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Iodised Salt: Processing, Determination and Impact on Health

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Abstract: Iodine is an essential micronutrient required for the synthesis of thyroid hormones that regulate growth, metabolism, and neurological development. Despite extensive global efforts, iodine deficiency remains a significant public health concern, particularly in developing regions, leading to disorders such as goitre, hypothyroidism, and cognitive impairment. Universal Salt Iodisation (USI) is recognised as the most effective and sustainable strategy to prevent iodine deficiency disorders (IDD). This study reviews the processing techniques, analytical determination, and health implications of iodised salt. Iodisation is typically achieved by incorporating potassium iodate (KIO_3) or potassium iodide (KI) into edible salt through methods such as dry mixing method, drip-feed process, spraying method, refining process or vacuum evaporation process to ensure uniform distribution and stability. Accurate determination of iodine content is essential to evaluate fortification quality and consumer safety. Analytical methods include iodometric titration, UV-Vis spectrophotometer and High Performance Liquid Chromatography (HPLC), each differing in sensitivity and precision. Environmental factors such as humidity, temperature, and light exposure significantly affect iodine retention during processing and storage. Adequate intake of iodised salt has been shown to markedly reduce IDD prevalence and enhance thyroid health across populations. However, continuous monitoring is vital to avoid both deficiency and excessive iodine intake. The findings underscore the importance of standardized iodisation processes, rigorous quality control, and effective policy implementation to maintain optimal iodine nutrition globally.

Keywords: iodised salt, iodine deficiency disorders, salt processing, iodine determination, public health nutrition.

Introduction

Iodine is an essential trace element that the human body requires in very small amounts. It plays a vital role in the synthesis of thyroid hormones, namely thyroxine (T_4) and triiodothyronine (T_3), which are produced by the thyroid gland. These hormones are responsible for regulating several key physiological processes including growth and development, metabolic rate and neurological and cognitive functions (Zimmermann & Boelaert, 2015). Adequate iodine intake is therefore critical for maintaining normal thyroid function and overall health. Insufficient iodine consumption can result in iodine deficiency disorders (IDD), which may lead to goitre, hypothyroidism and impaired cognitive development especially in children (World Health Organization, 2014). The human body is unable to produce iodine. Therefore, it must be obtained through dietary sources. Common sources include iodised salt, seafood such as fish and seaweed as well as dairy products like milk, yogurt and cheese. Other foods such as eggs, legumes (roasted soybeans and cashew nuts), certain fruits (prunes, strawberries and pineapples) and even some fast foods (vanilla milkshakes, nuggets and cheeseburgers) also contribute to iodine intake (Zimmermann & Andersson, 2012). Recognizing the importance of adequate iodine consumption, the Universal Salt Iodisation (USI) program was introduced in Malaysia as a National Public Health strategy to prevent iodine deficiency disorders (IDD) and ensure sufficient iodine intake among the population. The USI program mandates that all edible salt be fortified with iodine compounds such as potassium iodate (KIO_3) to

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maintain the recommended iodine levels for optimal thyroid function (Ministry of Health Malaysia, 2019). The Universal Salt Iodisation (USI) program in Malaysia was implemented in three main phases to ensure progressive coverage across the country. Phase 1, initiated in year 2000, focused on the state of Sabah, where iodine deficiency was identified as a significant public health issue. Following the success of the initial phase, Phase 2 was launched in year 2008, extending the iodisation requirement to the state of Sarawak. Finally, Phase 3, implemented in year 2018, marked the nationwide enforcement of mandatory salt iodisation, covering all states and territories in Malaysia (Ministry of Health Malaysia, 2019). This phased approach enabled the Malaysian government to strengthen monitoring, improve compliance among salt producers, and raise public awareness regarding the importance of iodine in preventing iodine deficiency disorders (IDD). The enforcement of the Universal Salt Iodisation (USI) program in Malaysia was implemented through the Amendment of Regulation 285 under the Food Act 1983 and Food Regulations 1985. This amendment mandates that all iodised fine salt or iodised salt intended for human consumption must contain either potassium iodide (KI) or potassium iodate (KIO_3). The iodine content must be not less than 20 mg/kg and not more than 40 mg/kg of iodine to ensure adequate and safe levels for public consumption (Akta Makanan 1983 (Akta 281) & Peraturan-Peraturan, 2023.) This regulation serves as a crucial legal framework to support the effective implementation of the USI program, aiming to eliminate iodine deficiency disorders (IDD) and maintain optimal iodine status nationwide.

Processing Of Iodised Salt

The Dry Mixing Method is one of the simplest techniques used in the iodisation of salt. In this process, an iodine compound most commonly potassium iodate (KIO_3) in dry powder form is mixed directly with dry salt crystals. The mixing process may be performed manually or mechanically using a blender or mixer to ensure adequate blending of the iodine compound with the salt (Bahagian Pemakanan KKM, 2020). This method is low-cost, easy to operate and particularly suitable for small-scale or rural salt production. However, it also has several limitations. The most significant drawback is the potential for uneven iodine distribution especially when mixing is done manually. Additionally, the method is not ideal for humid environments as moisture can cause iodine evaporation, leading to reduced iodine content and compromised product quality (World Health Organization, 2014).

The Drip-Feed Process is a widely used method for salt iodisation in medium scale salt production plants. In this technique, a solution of potassium iodate (KIO_3) is dripped slowly onto salt that moves along a conveyor belt or screw mixer. The continuous movement of salt allows the iodine solution to be evenly distributed, and the salt is subsequently thoroughly mixed to ensure uniform absorption of iodine throughout the batch (Bahagian Pemakanan KKM, 2020). Compared to the dry mixing method, the drip-feed process provides better homogeneity and more consistent iodine levels in the final product. However, this method requires careful control of both the dripping rate and mixing speed to maintain accuracy. It also depends on the availability of clean water and a precisely prepared iodine solution to ensure effective iodisation and product stability (World Health Organization, 2014).

The Spraying Method is one of the most efficient techniques used for salt iodisation, particularly in industrial scale production. In this process, an iodine solution is sprayed under pressure onto salt while it tumbles in a rotating drum or fluidized mixer, ensuring that the iodine is evenly distributed across all salt particles. This method provides an even coating and high uniformity of iodine concentration throughout the salt batch (Bahagian Pemakanan KKM, 2020). It also allows for automation and precise control of the iodisation process, making it suitable for large scale commercial operations. However, the spraying method involves a higher equipment cost compared to simpler iodisation techniques. Additionally, operators must carefully regulate the spray pressure and droplet size to prevent over or under fortification of iodine, which could compromise product quality and compliance with regulatory standards (World Health Organization, 2014).

The Refining Process is a sophisticated method of salt iodisation commonly used in medium to large scale industrial operations. In this process, raw salt is first dissolved in water to form a brine solution which is then purified to remove impurities such as sand, clay and other insoluble materials. The purified brine is subsequently recrystallized, producing high quality salt crystals. The iodine compound, usually potassium iodate (KIO_3), is added either during or after recrystallization followed by drying and packaging of the final product (Rahman et al., 2018). This method yields high purity refined salt with consistent quality and the absence of contaminants helps to stabilize the iodine content, reducing losses over time. However, the refining process involves multiple processing steps, higher production costs and requires technical expertise as well as strict quality control systems to ensure proper iodisation and product safety (World Health Organization, 2014).

The Vacuum Evaporation Process is an advanced technique used primarily in large scale, modern salt production facilities. In this method, salt is produced by evaporating purified brine under vacuum conditions which allows for the formation of uniform and high purity salt crystals. During the final stage of production, potassium iodate (KIO_3) is added to the salt before the drying process to ensure optimal iodine content and even distribution (Bahagian Pemakanan KKM, 2020). This method produces fine grained iodised salt with excellent iodine retention and stability, making it suitable for commercial and industrial purposes. However, the vacuum evaporation process requires specialized equipment, high capital investment and significant energy input, which increases production costs compared to conventional iodisation methods (World Health Organization, 2014).

Iodised salt production can be carried out using several methods, each differing in scale, cost, and efficiency. The Dry Mixing Method is a simple, low cost technique suitable for small scale or rural production, but it often results in uneven iodine distribution. The Drip Feed Process offers better mixing control and improved uniformity by dripping an iodine solution onto salt during mixing, making it suitable for medium scale operations. The Spraying Method, widely used in industrial production, ensures excellent iodine distribution and consistency through pressure spraying but requires higher investment and technical precision. The Refining Process involves purifying and recrystallizing salt before iodisation, producing refined, high purity salt with stable iodine content, though it demands higher cost and technical expertise. The Vacuum Evaporation Process is an advanced industrial method that yields fine, highly pure salt with superior iodine retention, but it requires specialized equipment and high energy input. Overall, the choice of iodisation method depends on production scale, available resources and desired product quality (Rahman et al., 2018; World Health Organization, 2014; Bahagian Pemakanan KKM, 2020)

Determination Of Iodine Content

The iodometric titration method is a classical analytical technique widely used for the quantitative determination of iodine content in iodised salt. This method is based on the redox reaction between iodate (IO_3^-) or iodide (I^-) compounds and reducing agents, enabling the accurate measurement of iodine concentration present in the sample (Bashir et al., 2024). It is considered one of the most reliable and cost effective techniques for routine quality control in salt iodisation programs. In this procedure, a known mass of iodised salt (typically 10 g) is dissolved in distilled water, followed by the addition of acidic medium, usually sulphuric acid (H_2SO_4), to create an environment suitable for redox reaction. Subsequently, potassium iodide (KI) is added, which reacts with iodate (KIO_3)

present in the salt to liberate free iodine (I_2) according to the following chemical equation:

$$IO_3^- + 5I^- + 6H^+ \rightarrow 3I_2 + 3H_2O$$

The liberated iodine imparts a brownish color to the solution, which is then titrated with a standard sodium thiosulfate ($Na_2S_2O_3$) solution until the solution becomes pale yellow. A few drops of starch indicator are then added, forming a blue coloured complex with the remaining iodine. Titration is continued carefully until the blue color just disappears, indicating the end point of the reaction. The amount of iodine in the sample is calculated based on the volume of sodium thiosulfate used, using the stoichiometric relationship between iodine and thiosulfate:

$$I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$$

The iodine concentration is expressed in milligrams of iodine per kilogram of salt (mg/kg). This method provides high accuracy and reproducibility when proper standardization and calibration procedures are followed. However, factors such as exposure to light, air or moisture can lead to iodine loss during analysis and therefore, the procedure must be performed under controlled laboratory conditions (Pino et al., 2016). Overall, iodometric titration remains a standard and cost-effective technique for monitoring iodine levels in iodised salt, ensuring compliance with national and international fortification standards such as the Malaysian Food Regulations 1985, which specify that iodised salt must contain 20–40 mg/kg of iodine (Akta Makanan 1983 (Akta 281) & Peraturan-Peraturan (2023).

The UV Visible spectrophotometer is an analytical instrument commonly used to determine the concentration of iodine in iodised salt based on the absorption of ultraviolet or visible light at specific wavelengths. In iodine analysis, potassium iodate (KIO_3) present in iodised salt is first reduced to molecular iodine (I_2) by reacting with potassium iodide (KI) in an acidic medium (usually hydrochloric acid, HCl). The liberated iodine produces a yellow brown color, which exhibits a characteristic absorption peak around 288 or 352 nm, depending on the solvent composition and reaction conditions. The absorbance intensity of this iodine solution is measured using a UV-Vis spectrophotometer and compared with a standard calibration curve prepared from known concentrations of KIO_3 or iodine solution. This analytical technique is simple, rapid and sensitive making it particularly suitable for both laboratory research and routine quality control in salt production industries. It provides a reliable estimation of iodine concentration, ensuring that salt fortification complies with national and international health standards. However, to achieve accurate and reproducible results, it is crucial to maintain proper calibration, use clean glassware and minimize interferences from impurities, oxidizing agents or excessive acidity that could affect absorbance readings (Araya et al., 2020; Wen & Tu, 2023).

High-Performance Liquid Chromatography (HPLC) is a highly precise analytical technique used for the separation and quantification of iodine species, such as iodide (I^-) and iodate (IO_3^-), in iodised salt. The method operates on the principle of differential partitioning between a stationary phase and a mobile phase, which allows efficient separation of target analytes. HPLC systems commonly employ reversed phase or ion pair chromatography, depending on the polarity of the compounds analyzed. Detection is typically performed using a diode-array detector (DAD) at wavelengths ranging from 225 to 290 nm, enabling simultaneous determination of multiple iodine species and providing a detailed compositional profile of the sample (Ravichandran & Kandasamy, 2022). HPLC effectively separates and quantifies iodine or iodate ions with high precision, ensuring accurate determination of individual iodine species in fortified salt. The method demonstrates excellent accuracy, reproducibility and sensitivity, making it ideal for both routine quality control and research based analytical studies. Additionally, the technique supports the validation of iodisation efficiency and stability in salt during processing and storage. Overall, HPLC remains a powerful and reliable tool for advanced quality monitoring of iodised salt, where precise differentiation and quantification of iodine compounds are critical

(Ravichandran & Kandasamy, 2022; Zhao & Wen, 2023).

Impact On Health

Iodine Deficiency Disorders (IDD) have been identified as one of the most serious public health problems worldwide, affecting more than 50 countries. According to the World Health Organization (WHO), an estimated two billion people globally are at risk of iodine deficiency, with approximately 30% of the world's population consuming inadequate levels of iodine, defined as less than 100 μg/L. The prevalence of iodine deficiency varies across regions, with the highest rates reported in Europe (57%), followed by the Eastern Mediterranean (54%), Africa (43%), Southeast Asia (40%), Western Pacific (24%) and Americas (10%). In Africa alone, approximately 260 million people are estimated to have insufficient iodine intake, which has been associated with an average reduction in intellectual capacity of 10–15% (Mezgebu et al., 2023). Iodine deficiency not only impairs cognitive and neurological development but also negatively affects economic productivity and overall community well-being.

Iodine deficiency can lead to a wide spectrum of disorders that interfere with endocrine and developmental functions, collectively known as Iodine Deficiency Disorders (IDD). These conditions occur when the thyroid gland fails to synthesis adequate thyroid hormones due to insufficient iodine intake, resulting in various physiological and metabolic disturbances (Lisco, 2023). One of the most common outcomes of iodine deficiency is goitre which involves the enlargement of the thyroid gland as a compensatory response to increased thyroid stimulating hormone (TSH) secretion. Prolonged stimulation of the thyroid gland may cause visible neck swelling and, in severe cases, lead to difficulty in breathing and swallowing. Another major consequence is hypothyroidism, a metabolic disorder characterise by reduced hormone synthesis, resulting in fatigue, cold intolerance, weight gain, impaired growth and fertility problems. Chronic hypothyroidism may also elevate cholesterol levels and increase the risk of cardiovascular disease (Wu et al., 2024; Yang et al., 2024). In extreme cases, iodine deficiency during pregnancy and early childhood can result in cretinism, a congenital disorder marked by irreversible intellectual disability, stunted physical growth, deaf mutism and motor dysfunction. Cretinism represents the most severe and tragic outcome of iodine deficiency, as the neurological damage is both permanent and preventable through adequate maternal iodine intake. Moreover, even mild iodine deficiency during critical stages of brain development has been associated with reduced intelligence quotient (IQ), poor cognitive performance and delayed learning ability in children. This impairment underscores the essential role of iodine in maintaining optimal neurological development and cognitive function (Baffa et al., 2024). Furthermore, iodine deficiency poses serious reproductive risks, particularly among pregnant women. Insufficient iodine intake increases the likelihood of miscarriage, stillbirth, and congenital abnormalities due to inadequate maternal and fetal thyroid hormone production. Collectively, these disorders illustrate the profound impact of iodine deficiency on human health, intelligence, and socioeconomic productivity. Addressing iodine deficiency through sustainable public health interventions, such as universal salt iodisation, remains a global priority to ensure normal growth, cognitive development, and reproductive health across populations.

Challenges In Iodised Salt Programs

Iodised salt programs have been implemented globally as a preventive measure against iodine deficiency disorders (IDD), such as goitre, impaired cognitive development and growth retardation. Despite being one of the most cost-effective and simple public health interventions, many countries continue to face persistent challenges in ensuring the success and sustainability of these programs. These challenges generally arise from industrial non compliance, weak enforcement, inadequate monitoring, iodine instability, low public awareness, and limited use of iodised salt in the food industry (Kissock et al., 2023; Rigutto-Farebrother et al., 2024).

One of the main issues lies in the lack of compliance among salt producers with the required iodisation standards. In many regions, particularly among small scale or unregulated producers, salt is either not iodised at all or contains iodine concentrations below the recommended levels. This inconsistency leads to wide variations in iodine content in the market, thereby compromising the effectiveness of universal salt iodisation (USI) programs (Kissock et al., 2023). In addition, weak enforcement of national regulations further undermines the success of these programs. Although iodisation laws and standards exist in most countries, enforcement mechanisms are often insufficient due to limited resources, inadequate manpower or lack of governmental commitment. Without strict monitoring or appropriate penalties, many producers continue to distribute non iodised salt without facing repercussions (Habib et al., 2023). Another significant challenge is the lack of regular and systematic monitoring and evaluation. Monitoring iodine levels in salt at various stages production, distribution and household levels is critical, yet in many countries these activities are not carried out consistently, resulting in inadequate feedback and delayed corrective measures (IGN, 2023). Furthermore, iodine instability during storage and distribution poses an additional obstacle. Iodine is highly sensitive to environmental factors such as light, heat, and humidity, which can significantly lower its concentration before the salt even reaches consumers. Poor packaging materials and prolonged storage exacerbate this problem especially in tropical and humid regions (Habib et al., 2023; ResearchGate review, 2025). Low public awareness remains a persistent issue in many countries. Consumers often lack knowledge about the health benefits of iodised salt and may choose cheaper, non iodised alternatives due to price considerations or limited understanding of labelling practices. Without sustained education campaigns, consumer demand for iodised salt is unlikely to increase (Hooshmand et al., 2024). Finally, the use of non iodised salt in the food industry represents a growing concern. In modern diets, a substantial portion of salt intake comes from processed foods rather than household salt. However, many food manufacturers continue to use non iodised salt in production, thereby limiting the population's iodine intake and undermining national iodisation efforts (Kissock et al., 2023

Conclusions

Iodised salt plays a crucial role in the prevention of iodine deficiency disorders (IDD) which remain a significant public health concern worldwide. The addition of iodine to salt is recognized as the most effective and sustainable strategy to ensure adequate iodine intake among populations (World Health Organization [WHO], 2014). To maintain the quality and safety of iodised salt, accurate analysis and continuous monitoring are essential. Proper processing and iodisation procedures ensure that iodine is evenly distributed and retained at effective levels to meet dietary requirements (UNICEF, 2021). However, several challenges persist including weak enforcement of iodisation regulations, low public awareness and inadequate monitoring systems in certain regions. Therefore, continuous global efforts including policy strengthening, public education and routine quality assessment are needed to sustain iodine sufficiency and prevent the re-emergence of iodine deficiency disorders.

Conflict Of Interest: The authors declare that there are no conflicts of interest concerning the publication of this article.

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