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# Effects of Storage and Cooking on the Iodine Content in Iodized Salt and Study on Monitoring Iodine Content in Iodized Salt

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In order to ensure that the intake of iodine from iodized salt is adequate, the effects of cooking, storage and iodination on iodine content in iodized salt have been studied. For monitoring the analytical performance, a quality control examination was also undertaken. The loss of iodine was greater when salt was stored in plastic bag than in glass bottle. The loss was greater in fortified salt stored at 37℃ and under 76% humidity than in that at 20 - 25℃ and under lower humidity. The retention of iodine varied with the kind of foods and also was influenced by the water content of cooked food. In general, the retention of iodine during cooking varied considerably (from 36.6% to 86.1%). The iodine concentration in salts varied greater from 3.0 to 100.3 mg/kg in salt for markets, and from 0 to 90.0 mg/kg in salts for households. 48.3% of samples from markets were found to be in compliance with national standards (30 ~ 50 mg/kg), and 72.0% of samples from households were in compliance with national standard (20 ~ 50 mg/kg). Analytical data collected from 8 of the cooperative laboratories for an analytical reference material showed a 95% confidence interval of the population mean for both precision and accuracy, falling within X ± 2SD and passing quality control examination.

## INTRODUCTION

Endemic goiter is an exceedingly common disorder of iodine deficiency disease (IDD). Endemic goiter may be accompanied by endemic cretinism. Various combinations of spastic diplegia or quadriplegia affect primarily the proximal muscle groups and deaf-mutism or dysarthria. Iodine deficiency also affects neonatal althyroid function and hence threatens early brain development. In China, 727 million people live in iodine deficiency regions.

Until now, 7.99 million people showed symptoms of goiter while 187 thousand people were afflicted with cretinism. Mild forms of IDD are found in 14 provinces, moderate and severe forms of IDD are found in 8 and 5 provinces respectively (Chen and Yan, 1996). Therefore, it can be concluded that IDD is an important public health problem in China. Iodized salt is a worldwide recognized measure for the control of iodine deficiency. The Chinese government is committed to eradicating IDD by the end of the year 2000. As the most effective and widely used intervention measure, a specific policy on salt iodination and a universal salt iodination program is being implemented. The Chinese government has recommended that the concentration of iodine in salt should be adjust to 20 ~ 50 mg/kg, WHO/UNICEF/ICCIDD has recommended that the level of iodine in household salt must be adjusted to 20 ~ 50 mg/kg (Sullivan *et al.*, 1995). In order to ensure an adequate intake of iodine from iodized salt, the iodine content of iodized salt needs to be monitored during the whole process of manufacturing, distribution, marketing and consumption.

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The techniques involved in the preparation of iodized salt and the problems of iodine loss from iodized salt have been reported previously (Li *et al.*, 1987). However, the loss of iodine in foods cooked with iodized salt has not been fully studied in China. On the other hand, China is a country with vast territory and diverse climates. The changes in the concentration of iodine in iodized salt stored under different conditions, such as high temperature with high humidity in the south and low temperature with low humidity in the north, also need to be studied. To ensure the analytical accuracy and precision in assessing the iodine concentration in iodized salt, proper studies on quality assurance were done. The findings of these studies and those on the monitoring are summarized in this paper.

## MATERIALS AND METHODS

### *Loss of Iodine During the Storage of Iodized Salt*

Salt was iodized with potassium iodide (KI), potassium iodate ($KIO_3$) or a mixture of KI and $KIO_3$ in our laboratory. The iodine level in KI- or $KIO_3$- fortified salt was about 50 mg/kg and in the mixed of KI/$KIO_3$-fortified salt was 40 mg/kg. These concentrations were chosen in accordance with the value of 20 ~ 50 mg/kg salt recommended by the legislation of Chinese government. The iodized salts were stored in ten plastic bags or sealed glass bottles and kept at room temperature (20 ~ 25℃) or high temperature (37℃). The relative humidity levels were 30% ~ 45% or 76% which corresponded to the relative humidity in northern and southern China, respectively. The iodized salts were sampled before and after storing for 0, 4, 8 and 12 months. The analytical method used was based on Ce-As-I catalytic reaction for the determination of iodine in salt (Li *et al.*, 1987). The concentration of iodine in iodized salts was determined in duplicate samples.

### *Monitoring of Iodine Content in Iodized Salt Found in Markets and in Households*

In order to ensure an adequate intake of iodine for residents, it is necessary to monitor the iodine content in commercial salt sold in the markets and kept in households. A nation-wide survey of the iodine concentration in table salt available to the population in China was conducted. Ninty-one salt samples were collected from 35 manufacturers in 11 selected provinces and 531 samples were collected from households in 165 districts of 25 provinces where the temperature ranged from − 25 to 30℃ and the relative humidity ranged from 15% to 85%. The analytical method for the determination of iodine in salt was the same as the method mentioned, i.e. Ce-As-I catalytic reaction method. All the analyses were performed by the central laboratory of the Department of Food Chemistry in the Institute of Nutrition and Food Hygiene (INFH).

### *Quality Assurance Program for Monitoring Nation-Wide Iodized Salt*

Analytical reference material (ARM) was prepared and a quality assurance program was developed to assess the accuracy of the analytical methods used by local laboratories. A mixed commercial iodized salt was packaged into 500 g samples, which were distributed to each participating laboratory. A total of 9 laboratories from 9 provinces participated in the practice using 2 inherently different methods. In the method used by the 9 local labs, free iodine was titrated with $Na_2S_2O_3$. The Ce-As-I catalytic reaction was used only by the INFH laboratory. The iodine content of the ARM measured by the INFH laboratory was used as the certified value. The analytical data of each participating laboratory was collected and assessed by the INFH. Each set of results submitted from the participating laboratories was first checked for outlier values by the Grubbs and Cochran test (Zhai, 1988), and then the data was evaluated by the quality control chart test (Neve *et al.*, 1992; Zhai, 1988). The mean and the standard deviation were then calculated.

*Effect of Various Cooking Methods on Iodine Loss From Iodized Salt*

In Chinese cooking, salt is usually added to foods during the cooking process. Cooking methods used in this study are typical of those used in domestic Chinese kitchens. Vegetables including leafy, tuberous, green beans, and other food including egg and pork were selected as the representative food in Chinese diets. The cooking methods used in the study included stir frying, deep frying, stewing, steaming and boiling as shown in Table 1.

TABLE 1

A Brief Description on the Cooking Methods and Foods

| Cooking Methods | Description | Food |
|---|---|---|
| Stir frying | Shredded, stir fried for 2 ~ 3 min after oil heated and then fried for another 1 min, after adding salt | Eggplant, cabbage, potato, green beans, egg, pork |
| Deep frying | Ground, mixed with starch, water and salt, made into a ball, deep fried for 10 min in oil | Pork meat ball |
| Stewing | Diced, stir fried for 1 ~ 2 min with oil then boiled in water with salt for 10 min | Eggplant, potato, green been and pork |
| Steaming | Ground meat or stirred egg with water and salt, made into meat ball or mixed egg fluid, steamed for 4 min for egg and 30 min for meat ball. Kelp steamed for 10 min with no salt. | Kelp and egg rich in iodine (fed high iodine content of feed), an pork meat ball |
| Boiling | Sliced kelp, boiled for 2 min in water no salt added, whole egg boiled for 10 min. | Kelp and egg enriched by iodine |

All of the cooked foods were sampled and analyzed by the catalytic method to determine the concentration of iodine. The samples were digested by the alkaline method (Li, 1987), modified by our laboratory. The uncooked samples added with the same content of iodized salt were analyzed by the same method as control.

## RESULTS AND DISCUSSION

*Loss of Iodine During the Storage of Iodized Salt*

The iodine content in each of the KI-, $KIO_3$- and $KI/KIO_3$-fortified salts was 50.4 ± 2.9, 51.8 ± 3.3, 38.4 ± 2.2 mg/kg respectively. The three types of iodized salts were then stored under different conditon for 12 months, from May 1996 to April 1997. The effects of storage on the iodine content of salt stored at room temperature (20 ~ 25℃) with a relative humidity of 30% ~ 45% or 76% and kept in sealed plastic bags or glass bottles are shown in Table 2. The effect of storage on the iodine content of salt stored at 37℃ with 76% humidity for 12 month is shown in Table 3. The results showed that salt kept in glass bottles retained a higher percentage of iodine than the salts stored in plastic bag. The loss of iodine was greater when iodized salts were kept in 30% ~ 45% humidity than when the humidity was 76% and the temperature maintained between 20 ~ 25℃. The results also showed that loss of iodine from $KIO_3$- and $KI/KIO_3$-fortified salts was greater than for KI-fortified salt stored in plastic bags at 20 ~ 25℃ with a relative humidity of 30% ~ 45%, which was different from other reported results (Chen *et al.*, 1991). This indicates that $KIO_3$-fortified salts are less volatile than KI-fortified salts.

TABLE 2

The Effects of Storage on Iodine Content of Iodized Salt Under Room Temperature (20 ~ 25℃) for 12 Months

| Fortified Salt | Before Storage (mg/kg) | Loss Rate of Iodine After Storage (%) | | | |
|---|---|---|---|---|---|
| | | 30% ~ 45% Humidity | | 76% Humidity | |
| | | Glass bottle | Plastic bag | Glass bottle | Plastic bag |
| KI | 50.4 ± 2.9 | 5.1 | 1.0 | 0.8 | $10.3^{a,b}$ |
| $KIO_3$ | 51.8 ± 3.3 | 26.8 | $55.8^{a,c}$ | $4.4^{b}$ | $10.2^{b}$ |
| $KI/KIO_3$ | 38.4 ± 2.2 | 19.5 | $79.7^{a,c}$ | $0^{b}$ | $4.2^{b}$ |

$^{a}P < 0.01$, compared with iodine loss in glass bottle, $^{b}P < 0.01$, compared with iodine loss stored at 30%—45% humidity, $^{c}P < 0.01$, compared with KI fortified salt.

TABLE 3

The Effects of Storage on Iodine Content of Iodized Salt Under 37℃ and 76% Humidity for 12 Months

| Fortified Salt | Before Storage (mg/kg) | After Storage | |
|---|---|---|---|
| | | In glass bottle | In plastic bag |
| | | Loss rate(%) | Loss rate(%) |
| KI | 50.4 ± 2.9 | 18.7 | $28.0^{a}$ |
| $KIO_3$ | 51.8 ± 3.3 | 26.8 | $38.0^{a}$ |
| $KI/KIO_3$ | 38.4 ± 2.2 | 19.5 | 27.6 |

$^{a}P < 0.01$, loss rate compared with samples stored in glass bottle.

### *Monitoring of Iodine Content in Iodized Salt on Markets and in Households*

Compliance of mandatory salt iodination was evaluated by analyzing the iodine content of iodized salt samples collected from food stores and households. The iodine content of the examined samples varied considerably, ranging from 3.0 to 100.3 mg/kg salt for market samples and from 0.0 to 90.0 mg/kg for households samples. The mean value of iodine in each province ranged from 15.2 to 70.2 mg/kg and from 20.8 to 48.2 mg/kg, respectively, for market samples and households samples. The province with the lowest median value of iodine content was Qinghai (14.2 mg/kg of market sample, 18.2 mg/kg of household sample), while the province with the highest median value was Ningxia (63.9 mg/kg for market sample).

48.3% of the samples obtained from markets were in compliance with the iodine level of 30 ~ 50 mg/kg. According to the policy for eradicating IDD by the year 2000, 50 mg of iodine should be added to one kg salt. Not less than 40 mg/kg should be maintained in salt from the manufacturer, and not less than 30 mg/kg salt in the market. In comparison with this regulation, 20.9% of the salt samples collected from the market did not meet the criteria. The lowest iodine concentration of salt was 15.2 ± 11.0mg/kg, which was collected from a market in Qinghai province. 9 of the 10 samples contained less then 30 mg/kg iodine. On the other hand, 30.8% of samples has exceeded the iodine standards. Higher concentrations were found in salts from markets in 9 provinces, especially in Ningxia Zutomatic Region, in which 7 of 8 samples contained a higher iodine concentration (70.2 ± 21.0mg/kg) than the 50 mg/kg standard. 72.0% of 531 samples taken from households were in compliance with the iodine national standard (20 ~ 50 mg/kg). 14.1% of the samples contained < 20 mg/kg, and 13.9% of the samples coontained > 50mg/kg. In all of the selected provinces, salt samples obtained from both markets and households contained < 20mg/kg iodine, and there were more unqualified samples from Shandong and Qinghai than from other provinces.

The results in Table 4 show that the iodine concentration of refined salt has a higher compliance rate than that of crude salt (50.8%) 9.4% and 49.2% of the samples were less than 20 mg/kg for refined and coarse salt respectively. But these were no crude samples contained iodine level less than that of 50 mg/kg.

TABLE 4

Iodine Concentration of Refined/Crude Iodized Salts Collected From Households

| Iodized salt | No. of Samples | Compliance rate(%)* | < 20mg/kg | | > 50mg/kg | |
|---|---|---|---|---|---|---|
| | | | Samples | % | Samples | % |
| Refined | 468 | 74.8 | 44 | 9.4 | 74 | 15.8 |
| Coarse | 63 | 50.8 | 31 | 49.2 | 0 | 0 |
| Total | 531 | 72.0 | 75 | 14.1 | 74 | 13.9 |

* Standard: 20 ~ 50 mg/kg.

In our study, the iodine level of salt samples was higher than previously reported (Lu *et al.*, 1991; Lu, 1994) found that more than 50% household samples from 22 selected area had iodine levels under 50 mg/kg.

*Quality Assurance Program for Nation-Wide Iodized Salt*

The analytical data from the 9 participating laboratories were first examined for outlier values. Since all of the data were reasonable and acceptable, they should be further analyzed for their repeatability and reproducibility. The mean concentration and variance were calculated for each laboratory. Table 5 shows that the relative standard deviation (RSD) of each mean value was less than 5%. Table 6 shows the precision of the reported indine concentration for ARM in six displicate samples determined on different days. The repeatability of the values was satisfactory ($r = 4.039$). From the data in Table 6, a precision quality control chart was drawn. The average of the mean values of iodine from eight laboratories was 45.59mg/kg which was used as certified values. 62.5% of the values fell within X ± SD (UAL & LAI) and 95% of the values fell in X ± 2SD (UWL & LWL) (Fig. 1). In the recovery test, the ratio of the iodine content in the sample and the iodine added to the sample was 2:1, 1:1 and 1:2 separately. Each individual value produced by a certain laboratory was the mean value calculated from 2 – 6 duplicate determinations. The range of recovery was 94.5% ~ 100.3% (Table 7), and the average of the mean values from eight laboratories was 99.4% ± 2.2% of the certified value. From the data in Table 7, an accuracy quality control chart was drawn. 72.7% of the value fell within P ± SD and 95% of the value fell within P ± 2SD (Fig. 2). All the eight laboratories have passed the quality control test for both precision and recovery examination (Fig. 2). This suggests that the two methods used for determining the amount of iodine in salt and the performance of analysis were satisfactory.

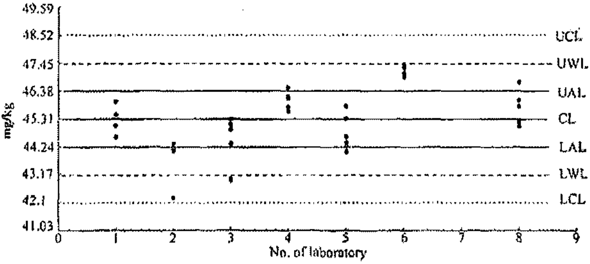


FIG. 1 Precision quality control chart.

TABLE 5

Duplicate Analytical Results for the Iodine Content of ARM (mg/kg) and RSD (%)

| Laboratory | 1 | 2 | 3 | 4 | 5 | 6 | X | RSD(%) |
|---|---|---|---|---|---|---|---|---|
| No. 1 | 45.06 | 45.83 | 46.16 | 45.84 | 45.73 | 45.71 | 45.72 | 0.79 |
| No. 2 | 44.13 | 44.22 | 44.30 | 44.05 | 44.05 | 44.22 | 44.16 | 0.23 |
| No. 3 | 42.60 | 46.65 | 42.60 | 44.30 | 43.45 | 43.88 | 43.91 | 3.42 |
| No. 4 | 46.37 | 46.41 | 46.72 | 46.55 | 46.33 | 46.55 | 46.49 | 0.31 |
| No. 5 | 45.16 | 45.44 | 44.30 | 45.16 | 45.58 | 45.70 | 45.22 | 1.11 |
| No. 6 | 47.73 | 47.20 | 47.46 | 47.46 | 47.20 | 47.46 | 47.42 | 0.42 |
| No. 7 | 50.16 | 48.40 | 47.25 | 46.70 | 46.80 | 46.00 | 47.55 | 3.16 |
| No. 8 | 44.79 | 43.60 | 44.12 | 44.02 | 45.14 | 43.95 | 44.27 | 1.30 |
| X ± SD | | | | | | | 45.59 ± 1.45 | |

*Effect of Various Cooking Methods on Iodine Loss From Iodized Salt*

The effect of cooking on iodine content was studied in order to assess the dietary intake of iodine. The amount of iodine retained in cooked food varies with cooking methods, including cooking time, cooking temperature, the amount of water added, and the nature of foods. The retention of iodine after stewing or steaming was usually higher than after frying, even when the cooking time was as long as 10 min for steaming/stewing and only 1 ~ 2 min for frying. The retention of iodine after stewing, steaming and frying was found to be respectively 53.9% and 44.5% in potato, 47.0 and 36.6% in green beans, 43.2% and

39.7% in pork, 97.9 and 81.3% in egg. Meat balls were made of ground meat mixed with iodized salt, starch and water. After meat balls were cooked by steaming for 30 min or deep

TABLE 6

Precision of Reported Iodine Concentration for ARM (mg/kg) and RSD(%)

| Laboratory | 1 | 2 | 3 | 4 | 5 | 6 | X | RSD(%) |
|---|---|---|---|---|---|---|---|---|
| No. 1 | 45.44 | 45.99 | 45.04 | 45.04 | 44.61 | 44.61 | 45.12 | 1.17 |
| No. 2 | 44.34 | 44.26 | 44.18 | 44.22 | 44.05 | 44.13 | 44.20 | 0.23 |
| No. 3 | 42.92 | 43.00 | 45.31 | 44.35 | 45.10 | 44.90 | 44.26 | 2.39 |
| No. 4 | 46.50 | 45.61 | 46.10 | 46.15 | 45.77 | 45.75 | 45.98 | 0.72 |
| No. 5 | 44.02 | 44.24 | 44.38 | 45.30 | 45.80 | 44.61 | 44.73 | 1.50 |
| No. 6 | 47.05 | 46.92 | 47.33 | 47.28 | 47.38 | 47.30 | 47.21 | 0.39 |
| No. 8 | 45.18 | 45.77 | 45.01 | 45.14 | 46.01 | 46.70 | 45.64 | 1.43 |
| X ± SD | | | | | | | 45.13 ± 1.07 | |

TABLE 7

Reported Results of Recovery Test and RSD (%)

| | 2:1 | | 1:1 | | 1:2 | | P(%) |
|---|---|---|---|---|---|---|---|
| | P1(%) | RSD(%) | P2(%) | RSD(%) | P3(%) | RSD(%) | (P1, P2, P3) |
| No. 1 | 100.8 | 1.74 | 99.8 | 3.46 | 99.9 | 1.26 | 99.8 |
| No. 2 | 98.0 | 0.46 | 99.0 | 0.68 | 99.0 | 1.36 | 98.6 |
| No. 3 | 100.2 | 2.57 | 100.2 | 2.44 | 100.6 | 1.69 | 100.3 |
| No. 4 | 95.9 | 0.68 | 94.2 | 1.11 | 93.4 | 2.71 | 94.5 |
| No. 5 | 100.8 | 1.74 | 99.6 | 2.43 | 101.7 | 3.15 | 100.7 |
| No. 6 | 101.1 | 0.32 | 102.0 | 2.26 | 100.9 | 2.08 | 101.3 |
| No. 7 | 98.3 | 3.38 | 100.1 | 3.11 | 97.3 | 3.56 | 98.6 |
| No. 8 | 100.4 | 1.57 | 100.6 | 0.63 | 102.0 | 0.87 | 101.0 |

*Note*. (1) the rate of iodine content of sample and iodine added in sample were 2:1, 1:1 and 1:2. (2) P1, P2 and P3 were the mean value calculated from 6 duplicate determinations.

TABLE 8

The Retention of Organic Iodine During Cooking

| | Kelp* | | | |
|---|---|---|---|---|
| | Uncooked (μg/g) | Cooked (μg/g) | Retention (%) | No. of analysis |
| Boiling | 11.390 | 11.100 | 97.5 | 3 |
| Steaming | 11.390 | 9.754 | 85.6 | 3 |

*The processed kelp purchased from market cut into pieces.

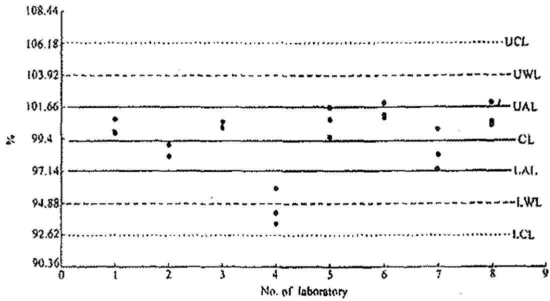


FIG. 2 Accuracy quality control chart.

frying for 10 min, the retention of iodine was 38.1% and 41.1%, respectively. For the meat balls, there was no significant difference between the two cooking methods. It could be interpreted that the salt was absorbed into the meat balls and that the coagulated outer covering of the meat ball may prevent the loss of iodine, even though the cooking temperature was much higher during deep frying.

The retention of iodine varied with food varieties. The retention rates after frying were 82.2, 86.1, 56.9, 44.5 and 36.6% for eggplant, green pepper, Chinese cabbage, potato and green beans respectively. The results showed that the retention rates were inversely correlated with the cooked food. Previous studies (Chen *et al.*, 1991) reported that the retention of iodine was 42.3% when iodized salt was dry fried with no food. Obviously, these result are not comparable to the results from his study.

It was reported that organic iodine from kelp and eggs from hens fed with feed enriched with organic iodine may be more stable than inorganic iodine. Table 8 shows that the retention of iodine in kelp after boiling for 2 min was 97.5%, and after steaming for 10 min was 85.6%. These results confirmed that the retention of organic iodine is higher when compared with that of inorganic iodine. The high-iodine eggs from hens fed with iodine enriched feed was cooked by stir frying and steaming. The retention of iodine was 81.3%, and 97.9%.

In preparing cold dishes, iodized salt was added to the raw mung bean sprouts 10 min before it was sent to the laboratory for iodine analysis. The iodine content was 0.253 mg/kg in sprouts and 0.95 μg/ml in the left-over liquid. This suggests that whole dish should be consumed, if you wish not to waste any of the added iodine.

In general, the retention of iodine during cooking varied considerably from 36.6% to 86.1%. The estimation of actual intake of iodine from iodized salt should be considered in line with those results. For the effective control of IDD, it is suggested to increase the iodine concentration from 50 to 100 mg/kg in iodized salt, even though the loss of iodine during the storage of iodized salt was considered minimal.

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## REFERENCES

Chen Zu-Pei and Yan Yu-Qin (1996). Prevention and cure of iodine deficiency disorders. *Chinese Public Hygiene* 12(9), 385-387. (In Chinese)

Chen Hui-Xing, Han Shu-Fang, Yang Wei (1991). A study of the effect of various temperature and storage time on the iodine escape from table salt iodized with KI or $KIO_3$. *Chinese J. Endem. Dis. Prev. Contr.* 6, 344-347. (In Chinese)

Chen Jian-An, Chen Hui-Qi, and Chen Ji-Xiang (1991). The loss of iodine of iodized salt during cooking-first study. *Chinese J. Endem. Dis.* 10, 69-70. (in Chinese)

Li Jian-Qun, Sun Xi, and Yu Zhi-Heng (1987). *A Comprehensive Practical Technique of Control Endemic Goitre and Endemic Cretinism*, 72-74, 99-105, 193-219. *Chinese Environmental and Chemical Sciences* Press, Beijing. (in Chinese)

Li Qing-Wu (1994). Some problems to be concerned of anti-iodine disorder disease at present. *Chinese J. Endem. Dis.* 13, 193. (in Chinese)

Li Jian-Guo, Liu Shou-Jun, and Li Jian-Qun (1991). Monitoring results from IDD monitoring station in 1990. *Chinese J. Endem. Dis.* 10, 178. (in Chinese)

Neve, J., Thomassen, Y., and Van Damme, M. (1992). Cooperative study on measurement of Concentrations of selenium in freezed-dried blood. *Pure & Appl. Chem.* 64, 765-780.

Sullivan, K., Horston, R., Gorstein, J., and Cervinskas, J. (1995). Monitoring Universal Salt Iodization Programmes, *PUMM/MI/ICCIDD*, 9-10.

Zhai Yong-Xing (1998). *Modern Manual of Food Analysis*, p. 135-175. Beijing University Press, Beijing. (in Chinese)

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