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ORIGINAL ARTICLE

Effect of different types of heat processing on chemical changes in tuna

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Abstract The chemical changes in skipjack tuna (*Katsuwonus pelamis*) subjected to cooking, frying, canning and microwave heating were studied. Raw tuna contained an unusual fatty acid C16:3 in high proportion (29.3%) followed by C18:2, C24:1, C16:0 and C18:3. Health beneficial fatty acids, eicosapentaenoic acid (EPA) (1.67%) and docosahexaenoic acid (DHA) (2.50%), were quite low with ω-3/ω-6 ratio 0.28. The total saturated fatty acids suffered major loss in fried (70%) and canned tuna (40%) due to loss of C16:0, C14:0 and C22:0. The monounsaturated fatty acids content increased (38%) in cooked and microwave heated tuna due to C24:1. The polyunsaturated fatty acids content increased in fried (50%) and canned (25%) tuna due to the uptake of frying and filling oil, respectively during processing. The loss of health beneficial ω-3 fatty acids, EPA and DHA were minimum in cooked tuna followed by microwave heated tuna. Canning totally destroyed these fatty acids. In fried tuna, the losses of EPA and DHA were 70 and 85%, respectively. Thiobarbituric acid – reactive substances values increased in heat processed tuna. Cholesterol increased in canned and microwave heated tuna but not in cooked tuna. Reduction of cholesterol in fried tuna was due to its migration into frying oil. This study indicated that cooking and microwave heating are the better processing methods to retain the health beneficial ω-3 fatty acids in comparison to frying and canning.

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Introduction

Fish lipids have gained more importance because of the presence of health beneficial omega-3 polyunsaturated fatty acids (ω-3 PUFA). These PUFA viz. eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) play a crucial role in the prevention of atherosclerosis, heart attack, depression, stroke, diabetes, obesity, premature ageing, hypertension, cancer and to improve the vision power and memory (Sanders 1993, Chin and Dart 1995). Recognizing the health benefits of ω-3-fatty acids and the serious consequences of their deficiency, the US National Institute recommended a daily intake of 650 mg of ω-3 fatty acids in the form of fish (Venugopal 2004). Information about PUFA content is mainly available only for raw fish. But, fish is normally consumed after different methods of processing. There were very few studies on the effect of processing on the stability of ω-3 PUFA fatty acids in fish (Aro et al. 2000, Garcia- Arias et al. 2003). Canned fish are products of economic importance in many countries. Canned fishery products are formally canned in vegetable oils and now available in water packs. The use of microwave for heating foods has increased considerably during the past few decades (Sumnu 2001). Fish is also consumed normally in cooked and fried forms. Data on the stability of ω-3 fatty acids of processed fish based on Indian cooking and frying methods are sparse.

Tuna is one of the most important and popular commercial fish and is mainly eaten after cooking and frying. Canned tuna is one of the chief fishery products with good export market. Microwave heating is also important in fast food restaurants. This work was therefore undertaken to examine the stability of ω-3 fatty acids in tuna subjected to different heat processing treatments.

Materials and methods

Skipjack tuna (*Katsuwonus pelamis*) procured from Tuticorin fish-landing centre of Tamilnadu, India, situated within 1 km from the laboratory was immediately brought to the laboratory in iced condition. The average length and weight of tuna were 74 cm and 6 kg, respectively. The fish was beheaded, eviscerated and made into steaks and washed in potable chlorinated water (5 ppm). The average dressing yield of tuna was calculated. Steaks weighing 100–150 g were divided into 5 lots. First lot was treated as control (raw) and designated as R. Second lot was subjected to cooking in a boiling water bath (100°C) for 10, 20 and 30 min and were designated as C1, C2 and C3, respectively. Third lot was subjected to shallow frying at 180°C using double refined sunflower oil on a frying pan for 5, 7.5 and 10 min and were designated as F1, F2 and F3, respectively. Fourth lot was subjected to canning using standard canning procedure (Saralaya 1978) in 8 oz cans at 110, 115 and 121°C for 90, 70 and 40 min, respectively and were designated as N1, N2 and N3, respectively. Canning was performed to achieve 12-D process at 3 different temperatures to examine the temperature effect. Fifth lot was subjected to microwave heating by placing the samples in a microwave oven (IFB, Kochi, India) operating at 2450 MHz (Gall et al. 1983) for 10, 15 and 20 sec and were designated as O1, O2 and O3, respectively. The processing yield of tuna after each heat treatment was calculated. Samples were analyzed for fatty acid composition and other chemical parameters in triplicates from each treatment.

Fatty acid composition: The lipid was extracted by the method described by Folch et al. (1957). Fish (25 g) after homogenization was extracted twice with chloroform: methanol at the ratio of 2:1. The chloroform extract was washed with 0.75% KCl solution and again extracted with chloroform, methanol and water at the ratio 3:48:47. The lower chloroform layer was evaporated to dryness in a rotary flash evaporator (Superfit, India) under the stream of nitrogen. The extracted lipid was then quantified.

The lipid fraction (250 mg) was weighed and esterified into fatty acid methyl esters using 5 ml of BF_3 methanol (AOAC 1990). Fatty acid composition was determined by gas chromatography as per the method of Candela et al. (1996) with slight modifications. Perkin-Elmer Autosystem XL gas chromatograph, USA, fitted with a flame ionization detector and a fused silica capillary column (PE –225, 0.25 mm ID, 30 m length) was used for the separation and identification of fatty acids. The operating conditions were injector temperature 250°C and detector temperature 300°C. A temperature gradient programme was followed with initial oven temperature set at 70°C for 1 min, which was then increased to 180°C at the rate of 3°C/min and then to 220°C at the rate of 10°C/min. The carrier gas used was nitrogen at 20 psi pressure. Peaks were identified by comparison of their retention times with those of authentic fatty acid standard mixtures (Sigma Chemicals Co., Product No. 189-19, St. Louis, USA, 99% purity specific for gas chromatography). The ratio of ω-3 to ω-6 fatty acids as well as of PUFA to saturated fatty acids (SFA) (P:S) were calculated.

Other chemical parameters: Moisture fat and cholesterol contents of fish were determined by AOAC (1995) methods. Thiobarbituric acid reactive substances (TBA-RS) were determined by the spectrophotometric method (Ke et al. 1984) by measuring absorbance of coloured fraction at 538 nm against a blank in an UV-vis spectrophotometer (Jasco V 530, Japan).

Statistical analysis: The least significant differences tests for triplicate results were carried out to examine the effect of different heat processing treatments on the changes in the omega-3-PUFA fish using SPSS 10.0 statistical package.

Results and discussion

Fatty acid profile of raw tuna: The SFA, MUFA and PUFA contents of raw tuna were 15.5%, 18.3% and 57.9%, respectively (Table 1). The major SFA were palmitic (C16:0), stearic (C18:0) and behenic (C22:0) acids. The C16:0 has been reported as the major fatty acid in marine fish followed by C18:0 by many authors (Gopakumar and Nair 1972, Bhuiyan et al. 1986, Beltran and Moral 1990, Sanchez-Muniz et al. 1992, Bandarra et al. 1997). Presence of C14:0, C15:0 and C17:0 fatty acids were also noticed. The major MUFA's were myristoleic (C14:1), cis-10-pentadecaenoic (C15:1) and oleic (C18:1) acids in raw tuna. Although high levels of C18:1 was reported in marine fish by many workers (Ackman et al. 1982, Bandarra et al. 1997), their occurrence was lower (1.38%) in tuna. Another major MUFA noticed in our study was nervonic acid, C24:1 (10.9%). The major PUFA identified in raw tuna were entirely different from other marine fishes. Presence of hexadecatrienoic (C16:3) in very high proportion (29.3%) in addition to linoleic (C18:3), γ linolenic (C18:3) and hexadecatetraenoic (C16:4) acids were noticed. The fatty acids, C16:3 and C16:4, have been identified as the major fatty acids of green algae belonging to Chlorophyta (Johns et al. 1979; Khotimchenko 1993; Li et al. 2002, Sanina et al. 2004). These fatty acids could have been assimilated in tuna muscle through the food chain. Fatty acid composition of fish lipid is highly dependent on the fish diets (Fowler et al. 1994, Sathivel et al. 2002, Sengor et al. 2003), fish species and their growth conditions (Hedayatifard and Moeini, 2007). The EPA (C20:5) and DHA (C22:6) were the dominant ω-3 PUFA as also reported by Bandarra et al. (1997). The proportion of ω-3 fatty acids was quite low (5.3%), although high proportions (80%) were reported in fish species of Pacific coast (19.0%). The P:S ratio was 3.74 and the ω3/ω6 ratio was quite low (0.28).

Fatty acid profiles of cooked tuna: The SFA contents varied from 17.4 to 11.0% with an increase in the duration of cooking (Table 1). Slightly higher values were noticed

Table 1 Fatty acid composition of tuna cooked for different durations

Fatty acids	R	C1	C2	C3
C14:0	0.90±0.11[a]	2.10±0.04[b]	1.65±0.30[b]	0.46±0.13[c]
C15:0	0.25±0.18[a]	0.41±0.02[b]	0.42±0.02[b]	0.09±0.04[c]
C16:0	7.83±1.21[a]	8.26±0.12[b]	8.81±1.01[b]	3.40±0.67[c]
C17:0	0.31±0.11[a]	0.32±0.06[a]	0.34±0.21[a]	0.65±0.12[b]
C18:0	2.94±0.34[a]	3.24±0.20[a]	3.19±0.17[a]	1.50±0.30[b]
C20:0	-	0.40±0.05	-	-
C22:0	3.24±0.33[a]	2.61±0.49[a]	2.50±0.81[a]	4.88±0.99[b]
Total SFA (S)	15.5±1.06	17.3±0.65	16.9±0.42	11.0±0.38
C14:1	3.94±0.16[a]	6.01±0.20[b]	5.68±0.12[b]	3.28±0.48[a]
C15:1	1.01±0.05	-	-	-
C16:1	0.40±0.15[b]	0.63±0.19[a]	0.58±0.38[a]	0.52±0.17[a]
C17:1	0.21±0.02[a]	0.21±0.01[a]	0.22±0.04[a]	0.21±0.01[a]
C18:1	1.38±0.14[a]	1.21±0.02[a]	1.24±0.21[a]	1.08±0.07[b]
C20:1	0.27±0.03[a]	0.45±0.03[b]	0.58±0.06[b]	0.55±0.82[b]
C22:1	0.13±0.02	-	-	-
C24:1	10.94±1.23[a]	10.25±1.15[a]	10.95±0.95[a]	18.89±1.25[b]
Total MUFA	18.3±0.13	18.8±0.27	19.2±0.29	24.5±0.47
C16:3 (n-4)	29.30±1.16[a]	30.54±1.20[a]	30.09±1.13[a]	23.05±0.72[b]
C16:4 (n-4)	3.42±0.02[a]	0.63±0.06[b]	2.18±0.12[c]	3.85±0.30[d]
C18:2 (n-6)	10.69±2.32[a]	14.58±0.34[a]	10.18±0.53[b]	9.46±0.34[b]
γ C 18:3 (n-6)	5.87±0.12[a]	1.73±0.06[b]	6.09±0.14[a]	12.63±0.13[c]
C18:3 (n-3)	1.11±0.05[a]	0.89±0.12[a]	0.76±0.37[a]	1.16±0.08[a]
C20:2 (n-6)	1.74±0.22[a]	1.27±0.21[b]	1.87±0.12[a]	0.44±0.02[c]
C20:3 (n-6)	0.36±0.03[a]	0.38±0.01[a]	0.32±0.11[a]	0.34±0.01[a]
C20:4 (n-6)	0.43±0.10[a]	0.25±0.08[b]	0.28±0.03[b]	0.22±0.06[a]
C20:5 (n-3)	1.67±0.21[a]	1.84±0.13[a]	1.85±0.12[a]	1.98±0.02[a]
C22:2	0.81±0.06	0.54±0.02	-	-
C22:6 (n-3)	2.50±0.10[a]	2.44±0.44[a]	2.50±0.18[a]	1.98±0.11[b]
Total PUFA (P)	57.9±0.39	55.1±0.24	56.1±0.28	55.1±0.18
n-3	5.28	5.17	5.11	5.12
n-6	19.09	18.21	18.74	23.09
n-3/n-6 ratio	0.28	0.28	0.27	0.22
P:S ratio	3.74	3.17	3.32	5.02

Means with different superscripts row-wise differ significantly ($p<0.05$) (n=3)

*Results expressed as percentage of total fatty acid methyl esters

R: Raw, C1: Cooking at 100°C for 10 min, C2: Cooking at 100°C for 20 min, C3: Cooking at 100°C for 30 min, SFA: Saturated fatty acid, MUFA: Mono unsaturated fatty acid, PUFA: Poly unsaturated fatty acid

in most of the SFA in cooked tuna compared to raw tuna except those cooked for 30 min. Aubourg et al. (1989) have also reported a slightly higher value in certain fatty acids of cooked tuna. However, there were significant losses ($p<0.05$) in C14:0, C16:0, C18:0 and C22:0 fatty acids in tuna cooked for 30 min. The total MUFA content increased with cooking time from 18.8 to 24.5%. This was mainly due to the increase in C24:1 fatty acid. The PUFA content in cooked tuna was more or less same as that of their raw counterparts. There was no significant decrease ($p>0.05$) in C20:5 fatty acid, however C22:6 suffered 21% loss ($p<0.05$). Losses were significant ($p<0.05$) with respect to C16:3, C18:2 and C20:2 fatty acids. Aubourg et al. (1989) also observed a significant decrease in C20:5 and C22:6 on cooking of albacore tuna. Reduction in omega-3 fatty acids was already reported in the conventionally heated (at 100°C for 20 min) seal meat product (Ghazala et al. 1996). Some fatty acids, especially C18:3 increased upon cooking.

A new C-16 series fatty acid peak was apparent in cooked tuna and was identified as C16:4, which was also another fatty acid found in marine algae. The P:S ratios of cooked tuna ranged from 2.9 to 5.0 and the ω-3/ω-6 ratios were almost similar to raw tuna.

Fatty acid profiles of fried tuna: Unlike cooked tuna, there was a major loss of ~70% in SFA upon frying (from 15.5% to 4.7%) which was mainly due to reduction in C14:0, C15:0, C16:0, C18:0 and C22:0 fatty acids. Candela et al. (1996) have also reported that SFA content decreased in fish after frying. The MUFA content also suffered 45% loss upon frying for 10 min (F3). This was mainly due to C14:1, C15:1 and C24:1 ($p<0.05$). The oleic acid (C18:1) increased ($p<0.05$), which may be due to their absorption from frying oil. The PUFA content increased 1.5 times in fried fish due to absorption of C18:2, γC18:3, C18:3 and C20:4 fatty acids from frying oil. The sunflower oil used for frying contained more of C18:1, γC18:3, C18:3 and C20:4 fatty acids (data not shown). Major fatty acids such as C14:0, C16:1 and C22:6 in raw fish fillets were lost during frying (Gall et al. 1983, and Candela et al. 1998). The uptake of C18:3 ω-3 fatty acids from the oil had increased the ω-3/ω-6 ratios to 0.77 and P:S ratios from 3.5 to 17.5. The fatty acid, C16:3, suffered loss upon frying, while C18:2 remained more or less constant. Maximum losses of C20:5 (69%) and C22:6 (84%) were observed in fried tuna compared to their raw counterpart. So, fried fish cannot be a good source of ω-3 fatty acids, although C18:3 is present and the same was also suggested by Steiner–Asiedu et al. (1991).

Fatty acid profiles of canned tuna: The SFA content decreased to 9.4% with the increase in the temperature employed for canning (Table 3). This significant loss was particularly due to C14:0, C16:0 and C22:0. Stearic acid (C18:0) remained more or less unchanged. The MUFA content decreased initially upon canning due to the significant decrease ($p<0.05$) in C14:1 and C24:1 fatty acids and later, increased due to the absorption of C18:1 fatty acid from sunflower oil used for canning. This was also observed in fried tuna. The PUFA content also showed an increase to a maximum of 69.4%. Medina et al. (1997) also observed a high content of PUFA in canned tuna. The reason for high PUFA is mainly due to the uptake of C18:2, γC18:3, C18:3, C20:2, C20:4 and C22:2 fatty acids from filling oil. Aubourg et al. (1990) also indicated an increase in C18:2 and C18:3 fatty acids in canned fish. The C16:3 fatty acids decreased ($p<0.05$) similar to that observed in fried tuna. Interestingly, complete destruction of fatty acids, C20:5 and C22:6 were noticed in fish processed at 121°C. In tuna processed at 110°C, the loss of C20:5 was 42%. Aubourg et al. (1990) also indicated that there was a proportional reduction in C14:0, C16:0, C20:5 and C22:6 fatty acids in canned albacore. Although the ω-3 fatty acid content of canned tuna was high (10.6–20.0%), they were not health beneficial ω-3 fatty acids. The higher uptake of ω-3 fatty acids, particularly C18:3 from filling oil was the reason for their high P:S ratios ranging from 4.8 to 6.9. A significant reduction ($p<0.05$) in ω-3 fatty acids observed in tuna canned at 121°C was due to the oxidation of C18:2 and C18:3 fatty acids. This has reflected in lower ω-3/ω-6 ratio of 0.26 compared to 0.92 for those processed at 110°C.

Table 2 Fatty acid composition* of tuna fried for different durations

Fatty acids	F1	F2	F3
C14:0	0.58±0.04^b	0.56±0.10^b	0.21±0.13^c
C15:0	0.16±0.02^b	0.05±0.02^c	0.06±0.04^c
C16:0	5.44±1.12^b	6.19±1.01^b	2.81±0.67^c
C17:0	0.22±0.06^a	0.22±0.21^a	0.07±0.12^b
C18:0	2.58±0.20^a	2.45±0.08^a	0.51±0.30^b
C20:0	0.40±0.05	-	-
C22:0	2.23±0.17^b	1.43±0.81^c	1.01±0.99^d
Total SFA (S)	11.6±0.24	10.9±0.37	4.7±0.37
C14:1	1.65±0.20^b	2.19±0.22^b	0.84±0.08^c
C15:1	0.45±0.05^b	0.52±0.08^b	0.34±0.07^b
C16:1	0.48±0.09^a	0.16±0.01^b	0.18±0.07^b
C17:1	-	-	-
C18:1	4.75±0.22^b	4.11±0.21^b	4.12±0.07^b
C20:1	0.40±0.08^b	0.58±0.06^b	0.24±0.02^a
C22:1	-	-	-
C24:1	8.17±1.15^b	4.60±0.95^c	4.71±0.25^c
Total MUFA	15.9±0.30	12.2±0.26	10.4±0.09
C16:3 (n-4)	14.92±1.20^b	13.35±1.13^b	11.04±1.12^b
C16:4 (n-4)	1.36±0.16^b	0.96±0.12^b	0.76±0.05^b
C18:2 (n-6)	12.55±0.34^a	13.25±0.53^a	15.11±0.34^b
γ C 18:3 (n-6)	13.85±0.06^b	15.32±0.14^b	20.01±0.13^b
C18:3 (n-3)	20.83±0.12^b	23.74±0.17^b	28.02±0.08^b
C20:2 (n-6)	0.43±0.01^b	0.55±0.02^b	0.39±0.02^b
C20:3 (n-6)	-	-	-
C20:4 (n-6)	2.55±0.08^b	3.89±0.03^c	3.67±0.14^c
C20:5 (n-3)	0.84±0.13^b	0.63±0.12^c	0.51±0.02^c
C22:2	1.64±0.02^b	1.76±0.10^b	1.62±0.05^b
C22:6 (n-3)	0.81±0.04^b	0.45±0.08^c	0.39±0.01^c
Total PUFA (P)	69.8±0.22	73.9±0.24	81.5±0.20
n-3	22.48	24.82	28.92
n-6	29.38	33.01	39.18
n-3/n-6 ratio	0.77	0.75	0.74
P:S ratio	6.01	6.78	17.46

Means with different superscripts row-wise differ significantly ($p<0.05$) (n=3)

*Results expressed as percentage of total fatty acid methyl esters

F1: – Frying at 180°C for 5 min, F2 – Frying at 180°C for 7.5 min, F3 – Frying at 180°C for 10 min SFA, MUFA, PUFA, P : S as in Table 1

Table 3 Fatty acid composition* of tuna canned by different processing conditions

Fatty acids	N1	N2	N3
C14:0	0.54±0.04[b]	0.28±0.10[c]	0.20±0.13[c]
C15:0	0.11±0.01[b]	0.07±0.01[b]	0.04±0.01[b]
C16:0	8.63±1.12[b]	5.30±1.01[a]	5.15±0.67[c]
C17:0	0.22±0.07[b]	0.17±0.05[b]	0.13±0.04[b]
C18:0	3.31±0.12[a]	2.63±0.38[a]	2.61±0.30[a]
C20:0	-	-	-
C22:0	1.51±0.17[b]	1.41±0.21[b]	1.31±0.19[b]
Total SFA (S)	14.3±0.36	9.9±0.43	9.4±0.32
C14:1	1.42±0.20[b]	0.50±0.12[c]	0.46±0.08[c]
C15:1	-	-	--
C16:1	-	-	-
C17:1	-	-	-
C18:1	7.75±0.22[b]	9.58±0.21[c]	9.33±0.07[c]
C20:1	0.48±0.10[b]	1.55±0.06[c]	4.21±0.20[d]
C22:1	-	-	-
C24:1	2.17±0.15[b]	1.51±0.05[c]	0.39±0.02[d]
Total MUFA	11.8±0.17	13.1±0.11	14.4±0.10
C16:3	23.26±1.20[a]	9.33±2.13[b]	10.03±1.22[b]
C16:4	0.21±0.01[a]	0.29±0.05[a]	0.23±0.03[a]
C18:2 (n-6)	14.12±0.34[a]	14.97±1.53[a]	6.08±0.34[b]
γ C 18:3 (n-6)	9.85±0.06[b]	15.08±0.14[c]	14.79±1.13[c]
C18:3 (n-3)	17.83±0.82[b]	19.78±0.27[b]	10.65±0.48[c]
C20:2 (n-6)	1.82±0.01[a]	1.75±0.32[a]	8.78±0.12[b]
C20:4 (n-6)	0.69±0.08[b]	1.73±0.03[c]	10.56±0.93[d]
C20:5 (n-3)	0.97±0.13[b]	0.26±0.12[c]	-
C22:2	0.64±0.12[a]	1.91±0.02[b]	4.11±0.12[c]
C22:6 (n-3)	-	-	-
Total PUFA (P)	69.4±0.35	65.1±0.57	65.2±2.46
n-3	18.80	20.04	10.65
n-6	26.48	33.53	40.21
n-3/n-6 ratio	0.92	0.60	0.26
P:S ratio	4.84	6.60	6.91

Means with different superscripts row-wise differ significantly ($p<0.05$) (n=3)
*Results expressed as percentage of total fatty acid methyl esters
N1: – Canning at 110°C for 90 min, N2: – Canning at 115°C for 70 min, N3 – Canning at 121°C for 40 min, SFA, MUFA, PUFA, P : S: As in Table 1

Table 4 Fatty acid composition* of tuna microwave heated for different durations

Fatty acids	O1	O2	O3
C14:0	1.04±0.04[a]	0.88±0.18[a]	0.74±0.13[b]
C15:0	0.30±0.04[a]	0.25±0.02[a]	0.19±0.04[c]
C16:0	7.41±1.12[a]	5.89±0.01[b]	4.84±1.07[b]
C17:0	0.54±0.06[b]	0.11±0.21[c]	0.13±0.12[c]
C18:0	2.98±0.20[a]	2.07±0.04[b]	2.17±0.04[b]
C20:1			
C22:0	3.15±0.17[a]	4.40±0.81[b]	4.56±0.99[b]
Total SFA (S)	14.4±0.45	13.6±0.87	12.6±0.17
C14:1	3.70±0.20[a]	3.76±0.12[a]	3.84±0.08[a]
C15:1	1.09±0.05[a]	1.09±0.07[a]	1.12±0.12[a]
C16:1	0.48±0.09[a]	0.50±0.18[a]	0.58±0.17[a]
C17:1			
C18:1	2.67±0.22[b]	1.54±0.41[a]	1.12±0.07[c]
C20:1	0.46±0.202[a]	0.22±0.06[a]	0.24±0.20[a]
C22:1			
C24:1	7.43±1.15[b]	17.73±0.95[c]	18.71±1.25[c]
Total MUFA	15.8±0.32	25.0±0.16	25.6±0.04
C16:3	26.66±1.20[a]	21.77±1.13[b]	21.04±0.12[b]
C16:4	1.90±0.11[b]	2.94±0.12[c]	2.76±0.50[c]
C18:2 (n-6)	12.35±0.34[a]	8.72±1.53[b]	5.11±2.34[c]
γ C 18:3 (n-6)	6.90±0.06[a]	11.32±0.14[b]	14.01±0.13[b]
C18:3 (n-3)	2.77±0.02[b]	1.53±0.07[c]	1.02±0.18[a]
C20:2 (n-6)	0.63±0.01[b]	0.46±0.22[c]	0.39±0.02[c]
C20:3 (n-6)	1.74±0.08[b]	0.11±0.09[c]	0.13±0.03[c]
C20:4 (n-6)	0.44±0.08[a]	0.15±0.03[b]	0.17±0.13[b]
C20:5 (n-3)	1.36±0.13[a]	1.38±0.12[a]	1.21±0.02[b]
C22:2	0.99±0.12[a]	0.50±0.32[b]	0.62±0.12[b]
C22:6 (n-3)	1.13±0.44[b]	1.06±0.68[b]	1.09±0.31[b]
Total PUFA (P)	56.9±0.32	49.9±1.42	47.6±1.23
n-3	5.26	3.97	3.32
n-6	22.06	20.76	19.91
n-3/n-6 ratio	0.24	0.19	0.17
P:S ratio	3.94	3.67	3.77

Means with different superscripts row-wise differ significantly ($p<0.05$) (n=3)
*Results expressed as percentage of total fatty acid methyl esters
O1: – Oven heating at 2450 MHz for 10 sec, O2: – Oven heating at 2450 MHz for 15 sec, O3: – Oven heating at 2450 MHz for 20 sec SFA, MUFA, PUFA, P : S: As in Table 1

Fatty acid profiles of microwave heated tuna: The SFA content of raw tuna (14.4%) was slightly reduced to 12.6% with the increase in the duration of microwave heating (Table 4). This slight loss was mainly due to the C16:0. More specifically, an increase in C22:0 was observed. The MUFA content increased in microwave heated tuna with the increase in heating duration, as noticed with cooked tuna. This was mainly due to the increase ($p<0.05$) in the C24:1 fatty acid. Fatty acids C14:1, C16:1 and C20:1 remained more or less same. The PUFA contents slightly reduced in microwave cooked tuna with the increase in the duration

of heating. Hearn et al. (1987) have reported that PUFA remained unaffected after microwave heating of fish. The destruction of C20:5 was very minimal (20–25%) in the microwave heated tuna, while the loss of C22:6 was 55%. Gall et al. (1983) have also reported that microwave oven heated fish had significantly lowered C22:6. The P:S ratios were similar to cooked tuna (Table 1). The ω-3/ω-6 ratios varied from 0.24–0.17.

Other chemical changes in heat processed tuna: In cooked tuna, the moisture content decreased significantly ($p<0.05$) with an increase in the duration of heat process giving up to 16% reduction (Table 5). Shakila et al. (2005) have observed a reduction of 6% moisture content in cooked tuna. In fried tuna also, the moisture reduced up to 19% with the increase in the duration of frying. The same was also observed with microwave heated tuna. Hearn et al. (1987) reported 22–25% reduction in the moisture contents of microwave cooked butterfish, mackerel, mullet and tuna. In canned tuna also, the moisture reduced and the different temperatures employed did not showed much variations.

The fat content of heat processed tuna was significantly higher than the raw tuna. Increase in the duration of cooking and microwave heating did not cause significant changes in fat contents. Gall et al. (1983) and Garcia-Arias et al. (2003) have reported that moisture content decreased and fat content increased in cooked fish fillets. Increase in the duration of frying as well as the temperature employed for canning had increased ($p\leq0.05$) the fat content. An increase in fat content was mainly due to the uptake of frying and canning oil during processing. Aro et al. (2000) reported that frying with oil normally affected the lipid and moisture contents of fish.

The TBA-RS value of fresh tuna was well below the acceptability limit of 1 to 2 μg of malonaldehyde/g of fat (Connell 1995). The TBA-RS values increased to a maximum of 1.31 μg of malonaldehyde/g of fat after cooking. Koizumi et al. (1987) have also reported that TBA-RS values increased during cooking of fish at 100°C for 30 min, but they were below 1 μg of malonaldehyde/g of fat. The evaporation of water and loss of juiciness during cooking might have also contributed to an increase in TBA-RS values after cooking (Pikul et al. 1984). Increase in the duration of cooking did not alter the values. In canned tuna, lower TBA values were recorded, however, increase in the temperature beyond 115°C had increased ($p<0.05$) TBA-RS values. The TBA-RS values of fried tuna increased with the increase in duration of cooking after 7.5 min and reached 1.68 μg malonaldehyde/g of fat. Mai and Kinsella (1979) also reported that the TBA-RS values increased from 0.44 μ to 0.94 μ mole malonaldehyde/100g in deep fried fish. Chia et al. (1983) reported an increased TBA-RS value in the rainbow trout and Pollock during storage. The increase in the TBA-RS values during frying at high temperature of 180°C was probably due to the oxidation of fat. The TBA-RS values also increased after microwave heating for more than 20 sec and reached 1.66 μg malonaldehyde/g of fat. Ke et al. (1978) also reported a 100% increase in TBA-RS values in microwave cooked mackerel compared to raw fish.

The fresh tuna contained 82 mg/100 g of cholesterol and it did not increase in cooked tuna (Table 5). Osada et al. (1993) reported that the cholesterol is stable during heating at 100°C. Aubourg et al. (1989) also observed no significant change in cholesterol content during cooking. Interestingly, the cholesterol content in fried tuna was initially high and later reduced to very low levels ($p<0.05$) particularly in those fried beyond 5 min. Candela et al. (1998) observed that cholesterol decreased in sardine on frying, while in mackerel it increased. The reduction in cholesterol content in fried tuna might be due to the elution of cholesterol in

Table 5 Chemical changes in tuna muscles during different methods of thermal processing

	Moisture, %	Fat, % on moisture free basis	TBA, μg malonaldehyde/ g of fat	Cholesterol, mg/100g
Raw	71.8±1.46^{a}	9.5±1.8^{a}	0.68±0.13^{a}	82.22±1.24^{a}
C1*	68.8±1.23^{b1}	13.0±1.7^{b1}	1.30±0.18^{b1}	83.12±0.98^{a1}
C2	65.6±0.84^{b2}	14.5±2.2^{b2}	1.31±0.21^{b1}	81.15±1.13^{a1}
C3	60.7±1.91^{b3}	16.4±2.1^{b3}	1.31±0.09^{b1}	84.08±1.07^{a1}
F1	57.7±2.10^{b1}	32.0±3.1^{b1}	1.33±0.16^{b1}	90.50±1.28^{b1}
F2	54.6±1.61^{b2}	36.5±2.7^{b2}	1.48±0.12^{b1}	24.40±0.54^{b2}
F3	45.0±1.48^{b3}	42.9±3.7^{b3}	1.68±0.13^{b2}	21.35±0.39^{b3}
O1	64. 0±1.10^{b1}	13.6±1.4^{b1}	1.30±0.04^{b1}	84.69±1.42^{a1}
O2	60. 8±0.90^{b2}	24.6±2.9^{b2}	1.40±0.12^{b1}	86.24±1.21^{b2}
O3	58. 8±2.16^{b3}	26.7±2.1^{b3}	1.66±0.09^{b2}	88.60±1.05^{b2}
N1	60.1±1.25^{b1}	18.6±2.0^{b1}	1.04±0.23^{b1}	73.22±1.07^{b1}
N2	60.0±1.58^{b1}	19.5±1.5^{b1}	1.48±0.12^{b2}	74.32±0.98^{b1}
N3	60.2±1.10^{b1}	18.7±1.4^{b1}	1.32±0.07^{b2}	71.61±1.21^{b1}

Mean values with different superscripts alphabet column wise and numbers within treatments differ significantly ($p<0.05$) (n=3)
*Thermal treatments as in Table 1–4

the frying oil and absorption of culinary fat (Mai et al. 1978, Sanchez-Muniz et al. 1992). Leaching of cholesterol to frying oil and high processing temperature could be the reason for the cholesterol reduction. The cholesterol content in canned tuna was higher than the raw tuna. Osada et al. (1993) reported that the cholesterol is unstable above 120°C. Cholesterol content was also higher ($p<0.05$) in microwave heated tuna with a maximum of 88 mg/100 g. Dudek and Elkins (1986) also observed an increase in cholesterol content in microwave cooked tuna from 65 to 74 mg/100 g as observed in to our study.

Conclusion

Cooking of tuna did not result in major destruction of omega-3 fatty acids (EPA and DHA) while microwave heating brought losses of 25% EPA and 55% DHA. Canning completely destroyed these fatty acids, while frying resulted in about 70% loss of EPA and 85% loss of DHA. The ratios P:S and ω-3/ω-6 did not reflect the presence of ω-3 fatty acids in tuna. TBA-RS values increased in all heat processed. No significant differences in cholesterol contents of heat processed tuna were observed, except fried tuna, in which it decreased. The study indicated that cooking and microwave heating can be employed to process tuna to retain omega-3 fatty acids.

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