

Fatty Acid Compositions of Raw Fish White Sardinella (Oom), Fish Paste (Tareeh), and Fish Sauce (Mehiawh): Fermented Fish Products Rich in Polyunsaturated Fatty Acids

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Objective: To evaluate the fatty acid contents of raw white sardinella fish and their two fermented products, fish paste (Tareeh) and fish sauce (Mehiawh).

Design: A Prospective Experimental Basic Science Study.

Setting: University of Bahrain, Bahrain.

Method: Four raw Oom fish, four fish paste, and four fish sauce samples were used from each batch. Raw fish samples were first grinded separately and one gram of each grinded raw fish, Tareeh and Mehiawh were homogenized with 10mL of 10% saline solution and 6mL of the homogenate were used. The homogenates were extracted with a mixture of methanol: chloroform (1:1 v/v) Lipids were extracted from the food samples, and their fatty acids methyl esters (FAMES) were analyzed by gas chromatography.

Result: The concentrations of saturated fatty acids and monounsaturated fatty acids were significantly lower in the fermented samples compared to raw samples, whereas the concentrations of unsaturated fatty acids and polyunsaturated fatty acids were significantly higher. The amount of omega-6, omega-3, eicosapentaenoic acid and docosahexaenoic acid were higher in the fermented samples. The unsaturated fatty acid C20:4 n6 was not present in the raw fish samples but was detected in the fermented samples. The findings of the present study have indicated the presence of some degree of desaturation and elongation activities during the fermentation process.

Conclusion: The findings of the present study have indicated the presence of some degree of desaturation and elongation activities during the fermentation process which might have resulted in the production of fermented fish products with elevated levels of polyunsaturated fatty acids (PUFAs), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA).

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The effect of fish consumption on the prevention of cardiovascular disease and cancer due to its high content of omega-3 (n-3) polyunsaturated fatty acids (PUFAs) including eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are well documented¹⁻⁴. Although all fish contain EPA and DHA, their concentrations vary among species as well as within the same species due to environmental conditions⁵.

Sardines are fatty fish and considered as an important source of high levels of EPA and DHA^{4,6,7}. The sardine species white sardinella (*Sardinella albella*) are widely distributed in the Arabian Gulf. They are commonly known in Bahrain, and the Arabian Gulf countries as "Oom" and are considered as good source of omega-3 fatty acids^{5,6,8}.

Fatty acids in fish decay easily due to the oxidation of the PUFAs resulting in limited shelf-life of oily fish during storage^{6,9-11}. Oxidation of highly unsaturated lipids is one of the main causes of the off-flavors and odors from stored fish¹².

Salting is the oldest technique used for preservation of food especially fish and still used in modified forms^{13,14}. Salting fatty fish involves a certain degree of fermentation¹⁵. Fermentation is one of the oldest techniques in food preservation as it does not only extend the shelf-life but also enhances the flavor and nutritional quality of the product¹⁶. Autolytic enzymes in the fish and microorganisms, in the presence of high salts, are responsible for the fermentation¹⁵. Lactic acid bacteria (LAB) are sometimes used to ferment fish along with other ingredients that also help to increase the shelf-life of fish as well as add new aromas and consistencies¹⁴. This bacteria produces lactic acid and other organic acids through fermentation that help to reduce the pH of the mixture and also inhibit the growth of pathogenic and spoilage microorganisms¹⁷.

The fermented fish product is a term used to define processed fish via maceration (softening) or hydrolysis of chemical constituents involving proteins via microbial and natural enzymes. Fermentation of fish to produce different products

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is commonly practiced in Asia^{18,19}. During fermentation, the microorganisms or the endogenous enzymes or those added to the fish convert organic substances present in the fish into simpler compounds such as peptides, amino acids and other nitrogenous compounds²⁰. Fish sauce (Mehiawh) and Paste (Tareeh) are two products that are made by fish fermentation. They are mainly produced in small-scale industry carried out at home. The process of fermentation is normally continued for a long time to develop the flavors and color of the product^{18,19}.

Preparation of both Tareeh and Mehiawh starts by thoroughly cleaning fresh sardines under running water followed by air drying. The dried fish is then mixed with salt and placed in large earthen containers and kept to ferment for a month to several months. After few months, a thick paste form which is known as Tareeh. Fish paste (Tareeh) is a thick product which includes the whole fermented fish without any addition of spices and undergoing only little straining during fermentation¹⁸. Mehiawh is a clear brown liquid prepared by further adding spices and water to the mashed fish paste and further fermenting it at room temperature for two weeks to one year¹⁸. Mehiawh is commonly used as a flavor enhancer or salt replacement in foods or simply as a spread on locally made thin bread. In the Arabian Gulf and Iran, fish sauce (Mehiawh) is a popular traditional food prepared from inferior type of fish such as (Oom). However, Tareeh is considered more nutritious product than Mehiawh^{14,18,19}.

To our knowledge fatty acid compositions of fish paste Tareeh and fish sauce Mehiawh has not been investigated. Therefore, the present study is the first attempt to provide information about the fatty acid contents of fish paste and fish sauce prepared from white sardinella.

The aim of this study is to evaluate the fatty acid contents of raw white sardinella fish and their two fermented products, fish paste (Tareeh) and fish sauce (Mehiawh).

METHOD

Eight home-made producers of fish paste (Tareeh) and fish sauce (Mehiawh) were asked to participate in the present study during their production of a new batch of Tareeh and Mehiawh. They were asked to provide us with samples of raw fish utilized, detailed production procedure, as well as their end products. Each producer purchased 50 Kg of fresh local white sardinella fish (*Sardinella albella*) (Oom) from the local central fish market in East Riffa (Bahrain) in October 2012 (batch 1) from which four fresh raw fish samples were kept aside to analyze to establish baseline for comparison purposes. Fish were cleaned thoroughly under running water, drained, mixed with 10 Kg of salt (20%), and kept in large containers to ferment under the sun for one month. At the end of the fermentation process, fish paste (Tareeh) was produced as thick brown liquid. Tareeh was further processed by adding a mixture of spices and was left to further ferment for two more weeks to produce the fish sauce (Mehiawh). The whole procedure was repeated in October 2016 (batch 2).

Four raw Oom fish, four fish paste, and four fish sauce samples were used from each batch. Raw fish samples were first grinded separately and one gram of each grinded raw fish, Tareeh and Mehiawh were homogenized with 10mL of 10% saline solution and 6mL of the homogenate were used.

The homogenates were extracted with a mixture of methanol:chloroform (1:1 v/v) by the procedure of Bligh and Dyer (1959) with some modifications as described by Freije and Awadh (2009)^{21,22}.

Fatty acids methylation was performed on stored lipid extracts according to the method of Morrison and Smith (1964) as described by Freije (2009)^{23,24}. Fatty acid methyl esters (FAMES analysis) was performed using a Perkin Elmer Autosystem XL Gas Chromatography (GC) as described by Freije (2009)²⁴.

Statistical analysis was performed using the statistical package of Excel 2007 and SPSS version 18. Means were compared and one-way analysis of variance (ANOVA) was also performed on the data. Post hoc analyses were then performed using Least Square Difference method and significance was set at P value ≤ 0.05 .

RESULT

The fatty acid compositions of raw fish and fermented fish samples Tareeh and Mehiawh are summarized in table 1 A-H. The unsaturated fatty acids (UFAs) C20:4 were detected in fermented samples but not in the raw fish samples. There were significant differences in saturated, unsaturated, monounsaturated, and polyunsaturated fatty acid values in their percentages between raw fish samples and fermented Tareeh and Mehiawh samples, see table 2. The fatty acid C18:0 was the predominant saturated fatty acid (SFAs) with the highest concentration detected in raw fish samples (30.14±1.40 to 30.84±1.93%) and was significantly higher than that present in Tareeh and Mehiawh samples (24.18±0.40 to 26.84±1.70%).

The predominant fatty acids were C18:0, C18:2 n6, C18:3 n6, C18:4 n3 and C24:1 n9 in both raw fish as well as Tareeh and Mehiawh samples. The highest proportion of MUFAs were in 24:1 n9 (15.38±1.56 to 15.53±1.31%) and PUFAs in C18:2 n6 (11.14±0.36 to 11.94±0.35%) in raw fish samples. Similarly, the highest proportion of MUFAs were in C24:1 n9 (5.59±0.11 to 8.12±0.33%) and PUFAs in C18:2 n6 (12.40±0.33 to 14.53±0.87%) in Tareeh and Mehiawh samples. The concentrations of MUFAs C16:1 n7 was almost constant throughout the study, whereas the levels of C24:1 n9 were significantly lower in Tareeh and Mehiawh samples compared to raw fish samples.

The concentrations of C18:3 n6 was higher in Tareeh and Mehiawh samples (9.44±1.42 to 10.77±0.14%) with significant difference ($p=0.031$) in comparison to raw fish samples (7.02±0.77 to 7.22±0.77%). Similarly, the fatty acid C18:3 n3 was significantly higher ($p=0.045$) in Tareeh and Mehiawh samples (2.76±0.39 to 3.64±0.54%) in comparison to raw fish samples (2.04±0.35 to 2.12±0.18%). The concentrations of the fatty acid C18:4 n3 was higher in Tareeh and Mehiawh samples (9.54±1.32 to 10.76±0.88%) in compared to raw fish samples (8.08±0.45 to 8.25±0.29%), whereas the fatty acid C20:4 n6 was not detected in raw fish samples, but their percentage values fluctuated in Tareeh and Mehiawh samples (1.78±0.19 to 2.98±1.50%). The profile of the fatty acid C20:5 n3 (EPA) was similar to that of C18:3 n3 in which the concentrations were significantly higher in Tareeh and Mehiawh samples (2.70±0.30 to 4.80±0.29%) in comparison to raw fish samples (2.44±0.23 to 2.76±0.43%).

Table 1 A: (Batch 1 - Sample 1) Fatty Acids Composition of Raw Fish (Oom), Fish Paste (Tareeh) and Fish Sauce (Mehiawh)

Fatty acids	Raw Fish Batch 1 Samples 1,2,3, 4	Sample 1	
		T1	M1
C16:0	6.47±0.62 ^b	6.20±1.20 ^{a,c}	6.52±0.24 ^b
C16:1 n7	1.21±0.19 ^b	1.68±0.14 ^{a,c}	1.20±0.05 ^b
C18:0	30.84±1.93 ^{b,c}	25.84±3.89 ^{a,c}	24.35±2.80 ^{a,b}
C18:1 n9	1.95±0.08 ^{b,c}	2.59±0.67 ^a	2.33±0.57 ^a
C18:2 n6	11.14±0.36 ^{b,c}	13.94±0.94 ^{a,c}	12.40±0.73 ^{a,b}
C18:3 n6	7.02±0.77 ^{b,c}	9.61±0.93 ^a	9.66±0.39 ^a
C18:3 n3	2.04±0.35 ^{b,c}	3.64±0.54 ^{a,c}	3.03±0.19 ^{a,b}
C18:4 n3	8.08±0.45 ^{b,c}	9.86±1.50 ^{a,c}	10.24±0.56 ^{a,b}
C20:4 n6	Nd	2.98±0.05 ^{a,c}	1.78±0.19 ^{a,b}
C20:5 n3 EPA	2.76±0.43 ^{b,c}	3.34±0.15 ^a	3.38±0.13 ^a
C22:1 n11	2.25±0.38 ^{b,c}	4.11±0.36 ^{a,c}	4.80±0.29 ^{a,b}
C22:4 n6	3.94±0.52 ^{b,c}	4.58±1.41 ^{a,c}	5.66±0.34 ^{a,b}
C22:5 n3	3.87±0.34 ^{b,c}	1.69±0.84 ^{a,c}	2.21±0.24 ^{a,b}
C22:6 n3 DHA	3.05±0.19 ^{b,c}	4.35±0.87 ^{a,c}	5.23±0.49 ^{a,b}
C24:1 n9	15.38±1.56 ^{b,c}	5.59±0.11 ^{a,b,c}	7.21±0.87 ^{a,b}

These values are expressed as percentage total fatty acid methyl esters; mean ± SD.

EPA: eicosapentaenoic acid **DHA:** docosahexaenoic acid
Nd: not detected

T1: Tareeh sample 1, M1: Mehiawh sample 1

T2: Tareeh sample 2, M2: Mehiawh sample 2

T3: Tareeh sample 3, M3: Mehiawh sample 3

T4: Tareeh sample 4, M4: Mehiawh sample 4

a: significantly different compared with raw fish

b: significantly different compared with T1

c: significantly different compared with M1

Table 1 B: (Batch 1 - Sample 2) Fatty Acids Composition of Raw Fish (Oom), Fish Paste (Tareeh) and Fish Sauce (Mehiawh)

Fatty acids	Raw Fish Batch 1 Samples 1, 2, 3, 4	Sample 2	
		T2	M2
C16:0	6.47±0.62 ^b	6.10±0.46 ^{a,c}	5.78±0.30 ^{a,b,c}
C16:1 n7	1.21±0.19 ^b	1.51±0.32 ^{a,c}	1.25±0.01 ^b
C18:0	30.84±1.93 ^{b,c}	25.49±3.28 ^{a,c}	24.18±0.40 ^{a,b}
C18:1 n9	1.95±0.08 ^{b,c}	2.33±0.24 ^a	2.12±0.02 ^{a,b}
C18:2 n6	11.14±0.36 ^{b,c}	14.15±0.54 ^{a,b,c}	13.26±0.23 ^{a,b,c}
C18:3 n6	7.02±0.77 ^{b,c}	9.44±1.42 ^{a,b,c}	9.71±0.06 ^a
C18:3 n3	2.04±0.35 ^{b,c}	3.15±0.84 ^{a,b}	3.58±0.13 ^{a,c}
C18:4 n3	8.08±0.45 ^{b,c}	9.54±1.32 ^{a,b,c}	9.91±0.05 ^{a,c}
C20:4 n6	Nd	2.33±0.87 ^{b,c}	2.03±0.16 ^{a,b,c}
C20:5 n3 EPA	2.76±0.43 ^{b,c}	4.82±0.74 ^{a,b,c}	3.98±0.18 ^{a,b,c}
C22:1 n11	2.25±0.38 ^{b,c}	3.77±0.32 ^{b,c}	4.89±0.22 ^{a,b}
C22:4 n6	3.94±0.52 ^{b,c}	4.67±0.88 ^{a,c}	5.48±0.03 ^{a,b}
C22:5 n3	3.87±0.34 ^{b,c}	2.00±0.25 ^{a,b,c}	2.39±0.07 ^{a,b,c}
C22:6 n3 DHA	3.05±0.19 ^{b,c}	4.56±0.17 ^{a,c}	3.44±0.16 ^{a,b,c}
C24:1 n9	15.38±1.56 ^{b,c}	6.14±0.17 ^{a,c}	8.00±0.41 ^{a,b,c}

These values are expressed as percentage total fatty acid methyl esters; mean ± SD.

EPA: eicosapentaenoic acid **DHA:** docosahexaenoic acid
Nd: not detected

T1: Tareeh sample 1, M1: Mehiawh sample 1

T2: Tareeh sample 2, M2: Mehiawh sample 2

T3: Tareeh sample 3, M3: Mehiawh sample 3

T4: Tareeh sample 4, M4: Mehiawh sample 4

a: significantly different compared with raw fish

b: significantly different compared with T1

c: significantly different compared with M1

Table 1 C: (Batch 1 - Sample 3) Fatty Acids Composition of Raw Fish (Oom), Fish Paste (Tareeh) and Fish Sauce (Mehiawh)

Fatty acids	Raw Fish Batch 1 Samples 1,2, 3, 4	Sample 3	
		T3	M3
C16:0	6.47±0.62 ^b	6.40±0.31 ^b	6.13±0.62 ^{a,c}
C16:1 n7	1.21±0.19 ^b	1.43±0.17 ^{a,b,c}	1.69±0.06 ^{a,c}
C18:0	30.84±1.93 ^{b,c}	25.28±0.66 ^{a,c}	24.56±1.01 ^{a,b}
C18:1 n9	1.95±0.08 ^{b,c}	2.75±0.15 ^{a,c}	2.49±0.75 ^a
C18:2 n6	11.14±0.36 ^{b,c}	14.05±0.47 ^{a,b,c}	14.53±0.87 ^{a,b,c}
C18:3 n6	7.02±0.77 ^{b,c}	10.56±0.55 ^{a,b,c}	10.77±0.14 ^{a,b,c}
C18:3 n3	2.04±0.35 ^{b,c}	3.44±0.16 ^{a,b,c}	2.33±0.17 ^{a,b,c}
C18:4 n3	8.08±0.45 ^{b,c}	10.41±0.50 ^{a,b,c}	9.55±0.16 ^{a,b,c}
C20:4 n6	Nd	2.76±0.07 ^{a,b,c}	2.76±0.37 ^{a,b,c}
C20:5 n3 EPA	2.76±0.43 ^{b,c}	2.70±0.36 ^{b,c}	3.26±0.22 ^a
C22:1 n11	2.25±0.38 ^{b,c}	3.96±0.15 ^{a,c}	4.24±0.21 ^{a,c}
C22:4 n6	3.94±0.52 ^{b,c}	3.28±0.21 ^{a,b,c}	4.82±0.65 ^{a,b,c}
C22:5 n3	3.87±0.34 ^{b,c}	2.70±0.17 ^{a,b,c}	1.53±0.19 ^{a,c}
C22:6 n3 DHA	3.05±0.19 ^{b,c}	4.22±0.07 ^{a,c}	3.22±0.56 ^{b,c}
C24:1 n9	15.38±1.56 ^{b,c}	6.06±0.23 ^{a,c}	8.12±0.33 ^{a,b,c}

These values are expressed as percentage total fatty acid methyl esters; mean ± SD.

EPA: eicosapentaenoic acid **DHA:** docosahexaenoic acid
Nd: not detected

T1: Tareeh sample 1, M1: Mehiawh sample 1

T2: Tareeh sample 2, M2: Mehiawh sample 2

T3: Tareeh sample 3, M3: Mehiawh sample 3

T4: Tareeh sample 4, M4: Mehiawh sample 4

a: significantly different compared with raw fish

b: significantly different compared with T1

c: significantly different compared with M1

Table 1 D: (Batch 1 - Sample 4) Fatty Acids Composition of Raw Fish (Oom), Fish Paste (Tareeh) and Fish Sauce (Mehiawh)

Fatty acids	Raw Fish Batch 1 Samples 1, 2, 3, 4	Sample 4	
		T4	M4
C16:0	6.47±0.62 ^b	6.87±0.17 ^{a,b}	5.84±0.72 ^{a,b,c}
C16:1 n7	1.21±0.19 ^b	1.40±0.05 ^{a,b,c}	1.18±0.11 ^b
C18:0	30.84±1.93 ^{b,c}	24.88±0.05 ^{a,b}	25.91±2.98 ^{a,c}
C18:1 n9	1.95±0.08 ^{b,c}	2.46±0.19 ^a	2.22±1.11 ^{a,b}
C18:2 n6	11.14±0.36 ^{b,c}	12.59±0.33 ^a	13.00±0.24 ^{a,b,c}
C18:3 n6	7.02±0.77 ^{b,c}	10.07±0.21 ^{a,b,c}	9.74±0.17 ^a
C18:3 n3	2.04±0.35 ^{b,c}	3.05±0.00 ^{a,b}	2.76±0.39 ^{a,b,c}
C18:4 n3	8.08±0.45 ^{b,c}	9.71±0.01 ^{a,c}	10.76±0.88 ^{a,c}
C20:4 n6	Nd	2.56±0.00 ^{a,b,c}	2.19±0.08 ^{b,c}
C20:5 n3 EPA	2.76±0.43 ^{b,c}	2.85±0.01 ^{a,c}	3.93±0.09 ^{a,b,c}
C22:1 n11	2.25±0.38 ^{b,c}	2.91±0.01 ^{b,c}	4.06±0.07 ^{a,c}
C22:4 n6	3.94±0.52 ^{b,c}	6.43±0.44 ^{a,b,c}	6.36±0.11 ^{a,b,c}
C22:5 n3	3.87±0.34 ^{b,c}	3.33±0.11 ^{a,b,c}	1.99±0.06 ^{a,b,c}
C22:6 n3 DHA	3.05±0.19 ^{b,c}	4.93±0.16 ^{a,b,c}	2.41±0.08 ^{a,b,c}
C24:1 n9	15.38±1.56 ^{b,c}	6.01±0.17 ^{a,c}	7.65±0.12 ^{a,b,c}

These values are expressed as percentage total fatty acid methyl esters; mean ± SD.

EPA: eicosapentaenoic acid **DHA:** docosahexaenoic acid
Nd: not detected

T1: Tareeh sample 1, M1: Mehiawh sample 1

T2: Tareeh sample 2, M2: Mehiawh sample 2

T3: Tareeh sample 3, M3: Mehiawh sample 3

T4: Tareeh sample 4, M4: Mehiawh sample 4

a: significantly different compared with raw fish

b: significantly different compared with T1

c: significantly different compared with M1

Table 1 E: (Batch 2 - Sample 5) Fatty Acids Composition of Raw Fish (Oom), Fish Paste (Tareeh) and Fish Sauce (Mehiawh)

Fatty acids	Raw Fish Batch 2 Samples 5, 6, 7, 8	Sample 5	
		T5	M5
C16:0	6.57±0.75 ^b	6.31±0.79 ^a	6.47±0.31 ^b
C16:1 n7	1.33±0.12 ^b	1.66±0.08 ^{a,c}	1.42±0.03 ^b
C18:0	30.14±1.40 ^{b,c}	26.80±2.15 ^{a,c}	26.06±1.61 ^{ab}
C18:1 n9	2.00±0.18 ^{b,c}	2.47±0.42 ^a	2.34±0.37 ^a
C18:2 n6	11.94±0.35 ^{b,c}	13.74±0.70 ^{a,c}	12.97±0.60 ^{ab}
C18:3 n6	7.22±0.77 ^{b,c}	9.34±0.80 ^a	9.37±0.53 ^a
C18:3 n3	2.12±0.18 ^{b,c}	3.58±0.66 ^a	3.42±0.48 ^a
C18:4 n3	8.25±0.29 ^{b,c}	9.51±0.83 ^{a,c}	9.70±0.36 ^a
C20:4 n6	Nd	2.63±0.19 ^{a,c}	2.03±0.26 ^b
C20:5 n3 EPA	2.44±0.23 ^{b,c}	3.33±0.15 ^a	3.35±0.14 ^a
C22:1 n11	2.34±0.20 ^{b,c}	4.23±0.56 ^{a,c}	4.57±0.53 ^{ab}
C22:4 n6	3.80±0.58 ^{b,c}	4.19±0.28 ^{a,c}	4.73±0.24 ^{ab}
C22:5 n3	3.31±0.49 ^{b,c}	1.78±0.48 ^{a,c}	2.04±0.18 ^{ab}
C22:6 n3 DHA	3.01±0.12 ^{b,c}	4.46±0.88 ^a	4.90±0.69 ^{ab}
C24:1 n9	15.53±1.31 ^{b,c}	5.97±0.49 ^{a,c}	6.63±0.87 ^{ab,c}

These values are expressed as percentage total fatty acid methyl esters; mean ± SD.

EPA: eicosapentaenoic acid **DHA:** docosahexaenoic acid
Nd: not detected

T1: Tareeh sample 1, M1: Mehiawh sample 1
T2: Tareeh sample 2, M2: Mehiawh sample 2
T3: Tareeh sample 3, M3: Mehiawh sample 3
T4: Tareeh sample 4, M4: Mehiawh sample 4

a: significantly different compared with raw fish

b: significantly different compared with T1

c: significantly different compared with M1

Table 1 F: (Batch 2 - Sample 6) Fatty Acids Composition of Raw Fish (Oom), Fish Paste (Tareeh) and Fish Sauce (Mehiawh)

Fatty acids	Raw Fish Batch 2 Samples 5, 6, 7, 8	Sample 6	
		T6	M6
C16:0	6.57±0.75 ^b	6.26±0.42 ^{a,c}	6.10±0.34 ^{ab,c}
C16:1 n7	1.33±0.12 ^b	1.58±0.17 ^a	1.45±0.01 ^b
C18:0	30.14±1.40 ^{b,c}	26.63±1.85 ^{ab,c}	25.97±0.41 ^a
C18:1 n9	2.00±0.18 ^{b,c}	2.34±0.21 ^a	2.24±0.10 ^b
C18:2 n6	11.94±0.35 ^{b,c}	13.85±0.50 ^{a,c}	13.40±0.35 ^{ab,c}
C18:3 n6	7.22±0.77 ^{b,c}	9.26±1.04 ^a	9.39±0.36 ^a
C18:3 n3	2.12±0.18 ^{b,c}	3.33±0.81 ^a	3.55±0.45 ^a
C18:4 n3	8.25±0.29 ^{b,c}	9.35±0.24 ^c	9.54±0.10
C20:4 n6	Nd	2.30±0.60 ^{ab,c}	2.15±0.24 ^{ab}
C20:5 n3 EPA	2.44±0.23 ^{b,c}	3.64±0.45 ^{ab}	3.65±0.17 ^{ab,c}
C22:1 n11	2.34±0.20 ^{b,c}	4.62±0.54 ^{ab}	4.62±0.49 ^{ab}
C22:4 n6	3.80±0.58 ^{b,c}	4.24±0.51 ^{a,c}	4.64±0.09 ^{ab}
C22:5 n3	3.31±0.49 ^{b,c}	1.93±0.18 ^a	2.29±0.09 ^{ab,c}
C22:6 n3 DHA	3.01±0.12 ^{b,c}	4.57±0.53 ^{a,c}	4.01±0.53 ^{ab,c}
C24:1 n9	15.53±1.31 ^{b,c}	6.10±0.52 ^{ab,c}	7.00±0.64 ^{ab,c}

These values are expressed as percentage total fatty acid methyl esters; mean ± SD.

EPA: eicosapentaenoic acid **DHA:** docosahexaenoic acid
Nd: not detected

T1: Tareeh sample 1, M1: Mehiawh sample 1
T2: Tareeh sample 2, M2: Mehiawh sample 2
T3: Tareeh sample 3, M3: Mehiawh sample 3
T4: Tareeh sample 4, M4: Mehiawh sample 4

a: significantly different compared with raw fish

b: significantly different compared with T1

c: significantly different compared with M1

Table 1 G: (Batch 2 - Sample 7) Fatty Acids Composition of Raw Fish (Oom), Fish Paste (Tareeh) and Fish Sauce (Mehiawh)

Fatty acids	Raw Fish Batch 2 Samples 5,6,7,8	Sample 7	
		T7	M7
C16:0	6.57±0.75 ^b	6.41±0.35	6.27±0.51 ^{a,c}
C16:1 n7	1.33±0.12 ^b	1.54±0.09 ^a	1.67±0.05 ^{a,c}
C18:0	30.14±1.40 ^{b,c}	26.52±0.54 ^{ab,c}	26.16±0.71 ^{ab}
C18:1 n9	2.00±0.18 ^{b,c}	2.55±0.16 ^{a,c}	2.42±0.46 ^a
C18:2 n6	11.94±0.35 ^{b,c}	13.80±0.47 ^{a,c}	14.04±0.67 ^{ab,c}
C18:3 n6	7.22±0.77 ^{b,c}	9.82±0.61 ^{ab,c}	9.92±0.40 ^{ab,c}
C18:3 n3	2.12±0.18 ^{b,c}	3.48±0.47 ^a	3.06±0.47 ^{ab,c}
C18:4 n3	8.25±0.29 ^{b,c}	9.79±0.33 ^{ab}	9.36±0.16 ^c
C20:4 n6	Nd	2.52±0.20 ^{a,c}	2.52±0.35 ^{a,c}
C20:5 n3 EPA	2.44±0.23 ^{b,c}	3.14±0.26 ^{a,c}	3.29±0.19 ^a
C22:1 n11	2.34±0.20 ^{b,c}	4.15±0.46 ^{a,c}	4.29±0.49 ^{a,c}
C22:4 n6	3.80±0.58 ^{b,c}	3.54±0.18 ^{a,b,c}	4.31±0.40 ^{a,c}
C22:5 n3	3.31±0.49 ^{b,c}	2.28±0.14 ^{ab,c}	1.70±0.15 ^{a,c}
C22:6 n3 DHA	3.01±0.12 ^{b,c}	4.40±0.48 ^{a,c}	3.90±0.73 ^{ab,c}
C24:1 n9	15.53±1.31 ^{b,c}	6.06±0.55 ^{a,c}	7.09±0.60 ^{ab,c}

These values are expressed as percentage total fatty acid methyl esters; mean ± SD.

EPA: eicosapentaenoic acid **DHA:** docosahexaenoic acid
Nd: not detected

T1: Tareeh sample 1, M1: Mehiawh sample 1

T2: Tareeh sample 2, M2: Mehiawh sample 2

T3: Tareeh sample 3, M3: Mehiawh sample 3

T4: Tareeh sample 4, M4: Mehiawh sample 4

a: significantly different compared with raw fish

b: significantly different compared with T1

c: significantly different compared with M1

Table 1 H: (Batch 2 - Sample 8) Fatty Acids Composition of Raw Fish (Oom), Fish Paste (Tareeh) and Fish Sauce (Mehiawh)

Fatty acids	Raw Fish Batch 2 Samples 5, 6, 7, 8	Sample 8	
		T8	M8
C16:0	6.57±0.75 ^b	6.64±0.28 ^{b,c}	6.27±0.55 ^{a,c}
C16:1 n7	1.33±0.12 ^b	1.52±0.03 ^a	1.41±0.06 ^b
C18:0	30.14±1.40 ^{b,c}	26.32±0.23 ^{ab,c}	26.84±1.70 ^{a,c}
C18:1 n9	2.00±0.18 ^{b,c}	2.41±0.18 ^a	2.29±0.91 ^{ab}
C18:2 n6	11.94±0.35 ^{b,c}	13.07±0.40 ^{ab}	13.27±0.35 ^{ab,c}
C18:3 n6	7.22±0.77 ^{b,c}	9.57±0.44 ^{ab,c}	9.41±0.42 ^a
C18:3 n3	2.12±0.18 ^{b,c}	3.28±0.39 ^{ab}	3.14±0.43 ^{ab,c}
C18:4 n3	8.25±0.29 ^{b,c}	9.44±0.08 ^c	9.96±0.52 ^{ab,c}
C20:4 n6	Nd	2.42±0.16 ^{ab,c}	2.23±0.20 ^{ab,c}
C20:5 n3 EPA	2.44±0.23 ^{b,c}	2.70±0.08 ^{b,c}	3.63±0.12 ^{a,c}
C22:1 n11	2.34±0.20 ^{b,c}	3.63±0.39 ^{ab}	4.20±0.42 ^{a,c}
C22:4 n6	3.80±0.58 ^{b,c}	5.12±0.29 ^{ab,c}	5.08±0.13 ^{ab,c}
C22:5 n3	3.31±0.49 ^{b,c}	2.60±0.11 ^{ab,c}	1.93±0.09 ^a
C22:6 n3 DHA	3.01±0.12 ^{b,c}	5.25±0.53 ^{ab,c}	3.49±0.49 ^{a,c}
C24:1 n9	15.53±1.31 ^{b,c}	6.03±0.52 ^{a,c}	6.85±0.50 ^{ab}

These values are expressed as percentage total fatty acid methyl esters; mean ± SD.

EPA: eicosapentaenoic acid **DHA:** docosahexaenoic acid
Nd: not detected

T1: Tareeh sample 1, M1: Mehiawh sample 1

T2: Tareeh sample 2, M2: Mehiawh sample 2

T3: Tareeh sample 3, M3: Mehiawh sample 3

T4: Tareeh sample 4, M4: Mehiawh sample 4

a: significantly different compared with raw fish

b: significantly different compared with T1

c: significantly different compared with M1

The values of the fatty acids C22:4 n6, and C22:6n3 (DHA) fluctuated in all fish samples studied. The concentrations of the fatty acid C24:1 n9 were significantly lower ($p=0.002$) in Tareeh and Mehiawh samples ranging from 5.59±0.11 to 8.12±0.33% in compared to the values of the raw fish (15.38±1.56 to 15.53±1.31%).

The sum of SFAs, UFAs, MUFAs, PUFAs, omega-6 (n-6), n-3, and EPA+DHA, in addition to the ratio of n-6/n-3 of raw fish, Tareeh, and Mehiawh samples are summarized in table 2 A-H. A significant difference in all those parameters was recorded among raw fish, Tareeh, and Mehiawh samples. Significantly lower values were detected among the total concentrations of SFAs and MUFAs in Tareeh and Mehiawh samples compared to raw fish samples. The concentration of SFAs were significantly higher (P value 0.012) in raw fish samples ranging from 36.71±2.55 to 37.31±2.55%, whereas as they ranged from 29.96±0.70 to 33.11±2.94% in Tareeh and Mehiawh samples. Similarly, MUFAs values ranged from 20.79±2.21 to 21.20±1.81% in raw fish samples compared to 13.97±1.28 to 16.26±0.66% in Tareeh and Mehiawh samples, whereas the concentrations of UFAs (66.89±6.52 to 69.31±4.86%) and PUFAs (52.10±3.52 to 55.47±1.27%) were significantly higher in Tareeh and Mehiawh samples than in raw fish samples (62.69±5.62 to 63.29±4.82%) and (41.90±3.41 to 42.09±3.01%) $p=0.002$, and P value 0.001 respectively.

The concentrations of n-6 fatty acids in Tareeh and Mehiawh samples (29.10±1.63 to 32.88±2.03%) were significantly higher (P value 0.024) than n-6 fatty acids in raw fish (22.10±1.65 to 22.96±1.70%), similarly the concentrations of n-3 fatty acids were significantly lower (P value 0.025) in raw fish (19.13±1.31 to 19.80±1.76 %), whereas they have ranged from 21.31±1.70 to 24.09±1.61%, in Tareeh and Mehiawh samples. The ratio of n-6/n-3 slightly fluctuated in all fish samples studied (1.00±0.06 to 1.12±0.12%). The sum of EPA+DHA significantly differed (P value 0.03) between raw fish samples (5.45±0.35 to 5.81±0.62%) and Tareeh and Mehiawh samples (6.34±0.71 to 9.38±0.91%).

Table 2 A: (Batch 1, Sample 1) The Sum of Different Types of Fatty Acids in Raw Fish (Oom), Fish Paste (Tareeh) and Fish Sauce (Mehiawh)

Fatty acids	Raw Fish	Sample 1	
	Batch 1 Samples 1, 2, 3, 4	T1	M1
Σ SFA	37.31±2.55 ^{b,c}	32.04±5.09 ^{a,c}	30.87±3.04 ^{a,b}
Σ UFA	62.69±5.62 ^{b,c}	67.96±8.51 ^a	69.13±5.04 ^{a,b}
Σ MUFA	20.79±2.21 ^{b,c}	13.97±1.28 ^{a,c}	15.54±1.78 ^{a,b}
Σ PUFA	41.90±3.41 ^{b,c}	53.99±7.23 ^{a,c}	53.59±3.26 ^{a,b}
Σ n-6	22.1±1.65 ^{b,c}	31.11±3.33 ^{a,c}	29.50±1.65 ^{a,b}
Σ n-3	19.80±1.76 ^{b,c}	22.88±3.90 ^{a,c}	24.09±1.61 ^{a,b}
n-6/n-3	1.12±0.09 ^{b,c}	1.36±0.09 ^{a,c}	1.22±0.05 ^a
EPA+DHA	5.81±0.62 ^{b,c}	7.69±1.02 ^{a,c}	8.61±0.62 ^{a,b}

These values are expressed as percentage total fatty acid methyl esters; mean ± SD.

EPA: eicosapentaenoic acid **DHA:** docosahexaenoic acid
 T1: Tareeh sample 1, M1: Mehiawh sample 1
 T2: Tareeh sample 2, M2: Mehiawh sample 2
 T3: Tareeh sample 3, M3: Mehiawh sample 3
 T4: Tareeh sample 4, M4: Mehiawh sample 4
 a: significantly different compared with raw fish
 b: significantly different compared with T1
 c: significantly different compared with M1

Table 2 B: (Batch 1, Sample 2) The Sum of Different Types of Fatty Acids in Raw Fish (Oom), Fish Paste (Tareeh) and Fish Sauce (Mehiawh)

Fatty acids	Raw Fish	Sample 2	
	Batch 1 Samples 1, 2, 3, 4	T2	M2
Σ SFA	37.31±2.55 ^{b,c}	31.59±3.74 ^a	29.96±0.70 ^{a,b}
Σ UFA	62.69±5.62 ^{b,c}	68.41±8.08 ^a	70.04±1.73 ^{a,b}
Σ MUFA	20.79±2.21 ^{b,c}	13.75±1.05 ^{a,c}	16.26±0.66 ^{a,b,c}
Σ PUFA	41.90±3.41 ^{b,c}	54.66±7.03 ^{a,b}	53.78±1.07 ^{a,b}
Σ n-6	22.1±1.65 ^{b,c}	30.59±3.71 ^{a,c}	30.48±0.48 ^a
Σ n-3	19.80±1.76 ^{b,c}	24.07±3.32 ^{a,b,c}	23.30±0.59 ^a
n-6/n-3	1.12±0.09 ^{b,c}	1.27±0.12 ^c	1.31±0.02 ^{a,c}
EPA+DHA	5.81±0.62 ^{b,c}	9.38±0.91 ^{a,b,c}	7.42±0.34 ^{a,c}

These values are expressed as percentage total fatty acid methyl esters; mean ± SD.

EPA: eicosapentaenoic acid **DHA:** docosahexaenoic acid
 T1: Tareeh sample 1, M1: Mehiawh sample 1
 T2: Tareeh sample 2, M2: Mehiawh sample 2
 T3: Tareeh sample 3, M3: Mehiawh sample 3
 T4: Tareeh sample 4, M4: Mehiawh sample 4
 a: significantly different compared with raw fish
 b: significantly different compared with T1
 c: significantly different compared with M1

Table 2 C: (Batch 1, Sample 3) The Sum of Different Types of Fatty Acids in Raw Fish (Oom), Fish Paste (Tareeh) and Fish Sauce (Mehiawh)

Fatty acids	Raw Fish	Sample 3	
	Batch 1 Samples 1, 2, 3, 4	T3	M3
Σ SFA	37.31±2.55 ^{b,c}	31.68±0.97 ^a	30.69±1.63 ^{a,b}
Σ UFA	62.69±5.62 ^{b,c}	68.32±3.26 ^a	69.31±4.68 ^a
Σ MUFA	20.79±2.21 ^{b,c}	14.20±0.70 ^{a,c}	16.54±1.35 ^{a,b}
Σ PUFA	41.90±3.41 ^{b,c}	54.12±2.56 ^{a,b,c}	52.77±3.33 ^a
Σ n-6	22.1±1.65 ^{b,c}	30.65±1.30 ^{a,b,c}	32.88±2.03 ^{a,b,c}
Σ n-3	19.80±1.76 ^{b,c}	23.47±1.26 ^a	19.89±1.30 ^{b,c}
n-6/n-3	1.12±0.09 ^{b,c}	1.31±0.04 ^{a,c}	1.65±0.06 ^{a,b,c}
EPA+DHA	5.81±0.62 ^{b,c}	6.92±0.43 ^{a,b,c}	6.48±0.78 ^{a,c}

These values are expressed as percentage total fatty acid methyl esters; mean ± SD.

EPA: eicosapentaenoic acid **DHA:** docosahexaenoic acid
 T1: Tareeh sample 1, M1: Mehiawh sample 1
 T2: Tareeh sample 2, M2: Mehiawh sample 2
 T3: Tareeh sample 3, M3: Mehiawh sample 3
 T4: Tareeh sample 4, M4: Mehiawh sample 4
 a: significantly different compared with raw fish
 b: significantly different compared with T1
 c: significantly different compared with M1

Table 2 D: (Batch 1, Sample 4) The Sum of Different Types of Fatty Acids in Raw Fish (Oom), Fish Paste (Tareeh) and Fish Sauce (Mehiawh)

Fatty acids	Raw Fish	Sample 4	
	Batch 1 Samples 1, 2, 3, 4	T4	M4
Σ SFA	37.31±2.55 ^{b,c}	31.75±0.22 ^a	31.75±3.70 ^a
Σ UFA	62.69±5.62 ^{b,c}	68.25±1.69 ^a	68.25±3.5 ^a
Σ MUFA	20.79±2.21 ^{b,c}	12.78±0.42 ^{a,b,c}	15.11±1.41 ^{a,b}
Σ PUFA	41.90±3.41 ^{b,c}	55.47±1.27 ^{a,b,c}	53.14±2.09 ^{a,b}
Σ n-6	22.1±1.65 ^{b,c}	31.60±0.98 ^{a,c}	31.29±0.60 ^{a,c}
Σ n-3	19.80±1.76 ^{b,c}	23.87±0.29 ^{a,b}	21.85±1.50 ^{a,c}
n-6/n-3	1.12±0.09 ^{b,c}	1.32±0.03 ^{a,c}	1.43±0.04 ^{a,c}
EPA+DHA	5.81±0.62 ^{b,c}	7.78±0.17 ^{a,c}	6.34±0.17 ^{a,b,c}

These values are expressed as percentage total fatty acid methyl esters; mean ± SD.

EPA: eicosapentaenoic acid **DHA:** docosahexaenoic acid

T1: Tareeh sample 1, M1: Mehiawh sample 1

T2: Tareeh sample 2, M2: Mehiawh sample 2

T3: Tareeh sample 3, M3: Mehiawh sample 3

T4: Tareeh sample 4, M4: Mehiawh sample 4

a: significantly different compared with raw fish

b: significantly different compared with T1

c: significantly different compared with M1

Table 2 E: (Batch 2, Sample 5) The Sum of Different Types of Fatty Acids in Raw Fish (Oom), Fish Paste (Tareeh) and Fish Sauce (Mehiawh)

Fatty acids	Raw Fish	Sample 5	
	Batch 2 Samples 5, 6, 7, 8	T5	M5
Σ SFA	36.71±2.15 ^{b,c}	33.11±2.94 ^a	32.53±1.92 ^a
Σ UFA	63.29±4.82 ^{b,c}	66.89±6.52 ^a	67.47±5.28 ^a
Σ MUFA	21.20±1.81 ^{b,c}	14.33±1.55 ^{a,c}	14.96±1.80 ^a
Σ PUFA	42.09±3.01 ^{b,c}	52.56±4.97 ^{a,c}	52.51±3.48 ^{a,b}
Σ n-6	22.96±1.70 ^{b,c}	29.90±1.97 ^a	29.10±1.63 ^a
Σ n-3	19.13±1.31 ^{b,c}	22.66±3.00 ^{a,c}	23.41±1.85 ^{a,b}
n-6/n-3	1.20±0.09 ^{b,c}	1.32±0.09 ^a	1.24±0.05 ^b
EPA+DHA	5.45±0.35 ^{b,c}	7.79±1.03 ^{a,c}	8.25±0.83 ^{a,b}

These values are expressed as percentage of total fatty acid methyl esters; mean ± SD.

EPA: eicosapentaenoic acid **DHA:** docosahexaenoic acid

T5: Tareeh sample 5, M5: Mehiawh sample 5

T6: Tareeh sample 6, M6: Mehiawh sample 6

T7: Tareeh sample 7, M7: Mehiawh sample 7

T8: Tareeh sample 8, M8: Mehiawh sample 8

a: significantly different compared with raw fish

b: significantly different compared with T5

c: significantly different compared with M5

Table 2 F: (Batch 2, Sample 6) The Sum of Different Types of Fatty Acids in Raw Fish (Oom), Fish Paste (Tareeh) and Fish Sauce (Mehiawh)

Fatty acids	Raw Fish Bath 2	Sample 6	
	Samples 5, 6, 7, 8	T6	M6
Σ SFA	36.71±2.15 ^{b,c}	32.89±2.27 ^a	32.07±0.75 ^a
Σ UFA	63.29±4.82 ^{b,c}	67.11±6.30 ^a	67.93±3.62 ^a
Σ MUFA	21.20±1.81 ^{b,c}	14.64±1.44 ^{a,c}	15.31±1.24 ^{a,b,c}
Σ PUFA	42.09±3.01 ^{b,c}	52.47±4.86 ^a	52.62±2.38 ^a
Σ n-6	22.96±1.70 ^{b,c}	29.65±2.65 ^{a,b,c}	29.58±1.04 ^a
Σ n-3	19.13±1.31 ^{b,c}	22.82±2.21 ^{a,b,c}	23.04±1.34 ^{a,b}
n-6/n-3	1.20±0.09 ^{b,c}	1.30±0.12 ^{a,c}	1.28±0.02 ^a
EPA+DHA	5.45±0.35 ^{b,c}	8.21±0.98 ^a	7.66±0.70 ^{a,c}

These values are expressed as percentage of total fatty acid methyl esters; mean ± SD.

EPA: eicosapentaenoic acid **DHA:** docosahexaenoic acid

T5: Tareeh sample 5, M5: Mehiawh sample 5

T6: Tareeh sample 6, M6: Mehiawh sample 6

T7: Tareeh sample 7, M7: Mehiawh sample 7

T8: Tareeh sample 8, M8: Mehiawh sample 8

a: significantly different compared with raw fish

b: significantly different compared with T5

c: significantly different compared with M5

Table 2 G: (Batch 2, Sample 7) The Sum of Different Types of Fatty Acids in Raw Fish (Oom), Fish Paste (Tareeh) and Fish Sauce (Mehiawh)

Fatty acids	Raw Fish Bath 2	Sample 7	
	Samples 5, 6, 7, 8	T7	M7
Σ SFA	36.71±2.15 ^{b,c}	32.93±0.89 ^a	32.43±1.22 ^a
Σ UFA	63.29±4.82 ^{b,c}	66.94±4.40 ^a	67.57±5.12 ^a
Σ MUFA	21.20±1.81 ^{b,c}	14.30±1.26 ^{a,c}	15.47±1.60 ^{a,b}
Σ PUFA	42.09±3.01 ^{b,c}	52.64±3.14	52.10±3.52 ^a
Σ n-6	22.96±1.70 ^{b,c}	29.68±1.46 ^{a,b,c}	30.79±1.82 ^{a,b,c}
Σ n-3	19.13±1.31 ^{b,c}	22.96±1.68 ^a	21.31±1.70 ^{a,b,c}
n-6/n-3	1.20±0.09 ^{b,c}	1.29±0.04 ^a	1.44±0.06 ^{a,b}
EPA+DHA	5.45±0.35 ^{b,c}	7.54±0.74 ^{a,c}	7.19±0.22 ^{a,c}

These values are expressed as percentage of total fatty acid methyl esters; mean ± SD.

EPA: eicosapentaenoic acid **DHA:** docosahexaenoic acid

T5: Tareeh sample 5, M5: Mehiawh sample 5

T6: Tareeh sample 6, M6: Mehiawh sample 6

T7: Tareeh sample 7, M7: Mehiawh sample 7

T8: Tareeh sample 8, M8: Mehiawh sample 8

a: significantly different compared with raw fish

b: significantly different compared with T5

c: significantly different compared with M5

Table 2 H: (Batch 2, Sample 8) The Sum of Different Types of Fatty Acids in Raw Fish (Oom), Fish Paste (Tareeh) and Fish Sauce (Mehiawh)

Fatty acids	Raw Fish Bath 2	Sample 8	
	Samples 5, 6, 7, 8	T8	M8
Σ SFA	36.71±2.15 ^{b,c}	32.96±0.51 ^a	33.11±2.25 ^a
Σ UFA	63.29±4.82 ^{b,c}	67.04±6.00 ^a	66.89±4.64
Σ MUFA	21.20±1.81 ^{b,c}	13.59±1.12 ^{a,b,c}	14.75±1.89 ^a
Σ PUFA	42.09±3.01 ^{b,c}	53.34±2.48 ^{a,b,c}	52.14±2.75 ^a
Σ n-6	22.96±1.70 ^{b,c}	30.18±1.29 ^{a,c}	29.99±1.10 ^a
Σ n-3	19.13±1.31 ^{b,c}	23.27±1.19 ^a	22.15±1.65 ^{a,c}
n-6/n-3	1.20±0.09 ^{b,c}	1.30±0.03 ^a	1.35±0.04 ^a
EPA+DHA	5.45±0.35 ^{b,c}	7.95±0.61 ^a	7.12±0.61 ^{a,b,c}

These values are expressed as percentage of total fatty acid methyl esters; mean ± SD.

EPA: eicosapentaenoic acid **DHA:** docosahexaenoic acid

T5: Tareeh sample 5, M5: Mehiawh sample 5

T6: Tareeh sample 6, M6: Mehiawh sample 6

T7: Tareeh sample 7, M7: Mehiawh sample 7

T8: Tareeh sample 8, M8: Mehiawh sample 8

a: significantly different compared with raw fish

b: significantly different compared with T5

c: significantly different compared with M5

Further evaluation of the results was done using the biochemical indexes of product-substrate relationship of elongation and desaturation in the PUFAs pathways using the following ratios: 18:0/16:0 ratio-saturated fatty acids; 22:6/20:5, and 20:5/18:3 ratios - the n-3 family; 22:4/20:4, 20:4/18:2, and 18:3 n-6/18:2 n-6 ratios -the n-6 family; and 18:1/18:0 ratio - the n-9 family, see table 3. There was a significant difference in all indexes studied. The ratios of 18:0/16:0 (n9) were lower, while ratios of 20:4/18:2 (n6), 22:4/20:4 (n6) were higher in Tareeh and Mehiawh samples than in raw fish sample. However, the ratio of 20:5/18:3 (n3), 22:6/20:5 (n3), and 18:1/18:0 (n9) slightly fluctuated in all fish samples.

Table 3 A: (Batch 1, Sample 1) Ratios of Some Selected Fatty Acids

Fatty acid ratio	Raw Fish Batch 1 Samples 1, 2, 3, 4	Sample 1	
		T1	M1
18:0/16:0 SFAs ¹	4.77±0.16 ^{b,c}	4.17±0.31 ^{a,c}	3.73±0.28 ^{a,b}
20:5/18:3 (n3) ²	1.35±0.01 ^{b,c}	0.92±0.06 ^a	1.12±0.04 ^a
22:6/20:5 (n3) ²	1.11±0.31 ^{b,c}	1.30±0.04 ^{a,c}	1.55±0.04 ^{a,b}
20:4/18:2(n6) ²	0	0.21 ^{a,c}	0.14 ^{a,b}
22:4/20:4 (n6) ¹	0	1.54±0.04 ^{a,c}	3.18±0.12 ^{a,b}
18:1/18:0 (n9) ³	0.06±0.00 ^{b,c}	0.10±0.01 ^a	0.10±0.03 ^a

Values are expressed as mean ± SD

SFAs: saturated fatty acids

1 Reflects the activity of elongase

2 Reflects the activities of Δ6 and Δ5 desaturases

3 Reflects the activity of Δ9 desaturase

T1: Tareeh sample 1, M1: Mehiawh sample 1

T2: Tareeh sample 2, M2: Mehiawh sample 2

T3: Tareeh sample 3, M3: Mehiawh sample 3

T4: Tareeh sample 4, M4: Mehiawh sample 4

a: significantly different compared with raw fish

b: significantly different compared with T1

c: significantly different compared with M1

Table 3 B: (Batch 1, Sample 2) Ratios of Some Selected Fatty Acids

Fatty acid ratio	Raw Fish Batch 1 Samples 1, 2, 3, 4	Sample 2	
		T2	M2
18:0/16:0 SFAs ¹	4.77±0.16 ^{b,c}	4.18±0.11 ^{a,c}	4.18±0.21 ^{a,c}
20:5/18:3 (n3) ²	1.35±0.01 ^{b,c}	1.53±0.08 ^{a,b,c}	1.11±0.14 ^a
22:6/20:5 (n3) ²	1.11±0.31 ^{b,c}	0.95±0.05 ^{a,b,c}	0.86±0.01 ^{a,b,c}
20:4/18:2(n6) ²	0	0.16 ^{a,b}	0.15 ^{a,b}
22:4/20:4 (n6) ¹	0	2.00±0.03 ^{a,b,c}	2.70±0.0 ^{a,b,c}
18:1/18:0 (n9) ³	0.06±0.00 ^{b,c}	0.09±0.01 ^a	0.09±0.00 ^a

Values are expressed as mean ± SD

SFAs: saturated fatty acids

1 Reflects the activity of elongase

2 Reflects the activities of Δ6 and Δ5 desaturases

3 Reflects the activity of Δ9 desaturase

T1: Tareeh sample 1, M1: Mehiawh sample 1

T2: Tareeh sample 2, M2: Mehiawh sample 2

T3: Tareeh sample 3, M3: Mehiawh sample 3

T4: Tareeh sample 4, M4: Mehiawh sample 4

a: significantly different compared with raw fish

b: significantly different compared with T1

c: significantly different compared with M1

Table 3 C: (Batch 1, Sample 3) Ratios of Some Selected Fatty Acids

Fatty acid ratio	Raw Fish Batch 1 Samples 1, 2, 3, 4	Sample 3	
		T3	M3
18:0/16:0 SFAs ¹	4.77±0.16 ^{b,c}	3.95±0.26 ^a	4.01±0.15 ^{a,c}
20:5/18:3 (n3) ²	1.35±0.01 ^{b,c}	0.78±0.01 ^{a,b,c}	1.40±0.13 ^{b,c}
22:6/20:5 (n3) ²	1.11±0.31 ^{b,c}	1.56±0.02 ^{a,b}	0.99±0.02 ^{b,c}
20:4/18:2(n6) ²	0	0.20 ^{a,c}	0.19 ^{a,c}
22:4/20:4 (n6) ¹	0	1.19±0.04 ^{b,c}	1.75±0.06 ^{a,b,c}
18:1/18:0 (n9) ³	0.06±0.00 ^{b,c}	0.11±0.00 ^a	0.10±0.03 ^a

Values are expressed as mean ± SD SFAs: saturated fatty acids

1 Reflects the activity of elongase

2 Reflects the activities of Δ6 and Δ5 desaturases

3 Reflects the activity of Δ9 desaturase

T1: Tareeh sample 1, M1: Mehiawh sample 1

T2: Tareeh sample 2, M2: Mehiawh sample 2

T3: Tareeh sample 3, M3: Mehiawh sample 3

T4: Tareeh sample 4, M4: Mehiawh sample 4

a: significantly different compared with raw fish

b: significantly different compared with T1

c: significantly different compared with M1

Table 3 D: (Batch 1, Sample 4) Ratios of Some Selected Fatty Acids

Fatty acid ratio	Raw Fish Batch 1 Samples 1, 2, 3, 4	Sample 4	
		T4	M4
18:0/16:0 SFAs ¹	4.77±0.16 ^{b,c}	3.62±0.37 ^{a,b,c}	4.44±0.38 ^{a,b,c}
20:5/18:3 (n3) ²	1.35±0.01 ^{b,c}	0.93±0.15 ^{a,c}	1.42±0.09 ^{b,c}
22:6/20:5 (n3) ²	1.11±0.31 ^{b,c}	1.73±0.03 ^{a,b,c}	0.61±0.04 ^{a,b,c}
20:4/18:2(n6) ²	0	0.20 ^{a,c}	0.17 ^{a,b,c}
22:4/20:4 (n6) ¹	0	2.51±0.16 ^{a,b,c}	2.90±0.08 ^{b,c}
18:1/18:0 (n9) ³	0.06±0.00 ^{b,c}	0.10±0.02 ^a	0.09±0.01 ^a

Values are expressed as mean ± SD SFAs: saturated fatty acids

1 Reflects the activity of elongase

2 Reflects the activities of Δ6 and Δ5 desaturases

3 Reflects the activity of Δ9 desaturase

T1: Tareeh sample 1, M1: Mehiawh sample 1

T2: Tareeh sample 2, M2: Mehiawh sample 2

T3: Tareeh sample 3, M3: Mehiawh sample 3

T4: Tareeh sample 4, M4: Mehiawh sample 4

a: significantly different compared with raw fish

b: significantly different compared with T1

c: significantly different compared with M1

Table 3 E: (Batch 2, Sample 5) Ratios of Some Selected Fatty Acids

Fatty Acid Ratio	Raw Fish Batch 2 Samples 5, 6, 7, 8	Sample 5	
		T5	M5
18:0/16:0 SFAs ¹	4.59±0.31 ^{b,c}	4.25±0.04 ^{a,c}	4.03±0.04 ^{a,b}
20:5/18:3 (n3) ²	1.15±0.03 ^{b,c}	0.93±0.04 ^{a,c}	0.98±0.12 ^a
22:6/20:5 (n3) ²	1.23±0.12 ^{b,c}	1.34±0.14 ^{a,c}	1.46±0.22 ^{a,b}
20:4/18:2(n6) ²	0	0.190.01± ^a	0.160.03± ^a
22:4/20:4 (n6) ¹	0	1.59±0.08 ^{a,c}	2.33±0.23 ^{a,b}

Values are expressed as mean ± SD SFAs: saturated fatty acids

1 Reflects the activity of elongase

2 Reflects the activities of Δ6 and Δ5 desaturases

3 Reflects the activity of Δ9 desaturase

T5: Tareeh sample 5, M5: Mehiawh sample 5

T6: Tareeh sample 6, M6: Mehiawh sample 6

T7: Tareeh sample 7, M7: Mehiawh sample 7

T8: Tareeh sample 8, M8: Mehiawh sample 8

a: significantly different compared with raw fish

b: significantly different compared with T5

c: significantly different compared with M5

Table 3 F: (Batch 2, Sample 6) Ratios of Some Selected Fatty Acids

Fatty Acid Ratio	Raw Fish	Sample 6	
	Batch 2 Samples 5, 6, 7, 8	T6	M6
18:0/16:0 SFAs ¹	4.59±0.31 ^{b,c}	4.25±0.05 ^{a,c}	4.26±0.01 ^{a,c}
20:5/18:3 (n3) ²	1.15±0.03 ^{b,c}	1.09±0.03 ^{a,c}	1.03±0.0 ^{a,b}
22:6/20:5 (n3) ²	1.23±0.12 ^{b,c}	1.26±0.21 ^{b,c}	1.10±0.00 ^{a,b,c}
20:4/18:2(n6) ²	0	0.170.01± ^a	0.160.04± ^a
22:4/20:4 (n6) ¹	0	1.84±0.31 ^{a,b,c}	2.16±0.33 ^{a,b,c}

Values are expressed as mean ± SD SFAs: saturated fatty acids

1 Reflects the activity of elongase

2 Reflects the activities of Δ6 and Δ5 desaturases

3 Reflects the activity of Δ9 desaturase

T5: Tareeh sample 5, M5: Mehiawh sample 5

T6: Tareeh sample 6, M6: Mehiawh sample 6

T7: Tareeh sample 7, M7: Mehiawh sample 7

T8: Tareeh sample 8, M8: Mehiawh sample 8

a: significantly different compared with raw fish

b: significantly different compared with T5

c: significantly different compared with M5

Table 3 G: (Batch 2, Sample 7) Ratios of Some Selected Fatty Acids

Fatty Acid Ratio	Raw Fish	Sample 7	
	Batch 2 Samples 5, 6, 7, 8	T7	M7
18:0/16:0 SFAs ¹	4.59±0.31 ^{b,c}	4.14±0.02 ^{a,c}	4.17±0.02 ^{a,c}
20:5/18:3 (n3) ²	1.15±0.03 ^{b,c}	0.90±0.04 ^{a,c}	1.08±0.06 ^{a,c}
22:6/20:5 (n3) ²	1.23±0.12 ^{b,c}	1.40±0.17 ^a	1.19±0.03 ^{a,b,c}
20:4/18:2(n6) ²	0	0.18±0.03 ^a	0.18±0.03 ^a
22:4/20:4 (n6) ¹	0	1.40±0.28 ^{a,b,c}	1.71±0.23 ^{a,b,c}

Values are expressed as mean ± SD SFAs: saturated fatty acids

1 Reflects the activity of elongase

2 Reflects the activities of Δ6 and Δ5 desaturases

3 Reflects the activity of Δ9 desaturase

T5: Tareeh sample 5, M5: Mehiawh sample 5

T6: Tareeh sample 6, M6: Mehiawh sample 6

T7: Tareeh sample 7, M7: Mehiawh sample 7

T8: Tareeh sample 8, M8: Mehiawh sample 8

a: significantly different compared with raw fish

b: significantly different compared with T5

c: significantly different compared with M5

Table 3 H: (Batch 2, Sample 8) Ratios of Some Selected Fatty Acids

Fatty Acid Ratio	Raw Fish	Sample 8	
	Batch 2 Samples 5, 6, 7, 8	T8	M8
18:0/16:0 SFAs ¹	4.59±0.31 ^{b,c}	3.96±0.03 ^{a,b,c}	4.28±0.04 ^{a,c}
20:5/18:3 (n3) ²	1.15±0.03 ^{b,c}	0.82±0.16 ^{a,b,c}	1.16±0.08 ^{a,b,c}
22:6/20:5 (n3) ²	1.23±0.12 ^{b,c}	1.94±0.09 ^{a,b,c}	0.96±0.06 ^{a,b,c}
20:4/18:2(n6) ²	0	0.19±0.02 ^a	0.17±0.01 ^a
22:4/20:4 (n6) ¹	0	2.12±0.22 ^{a,b,c}	2.28±0.11 ^{a,b}

Values are expressed as mean ± SD SFAs: saturated fatty acids

1 Reflects the activity of elongase

2 Reflects the activities of Δ6 and Δ5 desaturases

3 Reflects the activity of Δ9 desaturase

T5: Tareeh sample 5, M5: Mehiawh sample 5

T6: Tareeh sample 6, M6: Mehiawh sample 6

T7: Tareeh sample 7, M7: Mehiawh sample 7

T8: Tareeh sample 8, M8: Mehiawh sample 8

a: significantly different compared with raw fish

b: significantly different compared with T5

c: significantly different compared with M5

DISCUSSION

The current study has investigated the fatty acid contents of white Sardinella raw fish and its fermented products, Tareeh and Mehiawh. Sardines are consumed in many countries in different forms including the fermented products, and they are considered as an important source of n-3 PUFAs. The fatty acids profile of sardines and their derived products have been documented in several studies^{2,4,6,11,13,25}. However, no consistent pattern in the fatty acid contents of the different fermented fish product has been established.

The analysis of the Japanese fermented fish product of sandfish 'Hatahata-zushi' has revealed an increase in the concentration of SFAs and MUFAs while the contents of PUFAs decreased markedly during the process of fermentation²⁶. On the contrary, the fatty acid profile of a fermented fish product of Bouri fish in Egypt 'Feseekh' has shown a decrease in the concentrations of UFAs and an increase in the concentration of all SFAs except C16:0¹³.

In the present study, the fatty acid profile of raw fish differed significantly from that of the fish products Tareeh and Mehiawh. The FAs C20:4 n6 was not detected in the raw fish samples but was present in the fermented fish samples. The FAs C18:0, C18:2 n6, C18:4 n3, and C24:1 n9 were the predominant SFAs and UFAs in all fish samples. The predominant FAs in the fermented fish samples have differed from the predominant FAs in other fermented fish products such as 'Hatahat-zushi' in Japan and 'Feseekh' in Egypt^{13,26}. The current study has shown that the concentrations of the UFA C18:0 was significantly lower while the PUFAs were significantly higher in the fermented fish samples in compared to the raw fish samples.

In general, the production of PUFAs depends on two important groups of enzymes, desaturases, and elongases that work on increasing the degree of unsaturation of FAs obtained from diet^{27,28}. In the present study, the concentrations of the precursor of n-6 pathway C18:2 was higher than the concentrations of the precursor of n-3 pathway C18:3 in the raw fish and the fermented fish samples. However, the values of the FAs C18:2 n6, and C20:4 n6 were much higher in the fermented fish products. Similarly, the values of the FAs C18:3 n3, and C20:5 n3 (EPA) were much higher in the fermented fish products.

The ratio of n-6/n-3 around 1:1 to 2:1 is considered good for human health; however, any increase in the ratio is usually attributed to human diet⁷. In the present study, the ratio of n-6/n-3 ranged from 1.12±0.09 to 1.20±0.09 in the raw fish samples and ranged between 1.22±0.05 to 1.65±0.06 in the fermented fish samples. The increased proportion of EPA+DHA is considered a major protective factor for many diseases including cancers, apoplexy, thrombotic diseases, and allergic hypersensitivity. Therefore, the fish products Tareeh and Mehiawh can be considered as valuable food product since a ratio of between 3:1 and 4:1 for n-6 to n-3 PUFAs has been recommended by the World Health Organization (WHO) and others^{29,30}.

More enzymatic activities occur in lipids when kept for longer time³⁰. Many studies have revealed that the n-6 pathway starts with Linoleic acid (18:2 n6) and usually ends with arachidonic

acid (20:4 n6)^{31,32}. In the present study, further evaluation of the results was done using the biochemical indexes of the product-substrate relationship of elongation and desaturation in the PUFAs pathways. There was a significant decrease in 18:0/16:0 (SFAs), a significant increase in 20:4/18:2 (n6) and 22:4/20:4 (n6) ratios. Since the ratios of 20:4/18:2 (n6) reflects the activity of $\Delta 5$ - and $\Delta 6$ -desaturase, while the 22:4/20:4 (n6) reflects the activity of elongase, the results of this index indicates that the $\Delta 6$ -desaturase enzyme had higher affinity to n-6 family than n-3 family.

The enzymes that participate in the production of PUFAs are thought to be either fish tissue enzymes or microbial enzymes¹⁵. The bacterial flora of *Micrococcus* and *Bacillus* species were reported to be involved in the processing of the fish product 'Lona ilish' since these bacteria can tolerate high salt conditions¹⁵. However, other microorganisms were detected in the fermented Chinese fish product 'Suan yu' including lactic acid bacteria (LAB), *Staphylococcus*, and yeast³³. The effect of other treatments rather than fermentation on the FA profile of fish was reported by Chaijan et al¹¹. The changes of lipids in *Sardinella gibbosa* muscle during ice storage were investigated. The results of their study have revealed a marked decrease in UFAs especially C20:5 n3 (EPA) and C22:6n3 (DHA) as the storage time increased indicating the occurrence of lipid oxidation in sardine muscles¹¹. The study of MUSAIGER and D'SOUZA on the fatty acid profile of raw and cooked fish consumed in Bahrain has shown that cooking (curried, fried, and grilled fish) increased PUFAs, especially for pearl spotted rabbit fish commonly known as Safai⁴.

In the current study, the fermented fish product of white sardinella has shown higher concentrations of UFAs, PUFAs, omega-6, omega-3, EPA+DHA, and n6/n3 ratios while the values of SFAs, MUFAs, and were lower suggesting a unique fermentation process that might have been behind such significant difference. In addition, the nutritional value of Tareeh and Mehiawh of fatty acid contents was similar. Therefore, the results of this study open the door for great possible beneficial application of this fermentation process in the food industry to produce products rich in PUFAs especially omega-6, omega-3, EPA, and DHA.

CONCLUSION

The concentrations of SFAs and MUFAs were significantly lower in the fermented fish samples compared to raw fish samples, whereas the concentrations of UFAs and PUFAs were significantly higher. The amount of n-6 FAs, n-3 FAs as well as the proportions of EPA+DHA were higher in the fermented fish samples. The enzymatic activities of the enzymes elongases and desaturases were found to have higher affinity to n-6 FAs compared to n-3 FAs.

The high PUFAs contents in Tareeh and Mehiawh samples could be attributed to desaturation process. However, more investigations are needed to determine the microorganisms which are involved in the process of desaturation and elongation of fatty acids during the fermentation of white sardinella (Oom) fish.

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