation of Their Potential as Food and Feed. Journal of the Science of Food and Agriculture, 94(15), 3281–3290. https://doi.org/10.1002/jsfa.6681

Müssig, K. (2009). Iodine-Induced Toxic Effects Due to Seaweed Consumption. In V. R. Preedy, G. N. Burrow, & R. Watson (Eds.), Comprehensive Handbook of Iodine (pp. 897–908). Academic Press. https://doi.org/10.1016/B978-0-12-374135-6.00093-5

National Research Council, Committee to Assess the Health Implications of Perchlorate Ingestion. (2005). Health Implications of Perchlorate Ingestion. The National Academies Press.

Ohlhorst, S., Slavin, M., Bhide, J., & Bugusu, B. (2012). Use of Iodized Salt in Processed Foods in Select Countries Around the World and the Role of Food Processors. Comprehensive Reviews in Food Science and Food Safety, 11(2), 233–284. https://doi.org/10.1111/j.1541-4337.2011.00182.x

Pan American Health Organization. (1986). Towards the Eradication of Endemic Goiter, Cretinism, and Iodine Deficiency (Scientific Publication No. 502). Washington, DC.

Pandav, C. S., Yadav, K., Srivastava, R., Pandav, R., & Karmarkar, M. G. (2013). Iodine Deficiency Disorders (IDD) Control in India. Indian Journal of Medical Research, 138(3), 418–433.

Rao, P. S., & Mantri, V. A. (2006). Indian Seaweed Resources and Sustainable Utilization: Scenario at the Dawn of a New Century. Current Science, 91(2), 164–174.

Risher, J. F., & Keith, L. S. (2009). Iodine and Inorganic Iodides: Human Health Aspects (Concise International Chemical Assessment Document No. 72). World Health Organization.

Rohner, F., Zimmermann, M., Jooste, P., Pandav, C., Caldwell, K., & Raghavan, R., et al. (2014). Biomarkers of Nutrition for Development–Iodine Review. Journal of Nutrition, 144(8), 1322S–1342S. https://doi.org/10.3945/jn.113.181974

Rosenfeld, L. (2000). Discovery and Early Uses of Iodine. Journal of Chemical Education, 77(8), 984–987. https://doi.org/10.1021/ed077p984

Rousset, B., Dupuy, C., Miot, F., et al. (2000). Chapter 2: Thyroid Hormone Synthesis and Secretion. In L. J. De Groot et al. (Eds.), Endotext. MDText.com, Inc.

Saenko, G. N., Kravtsova, Y. Y., Ivanenko, V. V., et al. (1978). Concentration of Iodine and Bromine by Plants in the Seas of Japan and Okhotsk. Marine Biology, 47, 243–250. https://doi.org/10.1007/BF00541002

Schimmer, M., & Schimmer, D. (1955). The Role of Algae and Plankton in Medicine. Grune & Stratton.

Seal, J. A., Doyle, Z., Burgess, J. R., Taylor, R., & Cameron, A. R. (2007). Iodine Status of Tasmanians Following Voluntary Fortification of Bread with Iodine. Medical Journal of Australia, 186(2), 69–71. https://doi.org/10.5694/j.1326-5377.2007.tb00803.x

Sridhar, K. K. (n.d.). Tackling Micronutrient Malnutrition: Two Case Studies in India. In Food Fortification to End Micronutrient Malnutrition: State of the Art (pp. 32–36). Micronutrient Initiative. Report No. 113721.

Stanbury, J. B., et al. (1998). Iodine-Induced Hyperthyroidism: Occurrence and Epidemiology. Thyroid, 8(1), 83–100. https://doi.org/10.1089/thy.1998.8.83

Suzuki, H., Higuchi, T., Sawa, K., Ohtaki, S., & Tolli, J. (1965). Endemic Coast Goiter in Hokkaido, Japan. Acta Endocrinologica, 50(1), 161–176. https://doi.org/10.1530/acta.0.0500161

Thivy, F. (1957). Marine Algae Cultivation. Salt Research in India, 1, 23–28.

Trumbo, P., Yates, A. A., Schlicker, S., et al. (2001). Dietary Reference Intakes: Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc. Journal of the American Dietetic Association, 101(3), 294–301.

Umamaheswara Rao, M. (1970). Ecological observations on some Intertidal Algae of Mandapam Coast. Symposium on Marine Intertidal Ecology, Waltair, January 22–24.

Underwood, E. J. (1977). Iodine. In Trace Elements in Human and Animal Nutrition (4th ed., pp. 271–331). https://doi.org/10.1016/B978-0-12-709065-8.50015-8

Untoro, J., Mangasaryan, N., de Benoist, B., & Darnton-Hill, I. (2007). Reaching Optimal Iodine Nutrition in Pregnant and Lactating Women and Young Children: Programmatic Recommendations. Public Health Nutrition, 10(12A), 1527–1529. https://doi.org/10.1017/S1368980007705360

Vasuki, S., Ganesan, M., Rao, P. V., & Mairh, O. P. (2000). Seasonal Variation in the Growth of Marine Red Alga Asparagopsis Delilei (Rhodophyta/Bonnemaisoniales) from the Mandapam Region, southeast Coast of India.

Vermiglio, F., et al. (1990). Defective Neuromotor and Cognitive Ability in Iodine-Deficient School Children of an Endemic Goiter Region. Journal of Clinical Endocrinology & Metabolism, 70(2), 379–384. https://doi.org/10.1210/jcem-70-2-379

Winger, R. J., König, J., & House, D. A. (2008). Technological Issues Associated with Iodine Fortification of foods. Trends in Food Science & Technology, 19(2), 94–101. https://doi.org/10.1016/j.tifs.2007.08.002

World Health Organization & Food and Agriculture Organization of the United Nations. (2005). Vitamin and Mineral Requirements in Human Nutrition (2nd ed.). World Health Organization.

World Health Organization, Food and Agriculture Organization of the United Nations, Allen, L., de Benoist, B., Dary, O., & Hurrell, R. (Eds.). (2006). Guidelines on Food Fortification with Micronutrients. World Health Organization.

World Health Organization. (1990). Report to the 43rd World Health Assembly. Geneva.

World Health Organization. (2004). Vitamin and Mineral Requirements in Human Nutrition (2nd ed.).

World Health Organization. (2007). Assessment of Iodine Deficiency Disorders and Monitoring Their Elimination: A Guide for Program Managers (3rd ed., pp. 6–54).

World Health Organization. (2012). Guideline: Sodium Intake for Adults and Children.

World Health Organization. (2012). WHO Global Database on Iodine Deficiency.

World Health Organization. (2014). Micronutrient Deficiencies: Iodine Deficiency Disorders.

Yeh, T. S., Hung, N. H., & Lin, T. C. (2013). Analysis of Iodine Content in Seaweed by GCECD and Estimation of Iodine Intake. Journal of Food and Drug Analysis, 22(2), 189–196. https://doi.org/10.1016/j.jfda.2014.01.014

Zava, T. T., & Zava, D. T. (2011). Assessment of Japanese Iodine Intake Based on Seaweed Consumption in Japan: A Literature-Based Analysis. Thyroid Research, 4, 14. https://doi.org/10.1186/1756-6614-4-14

Zimmermann, M. B. (2009). Iodine Deficiency. Endocrine Reviews, 30(4), 376–408. https://doi.org/10.1210/er.2009-0011

Zimmermann, M. B., & Andersson, M. (2012). Assessment of Iodine Nutrition in Populations: Past, Present, and Future. Nutrition Reviews, 70(10), 553–570. https://doi.org/10.1111/j.1753-4887.2012.00528.x

Zimmermann, M. B., Jooste, P. L., & Pandav, C. S. (2008). Iodine-Deficiency Disorders. The Lancet, 372(9645), 1251–1262.