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ORIGINAL PAPER

Taurine content of raw and processed fish fillets/portions

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Abstract The health benefits of seafood are well recognised and fish and fish products are increasingly being advocated as functional foods. Taurine is also well recognised as beneficial to cardiovascular health, and seafood is a good source of this compound. This study investigated the taurine content of different fish species and also the use of vacuum tumbling and injection procedures for introducing additional taurine into fish. The taurine content of fish purchased in supermarkets was in the order plaice (146), cod (108), mackerel (78) and farmed salmon (60 mg/100 g fresh weight). Spot-sample tests on 14 other fish species showed a wide range (6–176 mg/100 g fresh weight) in taurine contents. Vacuum tumbling and injection in/with a taurine/sodium tripolyphosphate solution were used successfully to enrich tuna cubes (800 mg/100 g fresh weight) and salmon sides (891 mg/100 g fresh weight), respectively, with taurine thus making them (potentially) functional foods. The added taurine was well retained in processed tuna cubes and did not adversely affect the sensory acceptability of the samples. Taurine retention in cooked taurine-enriched tuna cubes was best for grilling followed by microwave heating and steaming.

Keywords Taurine · Health · Fish · Enrichment · Functional food

Introduction

The market for seafood products in Europe and worldwide has grown significantly [1] in recent years largely fuelled by the image of fish as a healthy component of the diet [2]. Fish and fish products are increasingly being promoted as functional foods [3]. Many of the health benefits are attributed to the so-called omega 3 fatty acids [2], to the low calorific content of fish, and to other key components including the amino acid taurine. The clinical utility of taurine in relation to cardiovascular health has been demonstrated [4–9]. Fennessy et al. [10] have shown that taurine modifies endothelial dysfunction in young smokers and restores normal flow-mediated dilation in the brachial artery. The extensive data on the physiological effects of taurine are not matched by corresponding data on the taurine content of foods. However, papers have been published on the taurine content of seafoods and other products [11–16].

The published data [4–9, 10] on the bioactive effects of taurine prompted the current study which embraced six trials. Trial 1 was on the taurine content of four fish species purchased from a local supermarket. The taurine content of spot samples of 14 fish species (mostly the so-called underutilised species) was investigated in Trial 2. The effect of storage at 4 °C for 10 days on taurine retention in raw plaice was the topic of Trial 3. Vacuum tumbling in a taurine/phosphate solution was used to enrich tuna cubes with taurine (Trial 4). The tumbled cubes were stored/processed by chilling, freeze-chilling and *sous vide* processing and were cooked/re-heated by microwave, grilling or steaming to study the retention of the added taurine. The second part of Trial 4 involved the use of a brine injector to enrich salmon sides with taurine. Trial 5 was on the sensory acceptability/preference of tumbled tuna cubes with and without taurine/phosphate. The tumbling of fresh versus frozen (thawed) yellowfin tuna cubes in taurine/phosphate solution was compared in Trial 6 as was cooking the tumbled samples by microwave heating, grilling or steaming.

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Materials and methods

Supermarket samples (Trial 1)

Triplicate portions of raw plaice (*Pleuronectes platessa*), cod (*Gadus morhua*), mackerel (*Scomber scombrus*) and farmed salmon (*Salmo salar*) were purchased bi-monthly (eight sampling dates in all) from the ice counter of a local supermarket. The samples were brought to the laboratory at Ashtown Food Research Centre (AFRC) and sub-samples (20 g) were removed and tested for taurine and moisture contents as outlined in the section on test procedures below. The experimental design was 4 species × 8 test dates × 3 replicates [analysis of variance (ANOVA)].

Tests on spot samples of fish species (Trial 2)

Spot samples of albacore tuna (*Thunnus alalunga*), ray wing (*Raja claviata*), wild salmon (*Salmo salar*), siki shark (*Centroscymnus coelolepis*), whiting (*Merlangius merlangus*), Greenland halibut (*Reinhardtius hippoglossoides*), roundnose grenadier (*Coryphaenoides rupestris*), black scabbardfish (*Aphanopus carbo*), blue ling (*Molva dipterygia*), cardinal fish (*Epigonus telescopus*), deepwater redfish (*Sebastes mentella*), haddock (*Melanogrammus aeglefinus*), megrim (*Lepidorhombus whiffiagonis*) and Baird's smoothhead (*Alepocephalus bairdii*) were received as frozen portions/fillets at AFRC. The samples were thawed at 4 °C overnight and tested for taurine and moisture contents as outlined later. The experimental design was 14 species × 3 replicates (ANOVA).

Effect of storage (2–4 °C) on the taurine content of raw plaice (Trial 3)

Fresh plaice fillets (each *circa* 150 g) were sourced locally and were packed in plastic (HDPE) trays (Dynopak, Ireland) in 30%O_2/40%CO_2/30%N_2 (MAP) or in air. All packs were sealed with a 340 mm antifog high barrier film (Dynopak, Ireland). The samples were stored at 2–4 °C for 10 days and were tested on days 0, 3, 6, 8 and 10 for taurine and moisture contents, and also for total basic nitrogen (TVBN) and total viable count (TVC) as outlined below. The experimental design was 2 atmospheres (MAP vs. air) × 5 test dates × 3 replicates (ANOVA).

Taurine enrichment by vacuum tumbling (tuna cubes) or injection procedures (farmed salmon) (Trial 4)

This trial involved vacuum tumbling (part 1) or injection (part 2) in/with an aqueous solution of taurine and sodium tripolyphosphate (STPP). In part 1, cubes (1.5 cm^3) of yellowfin tuna (*Thunnus albacares*) (2 kg), obtained from a local supermarket (5 days on ice post-catching) were tumbled (Inject-Star 25 l vacuum tumbler) in an aqueous solution (400 ml) of taurine (7.5% w/v) and STPP (5% w/v) at 4 rpm and 10 kPa (residual pressure) for 15 min. The vacuum tumbled samples were then subjected to five post-tumbling treatments: (i) vacuum tumbled only (control), (ii) vacuum tumbled + blast frozen (− 35 °C/2 h) followed by storage at − 20 °C for 4 days, (iii) vacuum tumbled + chilled at 2–4 °C for 6 days, (iv) vacuum tumbled + freeze-chilled [18], i.e. − 20 °C for 5 days followed by 6 days at 2–4 °C, and (v) vacuum tumbled + *sous vide* processed to a core temperature of 90 °C/10 min [17]. Samples from the treatments (i–v) were tested as raw and as microwave heated (3.5 min/850 W) for moisture and taurine contents, colour (Hunter L), gravity and centrifugal drip, cooking loss and TVC as outlined in the section on test procedures later. The design of the trial was 5 post-tumbling treatments × 2 cooking methods (none vs. microwave) × 3 replicates (ANOVA).

In part 2, an aqueous solution of taurine (5% w/v) and STPP (5%) was injected into two farmed salmon sides/fillets (each circa 1.5 kg) using a 26-needle brine injector (Fomaco Food Machine Company A/S, Denmark). Each fillet was cut in eight portions, packed in air in polythene bags, blast frozen (− 35 °C/2 h) and stored at − 20 °C until tested. The target concentration of taurine in the flesh as eaten was 1%. The frozen samples were thawed at 4 °C overnight and the taurine content of each piece determined as described below.

Table 1 Sensory tests on taurine-enriched microwave heated[a] tuna cubes[b]

Comparison	Preference ratio[c]	Accept. score[d]
Not-tumbled vs. tumbled taurine-phosphate	10/10 (NS)[e]	3.3 vs. 3.1 (NS)
Not tumbled vs. tumbled phosphate	14/6 (NS)	3.7 vs. 3.6 (NS)
Tumbled taurine-phosphate vs. tumbled phosphate	8/12 (NS)	3.4 vs. 3.6 (NS)

[a] See materials and methods section.

[b] Taurine content of taurine-tumbled microwave heated samples = 800 mg/100 g.

[c] Paired comparison taste panel; 20 tasters.

[d] On a 6-cm line with end-points of unacceptable (0) and very acceptable (6).

[e] Not significant.

Sensory tests on vacuum tumbled tuna cubes (Trial 5)

Batches of tuna cubes were vacuum tumbled (conditions as for Trial 4) in solutions of (i) taurine/STPP (7.5%/5% w/v) and (ii) in STPP (5% w/v) while a third batch (iii) was not tumbled. The samples were microwave heated at 800 W for 3.5 min and were presented to 20-member taste panels (see Table 1). Untrained panellists (familiar with tasting fish) were presented with two samples at each sitting and scored on two 6 cm lines with end-points 0 (unacceptable) and 6 (highly acceptable) to give both preference ratios and acceptability scores for the samples.

Effect of starting material and cooking methods on taurine uptake/retention (Trial 6)

The uptake of taurine/phosphate solution (vacuum tumbling conditions as for Trial 4) by tuna cubes that had not been frozen was compared with uptake in thawed cubes (previously blast frozen at -35 °C/2 h and thawed at 4 °C overnight prior to tumbling). The treated samples were cooked by microwave heating (800 W/ 3.5 min), grilling (6 min) or steaming (10 min) and were tested for taurine content and cook (weight) loss as described later. The design of the trial was 2 raw materials (fresh vs frozen) × 3 cooking methods (microwave heating, grilling, steaming) × 5 replicates (ANOVA).

Chemical and physical test procedures

Taurine was extracted from fish samples by homogenising (1 min/24,000 rpm) finely minced samples (2 g) in 70% ethanol (10 ml) using an Ulta-Turrax T25 tissue homogeniser (Janke and Kunkel, IKA Labortechnik, Germany). The samples were then centrifuged at $1000 \times g$ for 5 min using a Sanyo MSE Mistral 3000i refrigerated centrifuge (Davidson and Hardy, Dublin, Ireland). Analysis of amino acids was carried out using a modified version of the method of Bartok et al. [19] as described by Brunton et al. [20] using o-phthalaldehyde (OPA) derivatisation and high performance liquid chromatography (HPLC). Taurine levels were calculated in mg/100 g fresh weight (FW) of sample by external calibration using authenticated aqueous standards and calculations were performed using the equation:

$$[\text{Taurine}] = \left(\frac{\text{PA}_{\text{taurine}}}{\text{PA}_{\text{norLEU}}}\right) \times \text{CF} \times 2, \quad (1)$$

where $\text{PA}_{\text{taurine}}$ = peak area for taurine, $\text{PA}_{\text{norLEU}}$ = peak area for norLeucine and CF = correction factor calculated from external calibration curves.

Moisture content, colour (Huntre Lab), gravity drip and TVC were measured as described the Fagan et al. [18]. Total basic nitrogen (TVBN) was measured by the method of Malle and Tao [21].

Results and discussion

Taurine content of different fish species (Trials 1 and 2)

The taurine content of the samples purchased in supermarkets was in the order plaice > cod > mackerel > farmed salmon (Table 2) on a fresh weight basis. The values varied from test date to test date (eight in all; bi-weekly) but the relative order was always the same. In terms of taurine content, plaice contained much more than the other three species and so was more inherently functional.

Data for 14 other species (Trial 2) (spot samples) (Table 3) indicated a wide range in taurine contents. Albacore tuna and ray wing had much higher contents than the other species, and some of the deep water species had virtually no taurine. Wild salmon had a taurine content of 60 mg/100 g fresh weight, which is similar to the value for farmed salmon found in Trial 1. The variability found in taurine content between species in the current study, and even within species, may be a feature of genetic factors, habitat,

Table 2 Taurine content (mg/100 g raw wet weight)[a] in portions of four fish species purchased[b] in a supermarket

Plaice	146
Cod	108
Mackerel	78
Farmed salmon	60
F-test	$P < 0.001$
LSD[c]	7.78

[a]Values are means for eight test dates.

[b]Samples purchased bi-weekly over a 16-week period.

[c]Least significant difference.

Table 3 Taurine content (mg/100 g raw wet weight) in portions of 14 fish species (spot samples)

Species	Taurine content	Species	Taurine content
Albacore tuna	176	Whiting	40
Ray wing	149	Greenland halibut	32
Megrim	95	Haddock	28
Cardinal fish	70	Deepwater redfish	27
Wild salmon	60	Black scabbard	17
Blue ling	57	Roundnose grenadier	7
Siki shark	51	Baird's smooth	6
	F-Test	$P < 0.001$	
	LSD[a]	22.36	

[a]Least significant difference.

stage of maturity, available foodstock and other factors. The taurine contents reported from these trials are generally towards the lower end of the ranges reported for fish species in the literature. For example, Sakaguchi et al. [14] reported taurine levels of 973 and 26 mg/100 g in dark and white muscle, respectively, of mackerel (*Scomber japonicus*) and corresponding values of 1040 and 11 mg/100 g in yellowtail (*Seriola quinqueradiata*). Zhao et al. [11] reported a range in taurine content from 41 to 851 mg/100 g edible portion in 29 aquatic products. Contents were relatively high in flatfish and ray, and relatively low in silver pomfret, yellow croaker and baby croaker. Based on the current study, consumers eating 150–200 g portions of fish per day would fall short of the level of taurine supplement (1.5 g/day) given by Fennessy et al. [10] in a clinical trial with smokers. However, these workers did not test if lower levels of taurine intake would also be beneficial in alleviating endothelial dysfunction. Taurine intakes (from seafood and meat) by Chinese men from different regions in China ranged from 33.5 to 79.7 mg/day [11] while British males averaged 76 mg/day [22]. Tests were also conducted in the current study on the taurine content of raw meats (spot samples) for comparative purposes with fish. Taurine contents were in the order lamb chop (63), raw round steak (53), chicken fillet (51) and pork loin chop (21 mg/100 g fresh weight) ($P < 0.001$; LSD = 5.1).

Effect of storage (2–4 °C) on the taurine content of raw plaice (Trial 3)

This trial was conducted to study if length of storage time at 4 °C influenced the taurine content of the fish. This was prompted by the differences in taurine content found both between and within species in Trials 1 and 2. The taurine content of the plaice was not influenced ($P > 0.05$) by length of chill storage or by packing in MAP vs. air and the mean content of the raw fillets was 217 mg/100 g. This indicated that taurine is a stable molecule under the conditions of these tests. This was unexpected as it was anticipated that taurine would be degraded by enzymic or bacterial action during storage of the fish. *Rhodococcus* [23] and *Alcaligenes* sp. [24] utilise taurine as a nitrogen source but these are not common spoilage organisms in fish. Taurine occurs as a free amino acid in the cell [25] and not as part of a protein and so is not subject to proteolysis. However, TVBN values (5.3–44.5 mg/100 g) and TVC values (4.97–8.21 $\log_{10}$cfu/g) increased steadily over time indicating the generation of amines and related compounds, and also a significant increase in bacterial content. Moisture content (mean value 84.4%) was constant and was not influenced by atmosphere or length of storage. Gravity drip values from the chilled fish were small (1.6–2.9%) and were unlikely to influence (via leached taurine in the drip) the taurine content of the plaice.

Taurine enrichment by vacuum tumbling (tuna cubes) or injection procedures (farmed salmon) (Trial 4)

Vacuum tumbling in a salt solution is a well-known process for brining fish fillets [26] and results from the current study indicate that tumbling in a taurine/phosphate solution is also a suitable technique for enriching tuna cubes with taurine. Tuna has a robust texture and retained its integrity during tumbling. However, this might not be the case for softer-fleshed fish species. Taurine contents were in the range 710 (vacuum tumble only) to 917 mg/100 g (wet weight) for vacuum tumbling + chilling ($P < 0.001$) (Table 4) (target concentration *circa* 1%) and the added taurine was well retained in the cubes from the different process treatments. The inherent taurine content of the yellowfin tuna was low at 19 mg/100 g. Drip losses from the vacuum tumbled tuna cubes were small (0 to 5.5%) with the exception of the *sous vide* treatment. This was expected as *sous vide*-treated fish products often have significant drip loss [17]. Moisture contents of the vacuum tumbled samples were similar in practical terms (range 69.3–73.4%) but differed statistically ($P < 0.001$). The colour of the raw vacuum tumbled tuna cubes was typical of raw tuna but the Hunter L value for the *sous vide* sample was much higher (Table 5) indicating the lighter flesh colour obtained after heat treatment.

Table 4 Taurine content (mg/100 g wet weight) of vacuum tumbled[a] and processed[b] tuna cubes

Process[b]	Uncooked[c]	Microwave heated[b]
Tumbled[b]	710	741
Tumbled + frozen[b]	917	850
Tumbled + chilled[b]	856	941
Tumbled + freeze-chilled[b]	751	856
Tumbled + *sous vide* treated[b]	767	714
F-test: (process treatments)	$P < 0.01$ (LSD[d] = 75.4)	
F-test: (uncooked vs. microwaved)	NS[e] (LSD[d] = 47.6)	

[a,b] See Materials and methods section for details.

[c] Except for *sous vide*-treated sample.

[d] Least significant difference.

[e] Not significant.

Table 5 Colour (lightness) and total viable count (TVC) (log 10cfu/g) values for vacuum tumbled and processed tuna cubes. [a]See footnotes in Table 4.

Process	Uncooked		Microwave heated	
	Hunter L	TVC	Hunter L	TVC
Tumbled	29	3.93	59	2.13
Tumbled + frozen	29	4.37	59	2.60
Tumbled + chilled	32	6.77	60	4.37
Tumbled + freeze-chilled	32	6.63	58	3.23
Tumbled + *sous vide* treated	60	3.43	59	2.70
F-test (process treatments)	$P < 0.001$	$P < 0.001$		
LSD	3.6	1.11		
F-test (uncooked vs. m.wavd)	$P < 0.001$	$P < 0.001$		
LSD	4.9	0.70		

The cubes from the other process treatments attained similar lightness values following microwave heating (Table 5). Total viable counts (TVCs) were highest for the vacuum tumbled + chilled and the vacuum tumbled + freeze-chilled samples (Table 5). This was expected as the period in chill storage (2–4 °C) was 6 days; this finding agrees with data from previous studies on TVCs in freeze-chilled fish [18]. There was a positive rank correlation coefficient (r) between tuna moisture and taurine contents ($+0.80$) and negative coefficients between taurine content and centrifugal drip (-0.60) and taurine content and weight loss on cooking (-0.60).

Part 2 of this trial involved injecting a solution of taurine (5%w/v) and sodium tripolyphosphate (STPP) (5%w/v) into two salmon sides/portions (spot samples) using a multi-needle brine injector. The target taurine concentration was 1% in the flesh as eaten. The weight gains for fillets after injection were 20.9 and 21.3%, respectively and the calculated taurine content based on solution uptake was 0.86 (fillet 1) and 0.88% (fillet 2) (data on a fresh weight basis). These values were close to the measured values (means for eight portions/fillet) which were 0.91 (fillet 1) and 0.87% (fillet 2) (Table 6). The measured values also contained the taurine naturally occurring in the salmon which was *circa* 0.05%. There was a wide range in the taurine content of the eight portions for each fillet (Table 6) with highest contents in the middle of the fillets and lowest levels towards the head and tail for side 1, but not for side 2.

Table 6 Taurine content (mg/100 g raw wet weight) of injected[a] salmon sides[b]

	Side 1		Side 2	
	Left	Right	Left	Right
Head[c]	661	606	561	1049
	699	1035	416	1169
	1175	1463	788	580
Tail[c]	784	844	1347	1079

[a]Taurine/phosphate solution (see Materials and methods).

[b]Each side was cut in eight portions (post-injection) for analysis.

[c]From head to tail.

Sensory tests on vacuum tumbled tuna cubes (Trial 5)

This trial was conducted to see if the inclusion of taurine/STPP in tuna cubes (at the level used in trial 4) had an adverse effect on product acceptability. Details of the comparisons are given in Table 1 and embraced not-tumbled versus vacuum tumbled samples in taurine-phosphate or in phosphate solutions. None of the paired comparison tests showed a significant preference. The test procedure used scoring sheets with 6 cm lines with end-points of unacceptable (0) and very acceptable (6). This facilitated both preference response and acceptability scores. All the acceptability scores were above the mid-point of the 6-cm acceptability scale. This shows that added taurine/STPP did not adversely affect product acceptability.

Effect of starting material and cooking methods on taurine uptake/retention (Trial 6)

Using fresh versus thawed tuna cubes for vacuum tumbling did not influence taurine uptake (657 vs. 680 mg/100 g wet weight), tuna colour, TVCs, drip loss or cooking loss. Of the cooking methods, grilling gave the best retention of added taurine followed by microwave heating and steaming

Table 7 Effect of starting material (fresh vs frozen tuna cubes)[a] and cooking method on the taurine content (mg/100 g wet cooked weight) of vacuum tumbled tuna cubes

Starting material[a]	Cooking method[b]		
	Microwaving	Grilling	Steaming
Fresh/tumbled[c]	680	704	588
Frozen/tumbled[c]	687	765	588
F-test (starting material)	NS		
LSD[d]	75.2		
F-test (cooking method)	$P < 0.05$		
LSD	92.2		

[a]Fresh = not previously frozen; frozen = blast frozen and thawed prior to tumbling.

[b]See details in Materials and methods section.

[c]Vacuum tumbled in taurine/phosphate solution as for Trial 4.

[d]Least significant difference.

Table 8 Effect of starting material (fresh vs frozen tuna cubes)[a] and cooking method on weight loss (%) in vacuum tumbled tuna cubes

Starting material[a]	Cooking method[b]		
	Microwave heating	Grilling	Steaming
Fresh/tumbled[c]	6.96	1.36	0.80
Frozen/tumbled[c]	7.23	1.88	0.44
F-test (starting material)	NS		
LSD[d]	2.00		
F-test (cooking method)	$P < 0.001$		
LSD[d]	2.45		

[a]Fresh = not previously frozen; frozen = blast frozen and thawed prior to tumbling.

[b]See details in Materials and methods section.

[c]Vacuum tumbled in taurine/phosphate solution as for Trial 4.

[d]Least significant difference.

(Table 7). This may be due to the high temperature used in grilling, which formed a coagulated protein skin on the fish surface thus preventing exudation of taurine-containing drip. Cooking methods had no statistically significant effects on product TVCs, colour, drip loss or moisture content (Table 8).

Conclusions

The taurine content of fish purchased in supermarkets was in the order plaice > cod > mackerel > farmed salmon. Spot-sample tests on 14 other fish species showed a wide range in taurine contents. Vacuum tumbling or injection in/with a taurine/sodium tripolyphosphate solution were used successfully to enrich tuna cubes and salmon sides, respectively with taurine. The added taurine was well retained in processed tuna cubes and did not adversely affect the sensory acceptability of the samples.

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