# Combating iodine and iron deficiencies through the double fortification of fish sauce, mixed fish sauce, and salt brine

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## Abstract

*Two iodine and seven iron compounds were tested for use in the fortification of pure fish sauce, mixed fish sauce, and salt brine for cooking as a means to combat iodine and iron deficiencies. Ferrous sulfate, sodium iron ethylenediaminetetraacetic acid, ferric ammonium citrate, and ferrous lactate were combined with potassium iodide with no effect on sensory quality. Product shelf-life testing revealed that no iron or iodine losses occurred during a three-month storage period. Although the color of most products darkened, the color was not significantly different from that of nonfortified products after two to three months. Sensory home-use tests revealed that the fortified products were acceptable to highly acceptable, with only 1.2% to 8.2% of the dishes cooked using the fortified products being reported as discolored. The cost of fortification was minimal, at 0.13 to 2.73 baht per bottle (750 ml)(42 baht = US$1). Consequently, these products show a potential for inclusion in national programs for the prevention of micronutrient deficiencies in Asian countries where fish sauce and its products are routinely consumed.*

## Introduction

Micronutrient deficiency is a public health problem in most developing countries [1, 2]. In Thailand, iron-deficiency anemia affects such vulnerable groups as pregnant women and children, with prevalences as high as 70% in some rural areas [3]. Moreover, although the overall prevalence of iodine-deficiency disorders is low in Thailand (2.1%), food-based strategies are needed to maintain this level, as well as to reduce the prevalence of iodine-deficiency disorders in areas where it remains high [4].

Fish sauce and related products are potential vehicles for micronutrient fortification in Thailand and other countries such as Cambodia, Indonesia, Laos, Myanmar, and Vietnam, where such products are a traditional part of the cuisine. In Thailand especially, they are widely accessible to and used by people of all socioeconomic classes and in all parts of the country because of their availability, acceptability, and affordability [5]. In many parts of the country, fish sauce and related products are used instead of iodized salt for seasoning.

Thailand's Food and Drug Administration (FDA) classifies fish sauce-related products as those that are produced to lower the cost compared with pure fish sauce. Such products include mixed fish sauce (fish sauce mixed with other ingredients) and salt brine for cooking (salt brine and colorant mixed with liquid, which is a by-product of monosodium glutamate production). Technically, fish sauce products are in liquid form and can be homogeneously mixed with a suitable fortificant [6]. It is estimated that Thai people consume 15 ml of fish sauce products per meal [7].

Since 1998, fish sauce and soy sauce have been fortified with iron in Vietnam and China using sodium iron ethylenediaminetetraacetic acid (NaFeEDTA) [8, 9]. In Thailand, fortifying fish sauce with iron and the double fortification of fish sauce with iron and iodine were successfully achieved by using NaFeEDTA and potassium iodate as iron and iodine sources, respectively [5, 10]. However, NaFeEDTA is one of the most expensive iron fortificants. For a low-profit-margin product such as fish sauce, the cost of NaFeEDTA is not acceptable to Thai producers, thus hindering the nationwide fortification program. To determine the most economical and practical fortification method or methods, the present study on the technical feasibility of fortifying fish sauce and related products with iron and iodine with lower-cost fortificants was undertaken.

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

## Materials and methods

### Food and nutrient samples

Fish sauce, mixed fish sauce, and salt brine for cooking were obtained from the Rayong Fish Sauce Industry Co., Rayong, Thailand. Iodine sources, including potassium iodide and potassium iodate, were obtained from Ajax (Auburn, Australia). Seven iron fortificants were used, including ferrous sulfate from Ajax, NaFeEDTA from Akza Nobel (Singapore), ferrous lactate from Purac (Gorinchern, Netherlands), ferrous fumarate from Siam Union (Budenheim, Germany), ferrous bisglycinate from Albion (Utah, USA), ferric ammonium citrate from Merck (Frankfurt, Germany), and ferrous gluconate from Merck.

### Effect of individual and combined nutrients on product sensory appearance

Fish sauce, mixed fish sauce, and salt brine for cooking were fortified with individual and combined fortificants (for iodine and iron), packed in capped glass bottles, and incubated at room temperature for three months along with unfortified products as controls. The fortification dosage was 5 mg for iron and 50 μg for iodine per 15 ml of fish sauce product (one-third the Thai Recommended Dietary Intakes [RDI] per serving). Changes in the products' sensory appearance (color and precipitate) were observed during incubation.

### Modification of the production method

Citric acid was used in the modification process, since fish sauce producers use it as an acidulant and it is an efficient, economical chelating agent. To evaluate acceptable levels of acid, citric acid was added to the fish sauce products at concentrations of 0.1%, 0.3%, 0.5%, and 0.7%. The detectable acid level was determined using the sensory difference from controls to compare acidified with nonacidified samples [11, 12]. A boiled, 1-cm cube of chicken breast was used as the sample carrier. Thirty staff and students from Mahidol University performed the tests under daylight fluorescent light in individual testing booths at the Sensory Science Laboratory, Institute of Nutrition, Mahidol University.

### Selection of fortificants used in double fortification

The acidified double-fortified fish sauce and salt brine for cooking with different forms of iron and iodine fortificants were observed for changes in general sensory appearance compared with unfortified products during the storage period under accelerated test conditions (40°C, two weeks). Another selection criterion was fortified iodine stability. If the combination did not cause any loss in iodine, potassium iodide would be the first priority, because of its lower cost and greater stability.

### Shelf-life study

A shelf-life study was performed on the double-fortified products, which were acidified at different citric acid concentrations (0.1% to 0.3%). The products were packed in glass bottles and stored under severe (daytime, 34° to 36°C; nighttime, 32°C) and normal (daytime, 25° to 30°C; nighttime, 25°C) conditions for three months. The products were sampled on a monthly basis to determine residual fortified nutrients and sensory qualities. Differences from control and hedonic scales were used for the sensory analysis of changes in color during storage and acceptability of the products, respectively. Fifty nursing students from the Royal Thai Naval Nursing College in Bangkok performed the sensory analysis in individual testing booths under a daylight fluorescent lamp. Data from sensory analyses were assessed for significant differences ($p = .05$) by analysis of variance (ANOVA) and the Scheffé method.

### Chemical analysis

Iodine content was determined by the spectrophotometric method at 410 nm absorbency as noted by Moxon and Dixon [13] and Sandell and Kolthoff [14]. Iron content was determined after wet digestion by a flame atomic absorption spectrophotometer (model Spectr AA-20, Varian Associates, Australia) [15].

### Production trial at industrial level

The production trial was performed at the Rayong Fish Sauce Industry Co. by double-fortifying 100 L of fish sauce and mixed fish sauce with each kind of iron fortificant. The fortified product was then sensory tested, and comments were made by factory experts before it was filtered and bottled in 750-ml glass bottles and capped.

### Home-use test

Staff and students of the Institute of Nutrition, Mahidol University, performed the home-use test [11]. These panelists were divided into two groups of about 60 each, consisting of fish sauce users (higher-cost product) and mixed fish sauce users (lower-cost product). Every week each panelist was randomly given a bottle of a fortified fish sauce product for use in his or her normal cooking and asked to complete a questionnaire about its use. The panelists returned completed questionnaires after at least 10 dishes had been cooked,

giving overall product acceptability ratings according to a hedonic scale. If 25% of the questionnaires reported dishes to be different from normal, those dishes were cooked in the laboratory with that fortified product in order to confirm the findings and observe the abnormal sensory characteristics.

## Results and discussion

### Effect of individual and combined nutrients on product sensory appearance

The effects of fortified nutrients on sensory characteristics were found to be the same in all fish sauce products. Table 1 shows that neither potassium iodide nor potassium iodate affected the sensory appearance. The effects resulted solely from iron fortificants, which also affected the products in the case of combined nutrients. Food producers are greatly concerned with any changes in the sensory appearance of fortified food products. Most iron fortificants catalyzed an oxidation reaction and caused precipitate and color changes in all products. NaFeEDTA affected color only slightly, but the fortified products precipitated after 1.5 months. The shelf life of most unfortified fish sauce products is about three months.

### Modification of production method

Acetic and citric acids are commonly used in the acidification process to improve taste and prevent the formation of precipitate and crystals in fish sauce products. In other food industries, citric acid is also used as a metal chelator. In a preliminary study, only citric acid prevented the formation of precipitate, which was caused by the reaction of the iron fortificant and protein in fish sauce and its related products. In this study, the maximum level of citric acid that could be added without significantly affecting sensory quality was 0.7%. Citric acid was therefore the best choice for acidification because of its wide use and low cost.

### Fortificants used in double fortification

The results from the acceleration test indicated that four iron fortificants—ferrous sulfate, NaFeEDTA, ferric ammonium citrate, and ferrous lactate—could be used in all fish sauce products that had been acidified with citric acid (table 2). The other three kinds of iron fortificant caused precipitate and color changes that could not be prevented. However, different concentrations of citric acid were required for different iron fortificants. For example, only 0.1% citric acid was needed for NaFeEDTA, while 0.3% was needed for the other three kinds of iron fortificant. In some acidified products, the sources of iodine in combination with iron sources could also affect sensory appearance (darker color and precipitate) and cause losses of the fortified nutrients.

Acidified fish sauces fortified with ferric ammonium citrate and potassium iodate precipitated even when 0.3% citric acid was used. The same was found with ferrous lactate and potassium iodide. Only potassium iodate could be used for double fortification with ferrous sulfate in salt brine for cooking. When both forms

TABLE 1. Sensory appearance of fish sauce, mixed fish sauce, and salt brine for cooking fortified with different kinds of fortificants during different storage periods[a]

| Month | Iodine fortificant | Iron fortificant | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | None | Ferrous sulfate | NaFeEDTA | Ferric ammonium citrate | Ferrous lactate | Ferrous gluconate | Ferrous fumarate | Ferrous bisglycinate |
| 0 | None | — | X | — | X | X | X | X | X |
| | KI | — | X | — | X | X | X | X | X |
| | $KIO_3$ | — | X | — | X | X | X | X | X |
| 1 | None | — | X | — | X | X | X | X | X |
| | KI | — | X | — | X | X | X | X | X |
| | $KIO_3$ | — | X | — | X | X | X | X | X |
| 2 | None | — | X | X | X | X | X | X | X |
| | KI | — | X | X | X | X | X | X | X |
| | $KIO_3$ | — | X | X | X | X | X | X | X |
| 3 | None | — | X | X | X | X | X | X | X |
| | KI | — | X | X | X | X | X | X | X |
| | $KIO_3$ | — | X | X | X | X | X | X | X |

*a.* X, Precipitate and color change; —, no precipitate and no or slight change in color.

of iodine could be used without affecting the sensory characteristics, potassium iodide was preferred because of its lower cost. Table 3 shows the same result when the double-fortified products were packed in commercial packages and stored at normal and severe room temperatures. However, severe room temperature caused a higher amount of precipitate in some fortificants.

### Shelf-life study

Table 4 shows the amounts of iodine and iron in the fortified products. The nonfortified products or controls contained very small amounts of both nutrients. The amounts of the fortified nutrients did not change significantly during the three-month storage. The fish sauce fortified with ferrous sulfate lost more iodine than the others; however, the residual iodine after three months was still more than 80% of the expected dosage (333 μg/100 ml), which was still an acceptable amount. Ferrous sulfate and certain amino acids in the fish sauce would probably interact and have an oxidation effect on the fortified potassium iodide. The iron contents of the products fortified with NaFeEDTA, ferric ammonium citrate, and ferrous lactate were found to be only 80% to 90% of the expected values (33 mg/100 ml), which might have been related to the degree of purity and hygroscopicity of those fortificants. Even though the products were not stored in a 100% light-protected condition, the amounts of fortified nutrients did not change for at least three months.

The sensory scores for the double-fortified fish sauce were not significantly different, except for the lower acceptability of the NaFeEDTA-fortified product (table 5). The color of the fortified mixed fish sauce was also a problem, since the acceptability scores for those fortified with ferrous sulfate and ferrous lactate were significantly lower than the controls after three months. However, the scores for overall acceptability were not significantly different from those of the controls in both cases. There was a significant difference in the scores of certain characteristics of salt brine for cooking during storage periods, which showed that the sensory quality of the fortified products was different from that of the controls during the first one to two months. After the products had been stored for three months, the sensory characteristics of the unfortified products were not very different from those of the fortified ones.

TABLE 2. Sources of iron and iodine and concentration of citric acid used to prevent change in sensory appearance of the double-fortified products during the acceleration test (40°C for 2 weeks)

| Product | Iron source | Iodine source | % Citric acid |
|---|---|---|---|
| Fish sauce | Ferrous sulfate | KI | 0.3 |
| | NaFeEDTA | KI | 0.1 |
| | Ferric ammonium citrate | KI | 0.3 |
| | Ferrous lactate | $KIO_3$ | 0.3 |
| Mixed fish sauce | Ferrous sulfate | KI | 0.3 |
| | NaFeEDTA | KI | 0.1 |
| | Ferric ammonium citrate | KI | 0.3 |
| | Ferrous lactate | KI | 0.3 |
| Salt brine for cooking | Ferrous sulfate | $KIO_3$ | 0.3 |
| | NaFeEDTA | KI | 0.1 |
| | Ferric ammonium citrate | KI | 0.3 |
| | Ferrous lactate | KI | 0.3 |

TABLE 3. Effect of storage conditions on stability of the double-fortified products during three months of storage[a]

| % Citric acid | Time (mo) | Ferrous sulfate | | | | | | NaFeEDTA | | | | | | Ferric ammonium citrate | | | | | | Ferrous lactate | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fs (KI) | | MFs (KI) | | Sbc ($KIO_3$) | | Fs (KI) | | MFs (KI) | | Sbc (KI) | | Fs (KI) | | MFs (KI) | | Sbc (KI) | | Fs ($KIO_3$) | | MFs (KI) | | Sbc (KI) | |
| | | M | S | M | S | M | S | M | S | M | S | M | S | M | S | M | S | M | S | M | S | M | S | M | S |
| 0.1 | 1 | +1 | +2 | +1 | +2 | +1 | +2 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 |
| | 2 | +2 | +3 | +2 | +3 | +2 | +3 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | +2 | +1 | +2 | +1 | +2 | +1 | +2 | +1 | +2 | +1 | +2 |
| | 3 | +2 | +4 | +2 | +4 | +2 | +4 | 0 | 0 | 0 | 0 | 0 | 0 | +2 | +4 | +2 | +4 | +2 | +4 | +2 | +4 | +2 | +4 | +2 | +4 |
| 0.2 | 1 | +1 | +2 | +1 | +2 | +1 | +2 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 |
| | 2 | +2 | +3 | +2 | +3 | +2 | +3 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | +2 | +1 | +2 | +1 | +2 | +1 | +2 | +1 | +2 | +1 | +2 |
| | 3 | +2 | +4 | +2 | +4 | +2 | +4 | 0 | 0 | 0 | 0 | 0 | 0 | +2 | +3 | +2 | +3 | +2 | +3 | +2 | +3 | +2 | +3 | +2 | +3 |
| 0.3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

*a.* Fs, Fish sauce; MFs, mixed fish sauce; Sbc, salt brine for cooking; M, mild storage conditions (daytime 25° to 30°C, nighttime 25°C); S, severe conditions (daytime 34° to 36°C, nighttime 32°C); amount of precipitate is scored from 0 (no precipitate) to +1 (small amount) to +4 (large amount).

Table 6 shows that the subjects found a significant difference in color ($p < .05$) in the double-fortified products packed in glass bottles after the fortificants had been added. The rating showed that the colors of the fortified products were darker; however, in the case of fish sauce, the color of the nonfortified product darkened to the same degree or even more in comparison with the product fortified with NaFeEDTA after

TABLE 4. Amounts of fortificants (per 100 ml) in the double-fortified fish sauce products during three months of storage[a]

| | | 1 | | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|---|---|
| Product | Month | I (μg) | Fe (mg) | I (μg) | Fe (mg) | I (μg) | Fe (mg) | I (μg) | Fe (mg) |
| Fs | 0 | 270.12 | 34.20 | 347.60 | 27.48 | 332.27 | 30.58 | 340.64 | 27.00 |
| | 1 | 270.82 | 33.00 | 335.91 | 27.34 | 336.10 | 31.23 | 333.30 | 26.77 |
| | 2 | 272.32 | 32.62 | 352.91 | 27.50 | 320.30 | 29.86 | 335.26 | 26.99 |
| | 3 | 268.65 | 33.56 | 343.20 | 28.00 | 330.50 | 30.00 | 331.70 | 27.22 |
| MFs | 0 | 306.51 | 33.08 | 362.27 | 27.76 | 367.55 | 31.12 | 323.42 | 27.52 |
| | 1 | 305.60 | 33.10 | 336.65 | 29.10 | 341.44 | 31.10 | 310.01 | 28.10 |
| | 2 | 300.43 | 33.46 | 337.60 | 28.57 | 331.80 | 31.19 | 335.08 | 29.33 |
| | 3 | 304.24 | 33.20 | 338.06 | 28.02 | 321.02 | 31.50 | 338.82 | 29.54 |
| Sbc | 0 | 330.06 | 34.04 | 384.54 | 30.07 | 347.10 | 31.24 | 345.70 | 28.19 |
| | 1 | 340.89 | 34.04 | 364.55 | 30.35 | 310.30 | 31.80 | 326.17 | 28.40 |
| | 2 | 339.30 | 34.33 | 369.33 | 30.24 | 305.35 | 31.12 | 328.63 | 28.14 |
| | 3 | 329.36 | 33.95 | 362.85 | 30.43 | 313.00 | 31.34 | 321.97 | 28.18 |

*a.* Fs, Fish sauce; MFs, mixed fish sauce; Sbc, salt brine for cooking; 1, ferrous sulfate + KI for fish sauce and mixed fish sauce, and ferrous sulfate + $KIO_3$ for salt brine for cooking; 2, NaFeEDTA + KI; 3, ferric ammonium citrate + KI; 4, ferrous lactate + $KIO_3$ for fish sauce, and ferrous lactate + KI for mixed fish sauce and salt brine for cooking; nonfortified fish sauce, mixed fish sauce, and salt brine for cooking contained 0.90, 0.50, and 0.11 mg of iron, and 30.87, 19.59, and 16.04 μg of iodine per 100 g, respectively.

TABLE 5. Changes in sensory acceptability of the double-fortified fish sauce products as compared with the nonfortified products during three months of storage[a]

| | | Degree of significant difference of sensory acceptability score ($p = .05$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fs | | | | MFs | | | | Sbc | | | |
| Sensory quality | Month | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Overall | 0 | N | N | N | N | N | N | N | N | N | N | N | N |
| | 1 | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2 | N | N | N | N | N | N | N | N | * | * | * | * |
| | 3 | N | N | N | N | N | N | N | N | N | N | N | N |
| Color | 0 | N | N | N | N | N | N | N | N | N | N | N | N |
| | 1 | N | N | N | N | N | N | N | N | * | * | * | * |
| | 2 | N | N | N | N | N | N | N | N | * | * | N | * |
| | 3 | N | * | N | N | * | * | N | * | N | N | N | N |
| Odor | 0 | N | N | N | N | N | N | N | N | N | N | N | N |
| | 1 | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2 | N | N | N | N | N | N | N | N | * | * | * | * |
| | 3 | N | N | N | N | N | N | N | N | N | N | N | N |
| Saltiness | 0 | N | N | N | N | N | N | N | N | N | N | N | N |
| | 1 | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2 | N | N | N | N | N | N | N | N | * | * | N | * |
| | 3 | N | N | N | N | N | N | N | N | N | N | N | N |

*a.* Fs, Fish sauce; MFs, mixed fish sauce; Sbc, salt brine for cooking; 1, ferrous sulfate + KI for fish sauce and mixed fish sauce, and ferrous sulfate + $KIO_3$ for salt brine for cooking; 2, NaFeEDTA + KI; 3, ferric ammonium citrate + KI; 4, ferrous lactate + $KIO_3$ for fish sauce, and ferrous lactate + KI for mixed fish sauce and salt brine for cooking.

* Significant difference from the internal control sample ($p < .05$); N, no significant difference from the internal control sample.

being stored for two to three months. The color of the fortified products tended to be darker because of the catalytic effect of iron and certain compounds formed by iron itself and sulfur-containing amino acid in the products [16].

### Production trial at industrial level

The sensory evaluation and the preparation process affect whether the fortification program and its products would be accepted by the industry. To investigate these factors, a fish sauce expert, familiar with his own product, was asked to review and comment on the quality of the fortified products (table 7). In his assessment, the quality of the products and the preparation process differed according to the type and solubility of the iron fortificant. His final comment was that general consumers would probably not detect such differences in sensory characteristics; however, industrial producers would prefer the type of iron fortificant that was easily soluble.

### Cost estimation

Cost was calculated from the prices of both fortificants and citric acid (table 8). The cost of the raw materials used for fortification with ferric ammonium citrate plus potassium iodide was highest in both products, whereas the ones with ferrous sulfate plus potassium iodide were the lowest. Ferrous sulfate was the best choice for an iron fortificant to be used in a national fortification program.

### Home-use test

Table 9 shows the number of dishes that were cooked by the subjects at home. The subjects cooked approximately 300 to 400 recipes a total of 1,700 to 2,400 times.

TABLE 6. Results (mean ± SD) of the difference from control test for color of double-fortified fish sauce products compared with the nonfortified products (packed in the 750-ml glass bottle used for commercial distribution)

| | | Test score | | | | |
|---|---|---|---|---|---|---|
| | Month | Control | Ferrous sulfate + KI/ $KIO_3$ | NaFeEDTA + KI | Ferric ammonium citrate + KI | Ferrous lactate + KI/$KIO_3$ |
| Fish sauce | 0 | $4.97 \pm 0.93^{d}$ | $7.43 \pm 1.01^{ab}$ | $7.87 \pm 0.94^{a}$ | $6.70 \pm 1.15^{bc}$ | $5.97 \pm 1.07^{c}$ |
| | 1 | $5.47 \pm 1.25^{c}$ | $7.57 \pm 1.30^{a}$ | $6.33 \pm 0.99^{bc}$ | $7.10 \pm 1.09^{ab}$ | $6.20 \pm 1.00^{bc}$ |
| | 2 | $5.63 \pm 1.07^{c}$ | $6.80 \pm 1.16^{b}$ | $5.23 \pm 1.19^{c}$ | $7.40 \pm 1.28^{ab}$ | $8.07 \pm 0.98^{a}$ |
| | 3 | $5.80 \pm 1.35^{b}$ | $6.67 \pm 1.21^{b}$ | $4.80 \pm 0.96^{c}$ | $7.83 \pm 1.09^{a}$ | $6.10 \pm 1.18^{b}$ |
| Mixed fish sauce | 0 | $4.43 \pm 0.63^{c}$ | $7.57 \pm 1.00^{a}$ | $5.47 \pm 0.97^{b}$ | $5.60 \pm 0.81^{b}$ | $7.53 \pm 1.11^{a}$ |
| | 1 | $4.73 \pm 0.58^{c}$ | $7.97 \pm 1.22^{a}$ | $6.97 \pm 1.07^{b}$ | $6.53 \pm 1.04^{b}$ | $6.93 \pm 1.11^{b}$ |
| | 2 | $4.87 \pm 0.57^{d}$ | $7.90 \pm 0.96^{a}$ | $7.00 \pm 1.11^{b}$ | $6.17 \pm 0.91^{c}$ | $7.27 \pm 0.69^{ab}$ |
| | 3 | $4.30 \pm 0.84^{c}$ | $7.90 \pm 0.84^{a}$ | $7.27 \pm 1.01^{ab}$ | $6.73 \pm 0.94^{b}$ | $7.73 \pm 1.17^{a}$ |
| Salt brine for cooking | 0 | $4.67 \pm 0.61^{c}$ | $6.97 \pm 1.75^{a}$ | $5.17 \pm 0.95^{bc}$ | $7.73 \pm 1.48^{a}$ | $5.80 \pm 1.42^{b}$ |
| | 1 | $4.90 \pm 0.55^{c}$ | $7.97 \pm 1.03^{a}$ | $6.17 \pm 0.65^{b}$ | $5.93 \pm 0.83^{b}$ | $8.00 \pm 0.87^{a}$ |
| | 2 | $4.97 \pm 0.18^{d}$ | $8.23 \pm 0.73^{a}$ | $6.10 \pm 1.09^{c}$ | $6.00 \pm 0.87^{c}$ | $7.57 \pm 0.94^{b}$ |
| | 3 | $4.87 \pm 0.51^{e}$ | $8.00 \pm 0.59^{b}$ | $6.03 \pm 0.72^{d}$ | $8.77 \pm 0.43^{a}$ | $6.77 \pm 0.57^{c}$ |

The score of difference from control ranged from 1 (very much milder color) to 5 (no difference from control) to 9 (very much darker color). $KIO_3$ instead of KI was used with ferrous lactate and ferrous sulfate in fish sauce and salt brine for cooking, respectively. Means within the same row with different superscripts are significantly different from each other ($p < .05$).

TABLE 7. Comments made by a fish sauce expert on the sensory quality of the double-fortified fish sauce and mixed fish sauce produced at the industrial level

| Product | Fe+I | Preparation | Comment on sensory quality |
|---|---|---|---|
| Fish sauce | Ferrous sulfate + KI | Easy | Sour, cockroach excreta aroma |
| | NaFeEDTA + KI | Difficult | Not sour, banana leaf aroma |
| | Ferric ammonium citrate + KI | Medium | Not sour, no off-aroma |
| | Ferrous lactate + $KIO_3$ | Difficult | Not sour, chemical tincture aroma |
| Mixed fish sauce | Ferrous sulfate + KI | Easy | Not sour, fishy aroma after swollen |
| | NaFeEDTA + KI | Difficult | Sour, no off-aroma |
| | Ferric ammonium citrate + KI | Medium | Sour, slightly off-aroma |
| | Ferrous lactate + KI | Difficult | Strong sour, metallic aroma |

Fewer than 10% of the dishes that were cooked with fortified fish sauce products differed from normal in their sensory characteristics. The difference was greatest in the products with ferrous sulfate as the iron fortificant, whereas the product with ferric ammonium citrate showed the least difference. Since ferrous sulfate had the highest potential for national implementation (table 8), the dishes cooked with products fortified with ferrous sulfate (and which the subjects had identified as different from normal by more than 25%) were cooked again in the laboratory. Twenty-four dishes needed to be cooked with fish sauce fortified with ferrous sulfate plus potassium iodide, and only 10 were found to be different (mainly by having a darker color). Only 15 dishes needed to be cooked with mixed fish sauce fortified with ferrous sulfate plus potassium iodide, and only two of these were found to be different from normal. Table 10 reports the results from the home-use test questionnaire that indicated the comments on the sensory acceptability of fish sauce and mixed fish sauce fortified with the nutrients studied. Most of the double-fortified products were rated as acceptable to highly acceptable.

TABLE 8. Cost of fortificants and processing aid used in the preparation of double-fortified fish sauce products

| Fortificants | Cost of fortificant[a] |
|---|---|
| Ferrous sulfate + KI or $KIO_3$ | 0.13 |
| NaFeEDTA + KI | 0.62 |
| Ferric ammonium citrate + KI | 2.73 |
| Ferrous lactate + $KIO_3$ or KI | 0.83 |

*a.* Cost in baht per bottle (750 ml); 42 baht = US$1. Cost includes iron and iodine fortificants and citric acid.

## Conclusions

Double fortification at one-third of the Thai RDI per serving (15 ml) of fish sauce, mixed fish sauce, and salt brine for cooking was feasible with the use of ferrous sulfate, NaFeEDTA, ferric ammonium citrate, or ferrous lactate as the iron fortificant and with potassium iodide or iodate as the iodine source. However, the most promising for national implementation were the double-fortified products with ferrous sulfate as the iron fortificant, because they were lowest in cost. This study has identified these products as the most beneficial and cost-effective and thus as having the potential for incorporation into a national micronutrient prevention program in Thailand, as well as other countries in the south and east Asian region that are affected by iodine-deficiency disorders and iron-deficiency anemia, and in which fish sauce and its products are routinely consumed.

TABLE 9. Number (%) of dishes that had different sensory characteristic mentioned by the subjects who used double–fortified fish sauce and mixed fish sauce for cooking during the home-use test[a]

| Product | Total no. of recipes | Total no. of dishes | Fortificants | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | | 2 | | 3 | | 4 | |
| | | | N | D | N | D | N | D | N | D |
| Fish sauce | 433 | 2,355 | 493 (91.8) | 44 (8.2) | 526 (94.1) | 33 (5.9) | 587 (94.7) | 33 (5.3) | 598 (93.6) | 41 (6.4) |
| Mixed fish sauce | 344 | 1,676 | 422 (92.7) | 33 (7.3) | 390 (93.3) | 28 (6.7) | 400 (98.8) | 5 (1.2) | 376 (94.5) | 22 (5.5) |

*a.* 1, Ferrous sulfate + KI; 2, NaFeEDTA + KI; 3, ferric ammonium citrate + KI; 4, ferrous lactate + $KIO_3$ for fish sauce, and ferrous lactate + KI for mixed fish sauce; N, normal characteristic; D, different characteristic from normal.

TABLE 10. Results of home-use sensory acceptability test of fish sauce and mixed fish sauce double-fortified with different sources of iron and iodine[a]

| Comment | Frequency | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | |
| | Fs | MFs | Fs | MFs | Fs | MFs | Fs | MFs |
| Excellent (similar to normal fish sauce) | 16 | 8 | 14 | 11 | 16 | 10 | 14 | 15 |
| Acceptable | 42 | 36 | 42 | 33 | 37 | 31 | 40 | 26 |
| No comment | 1 | 0 | 4 | 1 | 3 | 2 | 2 | 2 |
| Needs more improvement | 3 | 4 | 4 | 0 | 2 | 2 | 3 | 1 |
| Absolutely unacceptable | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 63 | 48 | 64 | 45 | 58 | 45 | 59 | 45 |

*a.* Fs, Fish sauce; MFs, mixed fish sauce; 1, ferrous sulfate + KI; 2, NaFeEDTA + KI; 3, ferric ammonium citrate + KI; 4, ferrous lactate + $KIO_3$ for fish sauce, and ferrous lactate + KI for mixed fish sauce.

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