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Recent Advances in Stability of Iodine in Iodized Salt

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Abstract
The effectiveness of salt-iodization programmes depends on the conservation of iodine concentration in salt at various stages of production and the supply-chain. 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 are iodized sufficiently to meet World Health Organisation (WHO) standard. However, at the hosuehold level, the available iodine concentration most often fall short of WHO standard which estimate a lost of not more than 20% from production to household level (Damane, 2005). With a further anticipated additional deacrease of 20% loss during cooking, it is apparent that the available iodine consumed from iodized salt is far below the recommended level. This review seeks to bring to light recent findings on post-production losses of iodine concentration in commercial salts and the various factors accounting for losses below WHO recommended standard.

Key Words: Iodine, Iodization, Stability, Iodine Deficiency

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Introduction

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 difficiency 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 do 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 an 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 an NaCl content of ≥96% with a moisture content of <4% and <0.5% water-soluble Mg.

Salt Iodization Process

The Indian salt commissioner office, CSO (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 draw-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 iodised salt through twin outlets for bagging. Nowadays mobile salt iodisation 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.

Salt can also be iodised 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 appropriate regulating device. The salt manufactured by this method does not remain free flow and cakes during the long storage.

When the iodisation program started 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 sieve. The salt to be iodised 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 in to a worm-screw mixer conveyor through a process feeder so as to give the desired quality of Iodized Salt.

Stability Issues

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.

Iodization level

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.

Stability of iodine in salt

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 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 high amount of iodine is lost in the fluidized bed dryers during production to packaging. More studies is required to investigate this substantial lost 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. Tables 1 extracted from Diosady *et al* (1998) displays the chemical characteristics of salt samples respectively. The study 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.

TABLE 1. Chemical characteristics of salt samples

Sample no.	Source	pH	Moisture (%)	Carbonates (ppm)	Bicarbonates (ppm)	Total carbonates (ppm)	Calcium (ppm)	Magnesium (ppm)	Barium (ppm)	Potassium (ppm)	Iron (ppm)	Strontium (ppm)	Sulphur (ppm)
1	Tanzania	9.77	11.5	375	488	863	1,400	4,600	6.9	1,800	<50	48	3,500
2	Bolivia	8.48	2.1	10	443	453	2,600	380	<0.2	<500	<50	77	2,400
3	Indonesia (P.T. Garam)	8.78	6.0	35	442	477	1,100	3,300	<0.2	1,300	<50	57	2,500
4	China (Beijing)	8.58	0.2	23	361	384	910	260	<0.2	<500	<50	20	840
5	Ghana	8.32	9.5	5	430	435	2,500	1,700	<0.2	<500	<50	62	2,800
6	India (Arumuganeri)	8.28	2.1	2	454	456	3,800	540	2.3	<500	<50	260	3,200
7	Philippines (code PHI-MI4)	9.35	6.4	245	513	758	3,500	4,100	<0.2	<500	<50	71	4,700
8	Senegal	8.87	3.6	65	432	497	1,900	3,500	<0.2	1,400	<50	84	3,200
9	Canada	6.25	0.4	0	41	41	290	210	<0.2	<500	87	3	160
10	China repeat	8.58	0.2	23	361	384	910	240	<0.2	<500	<50	20	840
11	India (Kurkuch)	7.54	0.7	0	318	318	3,100	700	<0.2	<500	<50	37	2,700
12	Pakistan	9.08	6.2	83	1,396	1,479	5,800	4,300	<0.2	<500	75	180	12,000
13	India (Phoda)	7.86	0.8	0	287	287	2,600	690	<0.2	<500	<50	30	2,200
14	Guatemala	8.72	4.5	50	452	502	6,300	4,000	<0.2	1,600	<50	140	6,700
15	Indonesia (Central Java)	7.88	3.9	0	413	413	2,200	1,900	<0.2	<500	62	48	2,600
16	Philippines (code PHI-PCS)	9.07	3.2	118	671	789	3,100	4,000	<0.2	1,400	<50	85	4,600
17	Thailand	7.94	1.4	0	468	468	750	1,900	<0.2	<500	<50	45	1,600
18	Bangladesh	7.21	1.5	0	825	825	1,100	1,100	<0.2	<500	<50	32	1,300
19	India (Tuticorin)	8.62	3.6	19	363	382	3,000	3,000	<0.2	<500	<50	120	2,400
20	India ("crushed" sign)	7.48	1.8	0	379	379	3,700	740	<0.2	<500	<50	47	3,200

21	Indonesia (Madura)	7.78	5.0	0	1,256	1,256	1,700	3,400	<0.2	1,100	<50	66	3,000
22	Indonesia (West Java)	8.14	2.7	102	470	572	910	2,900	<0.2	<500	<50	42	2,200
23	Philippines (code PHI-B2M)	8.79	13.0	118	671	789	3,300	9,900	<0.2	2,700	<50	110	7,600

Source: Diosady *et al* (1998)

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. Their experiments reveal that at every 24 hours interval, Dangote salt consumed more quantities of thiosulphate than Mr. Chef salt. This indicates greater iodate stability in Dangote salt brand as shown in Figure 1.

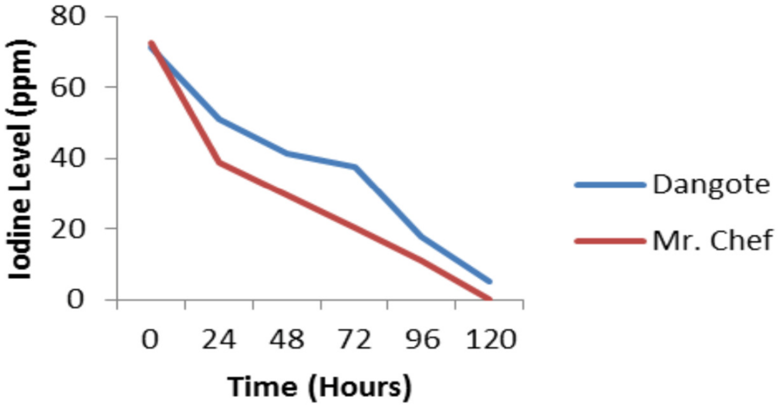

Figure 1: Iodine level (stability) in two salts brands after every 24 hours.
Source: Ekott, E. J., & Etukudo, U. I. (2019).

Habib *et al* (2023) conducted studies on more salt brands and reported sharp decrease in iodine concentration over a period of 50 hours as shown in figure 2.

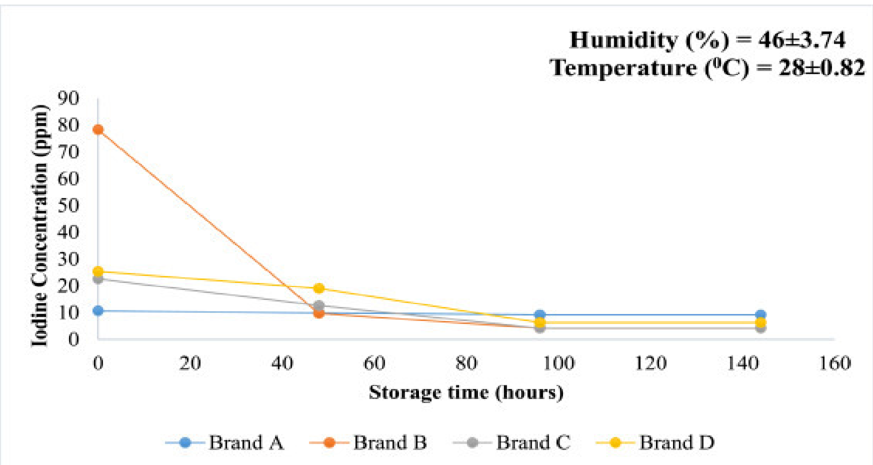

Fig. 2. Loss of iodine in Brand A, B, C, and D iodized salt over time with exposure to humidity and temperature. Source: Habib *et al* (2023).

Packaging materials

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. Tables 2, and 3 show the iodine retention in different packaging materials.

TABLE 2. Iodine retention in low-density polyethylene film bags at 40°C and 100% relative humidity

Sample	**Origin**	**% of original iodine remaining after storage for:**			
		1 month	**3 months**	**6 months**	**12 months**
1	Tanzania	88.0	89.6	72.2	22.4
2	Bolivia	91.7	95.0	67.8	41.4
3	Indonesia (P.T. Garam)	93.2	91.2	77.5	46.2
4	China (Beijing)	14.7	9.9	12.5	0
5	Ghana	95.9	100.0	72.8	17.9
6	India (Arumuganeri)	100.0	100.0	91.5	56.8
7	Philippines (code PHI-MI4)	99.3	99.3	89.0	62.4
8	Senegal	92.5	93.4	87.6	63.8
9	Canada	100.0	96.0	92.0	66.6
10	China repeat (100 ppm)	56.0	54.8	55.4	45.6
11	India (Kurkuch)	99.6	91.9	73.8	44.0
12	Pakistan	84.3	77.0	64.7	59.0
13	India (Phoda)	95.8	78.1	70.0	52.3
14	Guatemala	97.9	82.7	65.0	33.7
15	Indonesia (Central Java)	75.7	71.9	66.3	33.2
16	Philippines (code PHI-PCS)	94.2	90.6	74.9	55.0
17	Thailand	88.9	88.0	69.0	37.1
18	Bangladesh	100.0	86.1	78.1	50.7
	Average	87.1	83.1	71.1	43.8

Source: Diosady et al (1998)

TABLE 3. Iodine retention in woven high-density polyethylene bags at 40°C and 100% relative humidity

Sample	**Origin**	**% of original iodine remaining after storage for:**			
		1 month	**3 months**	**6 months**	**12 months**
1	Tanzania	51.0	12.0	2.4	0
2	Bolivia	85.8	64.9	9.2	0

3	Indonesia (P.T. Garam)	91.3	27.1	7.2	0
4	China (Beijing)	26.6	14.5	7.5	0
5	Ghana	92.2	90.9	61.4	3.9
6	India (Arumuganeri)	98.7	93.3	28.1	1.1
7	Philippines (code PHI-MI4)	92.0	36.7	3.4	0
8	Senegal	91.2	14.1	1.6	0
9	Canada	89.7	72.2	4.2	2.0
10	China repeat (100 ppm)	48.8	40.1	16.0	12.2
11	India (Kurkuch)	87.9	29.0	8.7	0
12	Pakistan	37.0	6.5	4.0	0
13	India (Phoda)	20.1	5.4	3.0	0
14	Guatemala	92.2	58.0	12.3	0
15	Indonesia (Central Java)	13.4	12.7	7.1	0
16	Philippines (code PHI-PCS)	39.4	6.2	0	0
17	Thailand	78.6	71.7	7.1	0
18	Bangladesh	81.0	7.4	3.5	0
	Average	67.6	36.8	10.4	1.1

Source: Diosady *et al* (1998)

Tables 2 and 3 clerarly show that by packaging salt in an effective moisture barrier, such as solid low-density polyethylene bags, iodine losses can be significantly reduced. The tables reveal 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. This 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 allaborate 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 salt as shown in figure 3. 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 call for redetermination of the shelf life of iodized salt.

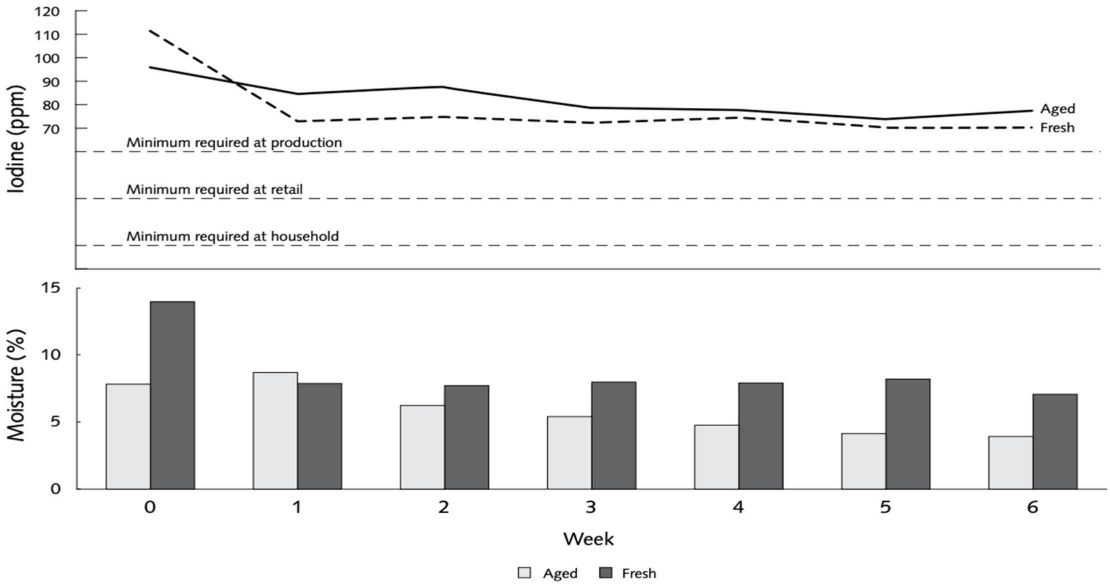

Figure 3. Iodine and moisture contents of iodized aged and fresh salt kept in woven polypropylene sacks and stored for 6 months. Source: Maramag *et al* (2007).

Conclusion

The observation of 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. Some authors have suggested increase in iodine concentration at production level so as to account for the significant loss during supply chain. Vithanage et al (2016) reported excessive iodine concentration in salt brands as a result of this approach suggesting that it should not be adopted. A monitoring and evaluation system needs to be established to ensure adequate supply of iodine along the distribution chain. Special attention is needed for the retailers and consumers. At these levels, dissemination of information regarding proper storage and handling of iodized salt is necessary to address the reported loss of iodine from salt.

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