Iodine deficiency is still a major problem in some parts of Europe and many other parts of the world (e.g. developing countries and mountain areas like the Alps). It can result in various disorders, e.g. goiter, increased infant mortality and mental retardation.

Different strategies have been developed to ensure a better iodine supply for man. The most common one is the iodisation of salt, but since the application is voluntary, it has not been effective enough. There still is a mild to moderate deficiency in the iodine intake of man of about 30% in Germany [2, 6, 8].

An alternative strategy is the addition of iodine to the feed of animals. Various marine algae are a rich source of iodine, e.g. *Laminaria digitata*, which contains about 4 g iodine per kg dry matter. Adding those iodine containing algae to the feed of pigs for example, leads to an evident increase in the iodine content of their meat [3]. Similar effects are shown for poultry [9]. Besides the large amount of iodine, the algae show several other advantages, such as a higher iodine stability and the occurrence of other essential trace elements and vitamins.

Marine fish is another rich source of iodine, however except in coastal areas, sea fish consumption e.g. in Germany...
is rather low. Freshwater fish, which is consumed to a larger extent, contains only small amounts of iodine [1, 7].

The purpose of this French-German EU funded project was to increase the iodine content of freshwater fish by supplementing the feed with brown algae containing large amounts of iodine, and to find out if the carry over of iodine from plant to fish to man is functioning.

Materials and methods

800 fishes (char, omble, Elsässer Saibling, Salvelinus sp.) were divided into two groups. The control group received a commercial fish feed with an iodine content of 2 mg / kg fish feed (crude protein 44 %, crude fat 20 %, crude ash 8.5 %, crude fiber 2.0 %), the remaining group was fed an algae-supplemented fish feed with an algae content of 0.8 % which leads to an additional iodine intake of 32 mg / kg fish feed. The algae supplemented to the fish feed were Laminaria digitata from coastal areas of Brittany/France. They contained about 4 g iodine per kg dry matter.

Every four weeks 10 fishes of both groups were slaughtered and their fillets were analyzed for the iodine content. At the end of the study we also compared the distribution of iodine in various parts (skin and fillet) of 10 algae-fed and 10 control fishes.

In addition, we were also interested in the influence of a smoking procedure on the iodine content. For this, we took fish from the algae and the control group. Half of the fish of each group were put in a brine, containing iodized salt, for the time of 12 hours. The remaining fish were put in a brine as well, but this time without using iodized salt. After the following smoking of the fish, the iodine content of the fillets without skin was analyzed.

The iodine determination is based on two steps: the preparation of the samples and the real iodine assay. The preparation of the samples is done in an alkaline ashing procedure: By addition of potassium hydroxide (KOH) the organic matter is destroyed. Zinc sulfate (ZnSO4) is added to inhibit iodine loss. Thereafter the samples are dried, crushed, powdered and at last ashed by increasing temperatures (max. 600°C for 2 hours). The real iodine determination is based on the Sandell-Kolthoff reaction: Iodine that is released after dry ashing catalyses a redox reaction between arsenic and cerium, in which the yellow Ce⁴⁺ is reduced to colorless Ce³⁺ through As³⁺ in acid surroundings.

\[ 2 \text{Ce}^{4+} (\text{yellow}) + \text{As}^{3+} \rightarrow 2 \text{Ce}^{3+} (\text{colorless}) + \text{As}^{5+} \]

The intensity of the color, which is proportional to the iodine content, was measured by a photometer at a wavelength of 405 nm.

Furthermore, quality parameters like pH-level, color and firmness of meat were measured at the beginning, in the middle and at the end of the feeding trial. This control was necessary because the algae might have a negative influence on the meat, such as yellow coloring, softness and a too fast decrease of the pH level.

Important for the success of the feeding study was the question if the carry over of iodine not only from plant to fish, but also from fish to man functions. For this purpose a bioavailability study was performed. 14 volunteers had to collect the first urine in the morning for a period of 6 days. In the evening of the third day each person received a meal (fillet) of algae fed char (250 g).

The iodine excretion via urine, which is a good parameter for iodine intake of man [4], was measured also by the Sandell-Kolthoff reaction. Because urine concentration varies significantly between individuals and between different conditions of diuresis, we used the ratio μg iodine / g creatinine and not iodine in relation to urine volume.

For statistical evaluation the software SAS for Windows, version 6.1 and Excel, version 97 were used.

Results

After a feeding period of nine months there was a significant difference between the iodine content of the skinned fillet of control and the algae fed group: 143 ± 10 μg iodine/kg w.w. compared to 539 ± 86 μg iodine/kg w.w. Suplementing the fish feed with algae therefore led to a fourfold increase of the iodine content (Table I).

There was no negative influence of the algae on meat quality like pH-level, color and firmness of meat. There was no significant difference in those parameters between the control and the algae fed group.

We also investigated the distribution of iodine in different parts of the fish. We analyzed the iodine content of fillet with and without skin, the skin alone and the complete fish (Figure 1). Interesting is the very high amount of iodine in the skin both of control (317 ± 56 μg iodine/kg w.w.) and algae fed fish (1421 ± 251 μg iodine/kg w.w.). Surprisingly the iodine content of the total fish was also very high.

Since this part of our feeding trial fell into spawning season of the fish, feed intake and therefore the iodine content was much lower (Figure 1) compared with previous results shown in Table I.

In algae fed fish as well as in control fish, smoking by using an iodine containing brine increased the iodine content of the fillet to a similar extent. However, as seen in Figure 2, this increase is significant lower than the effect of supplementing the fish feed with brown algae.

The bioavailability study clearly shows that the carry over of iodine from fish to plant to man functions. On days 1, 2, 3, 5 and 6 the mean iodine concentration of the urine ranged between 66 and 73 μg/g creatinine. Whereas on day 4 - the morning after the fish meal - the iodine concentration rose above 100 μg/g creatinine, which corresponds to an increase of about 45 %. Table II demonstrates that the average iodine excretion after the fish meal is significantly higher (p < 0.05) than on the other days of the bioavailability study.

Discussion

The results of the feeding study show clearly that by supplementing the feed of freshwater fish with marine algae, the iodine content of the fillet can be increased to a large extent.
MARINE ALGAE AS NATURAL SOURCE OF IODINE IN THE FEEDING OF FRESHWATER FISH

TABLE I. — Mean iodine content of the left fillet (without skin) of control and algae fed fish (n = 10) (mean value ± standard deviation).

<table>
<thead>
<tr>
<th>Months of feeding</th>
<th>Control group</th>
<th></th>
<th>Algae group</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>iodine content µg/kg wet weight</td>
<td></td>
<td>iodine concentration µg/kg wet weight</td>
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<tr>
<td>0</td>
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<td>140⁺</td>
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<td>3</td>
<td>136 ± 21</td>
<td>456 ± 135 *</td>
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</tr>
<tr>
<td>6</td>
<td>162 ± 48</td>
<td>416 ± 232 *</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>143 ± 10</td>
<td>539 ± 86 *</td>
<td></td>
</tr>
</tbody>
</table>

* significant difference of the iodine content compared to the control group (p < 0.05)

# significant difference in the iodine content compared to the group without iodized salt (p < 0.05)

FIGURE 1. — Distribution of iodine in different parts of control and algae fed fish (n = 10).

* significant difference in the iodine content (p < 0.05)

FIGURE 2. — Influence of smoking fish by using an iodine containing brine (n = 12), iodine content of the fillets without skin.
After nine months of feeding, the freshwater fish contained a similar amount of iodine as various marine fish, e.g. tuna (~ 500 µg/kg w.w.) and halibut (~ 400 µg/kg w.w.).

Comparing the iodine content of different parts of fish showed that especially the skin therefore is very rich in iodine. Fillet with skin contains about twice as much iodine than the skinned meat. Consuming fillet with the skin is therefore recommendable to increase the iodine intake of man.

The surprisingly high iodine content of the total fish is probably due to iodine depots in the thyroid gland. Also there is the possibility of remaining feed in the intestinal, although the fish were not fed on the day before slaughtering.

Using a brine containing iodized salt for smoking fish, is also possibility to increase the iodine content of the fillet significantly. However using algae-supplemented fish feed is a much more effective way to ensure a higher iodine intake of man.

The bioavailability study showed that the carry over of iodine from plant to fish to man functions. There was an evident increase in the iodine concentration of urine after consuming the algae fed char (Figure 3). Therefore, the iodine supply of man can be improved by eating freshwater fish fed marine algae high in iodine.

### References


<table>
<thead>
<tr>
<th>Day</th>
<th>Creatinine g/l</th>
<th>Iodine content µg/l</th>
<th>Iodine content µg/g creatinine</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>1.7 ± 0.6</td>
<td>115.1 ± 40.9</td>
<td>73.2 ± 22.5</td>
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<tr>
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<td>1.6 ± 0.9</td>
<td>92.9 ± 46.1</td>
<td>65.6 ± 21.6</td>
</tr>
<tr>
<td>3</td>
<td>1.4 ± 1.0</td>
<td>87.0 ± 46.6</td>
<td>72.6 ± 22.5</td>
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<td>4</td>
<td>1.2 ± 0.6</td>
<td>103.6 ± 38.0</td>
<td>100.4 ± 32.5 *</td>
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<td>89.5 ± 49.5</td>
<td>68.4 ± 22.6</td>
</tr>
<tr>
<td>6</td>
<td>1.4 ± 0.7</td>
<td>80.2 ± 35.8</td>
<td>66.5 ± 22.4</td>
</tr>
</tbody>
</table>

* significant difference in the iodine content compared to the other days (p < 0.05)

Table II. — Urinary iodine excretion in volunteers after a fish meal (n = 14) (mean value ± standard deviation).

* significant difference in the iodine content of the urine (p < 0.05)

Figure 3. — Average iodine content of the morning urine during the bioavailability study (n = 14).