Food Additives & Contaminants: Part A: Chemistry, Analysis, Control, Exposure & Risk Assessment

Stability of added iodine in processed cereal foods

B.M. Thomson

Institute of Environmental Science & Research Ltd., Christchurch, New Zealand

Available online: 07 Oct 2010

To cite this article: B.M. Thomson (2009): Stability of added iodine in processed cereal foods, Food Additives & Contaminants: Part A: Chemistry, Analysis, Control, Exposure & Risk Assessment, 26:1, 25-31

To link to this article: http://dx.doi.org/10.1080/02652030802258842

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.tandfonline.com/page/terms-and-conditions

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.
Stability of added iodine in processed cereal foods

B.M. Thomson*

Institute of Environmental Science & Research Ltd., Christchurch, New Zealand

(Received 6 April 2008; final version received 9 June 2008)

The stability of iodine from iodized salt was measured in white bread, grain bread, sweet biscuits and the breakfast cereals, Weetbix® (a flaked, pressed, wheat product), Ricies® (a puffed rice product) and toasted muesli, as part of the New Zealand Government’s initiatives to address the public health issue of low iodine intake by most New Zealanders. Triplicate runs of each product were manufactured by commercial food manufacturers between September 2006 and May 2007 with iodized and non-iodized salt. Triplicate samples were taken at various steps during processing of each food and analysed for moisture and iodine content. Iodine concentration was determined by inductively coupled plasma–mass spectrometry following an alkaline digestion. Iodine, at the equivalent of 25–65 mg of iodine per kg salt, was 100% retained in each of the selected foods from the time of mixing to the final product. These results imply that all iodine added via salt at the time of manufacture is available for consumption but not necessarily bioavailable. These data can be used for modelling the impact of strategies to increase iodine exposure. Salt as an ingredient is not a good predictor of iodine intake due to the inhomogeneity of iodine in iodized salt.

Keywords: iodine; stability; retention; processed foods; bread; cereals; iodized salt

Introduction

The dietary exposure of iodine in New Zealand has decreased over the past 25 years due to a move away from iodophore disinfectants in the dairy industry and changing consumption patterns (Thomson et al. 2008). Iodine intake is low for most New Zealanders, ranging 40–57% of the recommended daily intake across eight population subgroups in the most recent Total Diet Survey (Thomson et al. 2008). A low dietary intake of iodine is consistent with New Zealand studies showing low and decreasing urinary iodide levels and, hence, iodine status (Thomson et al. 1997; Thomson 2003; Skeaff et al. 2002, 2005). The New Zealand Government is working to address the public health issue of low iodine intake through the development of a food standard relating to the mandatory addition of iodine to selected foods (FSANZ 2006).

Processed foods have been identified as potential food vehicles for iodine fortification with iodized salt replacing non-iodized salt in targeted foods. Comparable risk assessment outcomes for all processed foods compared with cereal-based foods only, in conjunction with the consideration of cost impacts to industry and potential trade restrictions, led to a preference to replace non-iodized salt with iodized salt in cereal-based foods. Since approximately 95% of salt in cereal-based foods is derived from bread, breakfast cereals and biscuits, these foods are possible food vehicles for iodine fortification (FSANZ 2006).

Iodides and iodates of sodium and potassium are permitted salt additives in New Zealand and may be added at a level equivalent to 25–65 mg iodine per kg salt (FSC 2007). Iodine salts may be volatile and lost through processing (FAO 1996, Winger et al. 2008). However, there is only limited data on iodine losses as a result of different food processing situations (Kuhajek and Fiedelman 1973; Winger et al. 2005; FSANZ 2006).

The scope of the current project was to investigate the stability or retention of iodine from iodized salt when added to a selection of processed cereal foods, manufactured under normal manufacturing conditions.

Materials and methods

Selection of foods and source of salt

Commercially available white and grain bread, a sweet oatmeal and dried fruit biscuit, Weetbix® (a flaked, pressed, baked wheat cereal), Ricies® and a toasted muesli were targeted for iodine retention studies.
Iodized salt for the breads and biscuits was sourced from 2 kg bags of “Pam’s” iodized table salt purchased from a Christchurch supermarket. Each bag of salt was thoroughly mixed by manual rotation of the unopened bag before being used. The iodized salt used in the cereal products was “Solar salt” supplied by Dominion Salt and manufactured at Lake Grassmere, Marlborough, New Zealand, specified to contain 42–110 mg kg$^{-1}$ potassium iodate, equivalent to 25–65 mg kg$^{-1}$ iodine in accordance with Standard 2.10.2 of the Food Standards Code.

**Sampling**

For each selected food, a control and a test run were manufactured in the normal way by commercial food manufacturers, using either non-iodized or iodized salt. Test run batch sizes were as follows: bread (100 kg flour), biscuits (20 kg flour, 20 kg oats), Weetbix® (1500 kg wheat), Ricies® (2100 kg rice) and muesli (800 kg oats).

Triplicate samples were taken at various steps during processing as shown schematically for each product in Figure 1. Triplicate runs were prepared for each selected food with pilot study runs undertaken in September (white bread) and October 2006 (Weetbix®, Ricies® and toasted muesli) and subsequent runs undertaken in February 2007. An additional confirmatory run of toasted muesli was prepared in May 2007.

Samples of uncooked bread dough were analysed for moisture content on arrival at the laboratory in Christchurch and frozen before overnight courier dispatch for iodine analyses. Samples of the baked bread were taken after slicing and packaging. Total loaves of bread were homogenised and sub-samples frozen before moisture analysis and dispatch. Biscuits were homogenized in Christchurch before dispatch for both moisture and iodine analyses. All cereal samples were taken before packaging and refrigerated before overnight courier dispatch to the analytical laboratory.

**Analytical methods**

Moisture was determined by oven drying (103 ± 2°C) to a constant weight (Kirk and Sawyer 1991).

---

**Figure 1. Schematics of manufacturing processes for foods targeted for iodine retention studies.**
Salt (10 g) was prepared as a 20% solution with water and an aliquot (1 ml) of this solution digested in tetramethylammonium hydroxide (TMAH) and made to a final volume of 20 ml prior to analysis for iodine content.

Other food samples for iodine analysis were digested with TMAH, filtered and analysed by inductively coupled plasma–mass spectrometry (ICP–MS) by Hill Laboratories, Hamilton, based on the methodology of Fecher et al. (1998).

**Quality control procedures**

The following quality assurance procedures were undertaken to ensure robust results:

- The analytical repeatability for the iodine content, in terms of coefficient of variation (CV) was determined for each food matrix by analyzing selected samples in duplicate. The repeatabilities were 2, 4 and 5% for white bread, 2, 3 and 15% for grain bread, 3, 15 and 29% for the biscuits, 5, 12 and 24% for Weetbix®, 1, 3, 8 and 11% for rice bubbles and 4 and 5% for toasted muesli.
- Recovery is a measure of accuracy of the analytical method and compares the amount of analyte measured in a sample to which a known amount of analyte has been added with the amount of analyte measured in a non-spiked sample. The mean and (range) of recoveries of iodine from samples spiked at 0.2–4.0 mg kg⁻¹ iodine were 100 (97–104)%, 101 (94–107)% 125 (122–127)%, 102 (96–109)%, 108 (99–119)% and 108 (105–111)% for white bread (n = 6), grain bread (n = 6), biscuits (n = 3), Weetbix® (n = 3), rice bubbles (n = 4) and toasted muesli (n = 2), respectively. The biscuit recoveries were consistently high, indicating that the analytical results for this matrix may be an overestimate of the true amounts present. Assuming any overestimate applies to both the test and control samples, the impact on iodine retention, if any, is likely to be minimal.
- Certified reference materials (CRMs) were measured with each analytical batch. Measured iodine levels for non-fat milk powder (NIST 1549) of 3.3 ± 0.1 (n = 9) and of 2.4 ± 0.1 (n = 7) for whole milk powder (NIST 8435) were within certified values (3.4 ± 0.2 and 2.3 ± 0.4, respectively).

**Results**

### Concentrations of iodine in bread

Results of the mean iodine content of triplicate samples of white and grain breads with and without iodized salt for each of three runs are shown in Tables 1 and 2, respectively. Iodine retention was calculated as the amount of iodine in the final product, expressed as

### Table 1. Mean iodine content of triplicate samples of white bread with (test) and without (control) iodized salt (mg kg⁻¹ dry weight).

<table>
<thead>
<tr>
<th></th>
<th>Run 1 Test</th>
<th>Run 1 Control</th>
<th>Run 2 Test</th>
<th>Run 2 Control</th>
<th>Run 3 Test</th>
<th>Run 3 Control</th>
<th>Mean of runs 1–3 Test</th>
<th>Mean of runs 1–3 Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt</td>
<td>27.3</td>
<td>NA</td>
<td>18.6</td>
<td>NA</td>
<td>51.9</td>
<td>NA</td>
<td>32.6 ± 22.5</td>
<td>NA</td>
</tr>
<tr>
<td>Dough after mixing</td>
<td>1.07</td>
<td>&lt;0.01</td>
<td>1.20</td>
<td>&lt;0.01</td>
<td>1.03</td>
<td>&lt;0.01</td>
<td>1.10 ± 0.11</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Dough after proving</td>
<td>1.04</td>
<td>&lt;0.01</td>
<td>1.14</td>
<td>0.01</td>
<td>1.27</td>
<td>&lt;0.01</td>
<td>1.15 ± 0.15</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Bread after baking</td>
<td>0.90</td>
<td>&lt;0.01</td>
<td>1.30</td>
<td>&lt;0.01</td>
<td>1.13</td>
<td>&lt;0.01</td>
<td>1.11 ± 0.19</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

NA = not analysed, variability expressed as ±1 standard deviation (n = 9).

### Table 2. Mean iodine content of triplicate samples of grain bread with (test) and without (control) iodized salt (mg kg⁻¹ dry weight).

<table>
<thead>
<tr>
<th></th>
<th>Run 1 Test</th>
<th>Run 1 Control</th>
<th>Run 2 Test</th>
<th>Run 2 Control</th>
<th>Run 3 Test</th>
<th>Run 3 Control</th>
<th>Mean of runs 1–3 Test</th>
<th>Mean of runs 1–3 Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt</td>
<td>30.0</td>
<td>NA</td>
<td>30.0</td>
<td>NA</td>
<td>51.0</td>
<td>NA</td>
<td>36.7 ± 16.2</td>
<td>NA</td>
</tr>
<tr>
<td>Dough after mixing</td>
<td>1.11</td>
<td>0.03</td>
<td>1.00</td>
<td>0.09</td>
<td>0.90</td>
<td>0.02</td>
<td>1.00 ± 0.14</td>
<td>0.05 ± 0.08</td>
</tr>
<tr>
<td>Dough after proving</td>
<td>1.14</td>
<td>0.03</td>
<td>0.83</td>
<td>0.01</td>
<td>0.08</td>
<td>0.02</td>
<td>0.98* ± 0.18</td>
<td>0.02 ± 0.01</td>
</tr>
<tr>
<td>Bread after cooking</td>
<td>1.21</td>
<td>0.04</td>
<td>1.25</td>
<td>&lt;0.02</td>
<td>0.98</td>
<td>&lt;0.02</td>
<td>1.15 ± 0.15</td>
<td>0.04 ± 0.02</td>
</tr>
</tbody>
</table>

NA = not analysed, variability expressed as ±1 standard deviation.

*Excludes outlier result from Test Run 3.
a percentage of the iodine concentration of the ingredients when first mixed and sampled, and was calculated on the mean results of the multiple runs.

The concentration of iodine in the grain bread dough after proving from Run 3 was inconsistent with the results for Runs 1 and 2 and inconsistent with the iodine values obtained for the samples before and after this stage of the grain bread-baking process i.e. the mixed ingredients and the final product of the same test run. The low results were confirmed by repeat analysis of each of the three dough samples. The reason for this spurious result was unexplained but was perhaps due to timing of the sampling such that dough made with non-iodized salt was in fact obtained.

The substitution of iodized for non-iodized salt in grain bread, using salt as available from a supermarket, resulted in an iodine concentration of 1.1 mg kg\(^{-1}\) in the final product. The concentration of iodine was the same, within analytical variability, across the three runs for the mixed ingredients, the dough after proving and in the final cooked bread. The differences in measured salt iodine levels between runs were not observed in the food products after mixing. There was no measurable loss of iodine during the bread baking process, for both white and grain breads.

**Concentration of iodine in sweet biscuits**

Summary results of the mean iodine content of triplicate samples of the selected sweet biscuits with and without iodized salt for each of the three runs are shown in Table 3.

The sweet biscuit contained a low level of iodine, about 0.2 mg kg\(^{-1}\). Replacing non-iodized salt with iodized salt resulted in a 50% increase of iodine content to 0.3 mg kg\(^{-1}\).

The levels of iodine in the mixed ingredients and in the final biscuits after baking were the same, within the analytical variability of the measurements. Hence, retention of iodine in biscuits made with iodized salt was 100%.

**Concentration of iodine in cereal products**

Results of the mean iodine content of triplicate samples of Weetbix\(^{\text{C213}}\) and toasted muesli, with and without iodized salt for each of the three runs, are shown in Tables 4 and 5.

The substitution of iodized for non-iodized salt in Weetbix\(^{\text{C213}}\), at an iodine level equivalent to 25–65 mg kg\(^{-1}\) in the salt, resulted in a mean iodine concentration of 0.4 mg kg\(^{-1}\) in the final product compared with 0.02 mg kg\(^{-1}\) in the non-fortified product (Table 4). The concentration of iodine was the same, within analytical variability, across the three runs for the mixed ingredients at the stage of conditioning, after milling, after moulding and in the final cooked Weetbix\(^{\text{C213}}\). There was no measurable loss of iodine during the processing.

The mean concentration of iodine in the toasted muesli manufactured with iodized salt was 0.5 mg kg\(^{-1}\) in the final product compared with 0.03 mg kg\(^{-1}\) in the

---

**Table 3. Mean iodine content of triplicate samples of sweet biscuits prepared with (test) and without (control) iodized salt (mg kg\(^{-1}\) dry weight).**

<table>
<thead>
<tr>
<th></th>
<th>Run 1</th>
<th>Run 2</th>
<th>Run 3</th>
<th>Mean of runs 1–3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test</td>
<td>Control</td>
<td>Test</td>
<td>Control</td>
</tr>
<tr>
<td>Salt</td>
<td>29.8</td>
<td>NA</td>
<td>44.2</td>
<td>NA</td>
</tr>
<tr>
<td>Ingredients after mixing</td>
<td>0.33</td>
<td>0.21</td>
<td>0.31</td>
<td>0.18</td>
</tr>
<tr>
<td>Final biscuit</td>
<td>0.29</td>
<td>0.21</td>
<td>0.29</td>
<td>0.25</td>
</tr>
</tbody>
</table>

NA = not analysed, variability expressed as ±1 standard deviation (\(n=9\)).

**Table 4. Mean iodine content of triplicate samples of Weetbix\(^{\text{C213}}\) prepared with (test) and without (control) iodized salt (mg kg\(^{-1}\) dry weight).**

<table>
<thead>
<tr>
<th></th>
<th>Run 1</th>
<th>Run 2</th>
<th>Run 3</th>
<th>Mean of runs 1–3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test</td>
<td>Control</td>
<td>Test</td>
<td>Control</td>
</tr>
<tr>
<td>Salt</td>
<td>70.4</td>
<td>NA</td>
<td>73.3</td>
<td>NA</td>
</tr>
<tr>
<td>After conditioning</td>
<td>0.48</td>
<td>&lt;0.01</td>
<td>0.33</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>After milling</td>
<td>0.48</td>
<td>&lt;0.01</td>
<td>0.39</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>After moulding</td>
<td>0.48</td>
<td>&lt;0.01</td>
<td>0.42</td>
<td>0.02</td>
</tr>
</tbody>
</table>

NA = not analysed, variability expressed as ±1 standard deviation (\(n=9\)).
non-iodized product (Table 5). The concentration of iodine was the same, within analytical variability, across the four runs for the mixed ingredients and in the final toasted muesli showing no loss, and 100% retention, of iodine through the processing of toasted muesli.

The results for iodine measurements of the Ricies® samples prepared with iodized and non-iodized salt were too variable within and between runs to draw any conclusions about iodine retention of this product.

A summary of the mean concentrations of iodine in mixed ingredients compared with the final products across the five fortified grain foods is shown (Figure 2). The error bars, expressed as ±1 standard deviation, of nine measurements, reflect both the variability of replicate analyses of the same product batch and the variability between batches.

Variability of iodine concentration in iodized salt
Replicates of 3 or 5 sub-samples (10 g) of the iodized salt used in each run showed a high degree of variability in the iodine concentration with CV values within a run ranging from 3.3 to 57% (not shown) and variation between runs ranging from 44 to 69% (Tables 1–4), where % CV = (standard deviation/mean)×100. The mean concentration of the salt used for the rice bubbles (71.2 mg kg\(^{-1}\)) was above the specified range (25–65 mg kg\(^{-1}\)); however, the variability around this result means there is a reasonable probability (33%) that the true result was within the allowable range.

Discussion
The results, expressed on a dry weight basis, showed negligible loss, or 100% retention, of iodine when non-iodized salt was replaced by iodized salt in the manufacture of bread, biscuits, Weetbix® and muesli.

Commercially available iodized salt may contain iodine in the range of 25–65 mg iodine per kg salt (FSC 2007). Estimates of iodine based on recipe calculations were not meaningful in the current study due to the variability in iodine determinations of the salt used within one batch and between batches (Tables 1–5). In contrast, the consistency of the results for the various products, when ingredients were first mixed, was evidence that the concentrations determined were a true measure of the iodine concentration in those samples. The variability of iodine observed in the salt samples, but not the mixed ingredients, suggests inhomogeneity of the distribution of iodine in the salt. Salt as an ingredient, therefore, is not a good predictor of iodine intake. The implication for consumers is that they will be receiving highly variable, and unpredictable, amounts of iodine from the use of iodized salt. Manufacturers need to ensure better mixing of iodine in salt for consumers to achieve the recommended amount on a daily basis.

Limited data on iodine stability in processed foods is reported in the literature as a basis for comparison with the results reported in the current study. Data derived from a Tasmanian fortification program reported iodine losses of approximately 10% in baked bread, although details of the methodology were not available (Thomson 2003). Kuhajek et al. (1973) reported iodine retentions of 73–80% in white bread based on recipe calculations and iodine retentions of 70–74% after 10 days in the freezer, suggesting some loss of iodine with processing and a further small loss with freezing (FAO 1996). As stated above, there are difficulties in assessing iodine concentrations based on recipe calculations from commercially

Table 5. Mean iodine content of triplicate samples of toasted muesli prepared with (test) and without (control) iodized salt (mg kg\(^{-1}\) dry weight).

<table>
<thead>
<tr>
<th></th>
<th>Run 1</th>
<th>Run 2</th>
<th>Run 3</th>
<th>Run 4</th>
<th>Mean of runs 1–4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test</td>
<td>Control</td>
<td>Test</td>
<td>Control</td>
<td>Test</td>
</tr>
<tr>
<td>Ingredients after mixing</td>
<td>0.54</td>
<td>&lt;0.01</td>
<td>0.53</td>
<td>0.01</td>
<td>0.51</td>
</tr>
<tr>
<td>Final muesli</td>
<td>0.54</td>
<td>&lt;0.01</td>
<td>0.55</td>
<td>0.01</td>
<td>0.54</td>
</tr>
<tr>
<td>% Iodine retention</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>104</td>
</tr>
</tbody>
</table>
available iodized salt that may have any concentration of iodine ranging from 25 to 65 mg kg\(^{-1}\). Winger et al. (2005) prepared single batches of bread dough containing 1, 10, 100 or 1000 mg kg\(^{-1}\) iodine using either potassium iodate or potassium iodide. They reported losses of approximately 40% of the iodate and 20% of the iodide from the central crumb and 30% losses from the bread crust, across this concentration range. However, lower losses of 8–16% were observed for the bread crust, across this concentration range. The results of multiple samples from multiple processing runs in the current study, at 1 mg kg\(^{-1}\) iodine, that realistically represents the level of iodine that might be found if non-iodized salt is substituted for salt iodized at 25–65 mg iodine per kg salt, show no iodine loss within analytical variability.

The bioavailability of iodine, usefully reviewed by Hurrell (1997), is limited to early studies using radioisotopes, a technique no longer ethically acceptable. Virtually all inorganic iodide is absorbed from the gastrointestinal tract, irrespective of the food source (soil, seafood or fortified foods). Under normal intakes, 85–90% of absorbed iodide is excreted into the urine and the remainder, 10–15%, should be available for uptake from the bloodstream by the thyroid gland. There is limited evidence that food-derived or protein-bound iodine is less well absorbed than inorganic iodine (Hurrell 1997).

Iodide and iodates that may be added to salt are reactive species with the potential to undergo oxidation and reduction reactions within the food matrix (Winger et al. 2008). The high degree of retention of the iodine from the iodized salt seen in the current study indicates that there is no significant loss of iodine from these cereal products as elemental iodine. However, the analytical methodology used does not distinguish the form of the iodine and whether it is protein-bound; hence, not all the measured or added iodine will necessarily be bioavailable.

Given the apparent stability of iodine during the heating phase of the manufacture of bread, biscuits and cereal products observed in the current study, there is no reason to expect significant decreases in iodine content on storage. However, this is a data gap that would usefully augment the limited data regarding iodine retention.

**Conclusion**

Negligible loss, or 100% retention of iodine, was observed when non-iodized salt was replaced by salt fortified with iodine equivalent to 25–65 mg iodine per kg salt, in the manufacture of bread, biscuits, Weetbix\(^{®}\) and muesli. If iodized salt is used in place of non-iodized salt, the amount of iodine in the final product is predictably 100% of the added amount when loss of water during processing is taken into account. This information can be used for modelling the impact of strategies to increase iodine exposure via the use of iodized salt. The retention of iodine in rice bubbles was variable and inconclusive in our hands. Consideration must be given to the likely inhomogeneity of iodine in iodized salt if modelling iodine intakes on salt usage.

**Acknowledgements**

This work was undertaken by the Institute of Environmental Science and Research Ltd. as part of their contractual agreement with the New Zealand Food Safety Authority. The key participation of management and technical staff at Coupland’s Bakeries, Hornby, Christchurch (in particular Scott McLean) and Sanitarium, Auckland (in particular Richard Hark), is gratefully acknowledged. Thanks also to Shirley Jones, Christchurch Science Centre, for moisture analyses and sample dispatch.

**References**


Thomson BM, Vannoort RW, Haslemore RM. 2008. Dietary exposure and trends of exposure to nutrient elements,