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Commercially available iodized salts in Noakhali, Bangladesh: Estimation of iodine content, stability, and consumer satisfaction level

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ABSTRACT

The concentration of iodine in edible salt and its stability in different brands were evaluated in Noakhali district, Bangladesh using iodometric titration. Brand A and B had unacceptable amounts of iodine, whereas Brand C and D had appropriate amounts according to the Bangladesh Standards and Testing Institute (BSTI) standards. Iodine loss due to humidity and temperature gradually increased from 2 to 4 days for brands B, C, and D (slower in Brand A), and stabilizing after six days. The structural Model Equation (SME) revealed that, maternal education, family income, and consumer satisfaction level (CSL) positively affected different brands of salt use ($p \leq 0.05$). These findings provide a clear understanding that, Iodine content in different Salt Brands available in the Noakhali region varies and decreases with exposure to air over time, as well as CSL towards different salt brands (Brand A-least satisfactory and Brand D-most satisfactory). CSL was about 2.35 and 4.19 times higher in Brand C and D due to having iodized salt with the satisfactory range of BSTI ($p \leq 0.05$). The study emphasized that, care should be taken during the salt manufacturing and packaging process, distribution, and storage condition at the household level to ensure adequate intake of iodine.

Introduction

Iodine is a crucial mineral in our diet for ensuring good health and normal growth and development of the body. Typically, a healthy human has 15–20 mg of iodine stored in the body, of which 70–80% of iodine is stored in the thyroid gland (Prodhan et al., 2014). In the thyroid gland, the role of iodine is to produce T_3 (tri-iodothyronine) and T_4 (Thyroxine) hormones that take part in the hormonal regulation of our body as well as eliminate abnormal health problems (Rahman, 2015). These hormones are important for maintaining the body's metabolic rate, temperature regulation, ease of digestion, brain and sexual development, and maintenance of healthy body weight (Obregon et al., 2005). Iodized salt is considered an important source of iodine in our diet. A healthy person needs to ingest about 50 mg of iodine in the form of iodide, which is a year's requirement to form an optimum amount of T_4 or thyroxine, a hormone, produced by the thyroid gland and plays a crucial role in regulating metabolism, growth, and development of human body (Brownstein, 2009). Therefore, for maintaining optimum health and well-being, adequate iodine intake must be ensured through the consumption of iodized salt. Usually, natural foods contain a low amount of iodine which is not enough to meet the requirement of human health. For this reason, edible salt is fortified with iodine, which helps our body to maintain the daily requirement of this essential mineral.

Children and pregnant women are at higher risk of suffering from micronutrient deficiencies, especially iodine and iron (Modupe et al., 2019). Deficiency of iodine affects every stage in human life and is associated with issues such as physical and mental growth disturbances (cretinism, dwarfism), enlargement of the thyroid gland (goiter), muscular disorders, neurological disorders, mental retardation, spontaneous abortions, and hypothyroidism (Pearce & Zimmermann, 2023). Therefore, salt iodization programs are common practice throughout the world, and in Bangladesh, salt iodization programs began in 1989 at the Institute of Nutrition and Food Science (INFS), University of Dhaka (Yusuf et al., 1993). Evidence from many studies stated that, the main reason for iodine deficiency is probably less consumption of iodized salt or less iodine-containing salt or food (De Benoist et al., 2004). According to World Health Organization (WHO), it is estimated that an adult should take at least 150 µg of iodine per day. In contrast, a pregnant woman must take 200 to 250 µg of iodine per day (Organization, 2001, Kleks & Davidson, 1966) to avoid complications related to the lack of iodine in the diet.

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A review paper stated that, the stability of iodine in salt is most important for preventing iodine deficiency. It can be determined by several factors like- humidity, temperature, packaging, light, moisture in salt, and acidity or alkalinity (Fallah et al., 2020). It is estimated that, from production to the household level, the level of iodine loss in iodized salt with potassium iodide (KI) or more stable form, potassium iodate (KIO_3), is about 20% (De Benoist et al., 2004, Organization, 2007). However, there is a lack of appropriate information about iodine loss due to moisture, temperature, and packaging in iodized salt in Bangladesh. Hence, we selected iodized salt from a rural district of Bangladesh to examine the impact of humidity and temperature on its iodine content over time. This study aimed to investigate the stability of iodized salt from different brands, which is one of the first research works conducted in Bangladesh, to the best of our knowledge. Additionally, we assessed the consumer satisfaction levels towards various salt brands available in the area. The findings of this study provide valuable insights into the quality and stability of iodized salt in Bangladesh and can aid in developing effective strategies for improving the overall health and well-being of the population.

Methods

Study design and materials

A cross-sectional study was conducted on a total of 4 samples from 7 branded salts collected from local retailers in Subarnachar Upazila Noakhali, Bangladesh, based on a convenience sampling method. The study was carried out from September 2019 to November 2019 in *two phases* in a total of three (3) consecutive months in the Department of Food Technology and Nutrition Science, Noakhali Science and Technology University. *Phase-I* was the assessment of iodine content in different Brands of Salt and its stability in salt over time due to exposure to humidity, air, and temperature, and *Phase-II* was the assessment of Consumer satisfaction towards different Brands of available salts.

Phase-I: assessment of iodine content in different brands of salt and its stability over time

After selecting four (4) Brands out of seven (7) locally available Brands of salt based on their popularity (it means brands of salts that are comparatively cheap and mostly purchased by the local people), samples were collected from the local market and brought to the university laboratory. Then the salt samples were unpacked from their containers/packages; the required amounts were weighed immediately and then placed in identical vacuum containers. Each container was then adequately labeled and coded to ensure concealment of the allocation.

Iodometric titration method

The iodometric titration process assessed the iodine content (Organization, 2001) using the following chemicals. Three replicates were used for each sample (salt brand). Nowadays, iodization in iodized salt is commonly carried out using potassium iodate. The amount of potassium iodate in the salt is determined using the process of redox titration. This method involves the use of a reducing agent, which reacts with potassium iodate, resulting in the formation of iodine. The iodine produced in the reaction is then titrated with a standardized solution of sodium thiosulfate to determine the amount of potassium iodate present in the salt. This process is widely used to ensure that iodized salt meets the recommended standards for iodine content and is safe for human consumption.

In this method, the amount of iodate (IO^{3-}) in iodized salt is determined by first reacting the iodate-added iodide (I^-) under acid conditions to produce iodine:

$$IO^{3-} + 5I^- + 6H^+ \rightarrow 3I^2 + 3H_2O$$

Then the resulting free iodine is titrated with Thiosulphate using starch as indicator as follows:

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

Titration steps

10 g of salt from each sample was placed into a conical flask along with 50 ml of water, 5 ml of 10% KI, and 1 ml of concentrated H_2SO_4, one by one. Concentrated H_2SO_4 helps to liberate free iodine from iodate form of the salt sample. Then the solution turned into a yellow/brown color, as iodine was produced. This solution was titrated against the Standardized and Diluted Sodium thiosulfate ($Na_2S_2O_3$) until the yellow/brown color became very pale. The amount of $Na_2S_2O_3$ used depends on the liberation of iodine from salt. Then, 2–3 drops of Starch indicator solution were added, which produced a dark blue-black colored complex with iodine. The titration was continued until the color completely disappeared. The process was repeated three more times, and an average value for the volume of $Na_2S_2O_3$ was determinant. According to AOAC (Association of Official Analytical Chemists), no interference was found in adding sodium thiosulphate as stabilizing agent while determining iodine from salt, so this official method is considered as reliable one (Kleks & Davidson, 1966).

Calculation of iodine content: Iodine mg/kg (ppm) = titration volume in ml × 21.15 × normality of $Na_2S_2O_3$ ×1000 / salt sample (gm)

Phase-II: assessment of consumer satisfaction towards different brands of available salts

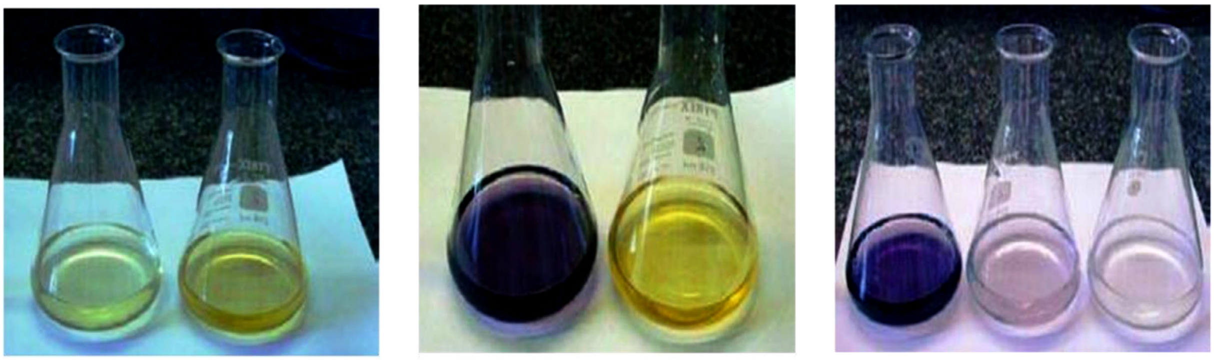
To assess consumer satisfaction levels regarding the use of various salt brands, we randomly surveyed a minimum of 25 women for each brand of salt from the Subarnachar Upazila of Noakhali. Women were chosen because of their active involvement in purchasing, cooking, and storing salt for household use, as well as cleaning fish and vegetables. We asked them about their experiences with using different brands of salt. This approach provided us with valuable insights into the preferences and opinions of salt consumers in this region. Thus, information was collected from 100 women for “four” Salt brands from the Noakhali region of Bangladesh. The satisfactory level was assessed by using the Likert scale (“1″ for *highly dissatisfied*, “2″ for *dissatisfied*, “3″ for *neither dissatisfied nor satisfied/neutral*, “4″ for *satisfied*, and “5″ for *highly satisfied*) (Joshi et al., 2015).

Statistical analyses

The data were analyzed using Microsoft Excel and statistical packages of social sciences (SPSS) software version 23.0. *Chi-square* (χ^2) test and multinomial regression analysis were performed to assess the association with dependent (satisfaction level of consumer) and independent variables (educational status and income level). Confirmatory Factor Analysis (CFA) was performed using SPSS Analysis of Moment Structures (AMOS) software version 26.0, and the confidence level was set at 95%. SME generated through SPSS AMOS was used to test the relationships between dependent (different salt brands) and independent (mother education, family income, and consumer satisfaction level).

Ethical approval

Ethical approval was taken from the Ethics Board of Noakhali Science and Technology University *(NSTU-EC-07/2019)* for conducting the study in the Food Technology and Nutrition Science department. All the names were kept anonymous for each salt Brand tested in the laboratory. For conducting the 2nd phase of the study, informed consent was taken from each of the 100 participants before data collection after discussing the pros and cons of the study.



(a): Titration **(b): Addition of Starch** **(c): Addition of Thiosulfate**

Fig. 1. (a): Right flask: yellow/brown color of iodine formed from the reaction of iodine inside salt with acidic iodide solution. Left flask: pale yellow color left when nearly all iodine reacted with added thiosulfate during titration. (b): Right flask: yellow/brown solution containing the last trace of iodine. Left flask: dark blue-black color formed when the starch indicator was added. (c): A series of flasks showing color changes as the last remaining iodine (with added starch indicator) was titrated with thiosulfate. The dark blue-black color disappeared, leaving a colorless solution at the endpoint.

Table 1
Comparison of iodine concentration in iodized salt from different brands with acceptable ranges for iodine concentration in ppm, published by BSTI (Bangladesh Standards and Testing Institute).

Brands	Replication			Mean iodine levels in brands (ppm)	Range of Iodine level in salt (ppm), established by BSTI
	1st (ppm)	2nd (ppm)	3rd (ppm)		
A	10.54	10.76	10.67	10.65	20–50
B	78.24	78.61	77.94	78.26	20–50
C	21.78	23.07	22.84	22.56	20–50
D	27.19	24.65	24.31	25.38	20–50

Ppm (parts per million), can be expressed as mg per litre.

Table 2
Iodine loss in different brand salts over time.

Brand Name	Iodine loss over time		
	48 h/2 days (%)	96 h/ 4 days (%)	144 h/ 6 days (%)
Brand A	6.7	13.5	13.5
Brand B	87.6	94.6	94.6
Brand C	43.8	81.3	81.3
Brand D	24.9	75.1	75.1

Day-to-day loss of iodine in brands A, B, C, and D, as exposed to air.

Result

Iodine concentration in salt was estimated from four iodized salt brands. Step by step procedure to assess the concentration of iodine in different brands was depicted in Fig. 1 (a, b, c).

Brand A salt contained very low amount of iodine (10.65 ppm) compared with acceptable range of iodine in salt established by BSTI. Brand B salt had the highest amount of iodine. Brand C and Brand D had acceptable levels of iodine in their salt (Table 1).

In Table 2, it was found that, after 48 h, the loss of iodine was higher in Brand B salt (87.6%) and lowered in Brand A (6.7%). The loss of iodine was much higher at 96 h in Brands B, C, and D. After 96 h; the loss became stable.

We measured the iodine loss for two days consecutively (Fig. 2). It was seen that the loss of iodine in Brand A did not differ much. In Brand B, the loss of iodine was noticeable in 48 h, although the concentration of iodine was gradually stable. But the loss of iodine in Brand C and Brand D was much lower. The initial loss of iodine in iodized salt is sharp, but after that, it stabilizes, and the loss of iodine over time becomes slow or negligible.

Table 3 shows the association of consumer satisfaction levels towards different brands of salt, where a significant association of satisfaction level was found with the income and educational status of the participants. Multinomial regression showed that satisfaction level was 3 times (OR: 3.171, 95%CI: 1.459–6.891) higher among high-income people than lower-income people, which was statistically significant. According to educational status, satisfaction level was higher among those with a certified educational background (OR: 2.638, 95%CI: 1.448–4.808). Compared with Brand A, which contains less amount of iodine than BSTI value, consumer satisfaction was more than 2 times (OR: 2.349, 95% CI: 1.35–4.09) and 4 times (OR: 4.195, 95% CI: 2.18–8.07) higher in Brand C and D respectively which contain the expected amount of iodine in their salt.

A structural equation model generated through AMOS was used to test the relationships among variables. The Goodness of Fit Index (GFI) and Root Mean Square Error of Approximation (RMSEA) measured above 0.90 (Hooper et al., 2008) and below 0.10 (MacCallum et al., 1996), respectively, were considered good fit. Thus, the hypothesized model had a good fit and is acceptable. The fit indices for the model shown in Table 4 fell within the acceptable range.

The squared multiple correlation was 0.523 for different salt brands, which showed 52% variance in different salt brands, accounted by the mother's education, consumer satisfaction level, and family income.

The study assessed the impact of mother's education, consumer satisfaction level, and family income on different salt brands. The effect of mother's education (H1), family income (H2), and consumer satisfaction level (H3) on different brand salt was positive and significant (β=0.263, t = 3.361, p = 0.001), (β=0.370, t = 4.731, p = 0.000), (β =0.320, t = 4.097, p = 0.000) respectively. These findings supported hypotheses H1, H2, and H3. Model fit indices and hypothesis results are presented in Table 4.

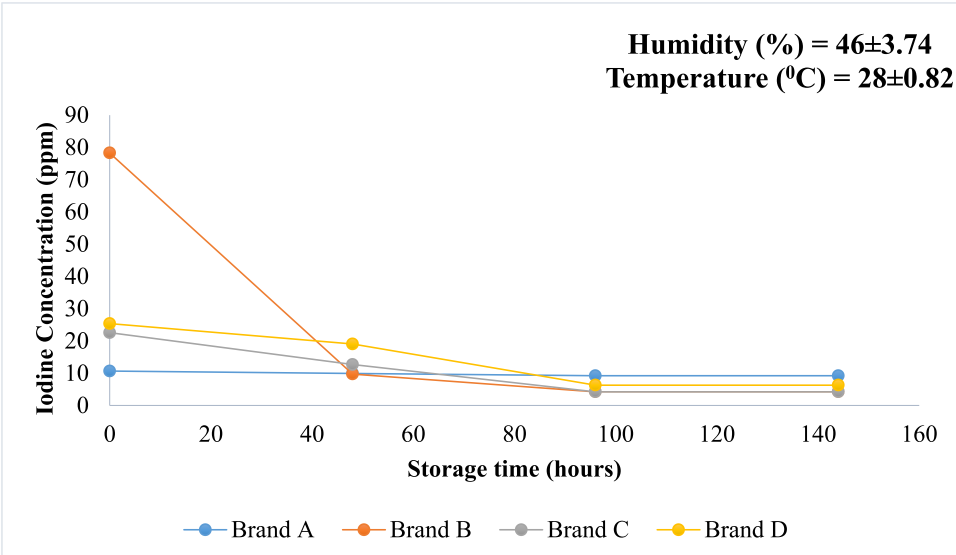


Fig. 2. Loss of iodine in Brand A, B, C, and D iodized salt over time with exposure to humidity and temperature.

Table 3
Association of satisfaction level with income and education status.

	Satisfaction level					*p-value*	OR (95% CI)
	Highly dissatisfied	Dissatisfied	Neutral	Satisfied	Highly satisfied		
Income (BDT)							
<10,000	3 (12.5)	4 (18.2)	3 (12.5)	1 (4.3)	1 (14.3)	*0.000******	1
10,000–20,000	11 (45.8)	12 (54.5)	9 (37.5)	6 (26.1)	0 (0.0)		0.89 (0.51–1.56)
20,000–30,000	9 (37.5)	6 (27.3)	8 (33.3)	11 (47.8)	1 (14.3)		1.21 (0.69–2.12)
>30,000	1 (4.2)	0 (0.0)	4 (16.7)	5 (21.7)	5 (71.4)		3.17** (1.46–6.89)
Education							
No formal education	10 (41.7)	12 (54.5)	6 (25.0)	4 (17.4)	1 (14.3)	*0.040**	1
Elementary	10 (41.7)	8 (36.4)	9 (37.5)	9 (39.1)	2 (28.6)		1.32 (0.89–1.97)
High School	3 (12.5)	1 (4.5)	6 (25.0)	3 (13.0)	2 (28.6)		1.72* (1.02–2.91)
Certified and above	1 (4.2)	1 (4.5)	3 (12.5)	7 (30.4)	2 (28.6)		2.63** (1.44–4.81)
Salt Brands							
Brand A	10 (41.7)	9 (40.9)	3 (12.5)	2 (8.7)	1 (14.3)	*0.000****	1
Brand B	10 (41.7)	8 (36.4)	5 (20.8)	2 (8.7)	0 (0.0)		0.96 (0.55–1.67)
Brand C	3 (12.5)	4 (18.2)	8 (33.3)	9 (39.1)	1 (14.3)		2.35** (1.35–4.09)
Brand D	1 (4.2)	1 (4.5)	8 (33.3)	10 (43.5)	5 (71.4)		4.19*** (2.18–8.07)

Data were collected from 100 participants (primarily women) from Noakhali region of Bangladesh. OR: Odds ratio, CI: Confidence Interval, *$p \le 0.05$, **$p \le 0.01$, ***$p \le 0.001$, was considered statistically significant.

Table 4
Hypothesized relationship of different salt brands on family income, mother education, and consumer satisfaction level.

Hypothesized Relationship		Standardized estimates	T	*P-value*	Decision
H1	Mother's education → Different salt brand	0.263	3.361	*0.001****	Supported
H2	Family income → Different salt Brand	0.370	4.731	*0.000****	Supported
H3	Consumer satisfaction level → Different salt brand	0.320	4.097	*0.000****	Supported
R- Square		0.523			
Model Fit		The goodness-of-fit (GFI) =0.989, and RMSEA=0.0413.			

All the hypothesized relationships were significant *$p \le 0.05$, **$p \le 0.01$, ***$p \le 0.001$, H1, H2, H3 (Hypothesis).

Discussion

Iodine deficiency disorder (IDD) is a major public health concern that affects millions of people around the world. In South-East Asia, including Bangladesh, more than 313 million individuals suffer from inadequate intake of iodine, making them vulnerable to IDD. This deficiency can lead to various health issues, such as goiter, cretinism, mental retardation, and developmental delays. The consumption of iodized salt is a cost-effective and easy way to prevent IDD, but there is a need to increase awareness about the importance of iodine in the diet and the risks associated with its deficiency to improve health outcomes in affected populations (Organization, 2004). Studies showed that, temperature and humidity could influence the iodine quality of iodized salt (Fallah et al., 2020, Yushina et al., 2020). The purpose of this study was to collect quantitative information on iodine loss in locally available iodized salt following exposure to air over time to find out if there are

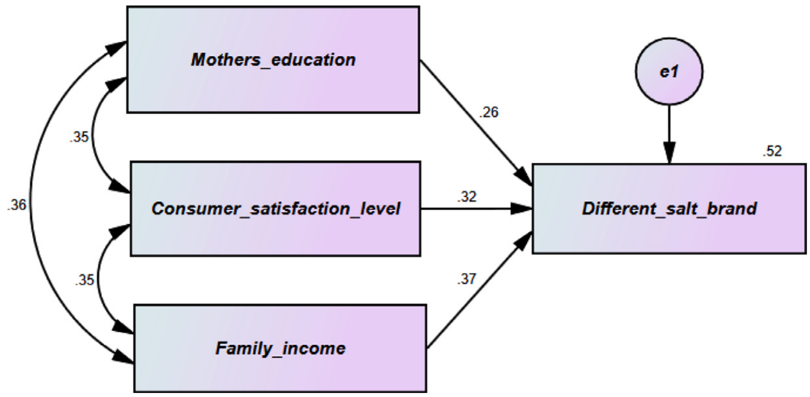


Fig. 3. Theoretical full structural model.

any differences in iodine content of our salt samples after exposure to air.

The study findings showed that, salt from three brands had iodine content of more than 20 ppm, and one brand contained only 10.65 ppm of iodine. According to BSTI, a typical salt brand should contain around 20–50 ppm of iodine to be acceptable as iodized salt (Nasreen & Ahmed, 2014). In our study, the concentration of iodine decreased over time with exposure to air, which was consistent with the findings shown by Diosady et al. (2002) where it was found that chemical compounds in iodized salt were broken down and evaporated when it is exposed to moisture and elevated temperature. Iodine retention was much affected by storage time and storage conditions (Diosady et al., 2002). Another study showed that, the loss of iodine would be higher with high relative humidity, and with low humidity, the loss would be lower (Dasgupta et al., 2008). In another study, it was observed that, at 200 °C, 41.16% of iodine was lost in 24 h, and when iodized salt was heated with the oxidized agent, the loss of iodine was up to 58.46% in 24 h (Biber et al., 2002). However, this was not consistent with the findings of our study, where more than 65% of iodine was lost over 96 h at 40–50% of relative humidity and 25–30 °C of temperature. This noticeable loss of iodine in salt may be due to the fortification method, packaging, sources of iodide in different salt brands, etc. The form in which salt is used can also affect the loss of iodine. It has been observed that the powder form of iodized salt is better at retaining iodine compared to granular iodized salt. This is because the larger surface area of granular salt allows for greater exposure to air, leading to a higher rate of iodine loss over time. In contrast, the finer particles of powdered salt have a lower surface area, which reduces the loss of iodine due to exposure to air. Therefore, the form of iodized salt used can have a significant impact on its iodine content and, ultimately, on the nutritional value it provides (Siddiq et al., 2022).

In our study, the loss of iodine in all brands was different. The possible causes may be packaging default, methods of iodization, shape, purity of salt, etc. One study also observed that cooking methods, the use of sugar, food additives, and the pH of food items could also affect the loss of iodine in iodized salt (Chavasit et al., 2002). The presence of Hydrogen peroxide (H_2O_2) in salt was also responsible for greater iodine loss (Biber et al., 2002). Iodine loss due to cooking methods was also described in many studies. According to Wang et al. (1999), the loss of iodine varies with the types of foods and water content. During cooking, 14–66% of iodine can be lost (Wang et al., 1999). The use of green curry paste, garlic, fresh chili, and paper is responsible for a high amount of iodine loss (Chavasit et al., 2002). Several methods have been developed to prevent iodine loss in iodized salt. A study found that, adding sodium hexametaphosphate (SHMP) to salt prevents interaction between iodine and iron and also slows down iodine loss. Fortification of salt with ferrous fumarate and potassium iodide was also reduced iodine loss in iodized salt (Diosady et al., 2002). Potassium iodate (KIO_3) is the most common form of iodine used for iodization of salt in the present day. This is because potassium iodide (KI) is volatile and can result in the loss of iodine content over time. However, in developing countries such as Bangladesh, the process of fortification with chemical compounds to prevent iodine loss can be challenging. This is a critical issue that requires attention, as ensuring an adequate supply of iodine is essential for the general population's health and well-being. Alternative methods to prevent iodine loss should be explored to prevent IDDs, a significant public health concern in many developing countries. Finding effective solutions to this problem is essential to ensuring that vulnerable populations have access to sufficient amounts of iodine for healthy growth and development. From the ordinal and multinomial regression analysis, a consumer satisfaction level was also assessed towards different brands of salts. It was found that iodized salt intake was associated with consumer satisfaction, and the satisfaction level was much higher in brands with acceptable iodine content. The satisfaction level was higher for brand D, while it declined consecutively for brand C, brand B, and then brand A. The reasons may be due to the appearance of salt (shape, size, color/purity, texture), product price, nutrition labeling on the container, etc. One study showed that consumption of iodized salt was higher among people from high socioeconomic status (SES) compared to those from lower SES in Bangladesh (Knowles et al., 2017, Khan et al., 2019). Fig. 3 and Table 4 indicated that use of iodized brand salt had a positive relationship with mother's education, family income, and consumer satisfaction level. Our findings correlate with another study where it was found that, knowledge, attitude, and practice of utilizing iodized salt relied upon maternal education and income of the households (Habib et al., 2021). People with higher education showed higher satisfaction levels. Our study also found that people with higher income and certified educational background had a higher satisfaction level towards salt with more iodine content, which is consistent with Khan et al. (2019). Knowledge of sensory evaluation (individualized) and the medicinal value of food (its impact on health) could also be determinants of consumer satisfaction (Andersen & Hyldig, 2015). Adequate intake of iodized salt can provide optimal nutrition to people over the world, whereas, inadequate or excess levels of iodine in iodized salt intake may lead to adverse health effects (Dhar et al., 2023, Abu et al., 2019). Although there is no data about consumer satisfaction and iodized salt intake, a recent study evaluated consumer's perception about iodine fortified foods. The acceptance of consuming iodine-fortified foods largely depends on health benefits, less market price, convenient and natural products (Welk et al., 2021).

Our study has several limitations, including the use of only the salt brands available in the Noakhali district, which may not represent the entire country of Bangladesh. We also faced limited laboratory facilities, which hindered extensive quantitative sample analysis. Additionally, we were unable to track iodine loss from production to shipping and packaging and only evaluated losses at the household level, where the common practice was to store salt in open containers. However, our study also had some strengths, such as the estimation of iodine content in locally available salt brands by comparing them with BSTI-recommended values of iodized salt in the Noakhali district. We also attempted to evaluate iodine loss with exposure to humidity and temperature over time, taking into account Noakhali's unique tropical climate and significant rainfall.

Conclusion

Our research in the Noakhali district, situated in the southeastern region of Bangladesh, discovered that, the iodine concentration of four widely used salt brands in this area decreased with time, with Brand D being the most popular and Brand A being the least. Purchasing behavior for salt among consumers was also related to factors like education and income. Despite the fact that government initiatives have decreased iodine-deficient illnesses, iodine loss in salt also needs to be addressed to avoid potential health hazards, especially for rural pregnant women. This can be accomplished by avoiding food adulteration, subpar manufacturing techniques (resulting in defective, unreliable, and unsafe products), and inadequate storage procedures. In order to make up for the unavoidable loss of iodine content over time due to exposure to air, one effective option could be to add extra iodine while making salt.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Mohammad Asadul Habib: Conceptualization, Data curation, Investigation, Formal analysis, Writing – original draft. **Akibul Islam Chowdhury:** Data curation, Formal analysis, Writing – original draft. **Mohammad Rahanur Alam:** Formal analysis, Supervision, Writing – review & editing. **Tanjina Rahman:** Formal analysis, Supervision, Writing – review & editing.

Data availability

Data will be made available on request.

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