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Effects of canning on total mercury, protein, lipid, and moisture content in troll-caught albacore tuna (*Thunnus alalunga*)

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Abstract

Fifty-six cans containing meat from either the dorsal loin or the ventral flap of 10 troll-caught albacore tuna were tested for total mercury concentration prior to and after canning and retort cooking. The albacore tuna were harvested off the US Pacific Coast during the 2004 season and weighed between 5.4 and 10.2 kg. Tuna meat was packed in cans raw or in water or olive oil, and cans were drained before post-canning analysis. The average concentrations of total mercury were: 0.17 ppm (range 0.09–0.24 ppm) in the pre-canned samples and 0.21 ppm (range 0.10–0.33 ppm) in the post-canned samples. Although the mercury concentration per gram of tissue was significantly higher following canning, the overall amount of mercury in the samples did not change significantly.

Keywords: Mercury; Albacore tuna; Canning; Lipid; Protein; Moisture

1. Introduction

Mercury is a naturally occurring toxic heavy metal that is found at trace amounts in living organisms. As a result of both natural and anthropogenic activity, elemental mercury can cycle through the environment and enter aquatic ecosystems. Once in water, mercury can be methylated by microorganisms to form organic mercury, the most common form of mercury in fish. Organic mercury biomagnifies through aquatic food chains, resulting in increased concentrations in fish at higher trophic levels.

A joint advisory released in 2004 by the Food and Drug Administration (FDA)/Environmental Protection Agency (EPA) warned pregnant women and young children to limit their weekly consumption of albacore tuna (FDA, 2004a). The advisory was based on canned albacore tuna reported to contain 0.35 ppm mercury (action limit is 1 ppm methylmercury) (FDA, 2004b). However, mercury levels in fish can vary greatly with factors such as catch location, size, and preparation method. Recently, raw muscle samples of US Pacific troll-caught albacore tuna were reported to be relatively low in mercury, at 0.14 ppm, and high in $\omega - 3$ fatty acids (Morrissey, Rasmussen, & Okada, 2004; Wheeler & Morrissey, 2002). Although the majority of the US Pacific troll-caught albacore harvested is sold canned, the mercury concentration in the canned product has not been evaluated.

Thus far, studies have focused either on mercury in raw *or* canned tuna, and although it has been shown that mercury concentrations in fish can be altered by various preparation methods (Burger, Dixon, Boring, & Gochfeld, 2003; Morgan, Berry, & Graves, 1997), none have examined the effects of canning. While a few studies have compared fresh/frozen tuna to canned tuna, the samples were from different fish and were not followed through the canning process; therefore, strong conclusions could not be made regarding how mercury concentrations change due to canning (Dabeka, McKenzie, Forsyth, & Conacher, 2004; Knowles, Farrington, & Kestin, 2003). The canning process has been reported to alter the proximate composition of albacore tuna, resulting in a large increase in

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percent lipid, some increase in percent protein, and a significant decrease in percent moisture (Garcia-Arias, Navarro, & Garcia-Linares, 2004; Garcia-Arias, Sanchez-Muniz, Castrillon, & Navarro, 1994). Because organic mercury is lipid soluble *and* can bind sulfur groups (i.e., cysteine), it is possible that mercury concentrations change as the lipid, protein, or moisture content of the meat changes during processing.

The objectives of this study were to: (a) determine the levels of mercury in canned US Pacific troll-caught albacore tuna, (b) examine the effects of canning on mercury concentration, and (c) determine any correlations between mercury concentration and changes in protein, moisture, or lipid content as a result of canning.

2. Materials and methods

2.1. Pre-canning

Albacore tuna were troll-caught off the US Pacific Coast during August 15–16 of the 2004 season near longitude 125°W and latitudes 43°N–44°N. Whole fish were bled and frozen at sea, landed in Ilwaco, WA, and transferred in ice to the Oregon State University Seafood Laboratory (OSU-SFL) in Astoria, OR, where they were stored at −30 °C for later analysis. The weight of each fish was recorded and ten tuna of various weights (range 5.4–10.2 kg) were selected for testing. Edible tissue was separately collected from 4 dorsal loin sections (right front, right rear, left front, and left rear) and the belly flap section of each fish. Each section was treated independently for chemical analysis and canning for each of the fish. A 100 g sample from each section was homogenized and stored at −18 °C for later determination of total mercury, lipid, moisture, and protein content. The remainder of each section was cut into ~20 g chunks and packaged into cans. The weight of each canned sample was recorded and packing material was added to the cans. Of a total of 56 cans, 20 cans received 27.6 ml (2 tbsp.) olive oil, 20 cans received 27.6 ml spring water, and 16 cans were raw packed (no added liquid). A 25 mg salt tablet was added to each can and the cans were then sealed, washed, and cooked in a retort at 117 °C for 75 min (USDA, 1986).

2.2. Post-canning

Post-canned weights of each sample were recorded and the contents of each can were drained as described under the Code of Federal Regulations 114.90, by draining for 2 min over a US standard No. 8 sieve (stainless steel) slanted at a 17–20° angle (Gavin & Weddig, 1995). Post-drained weights were recorded and each sample was homogenized using a mortar and pestle. The drained, homogenized tuna meat from each can was kept separate and stored at −18 °C for later determination of total mercury, lipid, moisture, and protein content.

2.3. Determination of total mercury concentration

Twenty-five grams of each homogenized sample were placed into separate disposable plastic containers and frozen. The samples were transported from the OSU-SFL to AM Test Laboratories in Redmond, WA, for total mercury analysis. Two-gram aliquots of each sample were digested with 2 ml 16 M HNO_3, 4 ml 18 M H_2SO_4, 1.5 g $KMnO_4$, and 8 ml 5% $K_2S_2O_8$. Samples sat overnight in reagents and were then cooked in a 98 °C water bath for 2 h. After digestion, 2 ml hydroxylamine hydrochloride and 2 ml stannous chloride were added, and the mercury content was measured using a Perkin–Elmer Atomic Absorption Spectrophotometer according to the cold-vapor atomic absorption EPA method 7471 A, with a detection limit of 0.0001 ppm. Quality control methods included running 1 duplicate and 1 matrix spike per 10 samples analyzed, as well as 1 blank and standard reference material per 20 samples analyzed. No more than a 20% difference was permitted between duplicate samples, and matrix spikes and standard reference spikes required a recovery of 80% or more.

2.4. Lipid, moisture, and protein analysis

Lipid, moisture, and protein content were determined for the pre- and post-canned samples. All tests were run in duplicate with no more than a 20% difference allowed between duplicate samples. Lipid content was measured according to a modification of the Association of Official Analytical Chemists (AOAC) Official Method 948.15 Fat (Crude) in Seafood, Acid Hydrolysis method, 1995 (Hungerford, 1995). Blended 3 g samples were mixed by vortex with 10 ml of 8 M HCl in 50 ml centrifuge tubes. Samples were digested in a water bath at 100 °C for 45 min, vortexed, and then heated for another 45 min. Following digestion, the samples were cooled, 5 ml of methanol were added, and the mixtures were vortexed. For lipid extraction, 15 ml of diethyl ether were added and samples were shaken vigorously for 1 min. Then a 15 ml aliquot of petroleum ether was added, and the samples were shaken for 20 sec. The samples were then centrifuged for 5 min at 1200 RPM using a swinging bucket rotor (radius = 19 cm), and the resulting ether-fat layer was transferred to a pre-weighed, pre-heated flask. The extraction step was repeated twice. Flasks were heated on a hot plate until the ether had evaporated (ca. 1 h). The flasks were then heated for 30 min in a 109 °C oven, cooled at room temperature for 30 min, and weighed.

Moisture content of samples was determined according to AOAC Official Method 950.46 B Convection, Gravity method, 1995, by measuring the mass of a sample before and after drying overnight in an oven maintained at 105 °C (Soderberg, 1995).

Protein content was determined according to a modified AOAC Official Method 940.25 Total Nitrogen, Kjeldahl method, 1995 (Hungerford, 1995). Exact weights for samples between 1.2 and 1.5 g were recorded to the thousandth

of a gram. The samples were then added to Kjeldahl flasks, followed by addition of 12 g of a copper catalyst mixture containing K_2SO_4 and $CuSO_4$ at a ratio of 3.5:1, 1–2 boiling chips and 15 ml 18 M H_2SO_4. Mixtures were digested at 410 °C for 60 min in a Kjeldahl Digestion System (Fisher Scientific DB 20), and then cooled at room temperature for 15 min. Next, 40 ml of deionized water was added and the mixtures were shaken to dissolve any solid salts. Distillation was carried out for 5 min using a Fisher Scientific Distillation Unit 100 with 50 ml of NaOH. The titration step was carried out with 0.1 N HCl and the volume of acid required to reach the endpoint was recorded. Total nitrogen in samples was calculated and converted to % protein using a factor of 6.25 (assuming that a pure protein mixture contains 16 % nitrogen (Pomeranz & Meloan, 1994)).

3. Results and discussion

3.1. Changes in mercury, protein, lipid, and moisture

As shown in Table 1, the mercury concentration in 56 samples of albacore tuna increased significantly ($p < 0.005$) from an ave. of 0.17 ppm in raw samples to 0.21 ppm in cans (23% increase). The ave. weight of tuna meat decreased significantly as a result of canning, with the post-canned samples having an ave. weight 12.8% less than the raw meat. Percent moisture also decreased significantly from 63.9% to 60.3% following the canning process. Although percent lipid decreased slightly after canning, the difference was not significant. However, the percentage of protein in tuna increased significantly from 23.6% in raw samples to 26.1% in canned. Changes in mercury concentration did not correlate directly with changes in protein, moisture or lipid on an individual-can basis.

It was expected that mercury concentration would correlate with changes in protein, lipid or moisture content due to the biochemical properties of organic mercury. Organic mercury is lipid-soluble and, therefore, might be expected to vary as lipid content varies. On the other hand, mercury is also known to strongly bind sulfhydryl groups, which can be found abundantly in proteins rich in the amino acid cysteine. This would result in a direct correlation of mercury with protein content. Also, the concentration of mercury could vary with moisture simply because a loss of moisture during cooking might cause mercury to concentrate more heavily in the meat, as suggested in previous studies that examined changes in mercury concentration as a result of pan-frying, baking, smoking, or boiling (Burger et al., 2003; Morgan et al., 1997). Since total mercury concentration did not correlate on an individual basis with protein, lipid or moisture, it is probable that mercury present in albacore tuna meat associates with more than one type of biomolecule.

3.2. Differences among packing materials

As shown in Fig. 1, the ave. concentration of mercury increased following canning with all three packing methods tested: water, oil, or raw packing. The highest percent mercury increase was observed in raw (38.6%), followed by oil (31.6%) and then water packing (25.1%). However, there was a wide variation of percent increase in mercury concentration with all three packing methods, and no significant differences were found. The ave. total mercury concentrations and standard deviations in the raw ($n = 16$), oil- ($n = 20$), and water-packed ($n = 20$) samples were: 0.232 ± 0.056 ppm, 0.206 ± 0.050 ppm, and 0.193 ± 0.052 ppm, respectively. The water- and oil-packed samples most likely had lower mercury concentrations than raw-packed tuna due to the dilution factor presented by the additional 27.6 ml of packing material.

3.3. Comparisons with other studies

As shown in Table 2, the albacore tuna analyzed in this study had a lower ave. mercury concentration (0.21 ppm) than canned albacore from other published studies. Mercury concentrations reported for canned albacore tuna

Table 1
Averages, standard deviations, and ranges for mercury concentrations, sample weights, lipid, moisture and protein contents before and after canning ($N = 56$)

	Pre-canned	Post-canned	% Change
Mercury concentration (ppm)	0.17 ± 0.04 0.093–0.243	$0.21^{*} \pm 0.05$ 0.104–0.334	23
Sample weight (g)	166.1 ± 23.4 111.1–195.1	$144.7^{*} \pm 20.3$ 90.5–175.3	−12.8
% Moisture	63.9 ± 5.4 49.3–70.7	$60.3^{*} \pm 4.4$ 46.9–67.8	−5.6
% Protein	23.6 ± 2.5 15.2–27.6	$26.1^{*} \pm 3.29$ 16.3–31.0	10.8
% Lipid	12.2 ± 6.9 4.2–30.7	11.8 ± 6.2 4.0–28.5	−3.8

The differences between raw and canned samples are shown as percent change [((Canned − Raw)/Raw) × 100], where a negative number indicates a decrease.

* Significant difference in pre- vs. post-canned ($p < 0.005$).

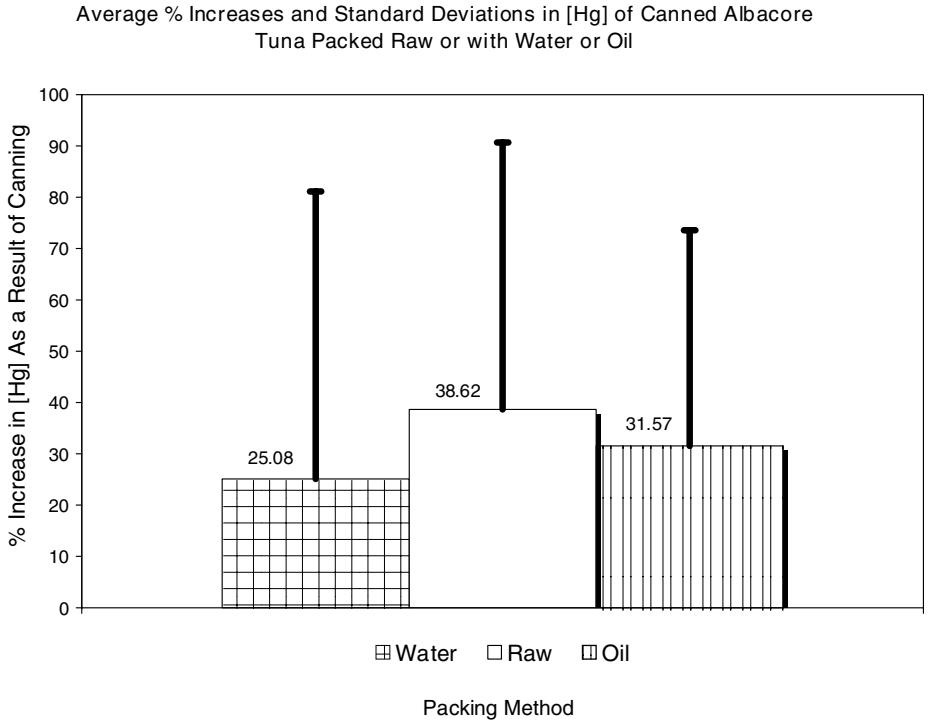

Fig. 1. Comparison of the average % increase in mercury concentration as a result of 3 different packing methods: water ($N = 20$), raw ($N = 16$) and oil ($N = 20$). Error bars display standard deviations.

Table 2
Comparison of the mercury levels in albacore tuna analyzed in the present study with those in canned albacore tuna from other studies

Canned fish sample	Sample size	Mean of total Hg and range (ppm)	Mean of MeHg and range (ppm)	Reference
Albacore	56	0.21 0.104–0.334	n/a	Present study
White	n/a	0.215 n/a	n/a	VanDerslice et al. (2004)
Albacore	5	0.238 0.080–0.376	n/a	Kouyoumjian et al. (2001)
Albacore	16	0.260 0.193–0.384	n/a	Dabeka et al. (2004)
Albacore	8	0.274 0.136–0.475	0.240 0.110–0.450	Cappon and Smith (1982)
Solid white	71	n/a	0.26 n/a	Yess (1993)
White/albacore	96	0.309 n/a	n/a	Shim et al. (2004)
Chunk white	19	n/a	0.31 n/a	Yess (1993)
Albacore	179	0.35 ND–0.85	n/a	FDA (2004b)
White	123	0.407 n/a	n/a	Burger and Gochfeld (2004)

The table reports total mercury (Hg) and methylmercury (MeHg) levels in canned tuna as reported in the referenced papers. ND stands for nondetectable. (Adapted from: Rasmussen et al., 2005).
Note: Canned white tuna refers to albacore. The sample identification used was that stated in the referenced papers.

range from 0.21 to 0.407 ppm. Considering that organic mercury bioaccumulates in the aquatic food chain, it is likely that the relatively small size of US Pacific troll-caught albacore tuna results in a lower mercury concentration in the canned product (Morrissey et al., 2004). It is hard to compare the effects of canning found in this study

to other reported data because no other published studies have followed the raw material through the canning process. Additionally, the results of different packing materials can only be compared with studies that reported mercury concentrations in the end product.

One study analyzed 26 cans of albacore, bluefin, skipjack, and yellowfin tuna packed in either water or vegetable oil (Cappon & Smith, 1982). The samples were obtained from a domestic canner and were drained prior to analysis. Although water-packed samples ($n = 20$) had a higher ave. total mercury content than oil-packed samples ($n = 6$), the sample size was too limited to perform statistical analysis. A total of 8 albacore cans were analyzed: 2 were water-packed and had an ave. total mercury concentration of 0.425 ppm (over twice the concentration found in this study) while the 6 oil-packed cans were comparable to those in the present study, with an ave. total mercury concentration of 0.223 ppm. The origin of the tuna was not reported.

A study conducted by the FDA in 1993 compared methylmercury concentrations in 220 samples of water- and oil-packed canned white (albacore) and light (generally skipjack) tuna (Yess, 1993). The author found a statistically significant difference between levels of methylmercury in water- and spring water-packed cans vs. oil- and vegetable oil-packed cans (0.18 and 0.21 ppm vs. 0.07 and 0.10 ppm, respectively). However, the lower concentrations in the oil-packed cans are most likely related to the fact that they were not drained prior to analysis, whereas the water-packed cans were. Mercury concentrations in water- vs. oil-packed cans of white tuna were not reported separately from the light tuna. As shown in Table 2, 71 cans of solid white tuna and 19 cans of chunk white tuna were reported to have ave. methylmercury concentrations of 0.26 and 0.31 ppm, respectively. Methylmercury has been found to account for anywhere from 67% to 95% of the total mercury in fish (Andersen & Depledge, 1997; Cappon & Smith, 1982; Vlieg, Murray, & Body, 1993).

Results from a Lebanese survey of 40 brands of white and light canned tuna revealed no significant difference in the total mercury content of tuna packed in oil or brine (Kouyoumjian, Tilbian, & Najjar, 2001). The ave. total mercury concentration was 0.125 ± 0.106 ppm, with a range of 0.018–0.412 ppm. However, these results are a combination of white and light meat tuna, and the definition of white meat in the Lebanese study appears to include yellowfin, skipjack, tongol, albacore, and numerous unspecified cans. The only five canned samples actually specified as albacore had an ave. total mercury concentration of 0.238 ppm, with a range of 0.080–0.376 ppm.

The results of a recent Canadian study reported an ave. total mercury concentration of 0.260 ppm (range 0.193–0.384 ppm) in 16 samples of canned albacore tuna (Dabeka et al., 2004). The tuna cans were purchased at various retails stores in Halifax, Toronto, and Vancouver, Canada, and the origin was unknown. In another study, total mercury levels were determined for 168 cans of white and light tuna purchased between 1998 and 2003 from a retail store in New Jersey (Burger & Gochfeld, 2004). The authors reported no significant difference between oil- and water-packed samples, and they reported the ave. total mercury concentration for canned albacore to be 0.407 ppm, almost double that reported in the present study.

The Washington State Department of Health analyzed mercury concentrations in 289 cans of white and light tuna and found no significant difference between water- and oil-packed samples (VanDerslice, Murphy, Patrick, McBride, & Magoon, 2004). The cans were purchased at randomly selected retail outlets throughout the state of Washington and the majority of the cans were from major, name-brand canning operations. Draining details were not reported and neither were individual concentrations for oil vs. water packing methods. Canned white tuna (albacore) was reported to have a mean mercury concentration of 0.215 ppm, just slightly higher than that reported for samples in the present study (0.21 ppm).

A recent study on mercury in canned fish reported no significant difference between total mercury in albacore (144 cans, 72 composite samples) packed in water (0.227 ppm), spring water (0.232 ppm), or soy oil (0.220 ppm) (Shim, Dorworth, Lasrado, & Santerre, 2004). However, water-packed albacore in foil pouches had a significantly higher mercury concentration (0.330 ppm) than the other three packing methods. The combined ave. mercury concentration for albacore tuna was 0.309 ppm. Interestingly, significant differences in packing materials were reported for light tuna: light tuna in vegetable oil (0.183 ppm) was higher in mercury than light tuna in water (0.054 ppm), and light tuna in soy oil (0.340 ppm) was significantly higher than in both vegetable oil and water. All cans were purchased from retail stores in Lafayette, Indiana, in 2003. Since the cans were not drained prior to analysis, it is hard to make a direct comparison with the results of the present study.

4. Conclusions

The total mercury concentrations in raw and subsequently canned samples of US Pacific troll-caught albacore tuna were well below the FDA action limit of 1 ppm methylmercury in fish. There was a significant increase ($p < 0.005$) in total mercury concentration as a result of canning, going from 0.17 ppm in raw samples to 0.21 ppm in canned. Although percent protein increased significantly and percent moisture decreased significantly after canning, none of the intrinsic factors correlated with changes in mercury concentration on an individual can basis. Raw packing resulted in the highest average percent increase in mercury concentration, followed by oil and then water packing; however, there were no significant differences among the three packing methods. In comparison to published studies on canned albacore tuna, the results of the present study showed the lowest total mercury concentration, most likely due to the relatively small size of US Pacific troll-caught albacore tuna.

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