Iodine content in bread and salt in Denmark after iodization and the influence on iodine intake

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Abstract

Objective To measure the iodine content in bread and household salt in Denmark after mandatory iodine fortification was introduced and to estimate the increase in iodine intake due to the fortification.

Design The iodine content in rye breads, wheat breads and salt samples was assessed. The increase in iodine intake from fortification of bread and the increase in total iodine intake after fortification were estimated.

Subjects Iodine intake before and after fortification was estimated based on dietary intake data from 4,124 randomly selected Danish subjects.

Main results Approximately 98% of the rye breads and 90% of the wheat breads were iodized. The median iodine intake from bread increased by 25 (13–43) μg/day and the total median iodine intake increased by 63 (36–104) μg/day.

Conclusions The fortification of bread and salt has resulted in a desirable increase in iodine intake, and the current fortification level of salt (13 ppm) seems reasonable.

Keywords: Iodine fortification, salt, Denmark, iodine intake

Introduction

Iodine deficiency remains a problem throughout the world (Vitti et al. 2001). Studies in Denmark in the 1990s demonstrated low iodine intakes of 50–110 μg/day (Pedersen et al. 1997), and a correspondingly high incidence of thyroid enlargement (Laurberg et al. 1993). The recommended iodine intake is 150 μg/day and the average requirement is 100 μg/day (Nordisk Ministerråd 2004).

Consequently, in 1998 the Danish Veterinary and Food Administration decided to initiate iodine fortification of all salt (sodium chloride) in Denmark. Until then it was illegal to sell iodized salt in Denmark. The fortification programme was voluntary, however, with the condition that iodized salt (fortified to a level of 8 ppm) would cover at least 80% of the market within 2 years. After 18 months iodized salt was still not
used by the food industry and only about one-half of household salt was iodized, making the voluntary approach ineffective.

Subsequently, the programme was revised, and salt iodization became mandatory in 2000 for household salt and for salt used in commercial bread production. The fortification level was increased to 13 ppm, estimated to increase the median iodine intake in Denmark by 50–60 μg/day.

It was decided to monitor and evaluate the effect of the iodine fortification programme according to the recommended criteria from the WHO, UNICEF and ICCIDD (2001). The monitoring included three main components: determination of iodine contents in salt and bread; measurements of iodine intake and thyroid pathology; and registration of all new cases of hyperthyroidism and hypothyroidism.

The objective of the present study was to measure iodine contents in bread and household salt covering the Danish market. Furthermore, the increase in iodine intake after fortification is estimated from a nationwide dietary intake survey.

**Methods**

**Bread**

A total of 312 bread samples were taken for analysis of the iodine content. Samples were representative of the bread used in Danish households, the sampling plan being based on a recent overview of the distribution of consumption (Hansen et al. 2000). Samples consisted of industrially manufactured breads as well as breads baked at retail shops, and included both conventional and organic bread. Organic bread is bread made with organically cultivated ingredients.

The investigation of iodine was part of a larger project aimed at determining contents of several nutrients in bread. Samples were categorized according to the fat content and so forth. Heterogeneity characterization and description of the bread articles on the market according to theory of Gy (1998) are important parameters in conducting a proper sampling.

Rye bread was divided into six categories, according to the extraction rate of rye grain, and the contents of added whole kernels and seeds. Wheat bread was divided into 14 categories, according to the extraction rate of wheat grain and the contents of added whole kernels, seeds, and other corn species, style (Italian, baguette, toast, sandwich) and size.

From each category, samples of all popular types/brands were taken; and for some categories only a few types/brands existed, thus covering the consumption of the Danish population optimally.

Industrially manufactured rye bread was sampled during autumn 2001, industrially manufactured wheat bread during winter 2002, while bread baked at retail shops was sampled during summer 2002. All bread samples were taken at retail dealers so as to be similar to household shopping. Depending upon the market share, individual commodities within each category were sampled one to three times from different batches and/or different shops.

About 1,500 g were taken of all samples when freshly baked, and prepared for storing within the next day. Samples were cut into halves or quarters, homogenized and stored in air-tight plastic bags at −18°C until analysis.
**Table salt**

Sampling of table salt was based upon information from industry and visits to shops representative for Danish household shopping. Samples of 18 different table salts, including all common commodities, domestic and foreign, were taken from shops in November 2002. Samples were stored at room temperature until analysis.

**Determination and quality assurance of iodine in bread and salt**

Bread samples were mixed with deionized water and homogenized in a blender to form slurry. A subsample corresponding to 1 g sample was transferred to a 50 ml polyethylene test tube fitted with a screw top. Following addition of 10 ml pure water (Millipore Super Q; Millipore, Milford, MA, USA), the mixture was stirred using a whirl mixer. The iodine content of the sample was extracted in alkaline solution at 90°C for 3 h (Rädlinger & Heumann 1998) using 2 ml of 25% aqueous solution of tetramethylammonium hydroxide, which was of ‘Electronic Grade’ (Alfa Aesar, Karlsruhe, Germany). The mixture containing the partially dissolved sample was taken to 50 ml by water and centrifuged at 3,500 rpm for 10 min. The supernatant, which was slightly cloudy, was cleared by passage through a SepPak C_{18} (Waters Associates, Milford, MA, USA) disposable cartridge. The salt (sodium chloride) samples were prepared for measurement of their iodine content by preparation of a 1 g/l solution in 2% tetramethylammonium hydroxide in water, as described for analyses of iodine in milk (Larsen et al. 1999).

The iodine content of the sample extracts or salt solutions was determined by inductively coupled plasma mass spectrometry using an Agilent 7500i instrument (Yokogawa Analytical Systems Inc., Tokyo, Japan) for detection of iodine at $m/z$ 127. Quantification of the bread samples was carried out using external standard curves recorded from a certified standard solution containing iodine as iodide and with tellurium as an internal standard. The method of standard additions was used in order to accurately quantify the iodine content of the salt solutions.

The accuracy of the analyses was controlled by analysis of two certified reference materials (CRMs) run in parallel with 25 unknown samples. The concentration of iodine (mean and one standard deviation) obtained for wheat gluten (CRM 8418; NIST, Gaithersburg, MD, USA) was $62 \pm 4 \, \mu g/kg$ ($n = 29$), and that for skim milk powder (CRM 063R; BCR, Brussels, Belgium) was $813 \pm 5 \, \mu g/kg$ ($n = 11$). These values were in close agreement with the certified values for iodine in the two CRMs of $60 \pm 13 \, \mu g/kg$ and $810 \pm 50 \, \mu g/kg$, respectively. Furthermore, the recovery of iodine spiked at 500 ng/ml to the bread sample extracts was (mean and one standard deviation) $101 \pm 5\%$ ($n = 41$). The repeatability, which was determined from double determinations ($n = 59$) of the bread and salt samples, was estimated at 4.7% and 4.3%, respectively. In each batch of analyses, blanks were run through the entire procedure. Based on three times the standard deviation of the blanks, the limits of detection for iodine were estimated at 9 μg/kg for bread and at 60 μg/kg for salt. The higher limits of detection for the salt samples were caused by the large dilution factor used for the solid sample relative to the final solutions for the iodine measurements. The laboratory was accredited to perform iodine analysis in food according to the EN 17025 norm.
Estimation of iodine intake from bread and of total iodine intake

Estimation of iodine intake from fortified bread in the Danish population was based on the measured content of iodine in bread and the intake of bread estimated in the Danish nationwide dietary survey 2000–2002 (Lyhne et al. 2005). In this survey a random sample of 4,124 subjects, aged 4–75 years, filled out diet records for 7 consecutive days. Likewise, the total dietary intake of iodine after fortification was estimated for the same subjects. The content of iodine in food was given by the Danish Food Composition table (www.foodcomp.dk). The increased iodine intake due to fortification was estimated from the total iodine intake after fortification of bread and household salt and subtracting the iodine intake calculated with no fortification of salt and bread; increase in iodine intake due to fortification = iodine intake after fortification calculated with bread\textsubscript{fortified} and salt\textsubscript{(13 ppm)} − iodine intake before fortification calculated with bread\textsubscript{(not fortified)} and salt\textsubscript{(0 ppm)}. The iodine content in bread before fortification was taken from Saxholt (1996). The iodine content in household salt was set at the mandatory level (13 μg/g) after fortification and at 0 μg/g before fortification.

Statistics

The iodine contents in bread and salt are presented as means and ranges. Comparison of the statistical difference of iodine content in various kinds of breads was performed with an unpaired \( t \)-test. The increase in intake of iodine is given as the median with 10th and 90th percentiles. Statistical analyses were performed with the Statistical Package for Social Sciences (SPSS version 13.0; SPSS Inc., Chicago, IL, USA).

Results

The iodine content after mandatory iodization in six different kinds of rye bread is shown in Table I. The mean content of iodine was 22 (1–38) μg/100 g bread. Three of the 125 samples (2%) were not iodized, defined as bread with iodine content of 4.5 μg/100 g, corresponding to the maximum iodine content in rye bread before iodization (Saxholt 1996). The non-iodized breads are commonly eaten breads (dark, wholemeal and dark, whole kernels and high-fat seeds).

<table>
<thead>
<tr>
<th>Rye bread</th>
<th>Number of samples</th>
<th>Iodine content [mean (minimum–maximum)] (μg/100 g)</th>
<th>Number of samples not iodized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rye bread, dark, wholemeal</td>
<td>30</td>
<td>22 (1.5–37)</td>
<td>1</td>
</tr>
<tr>
<td>Rye bread, dark with whole kernels</td>
<td>31</td>
<td>22 (1.4–37)</td>
<td>2</td>
</tr>
<tr>
<td>and high-fat seeds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rye bread, dark</td>
<td>20</td>
<td>22 (15–35)</td>
<td>0</td>
</tr>
<tr>
<td>Rye bread, soft with wheat, high-fat</td>
<td>25</td>
<td>22 (14–29)</td>
<td>0</td>
</tr>
<tr>
<td>seeds and whole kernels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rye bread, light</td>
<td>10</td>
<td>22 (17–26)</td>
<td>0</td>
</tr>
<tr>
<td>Rye bread, soft, no high-fat seeds</td>
<td>9</td>
<td>22 (13–38)</td>
<td>0</td>
</tr>
<tr>
<td>All</td>
<td>125</td>
<td>22 (1.4–38)</td>
<td>3</td>
</tr>
</tbody>
</table>
No statistical significant difference in iodine content was found between industrially produced rye bread (21 ± 5 μg/100 g) and rye bread baked at retail shops (22 ± 7 μg/100 g) ($P = 0.36$).

The iodine content in various wheat breads is presented in Table II. The mean iodine content was 21 (0–46) μg/100 g. Twenty of the 187 samples (10%) were not iodized. Non-iodized bread was defined as bread with an iodine content < 6 μg/100 g, which corresponds to bread with maximum iodine content before fortification (Saxholt 1996).

There was no statistically significant difference in iodine content between industrially produced wheat bread (21 ± 7 μg/100 g bread) and bread baked at retail shops (20 ± 12 μg/100 g bread) ($P = 0.48$).

The estimated increase in iodine intake from fortified rye and wheat bread in various age groups is presented in Table III. The total increase in iodine intake from bread after fortification was 25 (13–43) μg/day.

Table IV presents the iodine content in household salt, including sea salt. Three of the brands were not iodized, five had iodine contents above the maximum permitted level and five were fortified within the permitted range. The maximum permitted level is 150% of 13 ppm, equal to 19.5 ppm (Fødevaredirektoratet 2000). The iodine content in sea salt is very low, below the detection limit for four out of the five samples.

The increase in total daily dietary iodine intake after fortification is shown in Figure 1 for all 4,124 subjects who participated in the Danish national dietary survey 2000–2002. The median increase in iodine intake due to fortification of bread and household salt was 63 (36–104) μg/day. Before fortification 1,590 subjects (39%) had a total dietary iodine intake below 100 μg/day, whereas after iodine fortification only 239 subjects (6%) had an iodine intake below 100 μg/day.

Table II. Iodine content in various wheat breads.

<table>
<thead>
<tr>
<th>Bread</th>
<th>Number of samples</th>
<th>Iodine content, [mean (minimum–maximum)] (μg/100 g)</th>
<th>Number of samples not iodized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat bread, fine</td>
<td>30</td>
<td>21 (1.3–46)</td>
<td>4</td>
</tr>
<tr>
<td>Wheat bread, wheat with rye</td>
<td>24</td>
<td>19 (0.8–39)</td>
<td>5</td>
</tr>
<tr>
<td>Wheat bread, high-fat seeds</td>
<td>22</td>
<td>19 (1.8–33)</td>
<td>3</td>
</tr>
<tr>
<td>Wheat bread, Italian type</td>
<td>27</td>
<td>21 (1.4–44)</td>
<td>6</td>
</tr>
<tr>
<td>White bread, for toasting</td>
<td>11</td>
<td>21 (13–28)</td>
<td>0</td>
</tr>
<tr>
<td>White bread with rye, for toasting</td>
<td>11</td>
<td>18 (9.3–23)</td>
<td>0</td>
</tr>
<tr>
<td>Wheat bread, sandwich type, with high-fat seeds</td>
<td>4</td>
<td>20 (11–31)</td>
<td>0</td>
</tr>
<tr>
<td>Baguette, wheat, fine</td>
<td>18</td>
<td>25 (1.8–41)</td>
<td>1</td>
</tr>
<tr>
<td>Baguette, with rye</td>
<td>5</td>
<td>21 (16–31)</td>
<td>0</td>
</tr>
<tr>
<td>Baguette, with high-fat seeds</td>
<td>6</td>
<td>23 (15–31)</td>
<td>0</td>
</tr>
<tr>
<td>Rolls, white</td>
<td>8</td>
<td>24 (16–35)</td>
<td>0</td>
</tr>
<tr>
<td>Rolls, wheat with rye</td>
<td>6</td>
<td>24 (17–31)</td>
<td>0</td>
</tr>
<tr>
<td>Rolls, with high-fat seeds</td>
<td>10</td>
<td>21 (12–312)</td>
<td>0</td>
</tr>
<tr>
<td>Rolls, Italian type</td>
<td>5</td>
<td>19 (1.4–25)</td>
<td>1</td>
</tr>
<tr>
<td>All</td>
<td>187</td>
<td>21 (0.8–46)</td>
<td>20</td>
</tr>
</tbody>
</table>

*One sample was below the detection limit 0.7 μg/100 g.
In this study the iodine content in bread was measured after mandatory iodine fortification of bread salt was introduced. The mean iodine content of rye bread was 22 (1–38) mg/100 g and that of wheat bread was 21 (0–46) mg/100 g. The variation in iodine content within a bread type was quite large, but the mean content of the various breads was considerably stable, indicating that the same amount and type of salt are used in various types of bread.

### Table III. Increase in iodine intake from breada.

<table>
<thead>
<tr>
<th>Group</th>
<th>Intake of rye bread (g/day)</th>
<th>Increase in iodine intake, rye bread (µg/day)</th>
<th>Intake of wheat bread (g/day)</th>
<th>Increase in iodine intake, wheat bread (µg/day)</th>
<th>Increased iodine intake from bread (µg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n = 257)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls 4–9 years</td>
<td>49 (14–109)</td>
<td>9 (3–21)</td>
<td>74 (34–124)</td>
<td>13 (6–22)</td>
<td>23 (14–39)</td>
</tr>
<tr>
<td>(n = 235)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys 10–17 years</td>
<td>47 (16–103)</td>
<td>9 (3–19)</td>
<td>82 (35–159)</td>
<td>15 (6–29)</td>
<td>24 (14–45)</td>
</tr>
<tr>
<td>(n = 231)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls 10–17 years</td>
<td>37 (9–90)</td>
<td>7 (2–17.0)</td>
<td>75 (35–133)</td>
<td>14 (6–25)</td>
<td>23 (11–37)</td>
</tr>
<tr>
<td>(n = 248)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men 18–75 years</td>
<td>64 (17–135)</td>
<td>12 (3–25)</td>
<td>78 (33–151)</td>
<td>14 (6–28)</td>
<td>27 (15–46)</td>
</tr>
<tr>
<td>(n = 1,468)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women 18–75 years</td>
<td>54 (14–111)</td>
<td>10 (3–21)</td>
<td>72 (30–134)</td>
<td>13 (5–24)</td>
<td>24 (1–41)</td>
</tr>
<tr>
<td>(n = 1,685)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All (n = 4,124)</td>
<td>56 (15–119)</td>
<td>11 (3–22)</td>
<td>75 (32–142)</td>
<td>14 (6–26)</td>
<td>25 (13–43)</td>
</tr>
</tbody>
</table>

*aCalculations based on the national dietary survey 2000/2002 (Lyhne et al. 2005). Results presented as the median (10th –90th percentiles).

## Discussion

In this study the iodine content in bread was measured after mandatory iodine fortification of bread salt was introduced. The mean iodine content of rye bread was 22 (1–38) µg/100 g and that of wheat bread was 21 (0–46) µg/100 g. The variation in iodine content within a bread type was quite large, but the mean content of the various breads was considerably stable, indicating that the same amount and type of salt are used in various types of bread.

### Table IV. Iodine content in household salt.

<table>
<thead>
<tr>
<th>Brand name</th>
<th>Iodine content (µg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jozo, fine salt</td>
<td>11</td>
</tr>
<tr>
<td>Jozo, fine salt</td>
<td>12</td>
</tr>
<tr>
<td>Jozo, coarse salt</td>
<td>10</td>
</tr>
<tr>
<td>Jozo, grinding mill salt</td>
<td>&lt;0.6</td>
</tr>
<tr>
<td>Jozo, extra fine salt</td>
<td>24</td>
</tr>
<tr>
<td>Brøste, coarse salt</td>
<td>24</td>
</tr>
<tr>
<td>Aldi, fine salt</td>
<td>24</td>
</tr>
<tr>
<td>Aldi, coarse salt</td>
<td>31</td>
</tr>
<tr>
<td>Seltin, coarse salt</td>
<td>&lt;0.6</td>
</tr>
<tr>
<td>Seltin, fine salt</td>
<td>15</td>
</tr>
<tr>
<td>Seltin, fine salt</td>
<td>11</td>
</tr>
<tr>
<td>Santa Maria, fine salt</td>
<td>&lt;0.6</td>
</tr>
<tr>
<td>Dansk Krydderi Gourmet</td>
<td>21</td>
</tr>
<tr>
<td>Sea salt</td>
<td>&lt;0.6</td>
</tr>
<tr>
<td>Santa Maria, sea salt</td>
<td>&lt;0.6</td>
</tr>
<tr>
<td>Brøste, sea salt</td>
<td>0.9</td>
</tr>
<tr>
<td>Brøste, sea salt</td>
<td>&lt;0.6</td>
</tr>
<tr>
<td>Brøste Maldon, sea salt</td>
<td>&lt;0.6</td>
</tr>
<tr>
<td>Jozo, sea salt</td>
<td>&lt;0.6</td>
</tr>
</tbody>
</table>
The increase in iodine intake from fortified bread was estimated as 25 \( (13-43) \) mg/day. In the calculations the mean iodine content in the different kinds of breads was used. However, an individual may choose always to eat one specific bread, which obviously could be a non-fortified bread or a bread with high iodine content. This very specific information on the individuals’ bread choice is not available, so the deviation in iodine intake may be larger than the estimations indicate.

When the fortification programme was planned, a daily increase in mean population intake of 50–60 mg iodine was aimed for, approximately one-half of this amount from bread and the other half from household salt. Thus, the increase in iodine intake from bread is as planned. Furthermore, the portion of bread sold in Denmark that is fortified is satisfactory. Since imported bread is not subject to mandatory fortification, a higher degree of iodization cannot be expected.

Many countries have iodine fortification of salt, some countries on a voluntary basis and some on a mandatory basis (Bu¨rgi 1993). Reports from other countries on the actual contents of iodine in salt, compared with the legal requirements, are indeed sparse. In South Africa, salt at the production stage was assessed for iodine (Jooste 2003). Only 31% of the samples met the legal requirement of 40–60 ppm, 12% of the samples had higher iodine content and 58% a lower content (Jooste 2003).

In our study the median total iodine intake has increased by approximately 63 \( \mu g/ \) day due to fortification of bread and household salt. However, the intake of household salt is uncertain. The estimation of total dietary iodine intake is based on the content of salt in standard recipes taking into account that salt is partially lost into the cooking water (Sanchez-Castillo et al. 1987a); however, the individual variation in use of salt in recipes is probably huge (Sanchez-Castillo et al. 1987b). Furthermore, salt added at

![Increase in total iodine intake due to fortification (\( \mu g/ \) day). \( n = 4,124 \). Median increase was 63 \( \mu g/ \) day; 10th and 90th percentiles were 36 \( \mu g/ \) day and 104 \( \mu g/ \) day, respectively.](image)
the table was not included. All salt in the recipes had an added 13 μg iodine/g. Thus, the contribution of iodine from household salt is rather imprecise.

Large variations in the iodine content of iodized household salt between and within salt brands have been found (Jooste 1999). Because very few samples have been assessed in Denmark, the variation in iodine content within salt brands cannot be determined in the present study. A larger study should be performed regarding iodine content in household salt.

In Denmark it was decided to initiate mandatory iodization of household salt and bread salt when it was found insufficient to permit iodization of all salt on a voluntary basis, as described in the Introduction. Iodization of salt in other food items is not allowed (Fødevaredirektoratet 2000). Bread and salt is ingested by nearly everybody, and iodizing limited food sources makes it easier to control the iodine content than if many food items are iodized.

The total iodine intake in Denmark is now, based on estimates from the Danish national dietary survey (Lyhne et al. 2005), at the recommended level for adults and below the upper safe limit according to the Scientific Committee on Food (2002). Almost everybody has an iodine intake above 100 μg/day, which is the average requirement. Subjects with an intake of iodine below the average requirement are at increased risk of deficiency (Nordic Ministerråd 2004). However, the intake in children is close to the upper limit set by the Scientific Committee on Food (2002) for the approximately 10% with the highest intake, and would be above the limit for children with high intake who also take an iodine-containing vitamin-mineral supplement. The World Health Organization’s strategy (Andersson et al. 2003) to add 20–40 μg iodine/g salt will lead to an iodine intake above the safe upper limit for part of the Danish population, especially children.

Measurement of iodine excretion in urine is the recommended measure of iodine status (Hetzel & Dunn 1989). The calculated increase in iodine intake in Denmark is to be confirmed with measures of iodine excretion in urine samples from 3,500 subjects collected in 2004/2005 and analysed in 2006. However, it is also of importance to know the major iodine sources among foods to be able to adjust the iodine fortification if necessary.

In conclusion, fortification of bread and salt has resulted in a desirable increase in iodine intake in the Danish population and the fortification level of salt (13 ppm) seems reasonable. Further control of the iodine content in household salt is needed as very few samples have been analysed. The next step in the monitoring is to verify the higher iodine intake by measurement of iodine excretion in urine and by measurement of the thyroid volume to determine whether the iodine fortification programme has the expected clinical effect. When initiating a fortification programme it is important to monitor the content in the foods that are being fortified, the total intake of the nutrient, as well as the effect of the fortification on the relevant deficiency disorder.

References


