# Stability of iodine in iodized salt used for correction of iodine-deficiency disorders

L. L. Diosady, J. O. Alberti, M. G. Venkatesh Mannar, and T. G. Stone

## Abstract

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L. L. Diosady and J. O. Alberti are affiliated with the Department of Chemical Engineering and Applied Chemistry in the University of Toronto, Canada. M. G. Venkatesh Mannar is affiliated with the Micronutrient Initiative, International Development Research Centre in Ottawa, Canada, and T. G. Stone is with PATH (Programme for Appropriate Technology in Health) Canada in Ottawa.

Mention of the names of firms and commercial products does not imply endorsement by the United Nations University.

## Introduction

The food supply of more than 1.6 billion people is lacking in adequate levels of iodine, resulting in the widespread prevalence of a spectrum of iodine-deficiency disorders. This public health problem may be corrected by the regular delivery of small doses of iodine to the population in commonly eaten foods or condiments. Salt is an excellent carrier for iodine, as it is consumed at relatively constant, well-defined levels by all people within a society, independently of economic status. Over the past decade, as part of the Universal Salt Iodization (USI) initiative, a large number of developing countries have taken steps to ensure that all salt for human and animal consumption is iodized. The virtual elimination of iodine-deficiency disorders in the world by the year 2000 has been set as a goal at several international forums, including the World Health Assembly [1, 2] the World Summit for Children [3], and the International Conference on Nutrition [4].

Salt is iodized by the addition of fixed amounts of potassium iodide or iodate as either a dry solid or an aqueous solution at the point of production. 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;
» the extent of loss of iodine due to salt impurities, packaging, and environmental conditions during storage and distribution;
» loss of iodine due to food-processing, washing, and cooking processes in the household.

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## Introduction

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To determine the appropriate levels of iodization, an accurate estimate of the losses of iodine occurring conditions, lost up to 33% of their iodine after eight weeks [7].

A comprehensive review of the literature by Kelly [8] concluded that the stability of iodine in salt is determined by the moisture content of the salt and the humidity of the atmosphere, light, impurities in the salt, alkalinity or acidity, and the form in which the iodine is present. Kelly concluded that the iodine content will remain relatively constant if the salt is packed dry in a container with an impervious lining and kept dry, cool, and away from light. He recommended that iodate be used under adverse conditions, such those found in developing countries where the salt being iodized is crude, unprocessed, and usually not dried sufficiently.

Arroyave et al. [9] showed that potassium iodate mixed with calcium carbonate was stable when added to crude local sea salt stored in hemp fibre sacks. After eight months at ambient temperatures and relative humidities between 70% and 84%, an average of 3.5% of the added iodine was lost. There was no significant migration of iodine within the sacks, probably because of the low solubility of iodate.

A 1992 study by Chauhan et al. [10] compared the stability of iodine over 300 days in common salt iodized with iodate and packed in 5-kg solid high-density polyethylene bags or left in open heaps. The relative humidity varied from 41% to 83% (median, 52%) and the temperature from 30° to 39°C. Both the salt packed in high-density polyethylene bags and the salt left in the open lost 9% to 10% of added iodine within the first month, after which the values remained practically constant.

Other evidence of the magnitude of iodine losses from iodized salt comes from studies assessing the efficacy of stabilizing compounds in local salt. Findings from control samples (without stabilizers) suggest considerable variation in iodine stability, in spite of differences in experimental design.

Ranganathan and Narasinga Rao [11] found that coarse salt iodized with iodate at "normal" room temperature and humidity showed iodine losses of 15% at 3 months, increasing to 20% at 12 months. There was virtually no difference in iodine losses between salt iodized with iodide and salt iodized with iodate. Samples containing a stabilizer (calcium carbonate) did not appear to lose any iodine after 18 months under these conditions. Unfortunately, the type of packaging used by the researchers was not stated, and the samples appeared to be small.

In a later study, analysis of five types of Indian salt (including powder and crystal) iodized with iodate showed losses of 28% to 51% after 3 months, 35% to 52% after 6 months, and up to 66% after 12 months. The losses from powdered salt appeared to be lower. No information was given on packaging. The findings demonstrate the utility of sodium carbonate as a stabilizer [12].

In Hubei, China, the iodine losses from refined solar salt packed in open 1-kg plastic film bags, heated to 130°C for 2.5 hours (to simulate drying) and stored at ambient temperature, were 5.7% after 12 months and 11% after 3 years [13].

Although the literature and North American practice indicate that iodine loss is reduced by stabilizers such as carbonates, these are not used in most developing countries, and thus we chose not to use them in this study.

### Packaging materials

Salt may be sold to the consumer packaged or 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. The solid, non-woven polymer bags are the best moisture barriers, and if properly sealed and kept intact will maintain the moisture level in the salt throughout the distribution system, thus minimizing the loss of iodine resulting from the absorption of moisture and the subsequent chemical reactions.

### Objectives

The purpose of the present study was to assess the effects of humidity and packaging materials on the stability of iodine in typical salt samples from countries with tropical and subtropical climates, under controlled climatic conditions. In the short term, the results may be useful for assessing the potential losses of iodine from salt between the points of production and consumption. The overall goal of the study was to determine the range and timing of the iodine losses that may be expected from salt iodized with iodate under typical conditions, and to define cost-effective means of controlling or compensating for these losses, ensuring that populations at risk for iodine-deficiency disorders receive effective amounts of iodine in iodized salt.

## Materials and methods

### Materials

Potassium iodate, analytical reagent grade, was obtained from BDH Canada, Toronto. Samples of non-iodized salt consumed by low-income populations from eight countries (Bolivia, China, Ghana, India, Indonesia, the Philippines, Senegal, and Tanzania) were obtained through UNICEF country offices from routine production runs of local salt producers and shipped by air to Toronto. A sample of non-iodized refined Canadian salt was obtained from Toronto Salt Chemical Co., Toronto. The Toronto sample was used as a reference.

## Sample treatment

Salt samples with particles less than 2 mm in diameter were used without pre-grinding. Because wet salt could not be sieved, salt containing larger particles than this and with a moisture content of more than 3% were dried in a forced-convection oven at 70°C overnight, ground with a mortar and pestle, and passed through a 10-mesh sieve. The water content was then reconstituted to the original moisture level.

Two-kilogram samples of salt from each source were fortified to contain about 50 mg/kg iodine using potassium iodate added as a 30 g/L solution. The mixtures were blended to ensure uniformity using a 5-L ribbon blender (LeRoy Somer-LSTronics, Montreal PQ, Canada).

## Packaging materials

For each salt sample, three packaging methods were tested. For each treatment condition, three 500-g samples were prepared in solid, continuous-film, low-density polyethylene bags 0.07 mm thick, in open plastic containers, and in woven high-density polyethylene bags 0.15 mm thick. Both low-density and high-density polyethylene are clear transparent or translucent plastic materials that are extruded as a thin sheet. High-density polyethylene has a much higher tensile strength because it is made of longer molecular chains. Low-density polyethylene bags were made by folding the sheets into the appropriate shape and welding the seams by heating. High-density polyethylene bags were made by cutting the sheets into thin strips 1.5 to 2.5 mm wide and weaving them into a cloth, which was then sewed into bags. Although high-density polyethylene does not absorb water, the woven bags readily allow the passage of water through the weave.

## Storage conditions

The packages were stored under two conditions: elevated temperature (~40°C) and high humidity (100%), and elevated temperature (~40°C) and medium humidity (~60%). High-temperature, high-humidity conditions were maintained by using a controlled-temperature oven in which the air was saturated with water vapour by exposure to a tray of water. High-temperature, medium-humidity conditions were maintained in an environmental chamber manufactured by Associated Environmental Systems Division of Craig Systems Corporation, Toronto.

## Analytical methods

### Sampling

Packages of salt were sampled at the start of the experimental series and after 1, 2, 3, 6, and 12 months of storage. To obtain a representative and reasonably homogeneous sample for analysis, the complete solid salt contents of a bag were split into two equal subsamples by pouring them through a two-stemmed powder funnel. The splitting of the sample was repeated until only about 15 g of salt had been collected. This subsample was used for the analyses.

Some salt samples with hygroscopic impurities stored in open containers collected sufficient moisture at 100% relative humidity to develop a liquid layer on top of the solid salt. The liquid was filtered off from these samples, its volume was measured, the liquid was volumetrically sampled, and the contents of iodine and solids were determined. The solid phase was analysed separately. The overall iodine concentration in the combined liquid and solid sample was then calculated on the basis of the weight and iodine concentration of each phase.

### Moisture

The moisture content was determined gravimetrically. Samples of salt were weighed, then dried at 110°C for 16 hours and reweighed.

### Iodine

The iodine content was measured by neutron activation analysis or titration.

1. Approximately 1.25 g of salt was accurately weighed into a polyethylene vial. To decrease the interference due to the presence of a high concentration of chlorine in the sample, the sample was shielded with cadmium.
2. The vials were irradiated at 1 kW power with a neutron flux of $5.0 \times 10^{11}$ $cm^{-2}$ $s^{-1}$ for 3 minutes in the University of Toronto's SLOWPOKE nuclear reactor.
3. The samples were removed from the reactor and left for 6 minutes.
4. After 6 minutes, the gamma emission at 443 keV was measured with a hyperpure-germanium-based gamma-ray spectrometer.
5. The iodine content was calculated using a calibration curve established by a series of spiked samples that covered the range from 5 to 250 mg of iodine per kilogram of salt. The relative standard deviation of the analysis was determined to be 2%.

### Titration

1. Ten grams of salt was dissolved in approximately 100 ml of water. The pH was adjusted to 2.8 with 0.6% HCl.

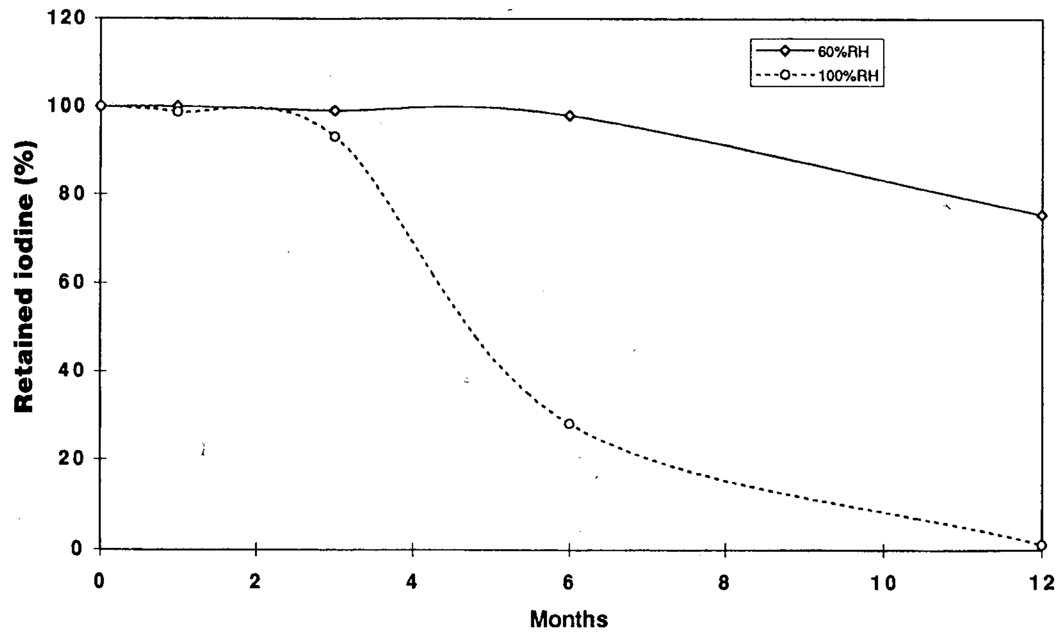


FIG. 1. Effect of relative humidity on the stability of iodine in salt from India stored in woven high-density polyethylene bags at 40°C

2. Thirty milligrams of KI powder was added to convert all of the iodate present to elemental iodine.
3. The liberated iodine was titrated with 0.004 N freshly prepared sodium thiosulphate solution. Starch was used as the end-point indicator.

The iodine value obtained by analysis immediately after the time of preparation was used as the starting or time=0 concentration for all subsequent analyses of the same batch.

## Results and discussion

All salt samples lost iodine over the 12-month sampling period. The losses ranged from less than 10% to 100% of the original iodine in the sample from a starting value of 50 $\mu g/g \pm 5\%$. The rate of iodine loss was influenced by the origin of the salt, the packaging material, and the relative humidity during storage.

### Relative humidity

In all cases the samples stored at 60% relative humidity lost iodine at a lower rate than those stored in saturated air (100% relative humidity). After six months of storage at 60% relative humidity, the loss ranged from ~0% to 20%, which is lower than might be expected on the basis of the ICCIDD/WHO/UNICEF tables.

At high humidity, the losses were more dramatic. Iodine losses over six months of storage ranged up to 98.5%, indicating that effectively all of the iodine added to the sample disappeared within six months. At high humidity, the samples stored in containers that allowed contact with the air lost two-thirds or more of the added iodine within the year. The results demonstrate the large effect of ambient humidity on the stability of iodine. Although it would be desirable to study the effects of other values of humidity on iodine loss, the results at the selected extremes of humidity give a good indication of the expected range of iodine loss from these samples in the field. Even under moist tropical conditions, it is unlikely that the relative humidity would remain at this extreme level for six months. However, within bags exposed to sunlight or in storage facilities heated by the sun, the high humidity will be retained, once moisture is absorbed into the bag's contents, and temperatures may readily rise to over 60°C. Only one month of exposure of the samples in open containers to 40°C at 100% relative humidity resulted in the loss of more than 25% of the iodine from most of the containers. The typical effect of relative humidity is illustrated in figure 1.

### Packaging material

Packaging affected the levels of moisture absorbed. Solid low-density polyethylene provided an excel-

TABLE 1. Stability of iodine in salt stored in low-density polyethylene film bags at 60% relative humidity and 40°C

| Source of salt | Initial iodine (mg/kg)[a] | % of original iodine remaining after storage for: | | | | |
|---|---|---|---|---|---|---|
| | | 0 mo | 1 mo | 3 mo | 6 mo | 12 mo |
| Bolivia | 55.6 ± 0.8 | 100.0 | 89.2 | 95.3 | 85.3 | 68.7 |
| Ghana | 54.1 ± 0.9 | 100.0 | 93.7 | 98.9 | 100.0 | 88.9 |
| India | 55.1 ± 1.1 | 100.0 | 100.0 | 98.7 | 99.1 | 87.4 |
| Indonesia | 54.3 ± 1.2 | 100.0 | 98.9 | 93.7 | 96.5 | 79.0 |
| Philippines | 55.3 ± 0.7 | 100.0 | 100.0 | 100.0 | 100.0 | 82.5 |
| Senegal | 54.7 ± 0.8 | 100.0 | 93.8 | 93.2 | 93.8 | 76.1 |
| Tanzania | 50.8 ± 0.6 | 100.0 | 95.1 | 97.8 | 83.9 | 70.3 |
| Canada | 55.1 ± 0.8 | 100.0 | 95.6 | 94.2 | 94.9 | 77.3 |

a. mg/kg = ppm.

TABLE 2. Stability of iodine in salt stored in low-density polyethylene film bags at 100% relative humidity and 40°C

| Source of salt | % of original iodine remaining after storage for: | | | | |
|---|---|---|---|---|---|
| | 0 mo | 1 mo | 3 mo | 6 mo | 12 mo |
| Bolivia | 100.0 | 91.7 | 95.0 | 67.8 | 41.4 |
| Ghana | 100.0 | 95.9 | 100.0 | 72.8 | 17.9 |
| India | 100.0 | 100.0 | 100.0 | 91.5 | 56.8 |
| Indonesia | 100.0 | 93.2 | 91.2 | 77.5 | 46.2 |
| Philippines | 100.0 | 99.3 | 99.3 | 89.0 | 62.4 |
| Senegal | 100.0 | 92.5 | 93.4 | 87.6 | 63.8 |
| Tanzania | 100.0 | 88.0 | 89.6 | 72.2 | 22.4 |
| Canada | 100.0 | 100.0 | 96.0 | 92.0 | 66.6 |

TABLE 3. Stability of iodine in salt stored in high-density woven polyethylene bags at 60% relative humidity and 40°C

| Source of salt | % of original iodine remaining after storage for: | | | | |
|---|---|---|---|---|---|
| | 0 mo | 1 mo | 3 mo | 6 mo | 12 mo |
| Bolivia | 100.0 | 92.1 | 95.0 | 98.4 | 68.7 |
| Ghana | 100.0 | 92.2 | 90.8 | 99.6 | 81.0 |
| India | 100.0 | 100.0 | 99.1 | 98.0 | 75.7 |
| Indonesia | 100.0 | 95.9 | 94.3 | 98.2 | 78.5 |
| Philippines | 100.0 | 98.6 | 98.4 | 99.6 | 78.8 |
| Senegal | 100.0 | 91.8 | 90.5 | 90.3 | 77.1 |
| Tanzania | 100.0 | 89.4 | 91.5 | 89.2 | 69.3 |
| Canada | 100.0 | 100.0 | 94.9 | 94.9 | 76.4 |

lent moisture barrier that maintained the total water content of the salt near the level at the time of packaging. Some absorption of moisture was possible because the bags were not sealed sufficiently to prevent some diffusion of air containing water, iodine, or both in and out of the bags (tables 1 and 2).

Woven high-density polyethylene bags allowed ready access of air to the salt, but they also allowed any condensed moisture to drip out of the bag in the form of a saturated salt solution containing iodate (tables 3 and 4). The woven bags behaved similarly to the open containers at 60% relative humidity, although at high humidity the open containers retained significantly more iodine than the woven high-density polyethylene bags in all but two cases.

Open containers of course allowed free contact

TABLE 4. Stability of iodine in salt stored in high-density woven polyethylene bags at 100% relative humidity and 40°C

| Source of salt | % of original iodine remaining after storage for: | | | | |
|---|---|---|---|---|---|
| | 0 mo | 1 mo | 3 mo | 6 mo | 12 mo |
| Bolivia | 100.0 | 85.8 | 64.9 | 9.2 | 0.0 |
| Ghana | 100.0 | 92.2 | 90.9 | 61.4 | 3.9 |
| India | 100.0 | 98.7 | 93.3 | 28.1 | 1.1 |
| Indonesia | 100.0 | 91.3 | 27.1 | 7.2 | 0.0 |
| Philippines | 100.0 | 92.0 | 36.7 | 3.4 | 0.0 |
| Senegal | 100.0 | 91.2 | 14.1 | 1.6 | 0.0 |
| Tanzania | 100.0 | 51.0 | 12.0 | 2.4 | 0.0 |
| Canada | 100.0 | 89.7 | 72.2 | 4.2 | 2.0 |

TABLE 5. Stability of iodine in salt stored in open containers at 60% relative humidity and 40°C

| Source of salt | % of original iodine remaining after storage for: | | | | |
|---|---|---|---|---|---|
| | 0 mo | 1 mo | 3 mo | 6 mo | 12 mo |
| Bolivia | 100.0 | 98.7 | 94.8 | 93.0 | 70.3 |
| Ghana | 100.0 | 98.2 | 96.3 | 95.4 | 79.7 |
| India | 100.0 | 100.0 | 96.7 | 98.7 | 75.7 |
| Indonesia | 100.0 | 88.0 | 87.5 | 92.8 | 76.2 |
| Philippines | 100.0 | 100.0 | 97.8 | 95.3 | 74.7 |
| Senegal | 100.0 | 85.2 | 83.0 | 81.4 | 70.7 |
| Tanzania | 100.0 | 100.0 | 99.0 | 87.4 | 69.3 |
| Canada | 100.0 | 100.0 | 90.6 | 90.6 | 80.9 |

TABLE 6. Stability of iodine in salt stored in open containers at 100% relative humidity and 40°C

| Source of salt | % of original iodine remaining after storage for: | | | | |
|---|---|---|---|---|---|
| | 0 mo | 1 mo | 3 mo | 6 mo | 12 mo |
| Bolivia | 100.0 | 60.4 | 33.8 | 17.8 | 81.1 |
| Ghana | 100.0 | 74.1 | 30.7 | 22.1 | 10.6 |
| India | 100.0 | 91.7 | 48.3 | 30.3 | 11.1 |
| Indonesia | 100.0 | 73.8 | 43.1 | 28.4 | 11.2 |
| Philippines | 100.0 | 84.1 | 53.5 | 36.5 | 19.2 |
| Senegal | 100.0 | 72.6 | 32.7 | 31.8 | 26.1 |
| Tanzania | 100.0 | 62.2 | 30.1 | 18.5 | 8.2 |
| Canada | 100.0 | 81.1 | 54.1 | 36.3 | 17.8 |

between the air and the salt sample. Any absorbed or condensed moisture would remain in the sample as a liquid and contribute to the instability of iodine (tables 5 and 6).

As expected, the best results in terms of iodine stability were obtained with the solid low-density polyethylene bags. The typical effect of the container type is presented graphically in figure 2.

## Country of origin

The physical characteristics of salt samples resulting from the profile of impurities and the extent of processing at the source had a major effect on the stability of the salt. The salt samples received varied in colour from very bright white to dark grey or rusty brown. The particle sizes ranged from ~100 μm to

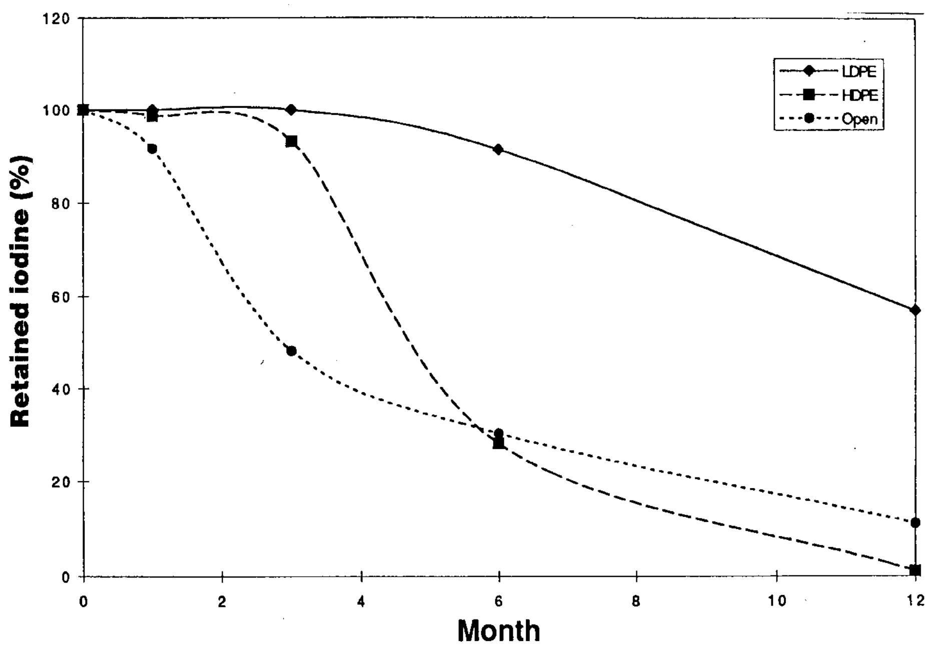


FIG. 2. Effect of packaging on the stability of iodine in salt from India stored at 100% relative humidity and 40°C. HDPE, Woven high-density polyethylene bags; LDPE, solid low-density polyethylene bags; Open, open containers

15 mm, with great variability in the homogeneity of particle size.

As expected, Canadian salt, which was of high purity and contained very little moisture or hygroscopic impurities, was relatively stable. At low humidity, the iodine loss was less than 10% after six months of storage and less than 25% after a year. At 100% humidity, the protection of the polyethylene bag maintained iodine losses at less than 8%, whereas in woven high-density polyethylene bags and open containers, 63% and 95% of the iodine were lost, respectfully.

Some salt samples with lower levels of purity and higher levels of moisture were as stable as the Canadian sample. Salts from Canada, India, the Philippines, and Senegal lost less than 15% of added iodine, even at 100% relative humidity, when stored in low-density polyethylene bags. Salts from Tanzania, Indonesia, and Ghana retained more than 70% of added iodine, and salt from Bolivia retained more than two-thirds of added iodine for the first six months, yet the Tanzanian salt retained only 22% of the iodine after a year under the same conditions.

At low humidity, the salt from Ghana lost very little iodine. At high humidity, the iodine content of Ghanaian salt remained high for the first three months and dropped sharply during the next three months, losing 83% after a year.

## Conclusions

The study clearly indicates that moisture plays a critical role in the stability of iodine. In particular, when salt is stored at temperatures characteristic of the storage and distribution conditions in many developing countries, moisture absorbed by hygroscopic impurities contributes to the rapid loss of iodine.

Although the use of highly purified salt would improve the stability of iodine in most cases, this would be expensive and probably not technically or economically feasible in the short term in many developing countries.

By packaging salt in an effective moisture barrier, such as solid low-density polyethylene bags, iodine losses can be significantly reduced. With solid low-density polyethylene packaging, the loss of iodine from salt stored for up to six months can be kept in the range of 10% to 15%. Unfortunately, woven high-density polyethylene bags are necessary for the bulk packing of salt to ensure adequate mechanical strength. Fitting woven high-density polyethylene bags with an impervious liner of high-density polyethylene or low-density polyethylene would appear to be an effective, low-cost method of improving the stability of iodine in iodized salt. However, because the loss of iodine exceeded 25% in many samples after 12 months, even with solid low-density polyethylene packaging, the time required for distribution, sale, and consumption should be minimized to ensure efficient and effective use of the added iodine.

The results indicate that the control of the moisture content of 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 source and quality of the salt and the way it was processed.

To evaluate the range of differences between salt sources, the study will be expanded to other countries with determination of the details of salt composition in an effort to identify the effect of impurities on the stability of iodine.

## Acknowledgements

This work is dedicated to the memory of Dr. Timothy R. Stone, Executive Director of PATH Canada, who was tragically killed while on a humanitarian mission in the crash of the hijacked Ethiopian plane in the Comoro Islands in November 1996. The project was a collaborative effort between PATH Canada, the Department of Chemical Engineering and Applied Chemistry of the University of Toronto, and the Micronutrient Initiative. We gratefully acknowledge the financial assistance of the Micronutrient Initiative and the assistance of UNICEF and UNICEF field offices in procuring representative salt samples.

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