

Original Article

The effect of cooking process on the total lipid and n-3 LC-PUFA contents of Australian Bass Strait scallops, *Pecten fumatus*

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A total of twenty-three Australian Bass Strait scallops, *Pecten fumatus* processed by three different cooking methods: steam, battered and deep-fry, and pan-fry were analysed to determine the total lipid and health-benefiting n-3 PUFA contents. Fry process resulted in a significantly higher lipid content ($p < 0.05$) with 1.98g/100g being found in deep-fried and 1.78g/100g in pan-fried scallops while 1.31g/100g was recorded in the fresh control group ($p < 0.05$). A higher concentration of α -linolenic acid (ALA, 18:3n-3), total n-6 PUFA and linoleic (LA, 18:2n-6) were also observed in fried scallops ($p < 0.05$). The two main n-3 LC-PUFA were eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3) and their concentration also varied depending on the cooking methods. Pan-fried scallops showed a higher concentration of EPA, DHA and total n-3 PUFA while steamed scallops had a higher concentration of DHA only ($p < 0.05$). The ratio of n-3/n-6 PUFA was markedly lower in both fried groups than in control and steamed scallops ($p < 0.0001$). Three frozen samples were also examined and no significant variations in the lipid profiles have been observed after 22 days. The variation of lipid profiles reflects mainly the uptake of vegetable oil components and loss of water during cooking process. Scallops represent a good source of n-3 LC-PUFA with the concentration ranging from 312.4 mg/100g in fresh scallops to 522.1mg/100g in pan-fried scallops.

Key Words: lipids, n-3 LC-PUFA, scallops**Introduction**

Seafoods are rich sources of omega-3 long chain polyunsaturated fatty acids (n-3 LC PUFA), mainly eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3). These n-3 LC-PUFA have a beneficial role in improving health, especially coronary heart disease. Clinical trials showed that regular consumption of fish oil n-3 PUFA can reduce the risk of incidence and recurrence of coronary heart disease through mainly reduction of plasma triacylglycerols, platelet aggregation, and lowering the blood pressure.^{1,2,3} n-3 LC-PUFA are also associated with the development of brain and retinal tissues in fetus and infants.^{4,5} Other health benefits of n-3 PUFA include improving inflammatory conditions, reducing the symptoms of asthma, rheumatoid arthritis, diabetes^{6,7,8,9} as well as a range of other disorders.¹⁰

Scallop is one of the commonly available seafoods in Australia. In 2002-2003 Australia produced 249,012 tons of fisheries products, and scallops accounted for 9,671 tons and represented a gross value of AUS \$33 million.¹¹ Previous study by Nichols *et al*¹² has shown that scallops, like other seafoods, have a high concentration of health-benefiting n-3 LC-PUFA and n-3/n-6 PUFA ratio. Su and Dinh¹³ reported that the concentration of n-3 PUFA and total lipid varied between the tissue types of scallops. There was no information available on the effects of cooking process on the lipid profiles of scallops. Data published by Nichols *et al*¹⁰ on the fish species showed that the method of cooking could cause changes in the lipid content and n-

3/n-6 PUFA ratio. Candella *et al*¹⁴ found a threefold decrease in EPA and DHA contents in fried sardines and mackerel. Sikorski and Kolakowska¹⁵ reported that heating for 20 minutes at 160 degrees could reduce markedly the concentration of DHA and EPA. In this study we examined the effects of three forms of cooking method commonly used by Australian consumers (steam, pan-fry and deep-fry in batter) on the total lipid and fatty acid contents, in particular n-3 LC-PUFA of Australian Bass Strait scallops, *Pecten fumatus*. In addition, three frozen samples from the same scallops used as a control were also examined.

Material and methods**Experimental design**

A total of twenty-three Bass Strait scallops, *Pecten fumatus* were obtained from the Queen Victoria Market, Melbourne, Victoria in June 2005. They were randomly divided into four groups: group one (n=6) was used as a control. The other three groups were processed by one of the common cooking methods: steam (n=6), battered and deep-fry (n=5), and pan-fry (n=6). The additional samples (Group 5) taken from three fresh control scallops were frozen (n=3) at -20 °C for 22 days prior to lipid extraction.

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Crisco vegetable oil was used for the two fry processes. Scallops coated in batter (mix comprised of self-raising flour, salt and water) were deep-fried in oil for 1.4 minutes. Pan-fry was processed in a small amount of oil for 2.4 minutes. The steam process was carried out in a traditional steamer for 2.3 minutes. After each cooking process the scallops were placed on a sheet of absorbent paper to allow excess cooking oil and water to be removed. The batter covering the scallop was also removed prior to lipid extraction.

Lipids and fatty acid analyses

All scallop samples were dried with a paper towel and approximately 5 g of muscle were cut finely and left in the dark overnight to extract lipid in 50mL of chloroform/methanol (2:1, v/v) containing 10mg/L butylated hydroxytoluene. The lipid content was then determined gravimetrically.¹⁶ Fatty acids methyl esters (FAME) were prepared by saponification of approximately 10 mg of lipid, using KOH (0.68 mol/L in methanol) followed by esterification with 14% boron trifluoride in methanol, with 0.25 mg of tricosanoic acid (23:0) added as an internal standard. FAME were separated by capillary gas liquid chromatography using a 50 m x 0.32 mm (I.D.) fused silica bonded phase column (BPX70, SGE, Melbourne, Australia). The column oven was programmed from 125 °C for 1 min to 220 °C at 8 °C/min with helium as carrier gas at a flow rate of 43 cm/sec. Identifications were performed by comparison of retention times with those of standard mixtures of FAME and the results were calculated using response factors derived from chromatograph standards of known composition (NU-Chek-Prep, Elysian, MN).

Statistical analyses

The data analyses were performed using SPSS software (12.0 for Windows). Differences between treatments were analysed using independent-measures one-way ANOVA. Post-hoc comparisons were conducted using Scheffe's test. The values were expressed as mean \pm SD except in Figure 1 where values are mean \pm SEM. *p* values <0.05 were considered as significant.

Results

Total lipid content

The total lipid contents (g/100g wet tissue) of five groups of scallops are shown in Figure 1. All the three cooking processes and freezing have caused a high total lipid content but only two fried groups showed a significant increase than the fresh scallops. The lipid content changed from 1.31g/100g in control group to 1.78g/100g in pan-fried and 1.98g/100g in deep-fried scallops ($p < 0.05$).

Total SFA, MUFA and PUFA contents

In all five groups of scallops PUFA were the dominant class of fatty acids and monounsaturated fatty acids (MUFA) were the least (Fig 2). Cooked and frozen scallops showed a higher total PUFA, saturated fatty acids (SFA) and MUFA than the control group (Fig 2). Statistically, compared to the control group, pan-fried scallops showed higher contents of PUFA, MUFA and SFA ($p < 0.05$), and deep-fried scallops showed higher PUFA and MUFA contents ($p < 0.05$). In addition deep-fried samples also contained markedly higher concentration of MUFA than steamed and frozen scallops ($p < 0.01$).

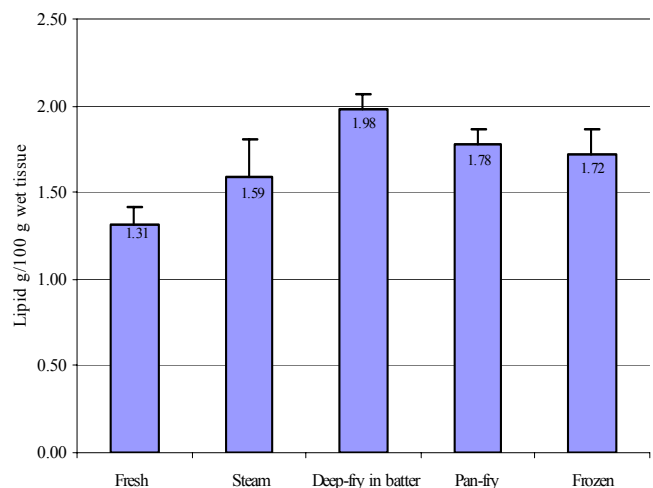


Figure 1. Total lipid content of Australian Bass Strait Scallops processed by various cooking methods (g/100g)

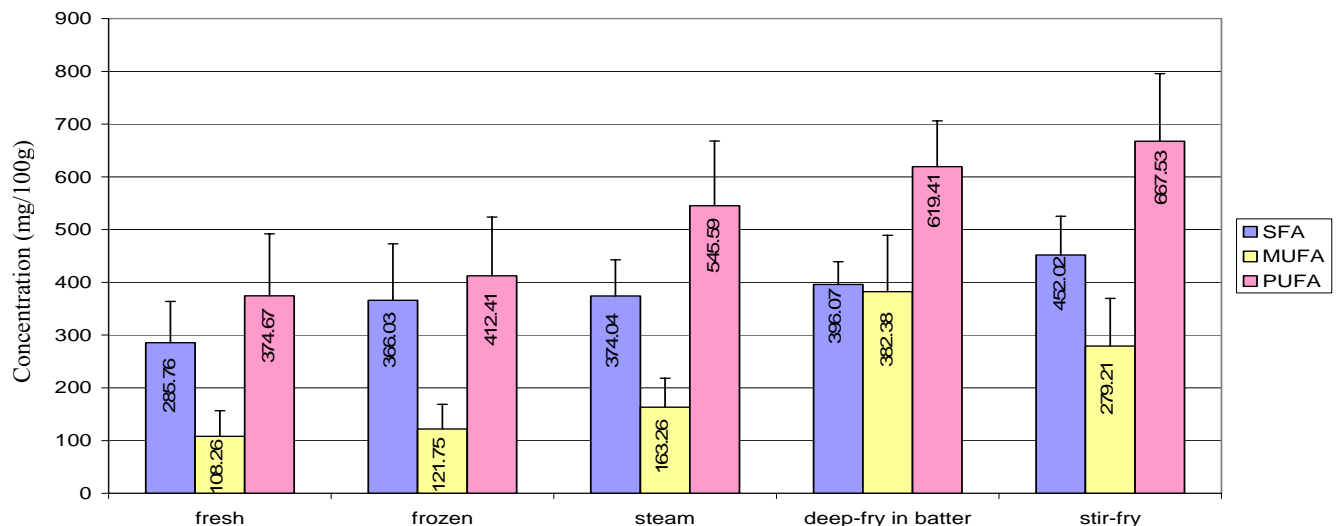
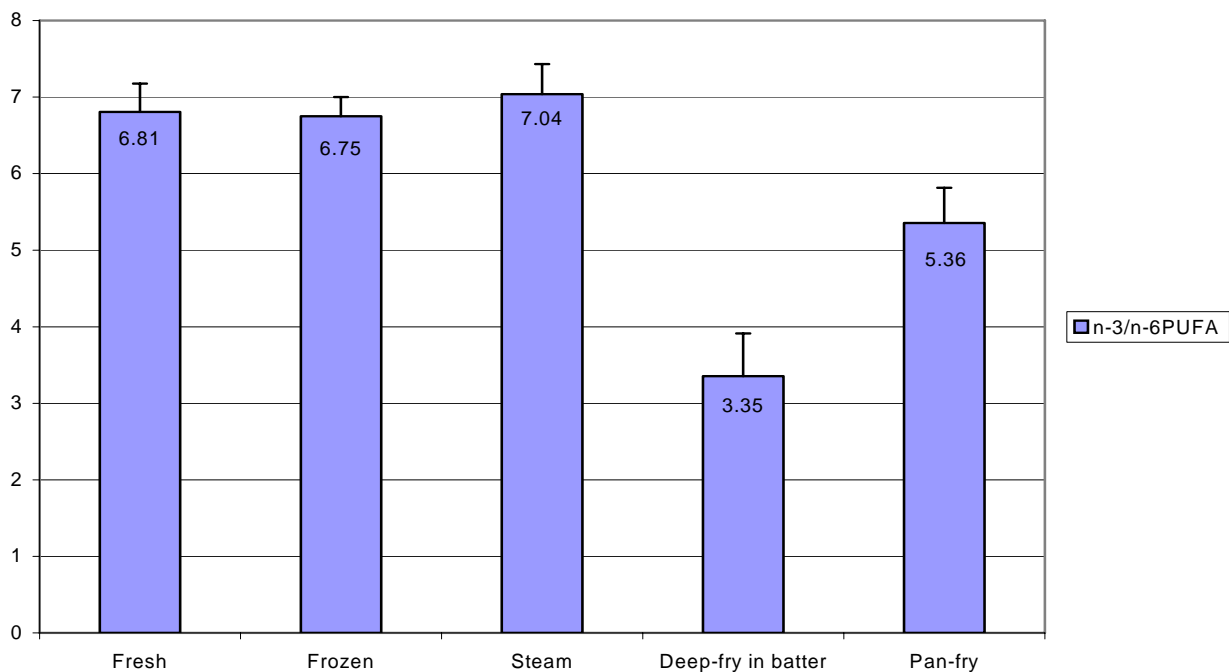


Figure 2. Contents of total SFA, MUFA and PUFA in Australian Bass Strait scallop processed by various cooking methods (mg/100g)

Table 1. Main n-3 and n-6 PUFA of Australian Bass Strait Scallops processed by various cooking methods (mg/100g)

Fatty Acid	Control ^(a)	Frozen ^(b)	Steamed ^(c)	Deep-fried in Batter ^(d)	Pan-fried ^(e)	One way ANOVA <i>p</i> -value
n-6 PUFA						
18:2	9.4 ± 3.6	10.2 ± 3.0	13.6 ± 3.6	96.8 ± 30.5	45.8 ± 19.4	0.0001
18:3	2.8 ± 1.7	2.4 ± 0.8	4.6 ± 4.0	3.5 ± 0.3	4.0 ± 0.7	0.529
20:2	5.0 ± 1.7	6.8 ± 0.9	6.4 ± 1.6	6.2 ± 1.4	8.5 ± 1.9	0.019
20:3	2.5 ± 0.7	3.3 ± 1.0	2.7 ± 1.5	2.5 ± 0.4	3.4 ± 0.9	0.434
20:4	18.5 ± 4.1	18.9 ± 4.3	26.0 ± 4.2	23.3 ± 1.2	28.4 ± 4.3	0.001
22:4	7.2 ± 2.6	8.7 ± 2.8	11.3 ± 3.8	10.2 ± 1.2	12.7 ± 2.3	0.021
22:5	2.4 ± 0.1	2.6 ± 1.1	3.8 ± 2.3	2.9 ± 0.3	3.4 ± 0.6	0.377
Total n-6	45.8 ± 13.2	52.9 ± 12.7	68.3 ± 17.3	145.4 ± 33.9	106.2 ± 26.1	0.0001
n-3 PUFA						
18:3	6.1 ± 3.9	6.8 ± 3.4	10.2 ± 4.5	50.5 ± 17.8	27.7 ± 11.8	0.0001
18:4	8.5 ± 2.6	8.3 ± 1.6	9.2 ± 2.0	10.1 ± 1.8	11.6 ± 1.8	0.090
20:3	0.8 ± 0.6	3.3 ± 1.0	1.5 ± 1.1	1.4 ± 0.3	1.7 ± 0.4	0.122
20:5	157.2 ± 51.3	172.8 ± 53.0	226.5 ± 58.5	209.7 ± 29.5	267.9 ± 55.6	0.013
22:3	1.2 ± 1.4	nd	nd	nd	nd	
22:5	14.1 ± 4.2	14.5 ± 2.9	19.4 ± 6.0	17.8 ± 1.6	19.9 ± 3.5	0.102
22:6	139.2 ± 42.4	156.3 ± 37.5	210.5 ± 36.1	184.4 ± 14.4	232.7 ± 33.8	0.001
Total n-3	326.9 ± 104.2	359.5 ± 98.8	447.3 ± 105.3	474.0 ± 34.0	561.4 ± 103.0	0.004

Values are expressed as mean ± SD. PUFA, polyunsaturated fatty acids; nd, not detected; Individual sample size are (a) 6 samples, (b) 3 samples, (c) 6 samples, (d) 5 samples, (e) 6 samples)

**Figure 3.** n-3/n-6 PUFA ratio of Australian Bass Strait scallops processed by various cooking methods

n-3 PUFA contents and n-3/ n-6 PUFA ratio

Table 1 shows the fatty acids of n-3 and n-6 PUFA classes in fresh, cooked and frozen scallops. EPA and DHA were the two main n-3 LC- PUFA with concentration of EPA being greater than DHA in all cases. Concentrations of EPA and DHA ranged from 157-268 mg/100g and 139-233 mg/100g respectively. In comparison to fresh samples pan-fried scallops showed a significantly higher concentration of EPA, DHA and total n-3 PUFA while steamed scallops showed a higher concentration of DHA only ($p < 0.05$).

Deep-frying resulted in a markedly higher concentration of α -linolenic acid (ALA, 18:3n-3) than any other processes ($p < 0.05$), and pan-fried scallops showed a significantly higher content than the fresh samples ($p < 0.05$).

No significant differences in the concentrations of docosapentaenoic acid (DPA, 22:5n-3) and 18:4n-3 ($p > 0.05$) were found across all samples.

The total n-6 PUFA concentration varied between 46 to 145 mg/100g (Table 1). Deep-fried scallops showed a significant higher total n-6 PUFA contents than all other groups except pan-fried scallops ($p < 0.001$). Pan-fried samples showed a higher n-6 PUFA content than fresh scallops ($p < 0.01$). The two main fatty acids of n-6 PUFA were linoleic acid (LA, 18:2n-6) and arachidonic acid (AA, 20:4n-6) in all samples. Deep-frying resulted in a significantly higher LA concentration than all other processes ($p < 0.001$) while pan-fried scallops showed a higher LA concentration than the control and steamed groups ($p < 0.05$). Although AA contents were relatively constant

across all sample groups (Table 1) pan-fried samples showed a higher concentration than frozen and fresh scallops and the concentration in steamed scallops was higher than in fresh samples ($p < 0.05$).

Both groups of fried scallops showed a lower n-3/n-6 PUFA ratio than fresh, steamed and frozen samples, in particular the deep-fried scallops where the ratio decreased from 6.8:1 to 3.4:1 (Fig 3) ($p < 0.001$). No significant variation was found in steamed and frozen scallops.

Discussion

Scallops contain high concentration of n-3 PUFA and relatively low concentration of n-6 PUFA. The predominant n-3 PUFA fatty acids were EPA, DHA, DPA, ALA and 18:4n-3, and n-6 PUFA were AA and LA.^{10,13} This study demonstrated that the content of beneficial n-3 LC-PUFA, n-3/n-6 PUFA ratio, as well as the total lipid could be affected by the cooking methods. The total lipid content significantly increased in both pan-fried and deep-fried samples than in fresh control samples. These results are consistent with Nichols *et al*¹⁰ on fish and possibly due to the fact that seafood experienced water loss in their tissues during the cooking process. The change of tissue mass recorded in the present study has further confirmed this. Prior to the cooking process the average weight of scallops was 20 g, but the weight after cooking process was 13.3 g for steamed, 12.7 g for pan-fried and 8.3 g for battered and deep-fried. The cooking process has reduced the body mass by 33% in steam, 36% in pan-fry and 58% in deep-fry.

The large increase in the total lipid content through frying processes may also reflect the uptake of vegetable oil components. Cooking oil mixed with scallop tissues and added extra to the total lipid value.^{10,14,17} As a result the more and longer time associated with cooking oil, the higher the lipid content was shown. This trend was illustrated in Figure 1 where from the highest to lowest lipid content was deep-frying, pan-frying, and steaming.

GC analyses of the vegetable oil used in frying processes found that the main fatty acids were 18:2n-6, 18:1, and 18:3n-3. Consistently fried scallops showed higher concentration of these three fatty acids (Table 1). The higher proportion of 18:2n-6 from the cooking oil also contributed to the lower n-3/n-6 PUFA ratio in fried scallops (Figure 3).

In the present study pan-frying resulted in a high concentration of n-3 LC-PUFA, DHA and EPA, and steam caused a higher content of DHA only. This could also be associated with the water loss during the cooking process. However deep-frying did not cause significant changes in the contents of EPA, DHA and total n-3 PUFA, and this may be attributed to the higher temperature during fry process. In the study of fish Sikorski and Kolakowska¹⁵ reported that heating for 20 minutes at 160 degrees could reduce the DHA contents to 45% and EPA levels to 20%. They also found that temperature is more effective than the duration of heating in the cooking process. Similarly Candella *et al*¹⁴ found a threefold decrease in EPA and DHA contents in fried sardines and mackerel. In this study deep-fry process took 1.4 minutes while pan-frying took 2.4 minutes and steam process was 2.3 minutes. The higher temperature during the deep-fry process seems to

have caused more effects than the longer duration in the steam and pan-fry processes and thus supports the results of Sikorski and Kolakowska.¹⁵

The ratio of n-3/n-6 PUFA is known to be of dietetic importance because it is the key factor for balanced synthesis of eicosanoids in organism.¹⁸ According to the current WHO recommendations, n-3/n-6 PUFA should not be lower than 1:5.¹⁹ This study showed that scallops, like other seafood, have a high n-3/n-6 ratio (6.8:1). Although fry process decreased this ratio (3.4:1 in deep-fry and 5.4:1 in pan-fry) the values are still higher than the recommended standard. Previous studies on fish also reported a decrease in n-3/n-6 ratio from 8.3 to 1.4 in fried salmon¹⁴, 8.3 to 0.2 in mackerel and 14.4 to 0.2 in sardines¹⁴. Celik *et al*²⁰ found the n-3/n-6 ratio reduced from 3.2 to 2.3 in boiled blue crab, *Callinectes sapidus*. Tarley *et al*²¹ observed a change from 2.2 to 0.2 in canned sardines.

Sikorski and Kolakowska¹⁵ found that chilled fish only maintained their n-3 PUFA concentration in the initial three to four days and after seven days, both EPA and DHA concentrations had decreased. In our study the frozen scallops after 22 days did not show significant changes although there was a slight increase in the total lipid content. The difference between the two studies might be due to species variation, the temperature in the freezing process, or the type of tissue analysed. It has been reported that the gonads of scallop contained a higher concentration of n-3 PUFA than the muscle tissue¹³ although the change in fatty acid profile after cooking process in these two tissue types were not determined. In the examination of fish fatty acids only muscle tissue was normally used while in the present study of scallops we used a mix of muscle and gonad.

Scallops are a good source of n-3 LC-PUFA. Pan-fry and steam resulted in a higher concentration of beneficial n-3 LC-PUFA. Although frying process reduced the n-3/n-6 PUFA ratio the absolute n-3 PUFA content is still high and comparable with other seafood groups.^{10,12} In addition, as suggested by Nichols *et al*¹⁰ the n-3/n-6 PUFA ratio could be improved if the cooking oils containing lower levels of n-6 PUFA is used.

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