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Mini review

Update of mercury in fish with a focus on its current status in Malaysia

Mohd Rosni Sulaiman*, Charmaine Ho Su Mei

School Of Food Science And Nutrition, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu Sabah, Malaysia

Corresponding author: rossulma@ums.edu.my

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ABSTRACT

Mercury poisoning is a serious threat to humans, and hence it is important to always keep up to date with current mercury levels in fish to avoid excessive accumulation of mercury. this mini review summarizes available data in the literature (2009–2013) on mercury contamination in fish with a focus on its current status in malaysia. issues on mercury in fish such as its determination and quantification, occurrence and toxicity are also discussed in this review. fish and seafood are abundant in malaysia and consumption of fish and seafood is widespread throughout the country. fish and fish products should be monitored from time to time to ensure that it is safe for human consumption. high risk groups like pregnant women and young children should avoid consuming fishes with known high level of mercury as they are more vulnerable and susceptible to mercury toxicity.

INTRODUCTION

Fish is one of the most common protein source consumed by Malaysians. This is also true in most Asian countries, especially South East Asia [1]. Fish and seafood are abundant in Malaysia and consumption of fish and seafood is widespread throughout the country. Seafood restaurants in Malaysia are also growing due to increase demands of tourist from overseas. This makes the aquaculture industry in Malaysia to have good potential for sustaining the aquatic food industry both in local and global trade [2]. Aquaculture is an important industry in Malaysia as many consumers rely on them to obtain fresh fish and seafood. Aquaculture industry not only provides food but also provide chance of employment to many people. It is a growing industry due to increased consumption of fish and seafood. However, this can also lead to some problems as fish can be a major source of trace metals bioaccumulated in them [3].

Trace metals can be found in food naturally and some are naturally required by the human body. However, long term consumption over time can accumulate harmful trace metals in the human body due to ingestion of food. Heavy metals can be transferred to human body through many ways. One of the most common pathways is through the food chain [4]. As human consume foods with trace metals, the heavy metals can slowly accumulate in the human body if it cannot be excreted. Although it may not bring any harm or effects immediately, accumulation of heavy metals can bring an effect after many years of repeated consumption as Tuzen in 2009 [5] reported that toxic elements can be very harmful even at low concentration when ingested over a long period of time. This is dangerous as the effects to the human body could be irreversible or result in fatality.

The marine ecosystem contain many organic pollutants and toxicants. Due to development, additional contamination to the marine ecosystem is widespread. Contamination with heavy metals especially is a serious problem due to their toxicity, persistence, bioaccumulation and biomagnification into the food chain [4, 6]. Contamination with toxic and heavy materials is a problem that continues to grow especially in developed countries or industries. Aquaculture is a promising industry for sustaining food supplies [2], therefore serious issues such as food toxicology has to be handled properly. It is difficult to prevent population exposure to heavy metals via fish consumption due to increased consumption of fish [7].

Contamination of fish can come from various sources. Polluted water sources such as river, ocean and sea contributes to the accumulation of heavy metals in fish. Mok and co-workers [2] reported that rapid industrialization and uncontrolled urbanisation have contributed to an alarming increase in the pollution levels of the aquatic environment. Man-made pollution contributes heavy metals released into the aquatic ecosystem [4]. This will cause accumulation of heavy metals in fish which are then transferred to human via consumption. Contamination of heavy metals in the food chain almost always follows the cyclic order: industry, atmosphere, soil, water, phytoplankton, zooplankton, fish and then human [6]. There are many sources of pollution such as waste products from the industry or domestic waste as well as increment in industrial, agricultural and recreational activities. Such activities which are observed near aquaculture farms could lead to an increase of contamination with toxic elements in the food products [2]. There are many trace metals which can be found in food like arsenic, cadmium, copper, lead, zinc and mercury. Some of these minerals are required by the human body in trace amounts. However, over a long period of time, excess accumulation occurs which results in heavy metal toxicity.

Mercury is one of the most dangerous heavy metals found in fish. It is considered to be one of the most toxic heavy metals in the environment [6]. The most common source of mercury found in humans is due to consumption of fish. As consumption of fish increases, it also increases the risk of mercury toxicity in human. Mercury can cause high toxicity even at low concentrations and it has the ability to enter into biological systems which makes it a serious environmental pollutant [1]. Mercury can be found in several forms in the environment such as mercury vapour (elemental mercury), inorganic salts and organic compounds, however, methylmercury is the most dominant form found in fish consumed by humans [8].

In light of these backgrounds, therefore, this mini review is aimed to summarize available data in the current literatures on mercury contamination in fish with a focus on its current status in Malaysia. Issues on mercury in fish such as its determination and quantification, occurrence and toxicity are also discussed.

Determination and Quantification of Mercury in Fish

Due to the nature of this heavy metal and its potential effects on human, it is highly important to assess the level of mercury in fish consumed by humans. Parts of fish used to sample are the muscle and liver tissues. Muscles in fish samples are the most commonly analysed tissues to assess mercury levels because the muscles represent the edible part of the organism associated with human health risk implications [9]. All of the papers reviewed included muscles as part of their analysis although various fish species were used. Bonsignore and co-workers [9] also reported that mercury accumulates over time more readily in liver compared to muscle tissues but muscle appears to retain mercury for a longer period of time and thus concluded that liver would only provide information on short-term exposure to mercury pollution. Hence, muscle tissues are more preferred to be used for analysis to assess possible risk of mercury toxicity in humans as the long-term exposure is of concern.

Both marine and freshwater fishes have been previously used to assess level of mercury. Types of fish that are commonly consumed in Malaysia were also included in various studies. Example of fish samples that were studied for mercury concentration are pomfret, seabass, sardine, tuna, snapper and mackerel. Most studies reported the concentration of mercury in fish as µg/g [1-6, 9].

There are several analytical techniques available for determination of trace elements in fish samples which are inductively coupled plasma optical emission spectrometry (ICP-OES), inductively coupled plasma mass spectrometry (ICP-MS), graphite furnace atomic absorption spectrometry (GFAAS) and flame atomic absorption spectrometry (FAAS). However, the most commonly used methods to determine mercury are the cold vapour atomic absorption spectrometry (CV-AAS) and cold vapour atomic fluorescence spectrometry (CV-AFS) [5]. Many studies have used the atomic absorption spectrometer to analyse total mercury content in fishes [1, 5-9]. Other methods of analysing mercury include mercury analyser [2] and the atomic fluorescence spectrometry [3]. Most of fish samples were digested prior to analysis.

Factors Affecting Mercury Accumulation in Fish

Concentration of mercury in fish depends on various factors. Accumulation of metals in fish tissues depends on ambient water concentrations, levels in prey or commercial feed, chemical uptake and elimination kinetics, chemical bioavailability, fish growth cycle, age and trophic position [3]. Other factors also include degree of pollution in water source as fish normally gets contaminated from its aquatic environments. The season also influences levels of mercury in fish as demonstrated by Saei-Dekhordi and co-workers [7]. They reported that there was a considerably higher metal content in winter which could be due to considerable rainfall which washed down the waste. The size of a fish also determines mercury accumulation. Mercury concentration in the muscles of marine fishes increases with size [9]. This is because as the size increases, there is a bigger surface area for mercury to be adsorbed into the fish.

Different fish samples would result in varying mercury concentrations. Fishes of same species but from varying countries would also produce different results in levels of mercury as the contamination level would be differing as well. Dietary intake is the predominant pathway whereby metals are accumulated in marine fishes [3]. This indicates that whatever the fish consumes has an influence on the amount of mercury. The length of fishes could also be a factor for concentrations of mercury [6].

Hence, there are many factors which could contribute to the mercury level in fishes. Certain factors could be controlled such as pollution level and season of fish harvesting. If high mercury concentrations have been known to occur during a certain season, high-risk groups should be advised against consuming fishes with known higher than usual mercury content. Precautionary steps could be taken if each of the factors are understood on the mechanism of mercury accumulation in fishes. All these factors are further discussed based on results obtained from various studies in the next sub-topic.

Occurrence of Mercury in Fish

In Malaysia, Mok and co-workers [2] reported that mercury concentration was less than 0.1µg/g in most species except pomfret and tiger grouper. The pomfret was collected from a site in Kota Kinabalu, Sabah, whereas the tiger grouper samples were collected from a few sites in Sabah namely Kota Kinabalu, Sandakan, Lahad Datu, Tawau and Semporna [2]. However, other species collected at these same sites showed lower mercury concentrations. This shows that there is variability between mercury accumulations in different fish species.

In Malaysia, mercury concentrations were found to be significantly higher in Kota Kinabalu, Sabah and Serdang, Selangor compared to other sampling sites [2]. High mercury concentrations in fish could be due to heavy industrial pollution and population concentrations in that area [2]. Rapid industrialization and urbanisation causes an increment in contaminants in the area and consequently causes increased heavy metal concentration in fish.

The muscle tissue of long tail tuna and mackerel recorded high total mercury concentration of 0.50±0.71µg/g and 0.45±0.56µg/g, respectively [1]. This study was conducted in Selangor, Malaysia. It can be seen that mercury concentration is higher in fishes collected by Hajeb and co-workers [1] compared to Mok and co-workers [2] although both studies are on Malaysian shores. The highest mercury concentration was recorded in pomfret with a reading of 0.155±0.009µg/g. Fishes collected from Selangor recorded readings of 0.043±0.003µg/g (catfish), 0.099±0.007µg/g (tilapia), 0.075±0.010µg/g (jade perch) and 0.069±0.007µg/g (seabass) [2]. This showed that although there were similar locations by both studies, the mercury concentrations were still lower in fish samples collected by Hajeb and co-workers [1]. There was a significant difference ($p<0.0001$) between fish species in terms of mercury concentrations [6]. Hence, the differences in mercury concentration could be due to different fish samples as different species have different metabolism and accumulation of heavy metals. It does not necessarily indicate that the site of collection has more contamination. More studies will be required to understand the factors contributing to the high mercury concentration collected.

Using seabass as a comparison, mercury concentrations in different sites in Malaysia can be observed. Most sites recorded almost similar readings except for Kota Kinabalu, Sabah and Port Dickson, Negeri Sembilan which recorded mercury concentrations in muscle of seabass of 0.140±0.007µg/g and 0.227±0.012µg/g, respectively [2]. High mercury concentration at these two sites could indicate high mercury contamination in these areas. It could be due to development activities as well as high population concentration causing high contamination. A similar trend can be observed in concentrations recorded in the liver tissues of seabass. The concentrations recorded from fish samples in Kota Kinabalu and Port Dickson were also highest with readings of 0.504±0.002µg/g and 0.197±0.0012µg/g, respectively [2]. This finding is consistent with findings obtained from muscle tissues of the fish.

We can also compare mercury concentrations between West and East Malaysia using African catfish, seabass and tilapia as fish samples. The average mercury concentrations recorded in these fishes from East Malaysia are as follows: 0.138±0.014µg/g (African catfish), 0.060±0.005µg/g (seabass) and 0.057±0.004µg/g (tilapia) whereas the results for West Malaysia were as follows: 0.023±0.002µg/g (African catfish), 0.085±0.019µg/g (seabass) and 0.038±0.004µg/g (tilapia) [2]. It can be observed that East Malaysia recorded higher average mercury concentrations in all fish samples except for seabass than West Malaysia. Rapid development has begun in recent years in East Malaysia and this could be a factor in increased mercury concentration in fishes over there. The higher average concentration could also be due to results from Kota Kinabalu, Sabah which recorded high mercury readings and therefore could influence the average concentrations as well.

In China, various sites were used to measure mercury concentration in farmed fish. Two sites were studied namely, Daya Bay and Hailing Bay and it was found that the concentration of mercury in seawater was higher in Daya Bay which may suggest that seawater is not the major source of mercury accumulated in the farmed fish as the average mercury concentration of fishes was higher in Hailing Bay than Daya Bay [3]. The same fish species were sampled in both sites which are the pompano and snapper therefore the differences in concentration could not be due to type of fish. This observation shows that there are many factors which contribute to mercury concentration in fishes and not one single factor can be singled out as the main cause. The total average concentrations of mercury in fish muscle were 0.18±0.11µg/g and 0.22±0.14µg/g for pompano and snapper, respectively [3]. In both sites, pompano recorded lower mercury concentrations. Pompano also recorded consistent trace metal readings with those in sediment whereas the snapper showed inconsistent readings which could mean that the pompano is more sensitive to the variation of trace metal concentrations in the environment compared to the snapper [3]. In Turkey, mercury in fish samples ranged from 0.025-0.084µg/g indicating lower mercury concentrations compared to the samples from China [5]. The mercury concentrations recorded are comparable with results from Malaysia.

The muscle tissue of sardines recorded the lowest mercury concentration (0.00±0.02µg/g) [1]. This is one of the lowest mercury concentration obtained in all fish samples and even from studies conducted by other researchers. Vieira and co-workers [6] also reported similar results as sardine also recorded the lowest mercury concentration compared to other species with a reading of 0.0182±0.0050µg/g. Both studies recorded mercury levels in muscle samples. Total mercury content is lowest in sardine and this could be due to the diet of the fish which consists primarily of water plants and plankton [1]. Qiu and co-workers [3] reported average mercury concentration of 0.08µg/g in sardines from Spain which is the second lowest average mercury concentration compared to other fish samples. This finding is consistent with previous findings.

Carnivorous fishes would accumulate more mercury as it consumes small fishes who already have mercury concentrations in them contributing to an even higher amount of mercury. This shows that the trophic position occupied by fishes can determine the amount of mercury accumulated. This is true as Hajeb and co-workers [1] reported that the muscle of predatory fishes contained significantly higher ($p<0.05$) content of total mercury compared to non-predatory fishes. Similar trend of the results was also reported [8] with the median mercury concentration of all carnivorous fish is higher than all planktivorous fish with median concentrations of 0.39nmol/g and 0.24nmol/g, respectively.

However, fish products in Saudi Arabian markets produced different results. Fishes collected for study included sardine, grouper and blackspot emperors. Alturiqi and Albedair [4] reported that sardines collected from East, North and South districts of Saudi Arabia had mercury concentrations of 0.055±0.011µg/g, 0.027±0.020µg/g and 0.041±0.008µg/g, respectively, whereas the mercury concentration found in grouper were as follows: 0.016±0.002µg/g (East), 0.036±0.003µg/g (North) and 0.043±0.006µg/g (South) and the means for blackspot emperors were 0.014±0.003µg/g (East), 0.024±0.002µg/g (North) and 0.026±0.002µg/g (South). This finding is inconsistent with the other findings as both grouper and blackspot emperors are carnivorous fishes but have also demonstrated lower mercury concentrations in certain districts as compared to sardines.

Mackerel is also a fish commonly consumed by Malaysians as they are also sold in cans for convenience or frozen. Mean of mercury concentrations in chub mackerel and horse mackerel found in the Atlantic Ocean were reported as 0.0956±0.1592µg/g and 0.1715±0.0857µg/g, respectively [6]. These values are higher than most of the fish samples recorded in Malaysia. Studies in Malaysia did not include mackerel fish as a sample. This could be because most mackerels found in Malaysia are imported. Hence, it is important to monitor levels of mercury of fishes from outside of Malaysia as well.

Mercury concentration was higher in pelagic fishes than benthopelagic species [7]. Pelagic fishes are fishes which live near the surface of the water whereas benthopelagic species are fishes that live just above the bottom feeding mostly on zooplanktons. Although these samples were obtained from the same site, its variation in mercury concentration could be due to their habitat in the water. The differences in mercury concentration could be due to the fishes' feeding habits as well.

Few studies also compared mercury concentrations between the muscle and liver tissues. Although muscle tissues are favoured in terms of assessing risk of toxicity in humans, liver tissues can be used to assess short-term exposure of fish to mercury. It could give an overview of recent mercury contamination status in sample collection sites. Hajeb and co-workers [1] reported that mercury content was higher in liver than muscle tissues in Selangor, Malaysia. Similarly, it is also a study [9] reported that the total mercury concentration was found to be 1.5 to 6 times higher in liver than those measured in muscles of the same fish species. Concentration of mercury in liver was higher than in muscle due to the role of liver in detoxification [2]. This then contributes to the higher amount accumulated in the liver of fishes regardless of the sampling site. Bonsignore and co-workers [9] analysed fishes from Southern Italy and found that mercury concentrations were ranged from 0.021-2.709µg/g in muscles and 0.029-9.720µg/g in liver tissues. It can be observed that liver tissues provide a wider range of concentration compared to muscles. Also, the highest concentration in liver also exceeded the maximum value obtained from muscle tissues. Another observation obtained from comparing muscle and liver tissues is that there was a significant difference in mercury concentration of liver tissues among different fish species, however, no significant difference was found for muscle tissues [1]. This could be due to different detoxification and metabolism rates in the liver of different fish species.

The main objective in analysing mercury concentration in fish is to assess whether the level of mercury is safe or not for human consumption. The calculated daily intake of mercury in all species did not exceed the guideline values which indicate that these aquatic products are safe for human consumption at present [2]. Mok and co-workers [2] also concluded that the concentration of mercury in the edible parts of the fish would pose no health hazards to consumers. However, precautionary steps has to be taken as chronic accumulation may occur. Mercury concentrations in fishes from Saudi Arabian markets were also found to be below the permitted limit in the edible portion [4]. The similar trend was observed in China as the concentrations of mercury in farmed fishes were also considered safe for human consumption [3]. Although most studies have shown that fishes are safe for consumption, current status of contamination has to be reassessed from time to time as contamination may increase dramatically or suddenly which can cause a spiked increase of mercury concentration in fish, making it unsafe for human consumption. The toxicity effects of it will be discussed under another section of this review.

Comparison of Mercury in Fish with Other Heavy Metals

According to Mok and co-workers [2], other heavy metals such as arsenic, copper, lead and zinc recorded higher concentration levels compared to mercury. Only chromium and copper recorded lower concentration levels in fishes compared to mercury. Mercury was detected in all fish species, however chromium was not detected in a few freshwater species which are jade perch, mad barb and river catfish [2]. When comparing with collection sites, arsenic concentrations recorded a similar pattern with mercury whereby the arsenic concentration of seabass were higher in each site collected from East Malaysia than West Malaysia.

In terms of order of heavy metal concentration in fish, the order of levels obtained from the three different fish species in three different sites are as follows in descending order; Iron, Zinc, Manganese, Lead, Copper, Cadmium and Mercury [4]. It can be observed that mercury has lower concentrations than most heavy metals in both studies. This could indicate that mercury concentration is still at a safe level, however monitoring procedures should be done to prevent toxicity as the toxicity effect of mercury is much greater although at low amounts.

Mercury Toxicity in Humans

Mercury toxicity in humans is a dangerous event as mercury is a highly toxic element. There are many ways which mercury poisoning can occur. It can occur acutely or through chronic accumulation which is normally caused by occupational exposure to mercury or food contamination [10]. The primary source of human exposure to mercury is via consumption of fish which is mainly present in the form of methylmercury, a highly absorbable form that can absorb through the skin and lungs [1]. Methylmercury is the most toxic form of mercury and is able to interfere with thiol metabolism which causes inhibition or inactivation of proteins containing thiol ligands and consequently leading to mitotic disturbances [9]. Methylmercury has also been classified as possibly carcinogenic to humans [6]. Therefore, it is highly important to monitor mercury concentrations in fish to minimize toxicity risks as well as risk of developing cancer in humans.

Mercury is able to accumulate in higher concentrations in the nervous system [10]. Hence, mercury toxicity affects the nervous system the most, however it has been known to cause other side effects in humans as well. Other complications include increased risk of cardiovascular diseases as well as foetal and infant growth impairment [8]. Mercury toxicity has also been linked with slow development, blindness, cerebral palsy and birth defects [1]. Pregnant mothers should therefore be careful with the amount and type of fish consume as heavy metal accumulation could be toxic to the growing foetus. Pregnant women and young children have been identified as high-risk groups for mercury toxicity and therefore should monitor fish consumption carefully. Long-term and frequent consumption of fish with high mercury levels is associated with toxic especially in pregnant women [9].

Mercury damages the brain as it is able to inhibit selenium-dependent enzyme activities in brain tissues [8]. The most common form found in fish, methylmercury binds to selenium which modifies the enzyme resulting in adverse effects related to mercury toxicity as selenoenzymes are required for brain function and protein synthesis [8]. Therefore this makes mercury toxicity a highly toxic event as it can cause irreversible damage to the brain and its neurological function. Neurological symptoms due to mercury toxicity might not be evident as it may not appear immediately [10]. This is even more dangerous as chronic accumulation of mercury will occur. When neurological symptoms finally appear, it might be too late to diagnose and treat the patients of the disease as the accumulation of toxic would have reached a highly toxic level. Brain damage might have already occurred at that time causing high risk of mortality.

Conclusion

Mercury poisoning is a serious threat to humans, and hence it is important to always keep up to date with current mercury levels in fish to avoid excessive accumulation of mercury. Fish and fish products should be monitored from time to time to ensure that it is safe for human consumption. High risk groups like pregnant women and young children should avoid consuming fishes with known high level of mercury as they are more vulnerable to mercury toxicity. In addition to that, they are also more susceptible to getting mercury toxicity.

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