ORIGINAL ARTICLE

Heme and Nonheme Iron Content of Animal Products Commonly Consumed in Thailand

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When estimating the iron bioavailability of a meal, the amount and type of meat consumed should be considered; therefore, animal products commonly consumed in Thailand were analyzed for iron attached to hemoglobin (heme iron) and other iron compounds (nonheme iron). Conventional household cooking methods, i.e., blanching, boiling and steaming, were used for sample preparation. The results showed that cooked chicken breast and drumsticks contained small amounts of heme iron (0.1 and 0.3 mg/100 g) and nonheme iron (0.3 and 0.6 mg/100 g). Heme and nonheme iron in cooked beef loin was found to be 1.1 and 1.3 mg/100 g, respectively. Liver is a good source of iron, particularly pork liver (12.6 mg/100 g), with approximately 2.3 mg/100 g of heme iron. Cooked blood curds from pork and chicken were the best sources of heme iron; the average was 9.2 and 15.4 mg/100 g, respectively. Cooked meatballs and sausage products contained only small amounts of heme and nonheme iron, ranging from trace to 0.3 and 0.2 to 0.5 mg/100 g, respectively. A good source of total and heme iron was also found in cooked shellfish, especially steamed green mussels and blanched cockle with approximately 14.7 and 17.7 mg/100 g for total iron, and 4.0–9.1 mg/100 g for heme iron, respectively. Of the animal products analyzed in this study and commonly eaten by Thai people, cooked blood curds were determined to be the richest source of dietary heme iron.

Key Words: heme; nonheme iron; animal product; boil; blanch; steam.

INTRODUCTION

Iron deficiency is one of the world's most common disorders that occurs when the intake amount of iron available is insufficient to meet an individual's nutritional needs. An estimation from the literature review indicates that over 2.5 billion people in developing countries suffer from iron deficiency and more than half of them are anemic (Oppenheimer, 2001). Accumulating evidence of iron deficiency anemia in developing countries has demonstrated that the amount of iron potentially available from food depends not only upon the amount of iron supplied but also on the form of iron and the composition of the diet which is consumed (Monsen, 1988). Dietary iron presents in food in two forms as heme and nonheme iron. Heme iron is that derived from hemoglobin and nonheme iron is all the other compounds present in a food. Although plant materials contain only nonheme iron, animal products contain both heme and nonheme iron. Heme iron is considered to be nutritionally important as it is higher in bioavailability ($>15\%$) than nonheme iron ($<5\%$) (Kalpalathika *et al*., 1991). Furthermore, its bioavailability is not greatly affected by other dietary components (Carpenter and Mahoney, 1992). However, the cooking process involved can decrease the amount of heme iron concentration in food (Clark *et al*., 1997). Therefore, the information on heme and nonheme iron content and the effect of cooking process upon their concentration in foods are necessary for predicting the total available iron in a meal using the mathematical model developed by Monsen *et al*. (1978). Unfortunately, there is little information regarding heme and nonheme iron values in animal products, particularly in the Thai Food Composition Table (Ministry of Public Health, Thailand, 1992; Institute of Nutrition, Mahidol University, 1999). The objective in this study was to determine heme and nonheme iron content in raw and cooked animal products (beef, pork, poultry, fish and seafood) that are commonly consumed in Thailand.

MATERIALS AND METHODS

Sample Collection

All animal products used in this study were selected based on the Fourth National Nutrition Survey of Thailand in 1995 which indicated animal products commonly consumed in Thailand as shown in Table 1 (Ministry of Public Health, 1995). From January to December 1999, all the samples were bought fresh from five representative markets in Bangkok area. At each market, 0.5–1 kg samples were purchased from three representative outlets. In addition, three samples (0.5–1 kg) of commercial meatballs and sausages from five different brands were bought from two representative supermarkets in Bangkok. Samples were homogenized individually and analyzed on the same day of sample preparation.

Sample Preparation and Cooking

Meats, cooked porcine blood curds, seafood and fish were washed with tap water several times to remove adhering slime and blood. They were then prepared individually using common household practices, i.e., eviscerating, descaling, deboning and beheading. The edible parts of each sample were separated and washed again with deionized distilled water, and drained on a stainless sieve until dry. Each sample was then divided into two portions. One portion was analyzed as a fresh sample and the other portion was prepared and cooked by either boiling, steaming or blanching according to common household methods (Table 1). The drained samples, fresh or cooked, were individually homogenized in an electrical blender (Moulinex Masterchef model 375).

Heme and Nonheme Iron Analysis

The homogenized sample of each fresh and cooked food was individually analyzed in triplicate for moisture, heme and nonheme iron content. The moisture content was

TABLE 1

Animal products commonly consumed in Thailand[1,2]

Common name	No. of sample	Moist (%)	Cooking time (min)	Scientific name
Meat products				
Beef loin, raw	15	76.4		*Bos taurus*
Beef loin, boiled	15	61.1	10	*Bos taurus*
Chicken blood curd, raw[3]	15	92.7		*Gallus domesticus*
Chicken blood curd, boiled[3]	15	92.1	1	*Gallus domesticus*
Chicken blood curd, boiled[3]	15	91.7	3	*Gallus domesticus*
Chicken breast, raw	15	76.5		*Gallus domesticus*
Chicken breast, boiled	15	70.2	5	*Gallus domesticus*
Chicken drumsticks, raw	15	75.5		*Gallus domesticus*
Chicken drumsticks, boiled	15	69.9	18–20	*Gallus domesticus*
Chicken liver, raw	15	76.4		*Gallus domesticus*
Chicken liver, boiled	15	72.5	5–6	*Gallus domesticus*
Pork blood curd, raw[3]	15	92.8		*Sus scrofa*
Pork blood curd, boiled[3]	15	91.7	1	*Sus scrofa*
Pork blood curd, boiled[3]	15	90.5	3	*Sus scrofa*
Pork liver, raw	15	72.9		*Sus scrofa*
Pork liver, boiled	15	68.7	8	*Sus scrofa*
Pork loin, raw	15	73.7		*Sus scrofa*
Pork loin, boiled	15	66.6	5–7	*Sus scrofa*
Pork tenderloin, raw	15	75.7		*Sus scrofa*
Pork tenderloin, boiled	15	68.9	5	*Sus scrofa*
Processed meat products: meatballs and sausages[4]				
Beef ball, raw[4]	15	73.2		—
Beef ball, boiled[4]	15	72.9	3	—
Chicken ball, raw[4]	15	60.5		—
Chicken ball, boiled[4]	15	61.4	3	—
Fish ball, raw[4]	15	81.7		—
Fish ball, boiled[4]	15	81.7	3	—
Pork ball, raw[4]	15	71.9		
Pork ball, boiled[4]	15	71.0	3	
Non-smoked chicken sausage, raw[4]	15	62.7		—
Non-smoked chicken sausage, boiled[4]	15	61.7	3	—
Non-smoked pork sausage, raw[4]	15	61.4		—
Non-smoked pork sausage, boiled[4]	15	60.8	3	—
Smoked chicken sausage, raw[4]	15	61.0		—
Smoked chicken sausage, boiled[4]	15	59.9	3	—
Smoked pork sausage, raw[4]	15	60.1		—
Smoked pork sausage, boiled[4]	15	59.3	3	—
Freshwater fish				
Freshwater catfish, raw	15	72.4		*Clarias macrocephalus*
Freshwater catfish, steamed	15	69.6	15	*Clarias macrocephalus*
Nile tilapia, raw	15	77.7		*Oreochromis niloticus*
Nile tilapia, steamed	15	73.1	15	*Oreochromis niloticus*
Striped snake-head fish, raw	15	76.3		*Channa striatus*
Striped snake-head fish, steamed	15	72.4	15	*Channa striatus*
Marine fish				
Short-bodied mackerel, raw	15	74.4		*Rastrelliger brachysoma*
Short-bodied mackerel, steamed[5]	15	71.3	2.5	*Rastrelliger brachysoma*
Steamed mackerel[6]	15	65.6		*Rastrelliger brachysoma*
Red snapper, raw	15	79.1		*Lutianus*
Red snapper, steamed	15	73.1	15	*Lutianus*
Prawn				
Giant tiger prawn, raw	15	80.1		*Penaeus monodon*
Giant tiger prawn, boiled	15	73.9	2.5	*Penaeus monodon*

TABLE 1 (*continued*)

Common name	No. of sample	Moist (%)	Cooking time (min)	Scientific name
Shellfish				
Baby clam, steamed	15	74.3	7	*Paphia undulata*
Cockle, blanched	15	87.7	1	*Arca granosa*
Cockle, blanched	15	83.6	3	*Arca granosa*
Green mussel, raw	15	87.7		*Perna viridis*
Green mussel, steamed	15	73.1	10	*Perna viridis*
Squid				
Splendid squid, raw	15	86.9		*Loligo formosana*
Splendid squid, boiled	15	79.9	3	*Loligo formosana*

[1]Food Composition Table.
[2]The Fourth National Nutrition Survey of Thailand by the Nutrition Division, Department of Health, Ministry of Public Health, Thailand, 1992 and 1995, respectively.
[3]Chicken and pork blood curd made from a mixture of fresh blood and water, and coagulated by heat (already prepared from slaughterhouse).
[4]*Processed meat products: meatballs and sausages* are ready-to-eat products, which have been cooked before distribution (made from a mixture of meat and starch and left to boil in a pan of water; smoking liquid is added to the smoking sausage products).
[5]Short-bodied mackerel, steamed; no adding condiment (salt solution) to the fish.
[6]*Steamed mackerel*: Sodium chloride solution (salt) is added to the fish before steaming (already prepared from the commercial).

determined by drying the sample in an hot air oven at $100 \pm 5°C$ until constant weight was obtained (981.10; AOAC, 1990). Heme iron was determined by using the acidified acetone extraction of Hornsey (1956) and Clark *et al.* (1997). The heme iron concentration in the sample was calculated by using a heamatin standard curve (1 µg of heamatin per gram of meat is equal to 0.0882 µg iron) (Merck, 1989). Nonheme iron was determined by the Rhee method (Rhee and Ziprin, 1987).

Quality Control

The quality of the results in each determination of moisture, heme and nonheme iron was controlled by simultaneous analysis of in-house control material consisting of freeze-dried liver prepared in our laboratory and heamatin from bovine blood (#3505) bought from Sigma. The control chart for the value of moisture, heme and nonheme iron was separately prepared using more than 30 single samples of in-house control material. Values within ± 2 S.D. were achieved for the control material of each set of analysis and percent recovery ranged from 95 to 97.

Statistical Analysis

For descriptive statistics, the mean standard deviation was computed for heme and nonheme iron content. All computations were performed by using SPSS for Windows version 9.01 software.

RESULTS

Heme Iron Content Analysis

Heme iron concentrations of raw and cooked food samples from animal products are shown in Table 2 as mean $\pm$S.D. mg/100 g of the edible portion.

TABLE 2

Heme and nonheme iron, total iron and percent heme iron content of raw and cooked animal products (mg/100 g of edible portion)[1]

Common name	Time (min)	Heme iron	Nonheme iron	Total iron[2]	Heme iron (%)
Meat products					
Beef loin, raw		1.3 ± 0.6	0.7 ± 0.3	2.1 ± 0.3	66.2 ± 7.0
Beef loin, boiled	10	1.1 ± 0.5	1.3 ± 0.5	2.4 ± 0.5	45.0 ± 4.5
Chicken blood curd, raw[3]		9.2 ± 1.9	2.4 ± 0.9	11.6 ± 1.5	79.3 ± 2.0
Chicken blood curd, boiled[3]	1	9.0 ± 1.9	2.8 ± 1.2	12.1 ± 1.3	76.3 ± 1.4
Chicken blood curd, boiled[3]	3	8.7 ± 1.9	3.4 ± 1.4	12.8 ± 1.5	72.2 ± 2.4
Chicken breast, raw		0.1 ± 0.0	0.3 ± 0.1	0.4 ± 0.0	30.0 ± 4.6
Chicken breast, boiled	5	0.1 ± 0.0	0.3 ± 0.1	0.4 ± 0.0	23.4 ± 2.9
Chicken drumsticks, raw		0.3 ± 0.1	0.6 ± 0.1	0.9 ± 0.1	33.3 ± 6.5
Chicken drumsticks, boiled	18–20	0.3 ± 0.1	1.0 ± 0.2	1.2 ± 0.2	22.4 ± 3.9
Chicken liver, raw		3.1 ± 0.6	6.7 ± 1.0	9.9 ± 0.8	31.1 ± 7.0
Chicken liver, boiled	5–6	2.6 ± 0.7	8.0 ± 1.3	10.6 ± 1.2	24.2 ± 5.3
Pork blood curd, raw[3]		15.4 ± 1.9	2.6 ± 0.9	18.0 ± 1.5	85.6 ± 6.3
Pork blood curd, boiled[3]	1	15.0 ± 1.9	3.2 ± 0.9	18.1 ± 1.8	81.9 ± 4.8
Pork blood curd, boiled[3]	3	14.8 ± 2.1	4.4 ± 1.8	19.4 ± 2.5	76.3 ± 6.7
Pork liver, raw		2.9 ± 0.5	9.4 ± 2.4	12.3 ± 3.5	23.3 ± 2.8
Pork liver, boiled	8	2.3 ± 0.3	10.3 ± 2.6	12.6 ± 2.5	18.2 ± 3.4
Pork loin, raw		1.3 ± 0.6	0.7 ± 0.3	2.1 ± 0.3	66.2 ± 7.0
Pork loin, boiled	5–7	1.1 ± 0.5	1.3 ± 0.5	2.4 ± 0.5	45.0 ± 4.5
Meat products					
Pork tenderloin, raw		0.3 ± 0.1	0.4 ± 0.1	0.8 ± 0.1	40.0 ± 8.6
Pork tenderloin, boiled	5	0.3 ± 0.1	0.6 ± 0.1	0.8 ± 0.2	30.9 ± 4.1
Processed meat products: meatballs and sausages[4]					
Beef ball, raw[4]		0.3 ± 0.2	1.1 ± 0.5	1.4 ± 0.6	23.6 ± 8.1
Beef ball, boiled[4]	3	0.3 ± 0.1	1.2 ± 0.5	1.4 ± 0.5	19.1 ± 7.2
Chicken ball, raw[4]		0.1 ± 0.0	0.7 ± 0.1	0.8 ± 0.3	16.3 ± 9.8
Chicken ball, boiled[4]	3	0.1 ± 0.0	0.8 ± 0.1	0.9 ± 0.3	8.8 ± 3.5
Fish ball, raw[4]		0.1 ± 0.0	0.8 ± 0.2	0.9 ± 0.2	5.6 ± 3.4
Fish ball, boiled[4]	3	Trace	0.9 ± 0.3	0.9 ± 0.7	3.4 ± 1.2
Pork ball, raw[4]		0.2 ± 0.0	0.7 ± 0.2	0.9 ± 0.4	16.7 ± 5.6
Pork ball, boiled[4]	3	0.1 ± 0.0	0.7 ± 0.2	0.8 ± 0.3	14.3 ± 6.9
Non-smoked chicken sausage, raw[4]		0.3 ± 0.1	0.5 ± 0.1	0.8 ± 0.4	41.3 ± 10.2
Non-smoked chicken sausage, boiled[4]	3	0.2 ± 0.0	0.5 ± 0.1	0.8 ± 0.3	31.6 ± 8.6
Non-smoked pork sausage, raw[4]		0.4 ± 0.0	1.4 ± 0.4	1.9 ± 0.4	23.2 ± 8.8
Non-smoked pork sausage, boiled[4]	3	0.4 ± 0.1	1.5 ± 0.3	1.9 ± 0.5	19.5 ± 8.9
Smoked chicken, raw[4]		0.4 ± 0.1	0.6 ± 0.1	1.0 ± 0.2	39.0 ± 8.2
Smoked chicken, boiled[4]	3	0.3 ± 0.1	0.7 ± 0.3	1.0 ± 0.3	33.7 ± 6.5
Smoked pork sausage, raw		0.6 ± 0.1	1.1 ± 0.5	1.7 ± 0.3	35.5 ± 7.7
Smoked pork sausage, boiled	3	0.5 ± 0.1	1.1 ± 0.6	1.6 ± 0.4	32.5 ± 9.9
Freshwater fish					
Freshwater catfish, raw		0.7 ± 0.1	1.2 ± 0.1	1.9 ± 0.2	36.8 ± 3.4
Freshwater catfish, steamed	15	0.5 ± 0.2	1.3 ± 0.2	1.8 ± 0.3	27.9 ± 5.4
Nile tilapia, raw		0.4 ± 0.1	0.7 ± 0.2	1.1 ± 0.3	36.6 ± 4.9
Nile tilapia, steamed	15	0.3 ± 0.1	0.9 ± 0.2	1.2 ± 0.2	27.1 ± 5.0
Striped snake-head fish, raw		0.4 ± 0.1	0.7 ± 0.1	1.1 ± 0.2	36.6 ± 3.7
Striped snake-head fish, steamed	15	0.3 ± 0.1	0.9 ± 0.2	1.2 ± 0.3	23.6 ± 2.5
Marine fish					
Red snapper, raw		0.4 ± 0.1	0.9 ± 0.2	1.2 ± 0.5	33.3 ± 6.2
Red snapper, steamed	15	0.2 ± 0.1	1.2 ± 0.2	1.4 ± 0.5	14.8 ± 5.8
Short-bodied mackerel, raw	15	0.8 ± 0.1	1.2 ± 0.5	2.0 ± 0.5	40.0 ± 9.5
Short-bodied mackerel, steamed[5]	15	0.6 ± 0.1	1.9 ± 0.2	2.5 ± 0.6	25.0 ± 3.0
Steamed mackerel[6]	15	0.9 ± 0.3	1.4 ± 0.3	2.4 ± 0.3	37.7 ± 7.0

TABLE 2 (*continued*)

Common name	Time (min)	Heme iron	Non-heme iron	Total iron[2]	Heme iron (%)
Prawn					
Giant tiger prawn, raw		0.1 ± 0.0	0.4 ± 0.1	0.5 ± 0.1	20.0 ± 4.0
Giant tiger prawn, boiled	2.5	0.1 ± 0.0	0.6 ± 0.1	0.7 ± 0.1	10.5 ± 5.0
Shellfish					
Baby clam, steamed	7	2.5 ± 0.7	12.0 ± 2.6	15.0 ± 5.3	16.7 ± 5.6
Cockle, blanched	1	9.1 ± 1.2	8.7 ± 2.0	17.7 ± 3.6	51.0 ± 12.0
Cockle, blanched	3	5.3 ± 0.8	12.3 ± 1.3	17.6 ± 2.8	30.1 ± 10.2
Green mussel, raw		5.0 ± 1.7	7.2 ± 1.4	12.3 ± 2.0	40.7 ± 7.5
Green mussel, steamed	10	4.0 ± 0.8	10.7 ± 1.4	14.7 ± 3.0	27.3 ± 8.8
Squid					
Splendid, raw		0.1 ± 0.0	0.4 ± 0.1	0.5 ± 0.1	20.0 ± 4.0
Splendid, boiled	3	0.1 ± 0.0	0.6 ± 0.1	0.7 ± 0.1	10.5 ± 5.0

[1]Each value is a mean ± S.D. of 15 samples analyzed in triplicate.
[2]Total iron: obtained from the summation of heme and nonheme iron concentration.
[3]Chicken and pork blood curd made from a mixture of fresh blood and water, and coagulated by heat (already prepared from slaughterhouse).
[4]*Processed meat products: meatballs and sausages* are ready-to-eat products, which have been cooked before distribution (made from a mixture of meat and starch and left to boil in a pan of water; smoking liquid is added to the smoking sausage products).
[5]Short-bodied mackerel, steamed; no adding the condiment (salt solution) to the fish.
[6]*Steamed mackerel*: sodium chloride solution (salt) is added to the fish before steaming (already prepared from the commercial).

Heme Iron Content in Meat Products

Analysis of the data showed that raw and boiled pork and chicken liver were good sources of heme iron (2.6–2.9 for raw liver and 2.3–2.6 mg/100 g for boiled livers). Heme iron concentration in raw and boiled beef was found to be 1.3 and 1.1 mg/100 g, respectively. The results of comparison of meat muscles showed that both raw and boiled pork and chicken muscle were lower in heme iron value (0.1–0.4 mg/100 g) than beef muscle (1.1–1.3 mg/100 g). The lowest values of heme iron were observed in raw and boiled chicken breast (0.1 mg/100 g). Cooked blood curds were found to be rich sources of heme iron concentration, ranging from 9.0 to 15.4 mg/100 g. When the boiling time was increased from 1 to 3 min, heme iron concentration in cooked blood curd slightly decreased by approximately 3 and 7%, respectively. Comparisons of results of meat products showed that cooked blood curds are better sources of total and heme iron than meat muscles.

Heme Iron Content in Processed Meats

Processed meats such as boiled meatballs and sausage products showed a wide variation of heme iron content which ranged from trace to 0.3 for meatballs and from 0.2 to 0.6 mg/100 g for sausage products.

Heme Iron Content in Shellfish and Marine and Freshwater Fish

Among shellfish, blanched and steamed shellfish were found to be good sources of heme and total iron, ranging from 2.5 to 9.1 mg/100 g for heme iron and from 15 to

18 mg/100 g for total iron, respectively. Steamed and uncooked fish (marine and freshwater fish) had similar heme iron contents which ranged from 0.2 to 0.9 mg/100 g. Among the animal food products, shellfish, particularly cockle shells (*Arca granosa*) and green mussels (*Perna viridis*), provided higher heme iron values than those of other animal products, except cooked blood curds.

Nonheme Iron Content Analysis

Nonheme iron contents of raw and cooked food samples from animal products are shown in Table 2 as mean ±S.D. mg/100 g of the edible portion.

Nonheme Iron Content in Meat Products

The results of comparisons of meat products showed that both raw and boiled pork and chicken livers had the highest nonheme iron contents, ranging from 7.0 to 10.32 mg/100 g, while cooked blood curd was found to be 2.4–4.4 mg/100 g. Comparison of raw and boiled blood curd from chicken and pork showed that nonheme iron in pork blood curd was higher than chicken blood curd by approximately 22%. When the cooking time was increased, nonheme iron content both in cooked porcine and chicken blood curd increased by approximately more than 20%. The results of comparisons of meat muscles showed that nonheme iron contents of both raw and boiled beef muscle were higher than pork and chicken muscles.

Nonheme Iron Content in Processed Meat Products

The nonheme iron content of raw and boiled meatballs and sausages ranged from 0.7 to 1.2 for meatballs and from 0.5 to 1.5 mg/100 g for sausage products and, after cooking, nonheme iron contents of boiled meatballs and sausage products were unchanged (Table 2).

Nonheme Iron Content in Shellfish, Marine and Freshwater Fish

The results of the comparison of nonheme iron values in raw and blanched shellfish, steamed marine and steamed freshwater fish, boiled prawn and squid showed that blanched cockle shell (3 min), steamed green mussel and steamed baby clam had the highest amount of nonheme iron, ranging from 7.2 to 12.3 mg/100 g. Both raw and steamed marine and freshwater fish provided moderate amounts of nonheme iron, ranging from 0.7 to 1.2 mg/100 g for raw fish and from 0.9 to 1.9 mg/100 g for steamed fish. Raw and boiled squid and giant tiger prawn had small amounts of nonheme iron. After cooking, the nonheme iron content in squid, marine and freshwater fish increased by approximately 10%, as shown in Table 2. Among the animal products, results showed that the best sources of nonheme iron were found in cooked shellfish and pork liver and chicken liver, in the range 8.0–12.3 mg/100 g.

DISCUSSION

Total, heme and nonheme iron contents in meat differ among species and vary with the type of tissue. When comparing heme and nonheme iron contents in red meat and light meat, our results showed significant differences between the two meats. Red meat muscle, such as beef, contains more heme and nonheme iron than pork and chicken muscle. This might be explained in that red meat is more supplied with blood vessels and contains more myoglobin and hemoglobin than light meat. Therefore, it would be expected to have higher concentrations of iron. Our findings are consistent with other studies (Clark *et al.*, 1997). Analysis of the data showed that both pork and chicken liver are not only the richest sources of nonheme iron but also contain the highest percentage of nonheme iron (80%) due to the storage site of iron (Hazell, 1985). A comparison of means of heme and nonheme iron values of raw meat products in this study with several previously published values demonstrated some similarities and variations (Kangsadalampai and Wattanapenpaiboon, 1987; Carpenter and Mahoney, 1992; Carpenter and Clark, 1995; Schricker *et al.*, 1982). The means of heme iron and nonheme iron values in raw meat products in this study were similar to those reported by Kangsadalampai and Wattanapenpaiboon (1987), which showed that heme and nonheme iron contents in meat products ranged from 0.1 to 14.2 mg/100 g for heme iron and from 0.5 to 9.0 mg/100 g for nonheme iron. In our study, heme iron contents of raw beef and pork loin (0.42 and 1.33 mg/100 g) were lower than those reported by Kangsadalampai and Wattanapenpaiboon (1987) (0.69 and 2.74 mg/100 g). In addition, there were differences in total iron content between our results and the Thai Food Composition Data (Ministry of Public Health, Thailand, 1992 and Institute of Nutrition, Mahidol University, 1999). Our results of total iron content for animal products, particularly meats and seafood, differed slightly from the values in the Thai Food Composition Table. However, there were no separate heme and nonheme iron values reported in those Tables. This study's total, heme and nonheme iron values do not completely agree with other published values. This lack of agreement may be due to a number of factors, including genetics, slaughter practices, different animal feed, sample preparation, seasonal variation and geographic location (Leonhardt and Wenk, 1997). Scheeder *et al.* (1994) have reported that heme iron content in veal was affected by the iron concentration of the feed. A wide variation in heme and nonheme iron content in meatballs and sausage products was observed perhaps due to the difference in the production process as well as the quality and type of meat. When comparing animal products, the results in this study interestingly showed that shellfish contained higher total and heme iron than other animal food products, except cooked blood curd. Iron bioavailability of shellfish might be expected to be higher than that of meat but it is not of much nutritional significance due to the infrequency of consumption.

Cooking processes are important because of their effect on nutrient loss. Results of this study showed that heme iron content in foods decreased during the cooking process, while nonheme iron increased. The increase of nonheme iron was derived from the alteration of hemoglobin and myoglobin structures. These findings are consistent with several observations (Ahn *et al.*, 1993; Wang and Lin, 1994). Cooking processes reduce the amount of heme iron, which is known to be the better absorbed form; however, heating processes are necessary for food safety and human digestibility. Comparison was made among the means of percent heme iron values of animal products in this study with previously published research (Cook and Monsen, 1976; Carpenter and Clark, 1995). Cook and Monsen (1976) reported that percent heme iron content ranged from 30 to 40% in raw pork and from 50 to 60% in raw beef. Kalpalathika *et al.* (1991), Carpenter and Mahoney (1992) and Carpenter and Clark (1995) reported that percent heme iron content in raw beef and chicken muscles was approximately 61% in beef and 25% in chicken muscle. Similarly, the analyzed data in this study showed that the means percent heme iron were found to be 66% for raw and 45% for cooked beef, 30–40% for raw and 30% for cooked pork, 33 for raw and 25% for cooked meat chicken, 16–50% for cooked shellfish, and 33–40% for raw fish and 14–38% for cooked fish. These results indicated that there are wide variations not only in heme and nonheme iron, and percentage of heme iron in each type of animal products, but also in total iron content. Therefore, the Monsen model which used the values of 40% for percent heme iron in meat, fish and poultry (% MFP) for evaluating or estimating iron bioavailability of individual meals, particularly in Thai foods may be an over- or underestimation (Monsen and Balintfy, 1982). Carpenter and Clark (1995) suggested that the values used in the Monsen model should not have been an unvarying 40%, but should be different for each particular type of meat consumed with a meal. Similar to Carpenter's results, our data showed that there are significant differences in the content of heme and nonheme iron in each type of animal product; therefore, when estimating the iron bioavailability of a meal, the amount and type of meat consumed should be considered.

CONCLUSIONS

When estimating the iron bioavailability of a meal, the amount and type of meat consumed should be considered. The result of this study showed that meat muscles, liver, and shellfish (cockle, green mussel), particularly blood curds of chicken and pork, are the best sources of total and heme iron values. In Southeast Asia, particularly Thailand, one of the best food sources of heme iron is cooked blood curd, which is readily available and affordable. Further research on iron bioavailability in cooked blood curd would be beneficial, especially for people in developing countries. Nutrient database developers should consider carrying heme iron as a nutrient, so iron bioavailability calculations can be facilitated.

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