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The impact of lipid content, cooking and reheating on volatile compounds found in Narrow – barred Spanish mackerel (*Scomberomorous commerson*)

Zakipour Rahimabadi, E.[1]*; Bakar, J.[2]; Che Man, Y.B.[2];
Abdul Hamid, N.[2], Arshadi, A.[1]

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Abstract

Effects of four cooking methods (microwave cooking, grilling, steaming and shallow fat frying) and reheating by microwave on volatile profile in *S. commerson* were evaluated. Thirty compounds were identified in GC-MS analysis of raw samples. The number of volatile compounds had increased to 36, 46, 45 and 45 compounds in microwave cooked, grilled, steamed and shallow fat fried samples, respectively. Total concentrations of volatile had increased from 72.80 to 111.06, 74.25, 112.19 and 92.37 µg/kg, respectively. The concentration and new flavor compounds were increased by chill-reheating, due to the fast oxidation. The concentration of alcohol and aldehydes increased significantly ($P<0.05$). The hexanal amount also increased in all samples and indicated a marked development of warmed-over flavor**.** Quantitative and qualitative ($P<0.05$) differences were observed in volatile compounds between raw and cooked samples.

Keywords: *Scomberomorous commerson*, Fish volatile compounds, Cooking, Chill-Reheating, GC-MS

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1-Department of Fisheries, Faculty of Natural Resources, University of Zabol, 98615-538 Zabol, Iran.
2-Department of Food Technology, Faculty of Food Science and Technology, universiti Putra Malaysia, 43400 Serdang, Malaysia.
* Corresponding author's email: e_zakipour@yahoo.com

Introduction

Flavor is one of the important sensory aspects of the overall acceptability of meat and seafood products. The application of n-3 fatty acids in seafood as a health supplement has been recognized for many years, but in contrast, the odor of fish oil is the major factor limiting its food application (Lin, 1994).

Food flavor and eating quality highly depends on the type and content of structural components such as lipid, protein and carbohydrates (Ho & Chen, 1994), and also cooking conditions, post preparation handling and also holding time before serving the product (Flick et al., 1989 and Mottram, 1998).

It is well known that variation in meat quality results in different eating qualities (Bejerholm & Aaslyng, 2003). A high degree of unsaturated fatty acid in fish, especially in phospholipids, makes them susceptible to oxidation during cooking. Generally heating process makes hidden volatile components become visible and identifiable (Josephson, 1991). During cooking, a complex series of thermally induced reactions occur between non-volatile components of lean and fatty tissue resulting in a large number of reaction products (Mottram, 1998).

Cooking procedures may result in different volatile compounds. The volatile composition of roasted and boiled shrimp (*Pleoticus muelleri*) was reported to contain different constituents of the sulfur-containing compounds (Kubota et al., 1986). The characteristic compounds in the roasted shrimp, amides, *N*-methyl-2-pyrrolidinone and *N*-methyl-2-pyridone, were not found under boiled shrimp. It has generally been accepted that precooked meat and meat products reheated after a short period of refrigerated and chilled storage develop a distinctive warmed-over flavor (Byrne et al., 2002). In addition to freshly cooked fish, in house preparation and also large scale catering operations, cooking and then chilling of cooked fish is common. These cooked samples could also be kept frozen prior to reheating just before serving (Bakar et al., 2008).

Scomberomorous commerson was selected for the study since it is among the most popular fish consumed in the Asian region. This fish, known as 'Shir Mahi' is one of the highly commercial fish in Iran**.** However, the number of reports concerning the effects of cooking and chill-reheat on fish volatile compounds is negligible. The purpose of this study was to investigate the effect of cooking methods and reheating on volatile compounds in *S. commerson*.

Materials and methods:

Seven fresh *S. commerson* (2.00 ± 0.15 kg and of 69 ± 4.00 cm length) were purchased from the local market in Kuala Lumpur. Fish were washed under running tap water, headed, gutted, cleaned and rewashed. Then, fish were cut to slices (1.9 cm average thickness). Slices were randomly divided into five homogenous groups. One group was analyzed immediately as the control (raw) group. Two groups of them were cooked by different cooking methods. One group was analyzed immediately, and the other group was stored in a chill room (5 °C) for two days and then reheated by microwave and analyzed.

Fish slices were fried for 5 min in palm oil (Seri Murni, Malaysia), which was preheated to 180 ºC for 2 min in a household non-stick pan. The temperature of the oil was monitored by a digital steel

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thermometer and the heating was slowed down when the oil temperature reached 165 ºC. The frying oil only covered 1/3 of the thickness of the fish slices and fresh oil was used for every batch of frying. The pans were washed, cleaned and dried after batch frying. Pieces were turned after 3 min. Then, fish slices were drained gently on stainless steel grills and allowed to be air cooled.

Fish grilling was performed for 13-15 min in an electrical griller (Fagor, SEM-60) (120 ºC). Fish slices were turned in the middle of cooking time. Cooked samples were air cooled for 25 min. 1.5 L of filtered tap water was poured into the bottom of a two-tier stainless steel home steamer and heated to boil. Fish slices were put in a single layer on the middle and upper layer of the steamer. Fish slices were then steamed for 12-14 min. They were then air cooled for 25 min.

Fish slices were placed on a flat dish and water was added to the dish without any cover. Microwave (Panasonic NN-K573 MF) cooking was carried out at a frequency of 2450 MHZ; at high power for 4-5 min. Cooked samples were air cooled for 25 min.Samples were reheated by microwave (2450 MHZ, 4 min). The internal temperature of the samples was 75-80 ºC. Temperature was measured by a digital steel thermometer. The initial temperature of fish slices was 10 ± 2ºC.

Lipid extraction was performed according to Kinsella et al. (1977). About 50 g of fish muscle was homogenized in a warring blender for 2 min with a mixture of 50 ml chloroform and 100 ml methanol. One volume of chloroform (50 ml) and one volume of distilled water (50 ml) were added to the mixture and blended for 30 sec, respectively. The homogenate was then filtered, and the filtrate was collected and transferred to a separator funnel to allow for phase separation. The lower fraction was collected and filtered. It was then transferred to a rotary evaporator for evaporation. The yield of lipid was determined gravimetrically after evaporating the solvent under a stream of nitrogen.

`The volatile components extraction was according to Prost et al. (1998) with a slight modification. A modified Likens and Nickerson apparatus was used for preparation of the simultaneous distillation-solvent extraction (SDE). Fish samples (100 g) were blended and mixed with 500 mL distilled water and then filled in a 1 L round bottom flask. Mantle heater/stirrer was used to heat the sample flask by a vigorous reflux. Another mantle heater was used to heat the solvent flask. A 100 mL round bottom flask consisting of 35 mL dichloromethane was attached to the solvent arm. Solvent and sample mixtures were heated to 40 and 70 ºC, respectively and then allowed to reflux for 2.5 h.

SDE extracts were kept at -20ºC overnight to facilitate water removal. After removing the water layer the residual moisture was dried over 2 g of anhydrous sodium sulfate (Na_2So_4). SDE extracts were stored at -20 ºC. Semi-quantitative data of flavor compounds were obtained by relating the peak intensities to an intensity of 0.4 µL 2, 4, 6-trimethylpyridine. Volatile extraction was repeated three times for each treatment.

Volatile analysis was carried out by GC-MS (Model Pegasus II LECO, LECO Corporation, USA). Separation of volatile flavor was achieved on SGE bpx 5 non-polar, bonded phase capillary column (50 m × 0.22 mm ID × 0.25 µm film thicknesses). Helium was used as carrier

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gas and the flow rate was 0.8 ml/min. Temperature was programmed at an initial temperature of 30 °C for 8 min. Temperature was gradually increased to 250 °C (15 °C per min) and held for 15 min. 1µL of extract was injected into the column, in the split-less mode. Electron ionization energy was set at 70 eV. Mass range, electron multiplier voltage and scan rates were set at 35-400 u, 1550 V and 10 spectra/second, respectively. Ion source temperature was maintained at 180 ºC.

Analysis of variance (ANOVA) was used to compare means. One-way ANOVA was used to analyze the effect of cooking by different methods on the control and two-way ANOVA was used to analyze the effect of chill-reheating on the cooked samples. Tukey’s test was used for mean comparison. Minitab software (version 14) was used.

Results

Thirty volatile components were identified in the GC-MS analysis of the raw samples of alkanes-alkenes (heptane, tetradecane, pentadecane, hexadecane, heptadecane and nonadecane), alcohols (1-penten-3-ol, 2-penten-1-ol,(Z)-, 1-heptanol, 1-octen-3-ol, 1-hexanol,2-ethyl, 2-octen-1-ol,(E)-), aldehydes (hexanal, heptanal, octanal, 2,4-hetadienal,(E,E)-, 2-octenal,(E)-, nonanal, 2,6-nonadienal,(E,Z)-, 2-nonenal,(E)-, benzaldehyde,4-ethyl-, tetradecanal and octadecanal), ketones (2,3- butanedione, 2-octanone, 2-undecanone), furans (furan,2-pentyl-), aromatic hydrocarbons (toluene), amines (trimethylamine) and s-containing compounds (benzothiazole) with concentration of 72.80 µg/kg. Volatile compounds of cooked samples by different cooking methods (Microwave, grilling, steaming and shallow fat frying) of *S. commerson* are listed in Table 1. The number of volatile compounds increased to 36, 46, 45 and 45 by cooking and the total concentration of volatiles were 111.06, 74.25, 112.19 and 92.37 µg/kg (of fish muscle) in microwave cooked, grilled, steamed and shallow fat fried samples, respectively.

Changes on flavor profile after chill-reheating are also listed in Table 1. 81 compounds were detected in the samples after chilling and reheating the cooked samples. 12 new compounds were generated after microwave reheating which are 2-octene, 2-methyl propanol, butanal, phenyl acetaldehyde, 2-decenal,(E)-, 2-decenal,(Z)-, 1-penten-3-one, 4-penten-2-one,4-methyl-, 2,4-pentanedione, 3-penten-2-one,4-methyl-, 2-decanone and 1, 2, 4-trithiolane. Volatile concentration was increased after chill-reheating in all cooking methods except microwave cooked samples (Table 1). The two way ANOVA analysis is shown in Table 1. Effects of cooking on volatile compounds were significant (P<0.05) except on dodecane, heptadecane, 1-penten-3-ol, 1-octen-3-ol, 4-heptenal, (Z)-, benzaldehyde, 4-ethyl-, 2, 3-butanedione, furan, 2-pentyl-. Effects of reheating was also significant (P<0.05) except on octane, undecane, nonadecane, pentanal, heptanal, 2-nonenal, (E)-, benzaldehyde, 4-ethyl-, decanal, undecanal, octadecanal, 2, 3-butanedione, 2-butanone, 3-hydroxy- and 2-heptanone. The interaction effect of cooking and reheating was not significant (P<0.05) in heptane, dodecane, pentadecane, undecane, 1-penten-3-ol, 1-octen-3-ol, pentanal, 4-heptenal, (Z)-, heptanal, 2, 6-nonadienal, (E, Z)-, benzaldehyde, 4-ethyl-, undecanal, 2, 3-butanedione, 2-heptanone.

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Table 1: Effects of reheating on volatile compounds (μg/kg) of cooked samples in *S. commerson*

Abbre-viation	Volatile compounds	Microwave		Grilling		Steaming		Shallow fat frying		R. T.
		Cooked	Reheated	Cooked	Reheated	Cooked	Reheated	Cooked	Reheated	(Min)
	Alkanes-Alkenes									
AK1	Pentane,2,2,4-trimethyl-	ND	ND	ND	ND	2.13 ± 0.00	ND	ND	ND	9.03
AK2	Heptane	0.21 ± 0.00 a	0.67 ± 0.17 a	0.28 ± 0.01 b	0.31± 0.00 a	0.31 ± 0.01 a	0.40 ± 0.15 a	0.64 ± 0.02 a	1.18 ± 0.19 a	9.54
AK3	Octane	0.91 ± 0.00	ND	ND	ND	ND	ND	1.98 ± 0.07 a	2.85 ± 0.35 a	12.67
AK4	2-Octene	ND	0.11 ± 0.00	ND	ND	ND	ND	ND	ND	
AK5	2,5-Octadiene	ND	ND	ND	ND	0.21 ± 0.02	ND	ND	ND	13.05
AK6	Dodecane	0.27 ± 0.07	ND	0.08 ± 0.00	ND	0.24 ± 0.05	ND	0.16 ± 0.02 ND	ND	18.67
AK7	Nonane	ND	ND	0.21 ± 0.00	ND	ND	ND	ND	ND	18.68
AK8	Tridecane	0.53 ± 0.03	ND	0.24 ± 0.02 b	0.51 ± 0.00 a	0.61 ± 0.05 a	0.72 ± 0.03 a	0.79 ± 0.04 b	0.50 ± 0.00 a	19.67
AK9	Tetradecane	1.26 ± 0.13 a	0.70 ± 0.10 a	0.67 ± 0.02 b	0.86 ± 0.02 a	1.57 ± 0.09 a	1.00 ± 0.05 b	22.14 ± 0.84a	1.05 ± 0.00 a	20.59
AK10	Pentadecane	32.75 ± 3.05 a	18.48 ± 1.58 b	18.86 ± 0.40 a	19.18 ± 0.40 a	32.26 ± 6.59 a	24.31 ± 0.85 a	ND	22.94 ± 0.65 a	21.46
AK11	Undecane	ND	ND	ND	ND	0.15 ± 0.04 a	0.12 ± 0.00 a	1.15 ± 0.25b	ND	22.16
AK12	Hexadecane	2.36 ± 0.13 a	1.41 ± 0.10 b	1.42 ± 0.01 a	1.45 ± 0.01 a	3.21 ± 0.13 a	1.89 ± 0.01 b	15.24 ± 1.34a	1.66 ± 0.04 a	22.27
AK13	Heptadecane	13.26 ± 5.27 a	14.89 ± 1.29 a	13.26 ± 0.52 a	14.68 ± 0.60 a	14.33 ± 3.10 a	14.16 ± 4.24 a	ND	16.41 ± 0.41 a	23.05
AK14	Octadecane	ND	0.84 ± 0.00	0.72 ± 0.07	ND	1.39 ± 0.07	ND	1.34 ± 0.03a	ND	23.83
AK15	Nonadecane	3.15 ± 0.87 a	1.85 ± 0.00 a	1.90 ± 0.10 a	2.44 ± 0.07 a	3.30 ± 0.00 a	3.63 ± 0.17 a		1.80 ± 0.12 a	24.67
	Total content	54.70	38.94	37.63	39.42	59.69	46.23	43.41	48.38	
	Alcohols									
AC1	1-Penten-3-ol	1.27 ± 0.04 a	5.81 ± 1.86 a	1.62 ± 0.09	1.90 ± 0.49 a	2.29 ± 0.21 a	5.27 ± 1.41 a	1.47 ± 0.07 b	3.40 ± 0.01 a	9.45
AC2	1-Pentanol	0.42 ± 0.07 b	0.76 ± 0.03 a	ND	ND	ND	0.59 ± 0.00	ND	0.81 ± 0.00	12.18
AC3	2-Penten-1-ol,(Z)-	ND	3.75 ± 0.01	0.38 ± 0.00	ND	ND	ND	ND	0.79 ± 0.01	12.28
AC4	1-Heptanol	ND	0.35 ± 0.03	0.36 ± 0.03 a	0.38 ± 0.00 a	0.37 ± 0.09 a	0.57 ± 0.12 a	0.81 ± 0.01a	0.72 ± 0.01 b	16.07
AC5	1-Octen-3-ol	1.48 ± 0.14 a	1.64 ± 0.48 a	1.01 ± 0.06 b	1.75 ± 0.05 a	1.37 ± 0.04 b	2.20 ± 0.03 a	0.92 ± 0.01b	2.32 ± 0.01 a	16.22
AC6	1-Hexanol,2-ethyl-	0.47 ± 0.06	ND	0.39 ± 0.01 a	0.33 ± 0.05 a	0.47 ± 0.04 a	0.51 ± 0.09 a	0.37 ± 0.01a	0.37 ± 0.01 a	16.84
AC7	2-Octen-1-ol,(E)-	0.19 ± 0.00 b	0.75 ± 0.03 a	0.11 ± 0.00 b	1.03 ± 0.00 a	ND	0.83 ± 0.21	ND	ND	17.07
	Total content	3.83	13.04	3.86	5.88	4.50	9.96	3.56	8.40	
	Aldehydes									
AD1	2-Methyl propanol	ND	ND	ND	0.16 ± 0.00	ND	ND	ND	ND	
AD2	Butanal	ND	ND	ND	ND	ND	ND	ND	1.43 ± 0.07	
AD3	Butanal,3-methyl-	ND	ND	0.48 ± 0.08	ND	ND	ND	ND	ND	8.46
AD4	Butanal,2-methyl-	ND	ND	0.31 ± 0.00	ND	ND	ND	ND	ND	8.78
AD5	Pentanal	1.82 ± 0.04 a	1.71 ± 0.08 a	1.26 ± 0.16 a	2.00 ± 0.20 a	1.73 ± 0.24 a	2.37 ± 0.31 a	2.80 ± 0.62 a	2.68 ± 0.0 a	10.02
AD6	2-Pentenal,(E)-	ND	1.21 ± 0.03	0.74 ± 0.13 a	1.32 ± 0.13 a	ND	1.72 ± 0.00	ND	1.54 ± 0.21	11.96
AD7	Hexanal	6.36 ± 0.33 a	7.22 ± 0.19 a	3.78 ± 0.17 b	5.79 ± 0.20 a	6.49 ± 0.04 b	8.11 ± 0.10	4.86 ± 0.46 b	8.63 ± 0.19 a	12.99
AD8	2-Hexenal,(E)-	0.69 ± 0.01 b	1.23 ± 0.11 a	ND	ND	ND	1.38 ± 0.10	ND	0.99 ± 0.01	14.23

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(Table 1: continued)

Abbre-viation	Volatile compounds	Microwave		Grilling		Steaming		Shallow fat frying		R. T.
		Cooked	Reheated	Cooked	Reheated	Cooked	Reheated	Cooked	Reheated	(Min)
AD9	4-Heptenal,(Z)-	0.62 ± 0.02a	1.04 ± 0.23 a	0.48 ± 0.05 b	0.83 ±0.02 a	0.64 ± 0.03 b	1.15 ± 0.01 a	0.45 ± 0.02 b	1.37 ± 0.19 a	15.00
AD10	Heptanal	1.09 ± 0.16a	1.14 ± 0.15 a	0.80 ± 0.05 a	1.01 ± 0.03 a	1.62 ± 0.48 a	1.39 ± 0.01 a	1.45 ± 0.02 b	2.32 ± 0.15 a	15.03
AD11	Benzaldehyde	ND	ND	0.61 ± 0.02	ND	ND	ND	0.40 ± 0.02	ND	16.21
AD12	Octanal 2,4-	1.59 ± 0.02a	1.51 ± 0.10 a	1.02 ± 0.06 a	1.24 ± 0.04 a	1.52 ± 0.05 b	1.57 ± 0.08 a	3.01 ± 0.06 b	3.93 ± 0.09 a	16.54
AD13	Hetadienal,(E,E)-	0.59 ± 0.00a	0.71 ± 0.11 a	0.35 ± 0.00 a	0.55 ± 0.06 a	0.45 ± 0.04 b	1.03 ± 0.01 a	0.33 ± 0.00 a	0.65 ± 0.13 a	16.78
AD14	Phenyl acetaldehyde	ND	ND	ND	0.56 ± 0.03	ND	ND	ND	0.49 ± 0.00	
AD15	2-Octenal,(E)-	1.09 ± 0.13a	1.03 ± 0.16 a	0.56 ± 0.04 b	0.90 ± 0.03 a	1.00 ± 0.08 a	1.06 ± 0.03 a	0.85 ± 0.02 b	1.56 ± 0.01 a	17.30
AD16	Nonanal	0.80 ± 0.08a	1.22 ± 0.38 a	0.53 ± 0.00 b	0.77 ± 0.01 a	0.89 ± 0.07 a	1.03 ± 0.07 a	4.75 ± 0.05 b	6.61 ± 0.09 a	17.79
AD17	2,4-Octadienal,(E,E)-	ND	ND	0.21 ± 0.02	ND	ND	ND	ND	ND	17.98
AD18	2,6-Nonadienal,(E,Z)-	0.60 ± 0.14a	0.93 ± 0.11 a	0.38 ± 0.05 a	0.82 ± 0.16 a	0.54 ± 0.02 b	0.81 ± 0.01 a	0.30 ± 0.65 b	0.62 ± 0.01 a	18.41
AD19	2-Nonenal,(E)-	0.56 ± 0.08	ND	0.35 ± 0.01	ND	0.54 ± 0.06 b	1.03 ± 0.04 a	0.61 ± 0.01 a	1.04 ± 0.14 a	18.46
AD20	Benzaldehyde,4-ethyl-	0.49 ± 0.00a	0.44 ± 0.08a	0.43 ± 0.07 a	0.49 ± 0.10 a	0.41 ± 0.10 a	0.64 ± 0.03 a	0.93 ± 0.40 a	0.66 ± 0.03 a	18.69
AD21	Decanal	ND	ND	0.19 ± 0.00	ND	ND	ND	0.47 ± 0.04 b	0.72 ± 0.04 a	18.89
AD22	2-Decenal,(E)-	ND	0.39 ± 0.00	ND	ND	ND	1.81 ± 0.00	ND	2.53 ± 0.00	
AD23	2,4-Nonadienal,(E,E)-	ND	ND	ND	ND	ND	ND	0.16 ± 0.00	ND	19.87
AD24	Undecanal	ND	ND	ND	ND	ND	ND	0.62 ± 0.02 a	0.67 ± 0.04 a	19.89
AD25	2,4-Decadienal,(E,E)-	0.33 ± 0.02a	0.33 ± 0.04 a	0.23 ± 0.00	ND	0.41 ± 0.00 b	0.81 ± 0.00 a	0.63 ± 0.04 b	1.26 ± 0.05 a	20.12
AD26	2-Decenal,(Z)-	ND	0.86 ± 0.00	ND	ND	ND	0.36 ± 005	ND	1.43 ± 0.05	
AD27	2-Undecenal	ND	ND	ND	ND	1.33 ± 0.00	ND	2.42 ± 0.00 a	2.91 ± 0.01 a	20.47
AD28	Dodecanal	ND	ND	ND	ND	ND	0.20 ± 0.00	0.53 ± 0.00 a	0.61 ± 0.05 a	20.82
AD29	Tetradecanal	10.85 ± 0.78a	4.78 ± 0.03 b	5.74 ± 0.17 b	6.65 ± 0.11 a	10.00 ± 0.49 a	8.91 ± 0.13 a	3.60 ± 0.32 a	5.66 ± 0.52 a	22.52
AD30	Pentadecanal	0.16 ± 0.00	ND	ND	ND	ND	2.07 ± 0.00	ND	ND	25.65
AD31	9-Octadecenal,(Z)-	ND	ND	ND	ND	0.58 ± 0.19	ND	ND	ND	25.85
AD32	Octadecanal	9.18 ± 0.01a	5.22 ± 0.00 b	5.41 ± 0.83 a	6.89 ± 0.15 a	8.61 ± 0.96 a	9.92 ± 0.39 a	2.34 ± 0.08 a	3.35 ± 0.80 a	26.06
	Total content	36.82	31.06	23.84	29.99	36.74	47.35	31.45	53.60	
	Ketones									
K1	2,3-Butanedione	3.38 ± 0.04 a	3.42 ± 0.81 a	2.31 ± 0.38 a	2.72 ± 0.42 a	2.69 ± 0.74 a	2.48 ± 0.20 a	2.91 ± 0.48 a	3.19 ± 0.23 a	6.18
K2	2-Butanone	ND	ND	1.63 ± 0.46	ND	ND	ND	ND	ND	6.35
K3	1-Penten-3-one	ND	ND	ND	0.07 ± 0.00	ND	ND	ND	ND	
K4	2-Pentanone	ND	ND	ND	ND	ND	0.43 ± 0.09	0.47 ± 0.00	ND	9.64
K5	2-Butanone,3-hydroxy-	1.40 ± 0.00	ND	1.52 ± 0.39 a	1.56 ± 0.00 a	2.50 ± 0.54 a	3.37 ± 0.62 a	0.85 ± 0.09 a	0.66 ± 0.00 a	10.54
K6	4-Penten-2-one, 4-methyl-	ND	ND	ND	ND	ND	3.39 ± 0.02	ND	ND	
K7	2,4-Pentanedione	ND	ND	ND	ND	ND	11.92 ± 1.39	ND	ND	
K8	3-Penten-2-one, 4-methyl-	ND	ND	ND	ND	ND	2.77 ± 0.13	ND	ND	
K9	2-Heptanone	ND	ND	ND	ND	0.20 ± 0.00 a	0.18 ± 0.03 a	0.59 ± 0.12 a	0.40 ± 0.09 a	14.80

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(Table 1: continued)

Abbre-viation	Volatile compounds	Microwave		Grilling		Steaming		Shallow fat frying		R. T. (Min)
		Cooked	Reheated	Cooked	Reheated	Cooked	Reheated	Cooked	Reheated	
K10	2,3-Octanedione	0.99 ± 0.13 a	0.95 ± 0.13 a	ND	0.94 ± 0.00	0.88 ± 0.05 a	1.22 ± 0.18 a	0.67 ± 0.04 b	0.95 ± 0.09 a	16.25
K11	2-Octanone	ND	ND	ND	ND	ND	0.16 ± 0.00	ND	ND	17.60
K12	2-Nonanone	ND	ND	ND	0.87 ± 0.00	0.25 ± 0.00	ND	ND	0.41 ± 0.10	17.61
K13	2-Tridecanone	ND	ND	ND	ND	ND	ND	0.81 ± 0.00	ND	18.72
K14	2-Undecanone	3.35 ± 1.00 a	0.43 ± 0.02 a	0.58 ± 0.18b	0.56 ± 0.05 a	0.98 ± 0.12 a	0.93 ± 0.12 a	1.19 ± 0.51 a	0.63 ± 0.02 a	19.72
K15	2-Pentadecanone	ND	ND	ND	0.12 ± 0.00	0.12 ± 0.00 b	0.64 ± 0.00 a	0.94 ± 0.11 a	0.90 ± 0.01 a	23.15
K16	2-Decanone	ND	ND	ND	ND	ND	0.16 ± 0.00	ND	ND	
	Total content	9.11	4.86	6.03	8.51	7.62	29.77	8.43	7.13	
	Furans									
F1	Furan,2-ethyl-	6.06 ± 0.25 a	6.20 ± 0.84 a	1.47 ± 0.05 b	3.71 ± 0.33 a	1.77 ± 0.13 a	5.85 ± 0.11 a	4.09 ± 0.00 a	2.96 ± 0.35 a	9.85
F2	Furan,2-pentyl-	0.54 ± 0.09 a	0.66 ± 0.05 a	0.37 ± 0.00 b	0.80 ± 0.04 a	0.52 ± 0.02 b	0.80 ± 0.01 a	0.45 ± 0.07 a	0.95 ± 0.10 a	16.32
F3	2-Ethyl-5-methyl-furan	ND	ND	ND	ND	ND	ND	0.20 ± 0.00	ND	19.76
	Total content	6.60	6.86	1.84	4.50	2.29	6.65	4.74	3.90	
	Hydrocarbons									
H1	3-Methyl undecane	ND	ND	ND	ND	0.15 ± 0.00	ND	ND	ND	19.31
H2	5-Octadecene,(E)-	ND	0.73 ± 0.00	0.42 ± 0.00	ND	0.94 ± 0.04	ND	ND	ND	21.34
	Aromatic hydrocarbone									
AH1	Toluene	ND	ND	0.24 ± 0.00	ND	ND	0.94 ± 0.00	0.34 ± 0.05 a	0.31 ± 0.00 a	17.28
	Amines									
A1	Tri methylamine	ND	ND	ND	ND	0.08 ± 0.00b	ND	ND	ND	23.99
	S-Containing compounds									
S1	1,2,4-Trithiolane	ND	ND	ND	ND	ND	ND	ND	0.06 ± 0.00	18.21
S2	Benzothiazole	ND	ND	0.18 ± 0.03	ND	0.18 ± 0.00	ND	ND	ND	19.55
	Pyrazines									
P1	Trimethyl pyrazine	ND	ND	0.21 ± 0.00	ND	ND	ND	ND	ND	16.63
	(K) Lactones									
L1	4-Nonanolide	ND	ND	ND	ND	ND	ND	0.44 ± 0.00	ND	19.62

Values are means and S.D. of triplicate; Means with the same letter within a row in each cooking method were not significantly different at $P<0.05$ level. ND: Not detected

Discussion

The total lipid content of *S. commerson* was 2.31%. According to the classification of Kent et al. (1992), *S. commerson* is a lean fish. The studies of Osman et al. (2001) and Bykov (1985) on total lipid content of *S. commerson* showed the same range of lipid content of this fish. Qualitative and quantitative aspects of volatiles were considered due to their impact on flavor quality as suggested by Shahidi (1998). The number of volatile compounds and their total concentration was increased by cooking. This result agrees with Liu et al. (2009) who reported that volatile compounds were significantly increased by cooking. The volatile profile of cooked samples by different methods was significantly different, due to the different temperatures used for cooking procedures and also due to the effect of cooking oil in frying method, which affect fatty acid composition.

The total volatile concentration of reheated samples compared with cooked samples was 1.19, 1.25 and 1.31 times higher in grilled, steamed and fried samples, respectively. In microwave reheated samples, the total flavor concentration was less compared to cooked samples (about 0.86 times). This result agrees with Byrne et al. (2002). They concluded that a rapid development of lipid oxidation happened during refrigerated storage.

Alkanes/alkenes group were the major volatile compounds group in all raw and cooked samples. The result is similar to the study carried out by Cha & Cadwallader (1995). In all samples, pentadecane and heptadecane were dominant compounds. After storing cooked samples in chill room and then reheating, the number of alkanes/alkenes and their amount were reduced in microwave cooked, grilled and steamed samples. In fried samples, the amount of alkanes/alkenes increased. There were significant ($P<0.05$) differences in the concentration of alcohol compounds in different samples, except in 1-heptanol. The flavor compounds and the concentration of alcohols increased in all cooked sample after reheating. Microwave cooked samples showed highest increment in amount of alcohols. This could be due to increase in the amount of 1-penten-3-ol and generating of 2-penten-1-ol, (Z)-. The alcohol concentration in reheated samples of microwave, grilled, steamed and fried samples were 3.40, 1.52, 2.21 and 2.34 times higher compared with cooked samples. Aldehydes play an important role in many food products and are responsible for a wide range of oxidized flavor (Vejaphan et al., 1988). There were significant ($P<0.05$) differences in the concentration of aldehydes between cooked and raw samples except for heptanal, 2, 6-nonadienal, (E, Z)-, and benzaldehyde, 4-ethyl-. Milo & Grosch (1996) showed (E, Z) - 2, 6- nonadienal and (E, E)-2, 4-decadienal are the key aroma compounds of raw and boiled salmon. It was also reported that (Z)-4-heptenal, (E, Z)-2, 6-nonadieal, and (E,E)-2, 4-decadienal contribute actively to turbot aroma (Prost et al., 1998). Hexanal was increased in all cooked samples after reheating. Byrne et al. (2001) showed hexanal is well documented as a prominent volatile marker compound for WOF in meat. Ketones are formed during the oxidation of fatty acids (Wettasighe et al., 2001). Eight compounds were generated during cooking in different methods. Microwave cooked samples with four ketones had the highest concentration among other cooked samples. Higher

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numbers of ketones were found in frying followed by steaming. 2, 3-butanedione was the dominant compound among the ketones. Prost et al. (1998) showed that 2, 3-butanedione is an active compound that contributes in trout aroma. Three furans were detected in *S. commerson* and only 2-pentylfuran was found in raw fish. 2-ethylfuran and 2-ethyl-5-methyl furan were generated during cooking. The latter was found only in fried samples. These compounds have also been reported by Prost et al. (1998) and Mjøs & Solvang (2005) which mainly associated with sweet, fruity, nutty or caramel-like odor impression. Alkanes/alkenes, alcohols, aldehydes and ketones may be produced by thermal oxidation and degradation of polyunsaturated fatty acid (Chen & Zhang, 2006; Mottram, 1998). It has been reported that lipid content has a highly significant effect on many of the texture and flavor attributes of the smoked and cooked Atlantic salmon (Robb et al., 2002). Results illustrated that there were obvious qualitative and quantitative differences between raw and cooked and cooked-chilled-reheated samples. Volatile compounds and fish flavor were affected by methods of cooking and storage before serving. Most of the flavor compounds represented are well known in lipid oxidation products. There were some compounds that generated via lipoxygenase, amino acid degradation and Maillard reaction. Aroma generated during heat process can be affected by lipid content and fatty acid composition of food. High proportions of unsaturated fatty acids in fish can give more unsaturated volatile aldehydes.

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