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Effect of cooking method on the fatty acid profile of New Zealand King Salmon (*Oncorhynchus tshawytscha*)

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ABSTRACT

Farmed New Zealand King Salmon (*Oncorhynchus tshawytscha*) was prepared according to common consumer techniques; raw, poached, steamed, microwaved, pan fried (no added oil), oven baked (no added oil) and deep fried (in sunflower oil). The fatty acid profile was investigated to determine the optimal preparation techniques to achieve both optimal sensory and nutritional qualities, in particular the levels of long chain polyunsaturated omega-3 fatty acids. The modified Bligh and Dyer method was used for lipid extraction and the Hartman and Lago method for FAMES preparation. Fatty acid composition was determined by gas chromatography. There were moisture and lipid losses during cooking amongst the different methods. The fatty acid profile showed only minor differences between the methods apart from an increase in PUFA in the deep fried salmon due to linoleic acid uptake from the frying oil. In all the cooking methods the omega-3 fatty acids were well preserved. However, deep fried showed the lowest amounts of omega-3 fatty acids. As the results showed good preservation of omega-3 fatty acids regardless of cooking method, there may be possible "internal protection" of omega-3 fatty acids in King Salmon that warrants future research.

1. Introduction

Currently there is major emphasis on the beneficial effects of including omega-3 fatty acids in the diet (Yashodhara et al., 2009). There have been studies showing omega-3 fatty acid involvement in lowering cholesterol levels and blood pressure, which is essential for cardiovascular health (Horrocks, 1999). Docosahexaenoic acid (DHA), a long chain polyunsaturated omega-3 fatty acid (n-3 LCPUFA), is essential for infant brain development and eye function (Birch, Hoffman, Uauy, Birch, & Prestidge, 1998). This includes potential therapeutic benefits of omega-3 fatty acids for rheumatoid arthritis, as there is a mechanism that involves immune system modulation to reduce the action of inflammatory compounds (Darlington & Stone, 2001).

Humans cannot synthesise omega-3 fatty acids, instead they have to obtain omega-3 fatty acids from those that pass through the food chain and become incorporated in fish and marine mammals. The types and levels of fatty acids found in fish vary with species, age, size, reproduction stage, season, geographical location and diet. Fatty acids from fish are considerably higher in proportions of 20 and 22 carbon chains (LCPUFA) on comparison with terrestrial animals. (Nettleton & Exler, 1992). The major n-3 LCPUFA in fish are docosahexaenoic acid (DHA 22:6 n-3) and eicosapentaenoic acid (EPA 20:5 n-3). Saturated fatty acids such as hexadecanoic acid (palmitic acid 16:0) and octadeconic acid (oleic acid 18:0) are also found in fish in substantial levels. There are also minor fatty acids, 18:3 n-3, 18:5 n-3, 20:4 n-3 and docosapentaenoic acid (DPA 22:5 n-3) present (Napolitano, Ratnayake, & Ackman, 1988).

A good source of omega-3 fatty acids, especially the n-3 LCPUFA, is from oily fish, in particular the salmon species. King Salmon is the largest of the salmon species and is also known as Chinook Salmon, Quinant Salmon and Spring Salmon. However, in New Zealand, King Salmon is generally consumed in a cooked state and therefore it is unclear whether different cooking processes have a negative effect on the omega-3 fatty acid content. At present consumers do not have information available on how best to prepare King Salmon to obtain the maximum omega-3 fatty acid content.

The effect of cooking method on the fatty acid profile of King Salmon has not been studied extensively with no literature available on King Salmon specifically. However, there are some studies in which the effects of cooking on fatty acid profile have been tested in different species of salmon and other fish. Throughout the literature, different cooking methods have been used which follow different protocol between studies. Also, different sampling sizes of fish tissue were taken from different locations on the fillet. Therefore, there are no standardised times and temperatures for a particular size of sample (i.e. fillet dimension or weight) available for any one cooking method.

Kolakowska, Domiszewski, Bienkiewicz, and Szczygielski (2001) studied the effect of heating on fish lipids in sprat, herring and bream. They found increases in peroxide value were proportional

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to heating temperature. DHA decreased by 20% after 1 h heating at 100 °C; a 45% decrease after 15 min heating at 160 °C and a 70% loss after 1 h at the same temperature. EPA under the same conditions reported losses of less than 20%.

Candela, Astiasaran, and Bello (1998) researched the affect of deep frying on the lipid fraction of three high fat fish; salmon, mackerel and sardines. The salmon, which had the lowest amount of DHA and EPA to start with, had the highest level after cooking. Candela et al. (1998) proposed that salmon lipids may have a relative higher stability during frying. The n-6/n-3 ratio increased 8.92-fold in the salmon after frying and presented the best ratio in this study due to its greater DHA and EPA stability and lower intake of linoleic acid during frying.

Gladyshev, Sushchik, Gubanenko, Demirchieva, and Kalachova (2006) studied the effect of cooking on the essential polyunsaturated fatty acids in muscle tissue of humpback salmon. The samples were fried, boiled, roasted and boiled in a small amount of water. They found that heat treatment did not decrease the EPA or DHA content during each method except for a moderate reduction found in the salmon that was fried. It was hypothesised that the absence of PUFA level reductions is due to salmon's high levels of natural antioxidants.

Al-Saghir et al. (2004) studied the effects of different cooking procedures on lipid quality of farmed salmon. They cooked the salmon by steaming or pan frying with olive oil, corn oil, or partially hydrogenated plant oil or without oil. They found that there was insignificant exchange between the oil and the salmon, but there were slight differences in fatty acid pattern according to the oil used. No change was found in the omega-3 fatty acid content with cooking method and no difference frying with or without oil.

The aim of this study was to determine the effect of different cooking methods for preparing King Salmon had on the fatty acid profile, in particular the omega-3 fatty acids. This research also aimed to determine optimal preparation technique(s) that can be recommended to obtain optimal nutritional qualities in the form of retaining omega-3 fatty acids.

2. Materials and methods

2.1. Materials and sample preparation

Fresh King Salmon was supplied by the New Zealand King Salmon Company, Nelson, New Zealand. All fish was transported to the lab chilled. The King Salmon was obtained as fillets without skin (May–August, 2007). One hundred gram sample sizes were taken from the same anatomical section in the King Salmon (Fig. 1), with a sample size of 27 for each cooking method. The salmon samples were cooked from fresh following AOAC 976.16 (method for cooking seafood).

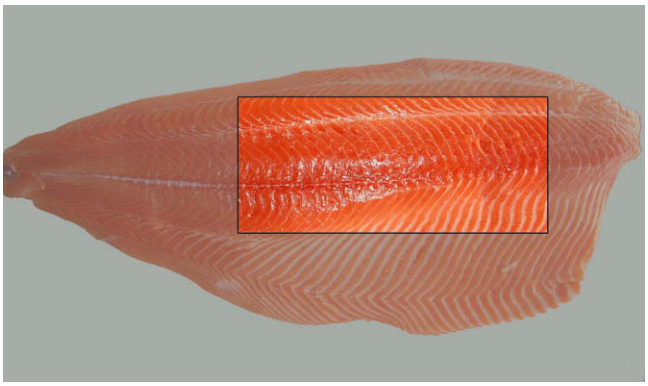

Fig. 1. Sampling location on King Salmon fillet.

Different heat treatments were selected as common cooking procedures used by consumers. These were poaching, steaming, microwaving, pan frying, oven baking and deep frying.

Poaching – the fish samples were added to a stainless steel pot of boiling water (500 mL) and cooked with the lid on for 3 min and 30 s. After cooking, the fish samples were removed and drained on absorbent paper towels.

Pan frying – the fish samples were placed in a frying pan (180 °C) bone side down for 3 min, then skin side down for 3 min. For the King Salmon samples, each short side was cooked for a further minute. Total cooking time per sample was 8 min. The cooking temperature was monitored with a digital probe. After cooking, the pan was wiped with pre-weighed absorbent paper towels to obtain the weight of excess oil exuded during cooking.

Microwaving – the fish samples were individually placed on a pre-weighed ceramic plate and cooked on 100% power (high) for 40 s (Panasonic Genius, Japan). After cooking the samples were placed on pre-weighed absorbent paper towels.

Oven baking – the fish samples were placed in a pre-weighed Teflon lined stainless steel baking dish and cooked in a convection oven at 180 °C for 10 min. After cooking, the samples were removed and the excess oil absorbed onto pre-weighed paper towels which were then weighed to obtain the weight of excess oil exuded during cooking.

Steaming – the fish samples were placed in a stainless steel steamer above a stainless steel pot of boiling water (500 ml) and cooked with the lid on for 5 min and 30 s. After cooking, the fish samples were placed on absorbent paper towels.

Deep frying – the fish samples were placed in a wire mesh basket and immersed in sunflower oil in a deep fryer (Sanyo easy clean, Japan) for 5 min at 180 °C. After frying, the basket was shaken and the samples placed on absorbent paper towels.

After all heat treatments, the samples were cooled to room temperature and weighed to obtain the cooked % yield, colour and texture were then measured. The samples were subsequently placed in freezer bags and frozen at −80 °C until further analysis, which took less than one week.

2.2. Analytical procedures

Moisture content was calculated by drying at 70 °C for 25 h in a vacuum oven (Heraeus Vacutherm, Kendro Lab. Products, Germany) at ≤100 mm Hg (13.3 kPa).

Total fat was determined following the modified Bligh and Dyer method (Smedes, 1999). The salmon samples were thawed to room temperature in a desiccator and cut manually into cubes (5 ± 1 mm). Samples (10 ± 1 g) were weighed into mixing tubes and homogenised using an Ultra Turrax blender, with a water:isopropanol:cyclohexane ratio of 11:8:10. The mixture was centrifuged and homogenised twice and the lipid layer was removed and rotoevaporated to obtain total extractable lipids which were stored under nitrogen.

Fatty acid composition was determined by gas chromatography and the Hartman and Lago method (1973) was used to prepare the fatty acid methyl esters (FAMES). Twenty milligrams of extracted lipid was used for methylation with two internal standards, tridecanoic acid (C13:0) and tricosanoic acid (C23:0).

A Hewlett Packard 5890 Series II Gas Chromatograph (Paolo Alto, CA, USA) equipped with a flame ionisation detector was used to analyse the methylated lipid samples containing the FAMES. The gas chromatograph (GC) was equipped with a DB-225 capillary column (50% cyanopropylmethyl:50% methylphenyl silicone phase, internal diameter 0.25 mm, film thickness 0.25 μm, length 15 m) from J&W Scientific (Fisons, Folsom, CA, USA). The GC was equipped with a 6890 HP automatic liquid sampler and a split less capillary inlet. Sample injection was via a standard 10 μl cone

tipped needle syringe. Data acquisition and instrument control were managed by HP GC Chemstation (Rev.A.06.03 509) software package (Hewlett Packard, USA) running on a Microsoft Windows NT Workstation 4.0.

The initial temperature for GC was 50 °C, this was increased by 25 °C/min to 175 °C. After which the temperature was increased by 4 °C/min to 225 °C and held for 5 min for a total run time of approximately 23.5 min.

Fatty acids were identified by comparing their GC retention times with the known standards (39-FAMES). These were quantified by comparing their integrals with those of two internal standards. These added internal standards provided a known ratio of area integration:mass of the FAMES and thus allowing the weights of the fatty acids in the samples to be calculated.

2.3. Statistical analysis

Data analysis was carried out using one way ANOVA with a Bonferroni *post hoc* test (SPSS). A significance level of $p < 0.05$ was used.

3. Results and discussion

The moisture content of raw King Salmon was 63.86%, higher than the cooked salmon samples (Table 1). Generally, the moisture content of fish sample seemed to be inversely related to the total extractable lipid content. This was observed in the deep fried King Salmon which had the lowest moisture content and the highest total extractable lipid content. Of the cooked samples, poached King Salmon had the highest moisture content and the lowest total extractable lipid content as expected as it is a 'wet' cooking method. Gladyshev et al. (2006) also found that fried humpback salmon had the lowest moisture content (63.9%) and boiled salmon had the highest moisture content (70.3%). The moisture contents for all the methods of King Salmon were within 13.5% of each other, quite similar to the study of Al-Saghir et al. (2004) on Atlantic Salmon *(Salmo salar)*. They showed the moisture content of the above fish samples to be within 10% of each other for the cooking methods they applied.

The total extractable lipid content of raw King Salmon was 21.61%. (Table 1). This is typical of New Zealand King Salmon which generally has higher lipid content than other salmon species. Measurements such as total extractable lipids are difficult to compare between studies as differences in lipid content can be caused by diet, season, or genetic factors. In addition the method of lipid extraction from the fish tissue can affect the total lipids extracted. In the current study, it was observed that during the lipid extraction process, lipids were more effectively extracted from the cooked fish samples rather than from the raw fish samples. This may have been due to bound lipids being released as free lipids during the cooking process making them easier to extract. The lipids in the raw fish samples would possibly still are bound in the tissue matrix and therefore much harder to extract. This difference could also be due to mechanical factors, whereby the cooked fish had much softer tissue that was more easily homogenised and therefore more lipids was able to be extracted. Extraction method is important to investigate further as currently there is no standard method to use on fish and therefore different extraction methods are used throughout the literature (Al-Saghir et al., 2004; Candela et al., 1998; Ågren & Hänninen, 1993).

The total extractable lipid content was altered the most by deep frying, through the addition of sunflower oil (Table 1). However, the uptake of frying oil only caused the deep fried salmon to have on average of 1.2 times more total extractable lipids than the raw King Salmon. The difference in oil absorption during frying of fish with different initial lipid contents has been observed in other studies. Sioen et al. (2006) found that the uptake of frying fats into fried fish samples was inversely related to total lipid content of the fish, with cod (total fat < 1 g/100 g) having greater total extractable lipid content than salmon after frying. Candela et al. (1998) reported that deep frying salmon in sunflower oil did not significantly change the total fat content. Mai, Shimp, Weihrauch, and Kinsella (1978) observed the same result in other fatty fish species. The current study showed changes in the fatty acid composition of deep fried salmon occurred due to fatty acid uptake from the frying oil. However, the addition of frying oil largely determines the fatty acid composition of low fat fish (Ågren & Hänninen, 1993). Changes also occur from the loss of fish lipids into the frying oil, although, not all of the fatty acid exchanges occur in equal proportions (Yanar, Kucukgulmez, Ersoy, & Celik, 2007). Oil selection is very important especially when frying low fat fish, but possibly not as important for higher fat fish such as King Salmon. However, the addition of frying oil did negatively affect the omega-3/omega-6 fatty acid ratio in the deep fried fish (Table 3) in favour of omega-6 fatty acids that are present in sunflower oil.

The pan fried and oven baked King Salmon had higher % total extractable lipids than the raw King Salmon and neither of these methods had fat added to them. A possible reason for this is greater moisture loss during cooking which causes an increase in the total extractable lipid. Al-Saghir et al. (2004) also found that significant increases in fatty acid content and fat content in general were caused by the loss of water through dehydration during cooking. They observed significant increases in fat content in fish samples cooked without oil as a result of greater water loss than those cooked in oil. They also found no significant differences in the total amounts of SFA, MUFA, and PUFA which supports the finding that lipid content increase was due to water loss, as was seen in the current study.

Observations showed that pan frying King Salmon caused the most lipids to be released during cooking. This was observed as lipid residue in the pan and was caused by fat migration out of the fillets during frying. Sioen et al. (2006) also observed this during pan frying of salmon. However, all the cooking methods caused fat migration out of the fillets during cooking to some extent. Poaching resulted in the lowest % total extractable lipids for King Salmon, free lipid was observed being released into the water during poaching, which probably accounted for the low % total extractable lipids compared to the other cooking methods.

Fatty acids respond differently to heat treatments. Generally, SFA are fairly heat stable in temperatures encountered during common cooking methods. However, when the temperature exceeds 150 °C and in the presence of oxygen, oxidation products occur (Sioen et al., 2006). Although the internal temperatures of the fish

Table 1
Total extractable lipid and total moisture content in raw and cooked King Salmon.

	Total lipid and moisture content of raw and cooked King Salmon						
	Raw	Poached	Steamed	Microwaved	Oven baked	Pan fried	Deep fried
% Lipids	21.61 ± 3.84	18.02 ± 2.45	21.20 ± 1.47	18.32 ± 5.84	24.68 ± 2.58	23.14 ± 2.67	26.30 ± 1.67
% Moisture	63.86 ± 2.04[a]	63.36 ± 0.17[a]	60.71 ± 0.65[a]	58.84 ± 1.47	59.43 ± 3.22	56.39 ± 6.47	50.45 ± 1.80[b]

[a,b] Different letters in the same row indicate a significant difference between methods ($p < 0.05$).

Table 2
Fatty acid content (% of total fatty acids) in raw and cooked King Salmon.

Fatty acid	Fatty acid content (% of total fatty acids)						
	Raw	Poached	Steamed	Microwaved	Oven baked	Pan fried	Deep fried
C14	3.74 ± 0.25	3.78 ± 0.29	3.72 ± 0.08	3.74 ± 0.26	3.84 ± 0.09	3.81 ± 0.41	2.96 ± 0.25
C15	0.25 ± 0.02	0.25 ± 0.03	0.24 ± 0.01	0.25 ± 0.02	0.24 ± 0.02	0.25 ± 0.03	0.2 ± 0.02
C16	17.9 ± 0.94	17.64 ± 1.46	17.3 ± 0.49	17.86 ± 1.1	17.72 ± 0.53	17.82 ± 2.13	15.56 ± 0.78
C17	0.32 ± 0.03	0.32 ± 0.04	0.31 ± 0.03	0.3 ± 0.04	0.32 ± 0.03	0.32 ± 0.05	0.26 ± 0.03
C18	5.26 ± 0.45	5.18 ± 0.51	5.16 ± 0.3	4.54 ± 1.38	5.25 ± 0.3	5.3 ± 0.7	4.93 ± 0.33
C20	0.35 ± 0.47	0.16 ± 0.03	0.15 ± 0.02	0.14 ± 0.02	0.17 ± 0.01	0.15 ± 0.03	0.17 ± 0.01
C21	0.06 ± 0	0.05 ± 0.01	0.06 ± 0.02	0.05 ± 0	0.05 ± 0.01	0.05 ± 0.01	0.03 ± 0
C22	0.14 ± 0.46	0.09 ± 0.01	0.1 ± 0.03	0.18 ± 0.23	0.08 ± 0.01	0.08 ± 0.02	0.19 ± 0.02
C24	0.02 ± 0.02	0.06 ± 0.07	0.01 ± 0.02	0.07 ± 0.1	0.01 ± 0.02	0.02 ± 0.02	0.08 ± 0.01
SFA total	27.97 ± 1.53	27.65 ± 2.35	27.19 ± 0.92	27.27 ± 2.37	27.84 ± 0.92	27.95 ± 3.36	24.51 ± 1.4
C14:1	0.13 ± 0	0.12 ± 0.02	0.14 ± 0	0.13 ± 0.01	0.15 ± 0.01	0.14 ± 0.02	0.1 ± 0.03
C15:1	0.05 ± 0.02	0.05 ± 0.03	0.05 ± 0.01	0.05 ± 0.01	0.05 ± 0.03	0.05 ± 0.02	0.03 ± 0.01
C16:1	6.97 ± 0.01	6.91 ± 0.01	6.93 ± 0	7.13 ± 0.02	7.12 ± 0	7.09 ± 0.01	5.49 ± 0.03
C17:1	0.53 ± 0.49	0.53 ± 0.39	0.53 ± 0.23	0.55 ± 0.34	0.56 ± 0.17	0.54 ± 0.59	0.41 ± 0.28
C18:1 c	32.36 ± 0.07	31.98 ± 0.04	32.35 ± 0.05	32.24 ± 0.03	33.03 ± 0.04	32.88 ± 0.03	30.6 ± 0.02
C18:1 n7	2.28 ± 2.41	2.24 ± 1.76	2.26 ± 0.97	2.29 ± 1.94	2.32 ± 0.66	2.25 ± 2.73	1.91 ± 0.82
C20:1	1.17 ± 0.13	1.74 ± 0.14	1.96 ± 0.04	1.74 ± 0.16	1.01 ± 0.02	1.66 ± 0.25	1.33 ± 0.11
C22:1	0.14 ± 0.68	0.14 ± 0.11	0.16 ± 0.64	0.14 ± 0.38	0.13 ± 0.65	0.1 ± 0.18	0.38 ± 0.16
C24:1	0.18 ± 0.01	0.15 ± 0.01	0.18 ± 0.05	0.13 ± 0.03	0.16 ± 0.01	0.16 ± 0.04	0.13 ± 0.1
MUFA total	43.8 ± 0.03	43.88 ± 0.06	44.55 ± 0.05	44.4 ± 0.06	44.51 ± 0.02	44.86 ± 0.02	40.39 ± 0.02
C18:2 t n6	0.09 ± 3.35	0.16 ± 2.37	0.14 ± 1.56	0.16 ± 2.34	0.07 ± 1.38	0.14 ± 3.71	0.16 ± 1.3
C18:2 c n6	9.54 ± 0[a]	9.64 ± 0.01[a]	9.57 ± 0.01[a]	9.64 ± 0.01[a]	9.86 ± 0.02[a]	9.82 ± 0.01[a]	21.03 ± 0.03[b]
C18:3 n6	0.46 ± 0.04	0.47 ± 0.06	0.47 ± 0.06	0.51 ± 0.06	0.49 ± 0.02	0.47 ± 0.05	0.36 ± 0.02
C18:3 n3	0.95 ± 0.67	1.04 ± 0.73	1.04 ± 0.19	1.03 ± 0.74	1.07 ± 0.16	1.06 ± 1.03	0.89 ± 2.88
C20:2 n6	0.29 ± 0.05	0.29 ± 0.04	0.33 ± 0.03	0.31 ± 0.03	0.29 ± 0.03	0.29 ± 0.04	0.21 ± 0.01
C20:3 n6	0.28 ± 0.2	0.28 ± 0.06	0.31 ± 0.04	0.34 ± 0.06	0.28 ± 0.02	0.26 ± 0.09	0.2 ± 0.04
C20:4 n6	0.69 ± 0.03	0.71 ± 0.02	0.78 ± 0.12	0.8 ± 0.07	0.59 ± 0.02	0.66 ± 0.04	0.53 ± 0.03
C20:3 n3	0.06 ± 0.02	0.05 ± 0.02	0.05 ± 0.08	0.16 ± 0.09	0.04 ± 0.02	0.08 ± 0.02	0.15 ± 0.02
C20:5 (n3) EPA	5.7 ± 0.05[a]	5.58 ± 0.05[a]	5.61 ± 0.2[a]	5.46 ± 0.2[a]	5.48 ± 0.19[a]	5.26 ± 0.05[a]	4.08 ± 0.03[b]
C22:2	0.04 ± 0.01	0.19 ± 0	0.17 ± 0.02	0.16 ± 0.14	0.16 ± 0.02	0.03 ± 0.1	0.15 ± 0.12
C22:5 (n3) DPA	2.79 ± 0.5[a]	2.64 ± 0.51[a]	2.7 ± 0.39[a]	2.44 ± 0.51[a]	2.6 ± 0.35[a]	2.53 ± 0.32[a]	1.97 ± 0.21[b]
C22:6 (n3) DHA	7.36 ± 0[a]	0.45 ± 0.1[a]	7.1 ± 0.11[a]	7.33 ± 0.08[a]	6.74 ± 0.1[a]	6.57 ± 0.01[a]	5.39 ± 0.08[b]
PUFA total	28.23 ± 0.3	28.48 ± 0.16	28.25 ± 0.18	28.33 ± 0.19	27.65 ± 0.09	27.19 ± 0.29	35.1 ± 0.24
Total fatty acid	100	100	100	100	100	100	100

[a,b] Differences between letters in rows indicate significant differences ($p < 0.05$). Note only significant differences for linoleic acid, EPA, DPA and DHA are shown.

Table 3
Long chain polyunsaturated omega-3 fatty acid content (g fatty acid/100 g fresh King Salmon) and the omega-3/omega-6 fatty acid ratio.

Fatty acid	Fatty acid content (g fatty acid/100 g fresh Salmon)						
	Raw	Poached	Steamed	Microwaved	Oven baked	Pan fried	Deep fried
C20:5 (n3) EPA	1.05 ± 0.11	0.86 ± 0.09	1.05 ± 0.08	0.89 ± 0.11	1.12 ± 0.09	1.06 ± 0.07	0.96 ± 0.06
C22:5 (n3) DPA	0.52 ± 0.06[b]	0.41 ± 0.03[a]	0.51 ± 0.04[b]	0.4 ± 0.04[a]	0.53 ± 0.02[b]	0.51 ± 0.07[b]	0.46 ± 0.06[c]
C22:6 (n3) DHA	1.36 ± 0.09[b,d]	1.15 ± 0.07[a,c]	1.33 ± 0.04[b,c]	1.19 ± 0.18[c]	1.37 ± 0.09[b,d]	1.32 ± 0.11[b,c]	1.27 ± 0.06[e]
n-3/n-6 ratio	1.48:1[a]	1.45:1[a]	1.42:1[a]	1.39:1[a]	1.37:1[a]	1.33:1[a]	0.56:1[b]

[a-e] Differences between letters in rows indicate significant differences ($p < 0.05$). Note only the n-3 LCPUFA EPA, DPA and DHA are shown.

did not exceed 75 °C in the current study, the sunflower oil used in deep frying was heated to 180 °C and the free lipid that was released from the fillets during cooking may have exceed 150 °C especially during oven baking and pan frying. Unsaturated fatty acids are more heat-labile and as the degree of unsaturation increases usually they become less stable, making PUFA the most unstable fatty acids (Sioen et al., 2006). This is of particular importance in fish as fish lipids have high proportions of long chain polyunsaturated fatty acids. Thermal treatment including cooking has been shown to increase the susceptibility of the omega-3 PUFA towards oxidation (Regulska-Ilow & Ilow, 2002). Lipid oxidation can also compromise the final food flavour and nutritional quality (Fillion & Henry, 1998).

In raw King Salmon, MUFA were the most abundant fatty acids (43.80% of total fatty acids) followed by PUFA (28.23% of total fatty acids) and SFA (27.97% of total fatty acids) (Table 2). This trend was also apparent in the cooked salmon. In all the salmon samples, MUFA was present in the highest amounts and was dominated by oleic acid (C18:1). Raw and cooked salmon showed no significant differences in MUFA content. Deep fried King Salmon had the lowest C18:1 and MUFA content.

The PUFA were dominated by linoleic acid (C18:2 n-6) as the most abundant omega-6 fatty acid and DHA (C22:6 n-3) and EPA (C20:5 n-3) as the most abundant omega-3 fatty acids, in the form of n-3 LCPUFA. Raw and cooked King Salmon showed similar levels of PUFA except for deep fried King Salmon which showed a significant increase ($p < 0.05$) in PUFA due to increased linoleic acid content as a direct result of uptake from the frying oil.

The SFA were dominated by palmitic acid (C16:0) and stearic acid (C18:0). The SFA were not significantly different between cooking methods, although there was a slight decrease in the deep fried King Salmon. This slight decrease was also apparent in the levels of C16:0 and C18:0 in deep fried King Salmon.

The omega-3 fatty acid content of King Salmon was of particular interest in this study. Results show that the omega-3 fatty acid content (as % of total fatty acids) in raw King Salmon was 14.41%. This omega-3 fatty acid content was predominately due to the LCPUFA, namely DHA (7.36%), EPA (5.70%) and DPA (2.79%). The minor omega-3 fatty acids (C18:3 n-3 and C20:3) were also taken into account when calculating the total omega-3 content.

There were no significant differences in the % of DHA, EPA or DPA across all the cooked King Salmon samples, except for the deep fried King Salmon which had significantly lower DHA, EPA and DPA compared with all the other methods ($p < 0.05$). Deep fried King Salmon had the smallest % of DHA, EPA and DPA due to the absorption of some fatty acids from the sunflower oil. In particular, the proportions of linoleic acid and oleic acid increased and in turn decreased the proportions of other fatty acids such as the long chain omega-3 fatty acids.

The omega-6 fatty acid content was significantly higher in the deep fried King Salmon (Table 2). The omega-6 fatty acid content was dominated by linoleic acid (C18:2 n-6). When calculating the ratio of omega-3 to omega-6 fatty acids, the levels of C18:2 n-6, DHA and EPA showed the greatest influence. The ratios ranged from 1.48:1 in raw King Salmon to 0.56:1 in deep fried King Salmon (Table 3).

Poached King Salmon and microwaved King Salmon had the smallest absolute amount of DHA, EPA and DPA in terms of g fatty acid/100 g fresh King Salmon (Table 3) despite showing high % DHA, EPA and DPA (Table 2). This is because it had much lower total extractable lipid content than some of the other cooking methods (Table 1). This relatively low lipid content was due to leaching of free lipids into the cooking water during poaching. In addition, the poached King Salmon had high moisture content as poaching is a wet cooking method and this effectively lowers the lipid content. Therefore, when the omega-3 fatty acids in the poached King Salmon were expressed as g fatty acid/100 g fresh King Salmon, it was found that there was less omega-3 fatty acids present in the fish than in other cooking methods. The microwaved King Salmon also had small amounts of omega-3 fatty acids in terms of g fatty acid/100 g fresh King Salmon due to lower total extractable lipids and high moisture content (Table 1). Gladyshev et al. (2006) stated the importance of expressing the mass of fatty acids as well as the proportion, as it highlights the quantity of fish that needs to be consumed to provide recommended omega-3 fatty acid intakes which has nutritional significance. Oven baked King Salmon and raw King Salmon had the greatest absolute amounts (in grams) of DHA, EPA and DPA per 100 g fresh King Salmon (Table 3).

The available literature on the effect of cooking method on fatty acid profiles in salmon varies considerably. Many studies on different species of salmon found no significant decreases in EPA and DHA during heat treatment. This was observed by Gladyshev et al. (2006) in boiled salmon and by Al-Saghir et al. (2004) during steaming. Although, other studies such as Ohshima, Shozen, Usio, and Koizumi (1996) found decreases in PUFA levels during grilling of salmon. These differences may be species specific or due to cooking method parameters as different protocols were employed between studies. In many of the studies available, either frozen fish was used or fish was frozen at some point between analyses. Some studies such as Gladyshev et al. (2006) did not investigate the effect of freezing and storage between analysis as well as pre-frozen fish on the levels of PUFA in the samples. Their reasoning was that any change would be insignificant, and corroborated this with unfrozen salmon data from similar studies by Torstensen, Froyland, Ornsrud, and Lie (2004). In the current study, the effect of freezing on the fatty acid profile was also investigated. Initially, the King Salmon were cooked and raw samples used as controls. Half the samples were frozen at −80 °C for 2 weeks. The other half was tested in their fresh state. After 2 weeks the frozen samples were also tested to determine the effect that frozen storage had on their fatty acid profiles. The results showed insignificant fatty acid, total extractable lipids and moisture content differences ($p > 0.05$) between frozen and fresh samples. Therefore, the samples used for the current study were all frozen after cooking and tested within 2 weeks.

This study showed that the omega-3 fatty acids (n-3 LCPUFA) in New Zealand King Salmon are well preserved during different cooking methods. It has been suggested that the omega-3 fatty acids in King Salmon are more heat stable than in other fish (Candela et al., 1998). The study by Kolakowska et al. (2001) showed that when lipids from sprat, herring and bream were heated, DHA decreased by 20% after 1 h heating at 100 °C, a 45% decrease after 15 min heating at 160 °C, and a 70% loss after 1 h at the same temperature. EPA under the same conditions reported losses of less than 20%. Therefore, it is possible that there is some form of 'internal protection' of omega-3 fatty acids in King Salmon tissue that prevent the large losses that occurred in the lipids. A possible explanation is the hypothesis by Gladyshev et al. (2006) where PUFA degradation during heat treatments in King Salmon may be prevented due to their high levels of natural antioxidants, through the red coloured pigments in their flesh. If this was correct, then the protective effect of antioxidants may be intensified in farmed King Salmon, which are supplemented with the red pigment astaxanthin, as in the current study. Also, highly unsaturated biological tissues usually contain high levels of vitamin E, a natural antioxidant. A possible ecological and biological role for this "internal protection" of PUFA arises from salmon spawning. After spawning, King Salmon die and their carcasses provide the predominant source of food for the juveniles either directly or indirectly through the food chain (Gladyshev et al., 2006). It has been speculated that the PUFA are preserved in the carcasses and have been found as a valuable source of omega-3 PUFA for the stream ecosystem (Heintz et al., 2004). Therefore, it may be an evolutionary adaptation in salmon to retain high levels of antioxidants to adapt to their ecological niche.

4. Conclusions

This study showed that New Zealand King Salmon is a good source of omega-3 fatty acids (n-3 LCPUFA) regardless of cooking method as the above fatty acids were well preserved across all cooking methods. Deep fried King Salmon showed a significant increase in omega-6 fatty acids due to uptake of linoleic acid from the frying oil. Apart from deep fried King Salmon, there were only minor differences in the fatty acid profiles across the different cooking methods.

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