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Quantification and Identification of the Flavor Volatile Compounds in Some Fresh and Processed Fish Products Using GC/MSD

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ABSTRACT

The effect of frying and smoking methods on the volatile flavor compounds profiles of grass carp, golden pompano, threadfin bream, and brushtooth lizardfish were determined in this study. A total of 84 substances were identified by GC/MSD. The samples obtained using frying and smoking methods have the following numbers of volatile components: 25 (RF), 26 (FF) and 19 (SF) in grass carp, 23 (RF), 10 (FF) and 15 (SF) in lizardfish, 22 (RF), 18 (FF) and 26 (SF) in golden pompano and 26 (RF), 21 (FF) and 30 (SF) in threadfin bream samples. Smoked golden pompano and threadfin bream samples had the highest values (328.478 and 351.666µg/ kg) compared to fried and raw samples, while raw grass carp and lizardfish samples had the highest total amount of volatile compounds (461.331 and 348.826µg/ kg) compared to other cooked samples. The procedure that had the biggest impact on the volatile compound's contents was smoking samples of threadfin bream and golden pom pano. However, considerable differences were observed in the formation of some volatile compounds in other samples. It was also concluded that alterations in volatile compounds influenced by smoking and frying processes did not exhibit uniformity in direction.

INTRODUCTION

Cooking is a heating procedure that causes variable degrees of change in the composition, physicochemical indices, and flavor of food items. Cooking alters the physicochemical properties and eating quality of beef, affecting its nutritional and organoleptic properties. Smoking has become the most popular fish processing method in recent years, driven by consumer demand for fish with distinct flavor, color, and texture **(Sokamte *et al*., 2020)**.

The smoking process produces a volatile that is made up of a variety of chemical compositions from the processes that take place when wood is burnt, and smoke interacts with fish fillets **(Varlet *et al*., 2007)**. The sensory attributes of smoked fish mostly result from the presence of volatile organic compounds (VOCs) that are absorbed by the flesh during the smoking process. It is well-known that phenolic chemicals help preserve smoked foods by acting as antioxidants and antimicrobials, and they also add substantially to the smoke flavor **(Yang *et al*., 2019)**. Lipids undergo enzymatic and auto oxidative reactions, and their resulting products interact with free amino acids and peptides, among other chemical processes that take place throughout the process **(Huang *et al*., 2019)**.

Frying is widely used in fish processing due to its high efficiency, flavor enhancement, digestibility improvement, and harmful microorganism inactivation. Because of the Maillard reaction and the thermal oxidation and breakdown of fatty acids, particularly polyunsaturated fatty acids, frying results in the creation of many volatile compounds **(Liu *et al*., 2009)**. Fried fish has distinct fragrance profiles due to the composition of volatile chemicals. Currently, volatile compounds in food are analyzed using both sensory and instrumental analysis; Gas chromatography-mass spectrometry (GC-MS) has long been the primary approach for volatolomics research due to its high sensitivity and strong identification capabilities for detecting and characterizing volatile species **(Diez-Simon *et al*., 2019)**.

This study includes four different varieties of fish. Three varieties of fish come from the Suez Gulf, while the fourth is freshwater fish. The threadfin bream (*Nemipterus japonicas*) is a demersal species from the Nemipteridae family that is economically important in the trawl fisheries of the Gulf of Suez. Brushtooth lizard fish (*Saurida undosquamis*) can be found in abundance in the Red Sea. It is a vital and important commercial species of the Synodontidae family found in Egypt's Suez Gulf and the Red Sea **(Mehanna, 2022)**. The golden pompano, (*Trachinotus ovatus*) is a species of mariculture fish that is economically significant **(Ni *et al*., 2022)**. Many customers like golden pompano because of its vibrant body color and delectable flesh. Consequently, as processing technology has advanced, so too has the output of golden pompano. Because of its quick development rate, ease of cultivation, high feed efficiency ratio, high nutritional content, and reasonable price, grass carp (*Ctenopharyngodon idellus*) is one of the most significant freshwater fish species in the world. However, there remains a lack of the effects of frying and smoking methods on the volatile flavor compounds, of grass carp (*Ctenopharyngodon idella*), golden pompano (*Trachinotus ovatus*), brushtooth lizardfish (*Saurida undosquamis*) and threadfin bream (*Nemipterus japonicus*). The purpose of this study was to understand the effect of common cooking methods (frying and smoking) on volatile flavor compounds of these commercial fishes. These results may give sight for evaluation of fish quality.

MATERIALS AND METHODS

Fish samples collection

Fresh grass carp (*Ctenopharyngodon idella*) fish were purchased from El-Serew Fish Research Station, while other seafood's fish, 3 species including the golden pompano (*Trachinotus ovatus*), threadfin bream (*Nemipterus japonicus*), and brushtooth lizardfish

(*Saurida undosquamis*) were collected from Suze City, Egypt. Table (1) displays the average length and total weight of the fish samples that were collected.

Sample preparation

Fresh fish samples were carefully washed with potable water were then packed in ice boxes and transported to Fish Processing and Technology Laboratory, National Institute of Oceanography and Fisheries, El-Kanater El-Khiria City, El-Qaluobia Governorate, Egypt. Fish samples were carefully washed with tap water, manually beheaded, gutted, filleted, rewashed carefully and drained.

Table 1. The average of total weight and length (Mean ± STDEV) for collected fish samples

Fish species	weight	length
Grass carp (*Ctenopharyngodon idella*)	6575±991.52	76.12±2.00
Threadfin bream (*Nemipterus japonicus*)	106.17±11.73	19.64±1.17
Brushtooth lizardfish (*Saurida undosquamis*)	103.75±26.01	23.89±2.52
Golden pompano (*Trachinotus ovatus*)	247.63±44.28	23.64±1.77

Thermal processing methods (cooking methods)

Frying process

Fish fillets samples were subjected for deep-frying in sunflower oil preheated at 160°C for 5- 6min.

Smoking process

The frozen fish fillets were thawed at room temperature, rinsed with tap water, salted for two hours with a 10% brine solution, and then rinsed again for one minute to get rid of any remaining salt. Salted fillets were partially dried (at 20- 23ºC) for about 2 hours before continuing the rest of the smoking procedure. Partially dried fillets were subjected to cold smoking in a laboratory smokehouse at Shakshuka Fish Research Station in Fayoum Governorate. The internal dimensions of the smokehouse were 1.20 × 1.0 × 3.5 meters. The smoking process stayed at 35- 45°C for 10-11 hours. Smoked fillets were cooled at room temperature, wrapped in polyethylene bags, and stored until analysis.

Volatile compounds

The analysis was performed in the National Research Center, Giza, Egypt using an Agilent 8890 GC System, coupled to a mass spectrometer (Agilent 5977B GC/MSD) according to **Centonze *et al.* (2019)**. The relatively volatile compounds contents of each component were calculated by the normalization method. Internal standard method was used to calculate the quantitatively concentration of each volatile compound **(Kesen, 2020)**. Relative volatile compounds contents = Content of specific sample/ Content of all detected samples x100%.

RESULTS AND DISCUSSION

The volatile flavor compounds in the raw and cooked fish samples were analyzed using GC-MS to determine how different cooking methods affected the flavor compounds contents of fish. As indicated in Table (2), a total of 84 substances were identified by GLC-MSS; these components were categorized into 11 groups: 19 alcohols, 5 phenolics, 10 alkanes, 6 hydrocarbons, 1carboxylic acids, 1 hydrochloride, 12 aromatic compounds, 8 aldehydes, 5 ketones, 3 esters and 14 others. The breakdown of proteins and lipids by both enzymatic and non-enzymatic processes is linked to the production of these volatile molecules **(Tian *et al*., 2020)**. The raw samples obtained using frying and smoking methods have the following numbers of volatile components: 25 (RF), 26 (FF) and 19 (SF) in grass carp, 23 (RF), 10 (FF) and 15 (SF) in the lizardfish, 22 (RF), 18 (FF) and 26 (SF) in the golden pompano and 26 (RF), 21 (FF) and 30 (SF) in the threadfin bream samples.

Variations in the quantity of volatile compounds can be ascribed to changes in raw materials, particularly the amount of fat and its oxidative state **(Sokamte *et al*., 2020)**. Fig. (1) and Table (2) show quantitative results for volatile compounds in raw and cooked fish samples. Raw grass carp and lizardfish samples had the highest total amount of volatile compounds (461.331 and 348.826μg/ kg) compared to other cooked samples, while the smoked golden pompano and threadfin bream samples had the highest values (328.478 and 351.666μg/ kg) compared to fried and raw samples. It could be seen that there were obvious differences in the types and contents of volatile components in fried and smoked samples. This may be due to different cooking conditions such as heat transfer mechanism, heating time, and temperature **(Erten & Cadwallader, 2017)**.

Alcohols, alkanes, aromatic compounds, aldehydes, and phenols formed most of the content. The volatile component classes differed among cooking methods (Fig. 2a, b, c and d). Aromatic compounds were most prevalent in the smoked samples: the grass carp 45.53μg/ kg, the golden pompano 66.438μg/ kg, and the threadfin bream 64.671μg/ kg, while in fried samples, alkane compounds were most abundant except for the golden pompano sample. Carboxylic acids and hydrochloride compounds did not exist in all samples except raw grass carp. Alcohols can provide flowery, fruity, or fermented flavors depending on their molecular weight and the molecules they interact with. Both the raw and cooked samples contained different amounts of alcohol. In raw lizardfish, alcohols consisted approximately 28.8% of total aroma compounds, as indicated in Table (2).

Fresh seafood samples always possessed more alcohols than deteriorated samples **(Zhang *et al*., 2010)**, as shown in Table (2). Except for grass carp samples, fried samples had the lowest alcohol amounts, while raw fish samples had the highest alcohol values with 100.493, 45.546 and 73.226μg/ kg in the lizardfish, golden pompano, and threadfin bream samples, respectively. The alcohol percentage of the fried and smoked lizardfish, golden pompano, and threadfin bream samples was lower than that of the raw samples. The prior data indicate a general tendency of reduced alcohol contents due to cooking methods, with a more decrease observed in fried samples compared to smoked samples.

Aldehydes are important flavor compounds that react easily with acids and alcohols due to their similarity. Table (2) demonstrates that the aldehyde contents were more closely associated with the smoking techniques of the threadfin bream and golden pompano samples, with the maximum aldehyde concentrations being 43.918 and 41.713µg/ kg. Additionally, furfural was detected in all smoked samples. The findings for the lizardfish and grass carp exhibited a divergent trend, with the total quantity of aldehydes being greater in the fried samples of grass carp and the raw samples of the lizardfish. The high relative concentrations of aldehydes were 12.699 and 12.488% in the threadfin bream and golden pompano samples, respectively. Aldehydes were produced from lipid oxidization, Strecker degradation of amino acids and Maillard reactions **(Chen *et al*., 2017; Hu *et al*., 2020)**. Because of their low flavor threshold, certain aldehydes have the potential to be major flavor compounds even when present in trace concentrations **(Cruz-Romero *et al*., 2008)**. The raw grass carp, lizard fish, and smoked grass carp and threadfin bream sample all showed to contain phenolic compounds. The raw grass carp had the highest content at 72.154, which decreased to 36.672 in the smoked sample. Except for the raw grass carp sample, none of the samples contained hydrochloride or carboxylic acids.

Table 2. Effect of different cooking methods on volatile flavor compounds contents (µg/kg) in some commercial fish species

Compounds name	Formula	Grass carp			Lizardfish			Golden pompano			Threadfin bream		
		RF	FF	SF	RF	FF	SF	RF	FF	SF	RF	FF	SF
Alcohols (19)													
Ethyl ether	$C_4H_{10}O$	1.851	1.816	1.811	1.782	ND	ND	1.827	1.816	1.827	1.822	1.816	1.816
2,3-Pentanedione	$C_5H_8O_2$	3.504	ND	ND	ND	ND	ND	3.447	3.424	ND	ND	ND	ND
2 Methylundecane	$C_{12}H_{26}$	22.971	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Methyltris(methoxyethoxy)silane	$C_{10}H_{24}O_6Si$	ND	11.698	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1-(1-Butyny)cyclopentanol	$C_9H_{14}O$	ND	11.841	ND	ND	ND	11.773	ND	ND	ND	ND	ND	11.773
4-Ethylbenzoic acid, 2-ethylcyclohexyl	$C_{13}H_{18}O_2$	ND	ND	9.724	ND	ND	ND	ND	ND	ND	ND	ND	ND
1-Octen-3-ol	$C_8H_{16}O$	12.419	12.425	ND	12.425	ND	ND	12.425	ND	12.442	12.425	12.436	12.436
1-Pentene-3-ol	$C_5H_{10}O$	ND	ND	ND	3.235	ND	ND	3.215	3.195	ND	ND	ND	ND
Cyclopentanol	$C_5H_{10}O$	ND	ND	ND	3.412	ND	ND	ND	ND	ND	ND	ND	ND
1-Pentanol	$C_5H_{12}O$	ND	ND	ND	4.191	ND	4.179	4.208	ND	ND	4.202	4.185	4.185
2-Octyn-1-ol	$C_8H_{14}O$	ND	ND	ND	15.984	ND	ND	ND	ND	12.442	19.989	12.436	12.436
2,7-Octadien-1-ol	$C_8H_{14}O$	ND	ND	ND	16.979	ND	ND	ND	ND	ND	ND	ND	ND
1,1,3,3,5,5,7,7-Octamethyl 7(2methylpropoxy) tetrasiloxan-1-ol	$C_{12}H_{34}O_5Si_4$	ND	ND	ND	19.303	ND	ND	ND	ND	ND	ND	ND	ND
Indole	C_8H_7N	ND	ND	ND	23.182	ND	23.531	ND	ND	ND	ND	ND	ND
α-Terpineol	$C_{10}H_{18}O$	ND	ND	ND	ND	ND	20.493	20.424	ND	ND	20.424	ND	ND
1,6-Dihydrocarveol	$C_{10}H_{18}O$	ND	ND	ND	ND	ND	ND	ND	ND	ND	14.364	ND	ND
Benzenol	C_6H_5OH	ND	12.631	ND	ND	ND	ND	ND	ND	12.648	ND	ND	12.619
Neodihydrocarveol	$C_{10}H_{18}O$	14.370	14.376	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dimethylsilanediol	$C_2H_8O_2Si$	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	4.128	ND
Total content		55.115	64.787	11.535	100.493	0	59.976	45.546	8.435	39.359	73.226	35.001	55.265
Phenolics (5)													
2,4-Di-tert-butylphenol	$C_{14}H_{22}O$	30.959	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Di-t-butyl-4-butylphenol	$C_{14}H_{22}O$	41.195	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
p-Creso	$CH_3C_6H_4OH$	ND	ND	16.179	ND	ND	ND	ND	ND	ND	ND	ND	ND
Creosol	$C_8H_{10}O_2$	ND	ND	20.493	ND	ND	ND	ND	ND	ND	ND	ND	20.493
Phenol, 4,4'-(1-methylethylidene)bis-	$C_{31}H_{48}O_2$	ND	ND	ND	44.909			ND	ND	ND	ND	ND	ND
Total content		**72.154**	**0**	**36.672**	**44.909**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**20.493**
Alkanes (10)													
Undecane	$C_{11}H_{24}$	9.484	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Compounds name	Formula	Grass carp			Lizardfish			Golden pompano			Threadfin bream		
		RF	FF	SF	RF	FF	SF	RF	FF	SF	RF	FF	SF
Dodecamethylcyclohexasiloxane	$C_{12}H_{36}O_6Si_6$	25.294	25.294	25.300	25.294	25.294	25.299	25.293	ND	25.299	25.294	25.030	25.299
Decamethylcyclopentasiloxane	$[(CH_3)SiO]_5$	ND	19.291	ND	ND	ND	ND	19.280	ND	ND	19.291	ND	ND
Tetradecamethylcycloheptasiloxane	$C_{14}H_{42}O_7Si_7$	30.753	30.753	30.754	30.752	ND	30.753	ND	ND	ND	30.747	30.758	30.758
n-Hexane	C_6H_{14}	ND	ND	ND	ND	ND	ND	ND	2.257	2.268	ND	ND	ND
1,2-Diethoxyethane	$C_{12}H_{28}O_4$	ND	ND	1.919	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pentadecane	$C_{15}H_{32}$	ND	ND	ND	ND	30.638	ND	30.644	ND	ND	ND	ND	ND
1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15Hexadecamethyloctasiloxane	$C_{16}H_{48}O_7Si_8$	ND	ND	ND	29.557	ND	ND	ND	ND	ND	ND	ND	ND
Hexadecamethyl-cyclooctasioxane	$C_{16}H_{48}O_8Si_8$	ND	ND	ND	36.171	ND	36.183	ND	ND	ND	ND	ND	ND
Pentadecane	$C_{15}H_{32}$	ND	ND	ND	ND	ND	ND	ND	30.644	30.644	ND	ND	ND
Total content		**65.531**	**75.338**	**32.673**	**121.774**	**55.932**	**92.235**	**75.217**	**32.901**	**58.211**	**75.332**	**55.788**	**56.057**
Hydrocarbons (6)													
3,5,5-Trimethyl-2-hexene	C_9H_{18}	12.19	ND	ND	ND	ND	ND	12.201	ND	12.219	12.196	ND	12.202
3-Carene	$C_{10}H_{16}$	ND	10.56	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,5Bis(trimethylsilyl)oxy]benzaldehyde	$C_{13}H_{22}O_3Si_2$	ND	17.804	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-Ditertiarybutylbenzene	$C_{14}H_{22}$	21.815	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
D-Limonene	$C_{10}H_{16}$	ND	ND	ND	ND	14.289	ND	ND	ND	ND	ND	ND	ND
γ-Terpinene	$C_{10}H_{16}$	ND	ND	ND	ND	ND	ND	ND	ND	15.475	ND	ND	ND
Total content		**34.005**	**28.364**	**0**	**0**	**14.289**	**0**	**12.201**	**0**	**27.694**	**12.196**	**0**	**12.202**
Carboxylic acids (1)													
Ethylene glycol - Adipate - Diethylene glycol	$C_{10}H_{18}O_6$	34.735	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total content		**34.735**											
Hydrochloride (1)													
Oxymetazoline	$C_{16}H_{24}N_2O$	40.801	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total contents		**40.801**											
Aromatic compounds (12)													
Benzene	C_6H_6	2.903	2.909	2.909	2.926	2.915	ND	2.966	2.909	2.920	2.920	2.914	2.926
Toluene	$C_6H_5CH_3$	4.941	4.941	4.946	ND	4.952	4.975	4.946	4.935	4.957	4.940	4.946	4.952
P-Xylene	$C_6H_4(CH_3)_2$	8.168	8.168	8.179	8.185	8.173	8.168	8.173	8.168	8.179	8.167	8.137	8.181
o-Xylene	$C_6H_4(CH_3)_2$	9.021	9.015	9.034	9.026	9.200	9.028	9.020	9.014	9.026	9.020	9.020	9.020
m-Xylene	$C_6H_4(CH_3)_2$	ND	ND	ND	ND	ND	ND	ND	ND	9.398	ND	ND	ND
p-Cymene	$C_{10}H_{14}$	14.136	14.13	ND	ND	ND	ND	ND	14.130	14.141	ND	ND	14.141
1,4-Cineole	$C_{10}H_{18}O$	13.735	13.781	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ethylbenzene	C_8H_{10}	ND	7.887	7.882	ND	ND	ND	ND	7.899	7.899	ND	7.887	7.893
Hydroxybenzene	C_6H_5OH	ND	ND	12.58	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzeneacetaldehyde	C_8H_8O	ND	ND	ND	ND	ND	ND	ND	ND	ND	14.876	ND	ND
β-Hydroxyethylbenzene	$C_8H_{10}O$	ND	ND	ND	ND	ND	ND	ND	ND	ND	17.586	ND	17.558
Methyl N-hydroxybenzen-ecarboximidoate	$C_8H_9NO_2$	9.661	9.827	ND	ND	ND	9.947	10.073	10.044	9.918	10.010	9.896	ND
Total contents		**62.565**	**70.658**	**45.53**	**20.137**	**25.24**	**32.118**	**35.178**	**57.099**	**66.438**	**67.519**	**42.8**	**64.671**
Aldehydes (8)													
2-Butyl isothiocyanate	C_5H_9NS	ND	2.257	2.257	ND	ND	ND	ND	ND	ND	ND	ND	2.234
Nonanal	$C_9H_{18}O$	ND	17.237	ND	ND	ND	ND	17.243	ND	17.245	17.273	17.243	17.249
Furfural	C_4H_3OCHO	ND	ND	6.926	ND	ND	6.949	ND	ND	6.960	ND	ND	6.949
Benzaldehyde	C_6H_5CHO	ND	ND	ND	11.595	ND	ND	ND	ND	11.612	ND	ND	11.601
Hexanal	$C_6H_{12}O$	ND	5.873	ND	5.884	5.897	ND	5.890	5.885	5.896	5.890	5.885	5.885
.(E)-2-Octenal	$C_8H_{14}O$	ND	ND	ND	12.196	ND	ND	ND	ND	ND	ND	ND	ND
2-Methyl-3-pentanal	$C_6H_{12}O$	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.452	ND	ND
β-Methylbutanal	$C_5H_{10}O$	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.823	ND	ND
Total contents		0	25.367	9.183	29.675	5.897	6.949	23.133	5.885	41.713	29.438	23.128	43.918
Ketones (5)													
2,6-Di-tert-butylbenzoquinone	$C_{14}H_{20}O_2$	29.522	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Compounds name	Formula	Grass carp			Lizardfish			Golden pompano			Threadfin bream		
		RF	FF	SF	RF	FF	SF	RF	FF	SF	RF	FF	SF
Isomenthone	$C_{10}H_{18}O$	19.068	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	19.047
4,6-Heptadiyn-3-one	C_7H_6O	ND	ND	3.63	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acetone	$(CH_3)_2CO$	ND	ND	ND	ND	1.782	1.776	ND	ND	ND	ND	ND	ND
2,3-dimethyl-2-cyclopentenone	$C_7H_{10}O$	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	14.691
Total contents		48.59	0	3.63	0	1.782	1.776	0	0	0	0	0	33.738
Esters (3)													
2-Methylamyl acetate	$C_8H_{16}O_2$	ND	ND	2.537	ND	ND	ND	ND	ND	ND	ND	ND	ND
βNDTerpinyl acetate	$C_{12}H_{20}O$	14.279	14.279	14.285	ND	ND	14.285	14.279	14.279	14.295	14.279	14.285	14.285
Benzyl acetate	$C_9H_{10}O_2$	ND	ND	ND	19.486	19.486	ND	19.486	19.492	19.491	19.491	19.492	ND
Total contents		14.279	14.279	16.822	19.486	19.486	14.285	33.765	33.771	33.786	33.77	33.777	14.285
Others (14)													
Phenol, 2-methoxy	C_7H_8O	ND	ND	16.654	ND	ND	ND	ND	ND	16.653	ND	ND	16.648
1,3-Pentanediol, 2,2,4-trimethyl-, diisobutyrate	$C_{16}H_{30}O_4$	33.556	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Octamethyltetrasiloxane	$[(CH_3)_2SiO]_4$	ND	13.335	ND	ND	ND	ND	13.334	13.335	13.346	13.334	13.346	13.340
2, 6,6-Trimethyl-4 (vinyloxy) bicyclo [3.1.1] hept-2-ene	$C_{20}H_{32}$	ND	15.469	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hexamethylcyclotrisiloxane	$C_6H_{18}O_3Si_3$	ND	16.459	ND	ND	ND	16.648	16.533	16.522	16.476	16.493	ND	ND
Undecyl chloride	$C_{11}H_{19}ClO$	ND	ND	ND	5.083	ND	ND	ND	ND	ND	ND	ND	ND
2-Pentanone, 4-hydroxy-4-methyl-	$C_6H_{12}O_2$	ND	ND	ND	7.269	ND	ND	ND	ND	ND	ND	ND	ND
2',6'-Dihydroxyacetophenone, bis(trimethylsilyl) ether	$C_{14}H_{24}O_3Si_2$	ND	ND	ND	ND	ND	ND	22.015	ND	ND	ND	ND	ND
Digitoxose	$C_6H_{12}O_4$	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.395	ND	ND
Methylene chloride	CH_2Cl_2	ND	ND	ND	ND	ND	ND	ND	1.896	1.908	ND	1.902	1.902
1-(2-Nitro-2-propenyl)-1-cyclohexene	$C_9H_{13}NO_2$	ND	ND	ND	ND	ND	ND	ND	ND	12.894	ND	12.888	12.906
Carbonic acid, hexyl prop-1-en-2-yl ester	$C_{10}H_{18}O_3$	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.60	ND
2-Isopropylpiperazine	$C_7H_{16}N_2$	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.434
Dihydroxydimethylsilane	$C_2H_8O_2Si$	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.807
Total contents		33.556	45.263	16.654	12.352	0	16.648	51.882	31.753	61.277	33.222	30.736	51.037
Total volatile compounds		461.331	324.056	172.699	348.826	122.626	223.987	276.922	169.844	328.478	324.703	221.23	351.666

***RF**: the raw fish; **FF**: fried fish and **SF**: smoked fish*

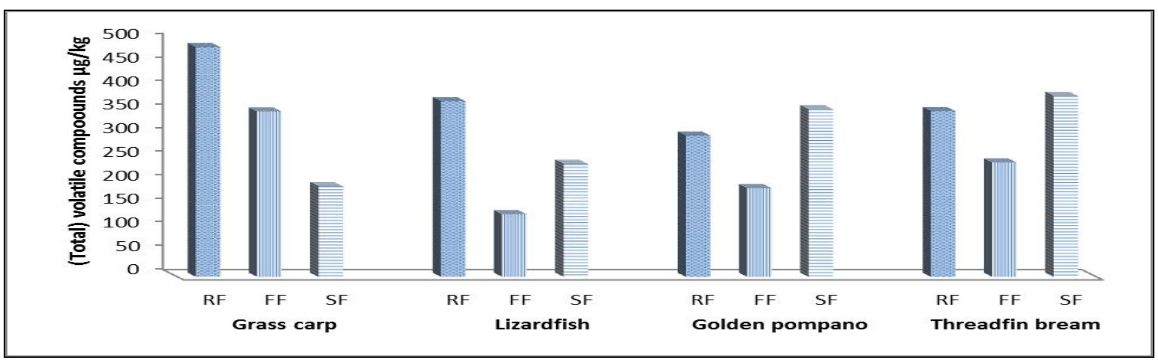

Fig. 1. Total volatile compounds (µg/kg) in fish samples prepared using frying and smoking methods. (RF: the raw fish; FF: fried fish and SF: smoked fish)

Table 3. Effect of smoking and frying methods on the relative content (%) of volatile compounds in fish samples

Volatile compounds	Relative content (%)											
	Grass carp			Lizardfish			Golden pompano			Threadfin bream		
	RF	FF	SF	RF	FF	SF	RF	FF	SF	RF	FF	SF
Alcohols	11.947	19.992	6.679	28.809	0.000	26.777	16.447	4.966	11.982	22.552	15.821	15.715
Phenolics	15.640	0.000	21.235	12.874	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.827
Alkanes	14.205	23.248	18.919	34.910	45.612	41.179	27.162	19.371	17.721	23.200	25.217	15.940
Hydrocarbons	7.371	8.752	0.000	0.000	11.653	0.000	4.406	0.000	8.431	3.756	0.000	3.469
Carboxylic acids	7.529	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hydrochloride	8.844	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aromatic compounds	13.562	21.804	26.364	5.773	20.583	14.339	12.703	33.618	20.226	20.794	19.346	18.389
Aldehydes	0.000	7.827	5.317	8.507	4.809	3.102	8.354	3.465	12.699	9.066	10.454	12.488
Ketones	10.533	0.000	2.102	0.000	1.453	0.793	0.000	0.000	0.000	0.000	0.000	9.593
Esters	3.095	4.406	9.741	5.586	15.891	6.378	12.193	19.884	10.286	10.400	15.268	4.062
Others	7.274	13.967	9.643	3.541	0.000	7.433	18.735	18.695	18.655	10.232	13.893	14.512

***RF**: the raw fish; **FF**: fried fish and **SF**: smoked fish*

Alkanes had the highest relative contents in all fried samples except fried golden pompano. Fried and smoked lizard fish had the highest relative contents in all samples with 45.612 and 41.179, respectively. The free unsaturated fatty acids are readily oxidized to lipid hydroperoxides, which are unstable and readily disintegrate into secondary oxidation volatile chemicals, including aldehydes, alcohols, ketones, furans, alkanes, and alkenes **(Frankel, 2005)**. The findings of the impact of cooking techniques on hydrocarbons were unclear; raw grass carp had the highest hydrocarbon content at 34.005 µg/kg, whereas the fried lizardfish had the highest relative content (11.653%). Hydrocarbon levels in fried grass carp decreased to 28.364, compared to 34.005µg/ kg in raw samples, while the lizardfish and golden pompano were detected exclusively in fried samples (Table 3). In threadfin bream, they were found in raw and smoked samples. The hydrocarbons are mainly derived from the oxidation and degradation of fatty acids in meat products, which are catalyzed by iron in hemoglobin or myoglobin **(Ramírez & Cava, 2007)**.

The highest relative concentrations of aromatic compounds were identified in smoked samples of grass carp, threadfin bream, and fried and smoked golden pompano, with values of 26.364, 18.389, and 33.618, 20.226%, respectively. Esters develop from the esterification of alcohols and carboxylic acids, providing pleasant and characteristic fruity aromas **(Ramírez & Cava, 2007)**.

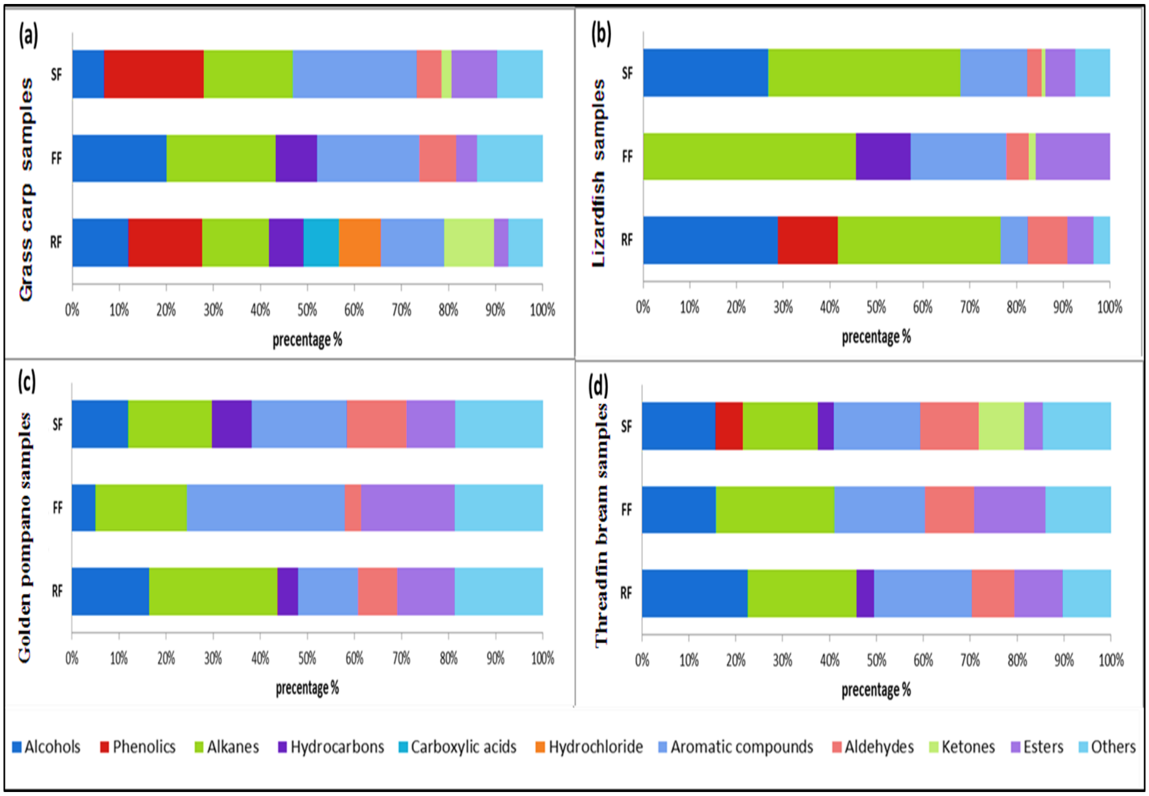

Fig. 2a, b, c and d. The percentages of volatile compounds in grass carp, lizardfish, golden pompano, and threadfin bream samples prepared using frying and smoking methods (**RF:** the raw fish; **FF:** fried fish and **SF:** smoked fish).

In this study, only two esters were detected, benzyl acetate and βND Terpinyl acetate. Frying and smoking methods altered the volatile flavor compounds profiles of the grass carp, golden pompano, threadfin bream, and brushtooth lizardfish. Cooking methods had varying impacts on alcohols, aldehydes, and ketones in cooked fish. During high-temperature ripening, these compounds will be destroyed, but numerous new compounds will be formed. The Maillard reaction, the interaction of amino acids or proteins with oxidized lipids, and the breakdown of long-chain molecules during heating can all contribute to this series of alterations **(Xun *et al*., 2020)**. As a result, the flavors of fish prepared using various cooking methods vary due to the accumulated effect of several volatile flavor compounds with varying characteristics.

CONCLUSION

In conclusion, GC-MS, was used to analyze effect of frying and smoking methods on the of volatile flavor compounds contents in the grass carp, golden pompano, threadfin bream, and brushtooth lizardfish. Smoked golden pompano and threadfin bream samples had the highest values (328.478 and 351.666μg/ kg) compared to fried and raw samples, while raw grass carp and lizardfish samples had the highest total amount of volatile compounds (461.331 and 348.826µg/ kg) compared to other cooked samples. It was also concluded that alterations in volatile compounds influenced by smoking and frying processes did not exhibit uniformity in direction.

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