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Iodine Stability in Iodized Salt: A Review

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Abstract— **Awareness of salt iodization programme and its benefits remains low among salt marketers and consumers, and this is important in salt iodization program. The effectiveness of salt-iodization programmes depends on the conservation of iodine concentration in salt at various stages of production and the supply-chain as well as the elimination of industrial salt in the food market. Iodization of salt is an effective and sustainable strategy to prevent and control iodine deficiency in large populations. Iodine is essential for good function of the thyroid, and its deficiency is of public-health importance. Most studies have revealed that commercial salt at production stage is iodized sufficiently to meet World Health Organization (WHO) standard. However, following laxity in policy implementation, monitoring and regulatory roles resulting in increasing access to non-labelled salt in the Nigerian market, salt iodization gains in the past decades are gradually being eroded. This paper reviews iodine stability and salt iodization in Nigeria.**

Index Terms— **Iodine, Iodization, Stability, Iodine Deficiency, Potassium Iodide, Potassium Iodate**

I. INTRODUCTION

Salt iodization gains in the past decades are gradually being eroded, following laxity in policy implementation, monitoring and regulatory roles resulting in increasing access to non-labelled salt in the Nigerian market. Iodization of salt is an effective and sustainable public-health strategy to prevent and control iodine deficiency and has been ongoing in several countries for over 70 years. Iodization of salt is currently undertaken following the universal salt-iodization initiative of WHO (Zhao, & van der Haar, 2004) and it continues to be recognized as the cheapest, safest, efficient, and long-term intervention that would address Iodine deficiency disorder (IDD).

Iodine is an essential mineral that is needed for proper physical and mental development among infants, young children, pregnant and lactating women. Iodine deficiency among infants slows down brain development, which leads to delayed growth and development (WHO, 2004). This also applies to older children. For pregnant women, it can cause miscarriage and stillbirths (Delong, 1994). Using adequately iodized salt when cooking at home is the cheapest and easiest way to prevent iodine deficiency (Wu *et al,* 2002). Some salt contains iodine but does not necessarily contain the right amount of iodine. Using adequately iodized salt is the cheapest, safest, efficient, and long-term intervention that would address Iodine Deficiency Disorder. Iodine is an essential mineral for the body to produce thyroid hormones, which controls metabolism, helps in bone health, immune response, and development of Central Nervous System, CNS (Wu *et al,* 2002).

Iodine is added to salt in the form of potassium iodide or potassium iodate. This is usually done by spraying or drop feeding the solution onto the salt at the beginning of a mixing process, which ensures homogeneity of the iodized salt. The salt may also be refined prior to iodization through a process of washing and drying to produce refined salt with a sodium chloride (NaCl) content of >98%, but this is optional to meet consumer requirements for whiter salt and not required for iodization. At the point of production, it is recommended that the salt contains 20–40 mg of iodine per kg (Damane, 2005). The actual availability of iodine from iodized salt at the consumer level can vary widely due to a number of factors: variability in the amount of iodine added during iodization, poor mixing resulting in uneven distribution within the batches or bags produced and instability of iodine in the salt (Shawel *et al,* 2000). These factors affect how much iodine is finally available for consumption. Various factors, such as moisture content of salt, ambient humidity, light, heat, impurities in salt, alkalinity or acidity, salt type (fine or coarse salt) and the form (potassium iodide or iodate) in which the iodine is present, affect iodine stability in salt (Jooste *et al,* 1999; Kelly, 1953). Hence, the effectiveness of salt-iodization programmes to deliver adequate amounts of iodine at the consumer level largely depends on the stability of iodine (Taga *et al,* 2004; Takele *et al,* 2003). To ensure adequate iodine retention, most countries have adopted a minimum standard for iodized salt. These typically require a NaCl content of ≥96% with a moisture content of <4% and <0.5% water-soluble Mg. (Ekott and Etukudo, 2025)

II. SALT IODIZATION PROCESS

The Indian salt commissioner office (2024) described that iodization of salt could be accomplished by Spray mixing process, Drip feed process, Dry mixing process. In the Spray Mixing Process, salt in crystalline or in crushed form, is dumped into a feed hopper. A stainless-steel wire-mesh (3' x 3'6") fitted to the hopper screens off lumps of salt and prevents gunny bags/baskets being drawn-in. From the feed hopper the salt is carried by an inclined rubber belt conveyor moving at a speed of 100 ft. per minute. The Salt is discharged from the belt conveyor into a mixing chamber at the rate of about 5 tonnes per hour. A 3 to 4% aqueous solution of KIO_3 is sprayed through special type of stainless nozzles designed to deliver a flattened spray that spreads over the entire width of the salt stream falling from the belt. The iodate solution is held under pressure in a stainless-steel drum of about 80 litres capacity. The pressure in the storage drum is maintained at 20 psi with the help of an air compressor equipped with a regulator. The salt crystals unevenly wetted with KIO_3 solution are mixed thoroughly by a stainless-steel screw conveyor which pushes out the iodized salt through twin outlets for bagging. Nowadays mobile salt iodization units are used widely for spray process which can be taken from salt works to salt works and within salt works in salt storage area. Crushers can also be fitted below the feed hopper for producing crushed and powdered variety of iodized salt (Ekott and Etukudo, 2025).

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Salt can also be iodized by Drip-Feed Process. In this process salt is fed into the grinder, where 3-4 percent solution of potassium iodate is fed through hollow needle at the inlet of the crushing zone. Mixing of the solution with salt crystals and grinding of salt crystals take place simultaneously. The ground salt is fed to screw conveyor underneath the roller grinder for effecting homogeneous mixing of potassium iodate. Here the flow of potassium iodate solution is being monitored and controlled through an appropriate regulating device. The salt manufactured by this method does not remain free flow and cakes during the long storage.

When the iodization program started, the Dry Mixing Process method was adopted by several companies for iodized salt production. In this Dry Mixing Process, a stock mixture of Potassium Iodate and anti-caking chemicals like Tri-calcium phosphate or Calcium Carbonate is prepared in proportion 1:10. The stock mixture is again mixed with 10 parts of free-flowing Sodium Chloride, the entire pre-mix passing through 180-micron 15 sieves. The salt to be iodized is fed into a hopper of bulk controller and passes into an enclosed worm-screw mixer. At a point near the base of the bulk-controller a mixture of Potassium Iodate and anti-caking agent is fed into a worm-screw mixer conveyor through a process feeder so as to give the desired quality of Iodized Salt (Ekott and Etukudo, 2025).

III. Iodine Stability

The actual availability of iodine from iodized salt at the consumer level can vary over a wide range as a result of variability in the amount of iodine added during the iodization process; uneven distribution of iodine in the iodized salt, within batches and individual bags; losses of iodine due to salt impurities, packaging, and environmental conditions during storage and distribution; and losses of iodine due to food processing, washing and cooking processes in the household (Rana and Raghuvanshi, 2013). In order to determine the appropriate levels of iodization, an accurate estimate of the losses of iodine occurring between the time of iodization and consumption is required.

The stability of iodine in salt and levels of iodization are questions of importance to national planners and salt producers, as they have implications for programme effectiveness, safety and cost. Higher levels of iodine may need to be added to compensate for losses due to known high levels of impurities in salt or the use of lower-grade packaging. This added cost must be compared with the cost of producing more stable, purified salt and the cost of enhanced packaging, while keeping in mind the consumer’s need for continuity in sensory qualities of the salt. Significant changes from the traditional products may result in higher costs to the producer and consumer, or reduced consumer acceptability, thus reducing the sustainability of the iodization programme. Typical iodization levels vary from approximately 30 to 100 mg of iodine per gram of salt in many iodization programmes in tropical and subtropical countries.

Elemental iodine readily sublimes and is then rapidly lost to the atmosphere through diffusion. Potassium iodide can be oxidized to elemental iodine by oxygen or other oxidizing agents, especially in the presence of catalysts, such as metal ions, and moisture (Diosady *et al,* 1998). Thus, in affluent markets, iodide is always added to salt together with a reducing agent, such as dextrose, and a desiccant or anti-caking agent is usually included.

Ekott and Etukudo (2017) studied different commercial brands of salts in Nigeria and reported large iodine lost in all the brands. Ekott and Etukudo (2019) further investigated the impact of storage on iodine stability in salt and reported 92.8% to 100% lost in the studied brands. Diosady (1997) reported that high humidity resulted in rapid loss of iodine from iodized salt, ranging from 30% to 98% of the original iodine content. Solid low-density polyethylene packaging protected the iodine to a great extent. The highest losses occurred from woven high-density polyethylene bags, whereas losses from open containers were intermediate. By using packaging with a good moisture barrier, such as low-density polyethylene bags, iodine losses can be significantly reduced, and in most cases, salt can be produced that has relatively stable iodine content for at least six months.

Deresa et al (2023) state that salt's iodine concentration is dramatically reduced by heat and light. The degradation of iodizing substances like potassium iodate and potassium iodide into the free form of iodine is thought to be accelerated by heat and light, which is one of the potential causes of iodine loss. In order to reduce the loss of iodine, it has been advised to add salt in the final few minutes or just after cooking, and to store salt in a place shielded from heat and light (Derasa *et al,* 2023). It has also been suggested that raising awareness of the ideal salt storage conditions for society and setting up a suitable monitoring system at various levels (during production, distribution, and consumption) be done. Ekott and Etukudo (2019) also recommended the use of solid low-density polyethylene materials in the marketing of salt to reduce humidity and heat transmission during storage. The exact mechanism (the detailed chemical processes) by which heat, and light promote iodine loss also needs further study.

SCO (2024) added that iodized salt is produced by injection of potassium iodate solution in a controlled manner into the wet salt from the centrifuge which is then dried in fluidized bed dryers and packed. Abdurrahim *et al* (2023) reportd that mean loss of iodine is higher during production (from pile to packet) than at retail. It is assumed that a high amount of iodine is lost in the fluidized bed dryers during production to packaging. More studies is required to investigate this substantial loss of iodine at this stage.

Potassium iodide can be reduced to elemental iodine by a variety of reducing agents in salt. Moisture naturally present in salt or abstracted from the air by hygroscopic impurities such as magnesium chloride acts as the reaction medium for the decomposition of added iodate (Diosady *et al,* 1998). The pH of the condensed moisture on the salt is influenced by the type and quantity of impurities present, and this may in turn affect the stability of the iodine compounds (Diosady *et al,* 1998). As in most chemical reactions, elevated temperature increases the rates of the reactions that form elemental iodine and increases the rate of evaporation of iodine. Salt is extracted from a variety of sources, and the degree of purity depends on the source, extraction and purification methods used. As a result, salt that is available for iodization may contain not only sodium chloride but also carbonate and sulphates, insoluble matter and moisture. Physically, salt may be sold as large, crude crystals or as a refined, pure, dry powder.

On the basis of the chemistry, losses of iodine were not unexpected, and there have been a number of published studies on the stability of iodine in salt. Diosady et al (1997) stated that high humidity reduces stability, while the use of a good vapour barrier, which prevents the penetration of moisture and the evaporation of iodine, clearly improved the stability of iodine in iodized salts. Diosady *et al* (1998) studied trace components of iodized salt samples and correlate the trace components with the observed iodine stability. Ekott and Etukudo (2025) reported that there was no clear and consistent correlation between iodine stability and the presence of any impurity. Clearly there are many competing reactions and interactions between the salt impurities and the added potassium iodate. There is a trend towards lower iodine retention with increased magnesium and sulphur content, but the sparing effect of carbonates was not observed at the levels present in the samples. During iodometric titration, salts consume thiosulfate equivalent to the level of iodine present in it. Ekott and Etukudo (2019) studied two salt brands and reported that the average amounts of thiosulfate consumed by the two salt brands with respect to time, at room temperature is a strong indicator of iodine stability. Habib *et al* (2023) conducted studies on more salt brands and reported sharp decrease in iodine concentration over a period of 50 hours.

Salt is sold in developing countries both in consumer packages of up to 2 kg and in bulk. Packaging materials in wide use in developing countries include paper, high- and low-density polyethylene, and woven bags made of jute, straw, or high-density polyethylene. Jabbour et al (2015) contributed to knowledge on effect of storage condition on iodine stability in salt and collaborated Diosady et al (1997) which indicated that solid, non-woven polymer bags were the best moisture barriers and, if properly sealed and intact, would maintain the moisture level of the salt throughout the distribution system, thus minimizing the loss of iodine following the absorption of moisture and subsequent chemical reactions.

Diosady *et al* (1998) reported that by packaging salt in an effective moisture barrier, such as solid low-density polyethylene bags, iodine losses can be significantly reduced. They revealed that with solid low-density polyethylene packaging, the losses of iodine from salt stored for up to six months can be kept in the range of 10% to 15%, but the losses generally increase significantly over the next six months of storage, and therefore the time required for distribution, sale and consumption should be minimized to ensure effective use of the added iodine. These findings aligned with the recent studies by Habib *et al* (2023). They reported that loss of iodine content in packed salt was increasing with duration of storage. The results indicate that the control of moisture content in iodized salt throughout manufacturing and distribution by improved processing, packaging, and storage is critical to the stability of the added iodine. In order to make allowances for the probable losses of iodine, countries must determine iodine losses from local iodized salt under local conditions, as these will be greatly affected by the quality of the packaged salt.

Maramag *et al* (2007) conducted elaborate studies on different salt samples and reported that all salt samples lost iodine over 4 weeks of exposure in an open heap or repacked in low-density polyethylene bags; the loss ranged from less than 1% to 25% for aged salt and from 5% to 34% for fresh. Iodine loss was also observed in the stored salt over the 6-month storage period, ranging from 9% to 24% for aged salt and from 33% to 49% for fresh salt. The iodine reduction rate was higher in fresh salt than in aged salt after 4 weeks of exposure and 1 month of storage. This study suggests that consuming an unaged, iodized salt offers a better opportunity for higher iodine concentration. This calls for redetermination of the shelf life of iodized salt.

IV. Monitoring and Assessment

Ideally, monitoring the iodine content of salt should be conducted internally by the salt producer at the site of iodization, as well as externally by the health or regulatory authorities. Internal monitoring should be done routinely, and external monitoring intermittently, and where feasible, both these monitoring systems should use the titration method for determining the iodine content of salt. The different steps of the monitoring process are summarized in Figure 1.

A critical indicator of adequate salt iodization is a measure of the quality of iodized salt leaving production facilities. This may be reflected in a proportion of samples meeting government standards. External monitoring is based upon the establishment of a law which mandates that all salt for human consumption is iodized. Details of implementation, inspection, and enforcement are usually set out in the regulations. When countries first began to introduce salt iodization, inspection systems were used largely to guide salt iodization programme managers in identifying problems with salt iodization and were rarely used for enforcement purposes. As countries increase the coverage to 50%, these systems should be strengthened and used for enforcement against those producers who fail to comply with the law. It is often the less expensive non-iodized salt in the market that prevents the realization of the elimination of IDD. Indeed, as coverage of iodized salt increases, special efforts need to be made to identify the non-compliant importer, producer and distributor and systematically eliminate that problem. To this end, a national register of all salt producers supplying iodized salt to the market and of distributors/traders of iodized salt will enhance the interaction with health authorities and will create the opportunity of efficient external monitoring and mutual exchange of relevant IDD information in an effort to strengthen the salt iodization programme.

An IDD control programme based on salt iodization clearly cannot succeed unless all salt for human consumption is being adequately iodized. Therefore, the most important indicator to monitor is salt, and the most important place to monitor salt is at the site of production and importation. If all salt leaving production facilities and imported salt is properly iodized, packaged, and labelled, populations consuming this salt are likely to have their iodine requirements met. Monitoring salt iodine at the production site provides an answer to the question: "Is the salt adequately iodized, i.e. according to the level required by the law of the country?" In view of the potential loss of iodine further down the supply chain, this is the appropriate place where law enforcement can take place. Salt monitoring at the site of production is the responsibility of both the salt producer (internal monitoring) as well as NAFDAC (external monitoring). Importers should certify at the port of entry that the salt they produce is iodized within a specified range as regulated by NAFDAC. Monitoring the iodine in salt at the retailer level provides an answer to the question: "What is the availability of iodized salt to the consumer?" Monitoring at this level yields a quick and easy indication of whether or not iodized salt is available in the marketplace, and the degree to which non-iodized salt is competing for household use.

In Nigeria, universal salt iodization was considered largely successful following adequate fortification of over 90% of domestic salt within ten years of implementation (Ariyo et al, 2023). Studies have found continuous compliance with the recommended level of 30ppm in some Nigerian retail common branded salts, however, iodine is either completely absent or lower than recommended in non-branded salts (Etesin et al, 2017). Interestingly, the market share of non-branded/non-iodized salt has been on the rise in Nigeria from less than five percent in 1994 to about 25 percent presently (Ariyo et al, 2023). Presently, West Africa including Nigeria has the lowest coverage of iodized salt and about 25% of the population consumes salt without any iodine (United Nations Children's Fund, 2019). Pockets of studies within the country have put the proportion of household consuming salt without iodine at about 30 percent (Umenwanne and Akinyele, 2000). Zimmermann and Andersson (2020) reported global compliance to salt iodization program and stated as shown in figure 2 that Nigeria is lacking in data in this regard.

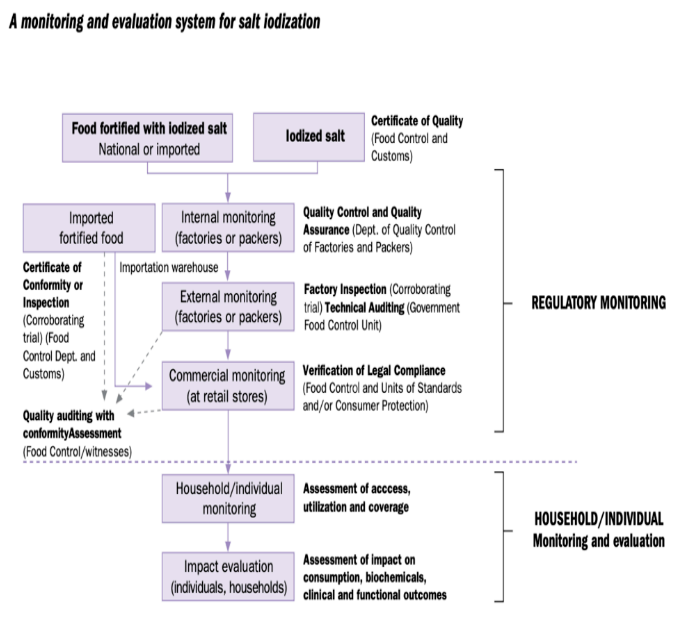

Figure 1. A monitoring and evaluation system for salt iodization.
Source: World Health Organization (2007).

In Nigeria, policy, regulation, and enforcement process have been integrated in the salt iodization system with strong public private partnerships. In 2002, an official multi-sectoral IDD-Universal Salt Iodization Task Force was established in Nigeria, with the support of UNICEF Nigeria, with a secretariat at Standard Organization of Nigeria and participation by Federal Ministry of Health, Federal Ministry of Education, NAFDAC, salt producers and the micronutrient initiative. The Task Force routinely monitors the marketplace through product registration, surveillance and inspection activities. In addition, consultation meetings and workshops, and public education and social marketing activities were initiated to ensure communication among partners and sustain awareness.

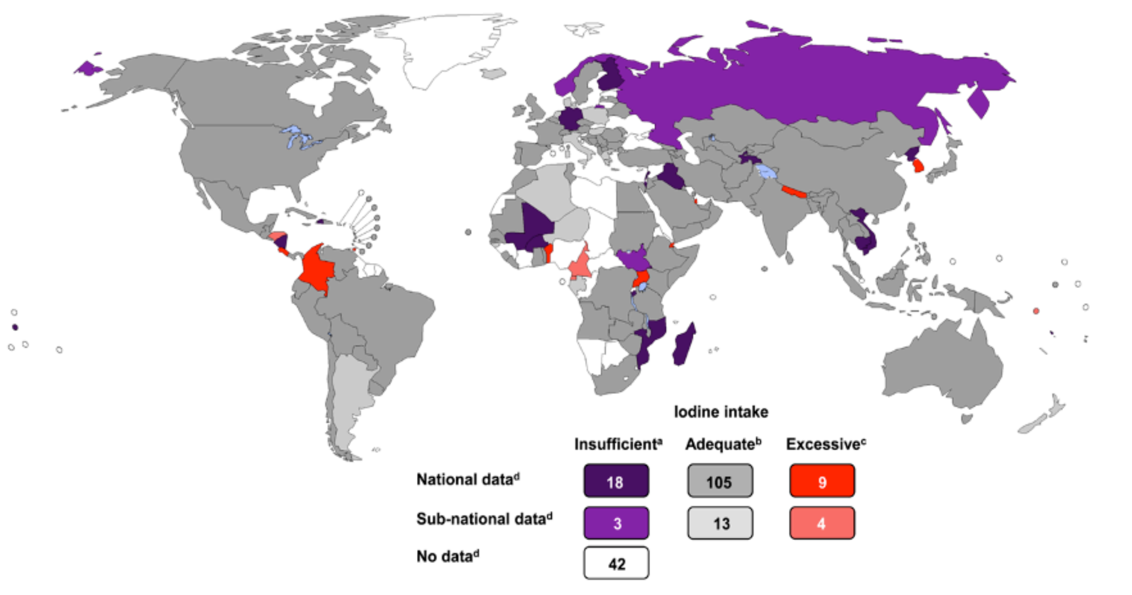

Figure 2. Estimated iodine nutrition in 194 WHO Member States in 2020 based on national median UIC in school-age children obtained from studies conducted between 2005–2020

Source: Zimmermann and Andersson (2020)

The National Agency for Food and Drug Administration and Control (NAFDAC), established as a parastatal of the Federal Ministry of Health in Nigeria in 1999 with the mission to "safeguard public health by ensuring that only the right quality of drugs, food and other regulated products are manufactured, imported, exported, distributed, advertised, sold and used," became a key new partner in the multi-sectoral body. With firm commitment to Universal Salt Iodization and wide-ranging enforcement powers, NAFDAC is reported to have destroyed more than 10,000 bags (20 kg) of non-iodized salt at the distributor and retail level since it joined the Task Force. In addition to providing a platform for opening channels of communication among government agencies, the private sector and consumers, the Task Force clearly defined roles and responsibilities for enforcing and monitoring Universal Salt Iodization:

- Standard Organization of Nigeria: Inspection of consignments at ports and at least bi-annual inspections of salt companies – with number of inspections based on performance.
- NAFDAC: Ongoing distributor and retail level inspection and enforcement throughout the country including registration of consumer products – which requires good manufacturing practice compliance of salt companies with iodization integrated into good manufacturing practice.
- Federal Ministry of Education: Coordinates annual collection of salt samples from school children in primary schools as proxy for household access to iodized salt.
- Salt Companies: Keep internal quality control records including tests by titration as well as comply with over-all good manufacturing practice.

Since 2002, these institutions have demonstrated the commitment and capacity to continuously monitor the marketplace generating continuous data tracking trends that may impact the effectiveness, safety, and sustainability of universal salt iodization.

Despite these measures, the gains of the past years have gradually been eroded following weak continuous monitoring. Other measures such as a ban on domestic salt packaging in 25kg sacks and introduction of mandatorily packaged salt in small retail sizes (1kg and less) to enhance retention of quality iodine and content and ban on marketing or hawking of salt in non-shaded stalls have also been introduced. These measures enable consumers to store salt in proper containers at home and distinguish between salts for industrial and domestic use. Yet, increasing cases of marketing of salts in household measures and in open spaces have been observed in recent times. Akinola et al (2020) reported increasing access of consumers to non-branded salt in Nigeria's open markets. These practices have implications on the iodide content of domestic salt, and ultimately on the health and well-being of the consumers. Continued deprivation of the segment of the population access to adequate iodine intake through universal salt iodization has consequences on the burden of stunting, intelligence quotient and cognition, and workforce productivity. Evidence has shown that iodized salt helps children achieve 8.18% increased intelligence quotient, 1.85cm increase in height, 4.81% and 2.67% increase in basic numeracy skills for girls and boys, respectively and 1.2 percentage points increase in labor force participation among women, and 11% increase in total income (Ariyo et al, 2023).

Reversing the downward trends of universal salt iodization in Nigeria requires involvement of all stakeholders across the salt supply chain including the salt producing companies, marketers, government regulatory bodies, and consumers. Presently, there is a dearth of information on what motivates the increasing marketing and patronage of non-branded salts in Nigeria. Understanding this reasoning is important in promoting appropriate strategies to increase uptake and use of iodized salt and strengthen universal salt iodization programme in Nigeria.

Ariyo et al (2023) reported that compliance to recommended salt storage and handling practices in Nigeria at retail and household levels is poor and industrial salt is marketed for domestic use. Also, consumers preference for non-branded salts is high following relative cost advantage and intensiveness over branded salt products, and this informed retail marketers' stock. Awareness of the benefits of salt iodization is low and poor handling practices is predominant among the retail marketers and the consumers. They further reported that in Nigeria, the poor regulation of food marketing activities favours marketers' non-compliance with recommended storage practices for many foods including salt. In many local markets, open vending of salt and exposure to direct sunlight, and fluctuating temperature have implications on its iodine content. They also reported that the increasing access to industrial salt for domestic use constitutes a concern in the country and confirms that access to appropriately iodized salt is declining in Nigeria. In addition, the development re-introduces the unsafe practices of salt marketing in household measures; creates room for marketing of industrial salt for domestic uses and allows for unhygienic practices in salt marketing. Moreover, the practice violates the national recommendation that iodized salt be packaged in airtight, high-density polyethylene or polypropylene or LDPE-lined jute bags and not be exposed to rain, excessive humidity, or direct sunlight at any stage of storage, transportation, or sale (National Agency for Food and Drug Administration and Control, 2019). High level of heavy metals and other impurities have been reported in industrial and unrefined salts in Nigeria and its consumption has serious health consequences if unchecked (Ukwo, 2021).

CONCLUSION

The magnitude of losses of iodine from production to household reported in published articles calls for additional studies to determine the actual concentration of iodine consumed at the household level. Awareness of salt iodization programme and its benefits remain low among salt marketers and consumers in Nigeria. Consequently, compliance with recommended salt storage and handling practices at retail and household levels is poor. The introduction of industrial salt in the food market should be urgently reversed. At all levels, dissemination of nutrition information regarding proper storage, handling and use of iodized salt is necessary to address the reported loss of iodine from salt and marketing of non-iodized salt.

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