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Volatiles of canned tuna fish and the effects of different parameters: A Review

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Abstract

Tuna is one of the most important commercial fish species due to its economical and high nutritional values. There are many species of fish, which are eaten raw, used in home-cooked dishes and subject to various industrial activities, such as canning. The overall quality of fish and fishery products has become a major concern in fish industry in the world. Tuna processing methods mainly consist of freezing, cooking, smoking and canning after heat treatment like sterilization. The species used for canning are mainly yellowfin, skipjack and albacore tuna. The volatile components of tuna vary depending on the processing method. Different temperature conditions applied in canning productions significantly affect the volatile profiles. The aroma is one of the main indicators on which consumers judge the fish's freshness. Fish flavour quality is changing rapidly according to the freshness of the product, and therefore, sensorial evaluation of the flavouring is used by consumers, researchers and the fishing industry as a whole to evaluate the quality of fish. Each species of fish has a tender and distinctive aroma, which can be influenced by processing technology, post production and storage methods. Volatile compounds derived from lipid are produced mainly by oxidative-enzymatic reactions and auto oxidation of lipids. Oxidation derived volatiles play crucial roles in the formation of overall fish aroma providing them a specific aroma character. Therefore, this review highlights the impact of various parameters on volatiles of canned tuna.

Keywords: *aroma, canned tuna, cooking, freezing, smoking*

1.INTRODUCTION

Tuna is one of the most commercial fish species, due to its excellent economic and nutritional benefits. It can be consumed raw, evaluated under culinary or even industrial processes such as canning. The main processing methods for tuna are freezing, cooking, smoking and canning after being thermally processed (Miao et al., 2017). Generally, the species used for canning are yellowfin, skipjack and albacore tuna (Zhang et al., 2019). Tuna is one of the most widely consumed fish in terms of international seafood production (8%) and is sold commercially all over the world (4.3 million tonnes) (Kumar & Kocour, 2015). Tuna has a lot of differences compared to other fish in terms of growth rate, size, lifespan, maturity age and spawning period. Species which are restricted to tropical and sub-tropical areas (skipjack and yellowfin tuna) are distinguished by their small to medium size, quick growth, and early ripening. The bluefin tuna, instead, shows the characteristics of a highly variable life with a longer spawning period and a shorter lifetime compared to other tuna species (Fromentin and Fonteneau, 2001).

Skipjack tuna has a black and purplish blue upper part and 4 to 6 stripes on the abdomen. Their body shapes are longitudinally round. While these fish prefer waters with a temperature about 25°C during their larval stage, they deserve to live in water at a temperature around 15°C when they reach the growth stage. The depth distribution ranges from about 260 meters from the surface during the day, they live near surface waters. The skipjack spawns all year long in subtropical waters, but it gets shorter and further away from the equator. Female skipjack tuna with a fork length of 41 to 87 cm can lay anywhere between 80,000 and 2 million eggs (FAO, 2020a).

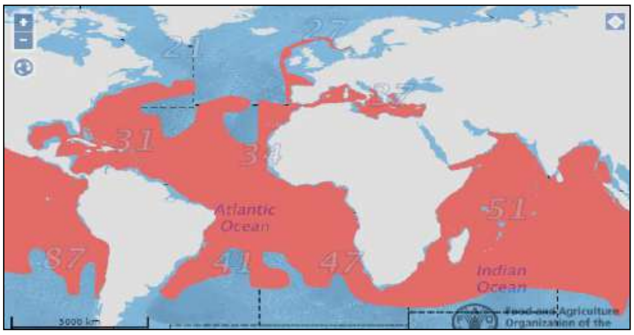

Figure 1: Habitats of Skipjack Tuna (FAO, 2020a)

As important commercial species, In 2018, the primary target of purse seine fishing in the Eastern Pacific Ocean was *Katsuwonus pelamis* with 289,000 tons (IATTC 2019). In China, large quantities of fish by-products are produced during processing of canned tuna production, including flakes, skin, heads, and viscera, and compounds such as collagens, gelatines, and bioactive peptides are obtained from these bones, heads, and black muscles (Yang et al., 2019; Liu et al., 2015; Chi et al., 2015).

Yellowfin tuna is the second tuna species mostly consumed worldwide and responsible for 27% of the total world catch (ISSF, 2015). Yellowfin tuna reached a maximum length of 208 cm and a maximum weight of 176.4 kg. The black and dark blue color and the silver colored belly characterize the Yellowfin tuna. Anal and dorsal fins are light yellow in color. These fish usually feed on fish, squid and crustaceans. Although their breeding season is known as summer, they actually multiply all year long (FAO, 2020b).

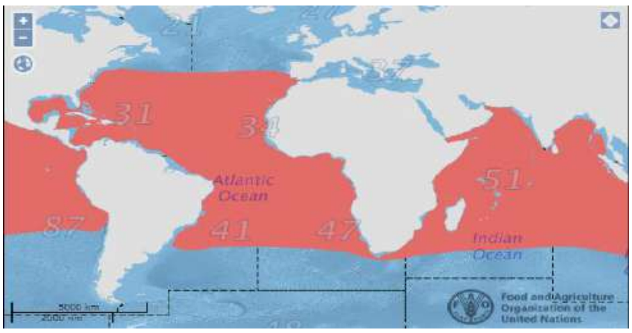

Figure 2: Habitats of Yellowfin Tuna (FAO, 2020b)

Seafood is nutritionally rich in protein, omega-3 fatty acids, unsaturated fatty acids, vitamins, micro and macronutrients, and their consumption by humans is increasing worldwide (Pieniak et al., 2010). Fish consumption reduces chronic non-communicable diseases such as cardiovascular disease, mental disorders, rheumatoid arthritis, as well as several cancers, and promotes normal neuronal development in children (Di Giuseppe et al., 2014; Swanson et al., 2012; Virtanen et al., 2008). Moreover, the consumption of omega-3 fatty acid has proved its role in preventing irregular heart rhythms, controlling rheumatoid arthritis and suppressing breast cancer (Geusens et al., 1994; Belch and Muir, 1998; Nair et al., 1997; Rose and Connolly, 1990 Rose, 1997). Omega-3 fatty acids such as eicosapentaenoic acid (EPA; 20: 5n-3) and docosahexaenoic acid (DHA; 22: 6n-3) have major health benefits: for brain and retina development and the prevention of coronary artery disease (Swanson et al., 2012; FAO / WHO, 2010). Omega-3 fatty acids that cannot be synthesized in the body are recommended to be taken from diets and food (Plourde and Cunnane, 2007).

In this review, the effects of different processing parameters (such as production techniques, temperature, drying, cooking, smoking and freezing) on the aroma compounds of canned tuna have been compiled, since no such study has been conducted in the literature before.

2. VOLATILES OF CANNED TUNA

The canning process is one of the most important methods of preserving fish for a long time. Canned fish and fish products play a crucial role in human diet. Fish species possess different nutrient compositions and they become stable when the fish is subjected to thermal treatments during canning process. According to a report, lean fish is not recommended in the canning process, since the meat breaks down under high temperatures, thereby losing both its taste and texture (Aberoumand, 2014). The aroma changes during the canning process depending on compounds derived from lipid oxidation and thermal degradation of carbohydrates, or the compounds originating from other reactions such as Strecker degradation and the Maillard reaction. The principal changes occur due to sterilization during the canning process which results in the release of furans, nitrogenous compounds, branched aldehydes and sulphur compounds (De Quirós et al., 2001). The canning process improves the organoleptic properties of fish obtained from canned silver. Canned smokes as well as minced fish from cans possess a marked increase of taste and color. The overall acceptance is gradually declines in all groups of canned fish (Khallaf et al., 1997). In the canning process, both enzymes and bacteria population should be permanently inactivated by heat treatments and when no re-infection or negative interaction takes place with the container, heat-processed fish can be kept for a very long time. On the other hand, a number of adverse effects also exist in the canning process, such as, loss of essential nutrients, release of unwanted compounds, browning, deterioration of lipids and proteins (Lukoshkina and Odoeva, 2003).

Temperature, used in seafood processing, has an enormous influence on the type and quantities of aroma and aroma-active compounds (Moreira et al., 2013). A number of studies have been conducted to aroma and aroma-active compounds from various cooked fish and other types of marine products (Milo et, al., 1993; Tao et al., 2014). Volatile compounds produced by oxidation during heat treatments of fish have been identified in several reports (Medina et al. 1999). De Quirós et al. (2001), identified the volatile compounds present in fresh and preserved sea urchins (*Paracentrotus lividus, Lamarck*) and reported that the sterilization process gave rise to significant changes in the profile of volatile compounds.

2.1. The effect of different production techniques on volatile composition of fish

2.1.1. Effect of drying

Drying is known to be a crucial parameters to prolong the shelf-life of fresh fish and other fishery products. It is possible for fishes to be maintained by solar drying, which focuses on reducing the water content to reduce or stop the activity of microorganisms (Farid et al. 2014). By long exposure to sunlight, fish may be oxidized, which can contribute to a reduction in nutrient quality and to increased health risks for consumers (Smida et al. 2014). Apart from health risk and nutritional loss, organoleptic character (such as aroma, color, texture etc.) of fish affects substantially from drying conditions. Aroma normally characterises foods sensory properties, and plays an important role when evaluating nutritional qualities and freshness (Diez-Simon et al., 2019; Dominguez et al., 2019). Previous studies have proven that most volatile compounds in dried meat products originate from fat oxidation (Kawai & Sakaguchi, 1996; Toldrá, 1998; Chung et al., 2007; Czerner et al., 2011). Furthermore, most of these substances are unstable and may undergo further reactions during storage in order to form other stable substances and chemical reactions intermediated by enzymes and micro-organisms continue to produce adverse volatile substances which effect the quality and limit the shelf life of the products (Jia et al., 2019; Shi et al., 2019). So far, most studies have focused on aroma changes during dried fish processing or storage (Ganguly et al., 2017; Leduc et al., 2012; Roseiro et al., 2017). In a recent study, Zhang et al. (2020) focused on the alterations of volatile compounds in dried fish at 4°C and 25°C during storage were investigated by HS-GC-IMS fingerprinting in combination with principal component analysis (PCA). In the 4°C stored samples, the most important volatile compounds were 3-methyl butanal, dimethyl ketone, and hexanal; whereas hexanal, 1-octan-3-ol, and 3-methyl butanal were the dominant compounds of dry cured fish stored at 25°C while butyl methyl ketone was only seen at 25°C. According to results of this study, the PCA differentiated the samples clearly with respect to their storage temperature and time. Moretti et al. (2017) studied the chemical changes and volatile formation during processing and maturation of a traditional salted fresh inland fish product (*Alosa fallax lacustris*). The researchers observed a sharp increase in volatile compounds of fresh fish to 9, 40, 70 and 100 days maturated and salted samples and the total aroma concentrations were showed a positive correlation with the drying process. In the light of these information, the process of drying is probably the critical stage of the quality of fish and fishery products, assisted by the fact that there are higher levels of volatile substances and malondialdehyde associated with rapid oxidation.

2.1.2. Effect of cooking

There are a number of uses of heating in fish processing, including cooking, baking, grilling, and roasting (Boonsumrej et al., 2007). Heat is an important parameter in the processing of fish for the purpose of improving flavour and taste, and to extend the shelf-life of fish and seafood products. Tuna flavour varies greatly depending upon the processing method used. Although quality features are very important for the economic value of tuna, there is very little information about the volatile and non-volatile compounds in tuna meat over the canning process (Zhang et al., 2019). It is well known that the heating process leads to changes in the complex taste patterns of fish meat. It is estimated that these changes are caused by proteolytic and lipolytic reactions. The changing aroma profile correlates with the taste changes that have been observed after exposure to heat in tuna meat. Various studies have been carried out on the quality characteristics of species of fish affected by heat treatment.

An earlier study characterized the volatile composition of boiled and steamed red mullet (*Mullus barbatus*) (Salum et al., 2017). According to results, hexanal and 2-phenoxyethanol compounds were found in raw fish samples while 3-hydroxybutan-2-one, 2,3-octadienone, (E,E)-2,4-heptadienal, linalool, γ-butyrolactone, 1-methylpyrrolidin-2-one, 2H-furan-5-one and pyrrolidin-2-one were detected in cooked fish samples. Another research focused on the effects of different cooking practices to characterize lipid compositions and volatile profiles of farmed and wild sea bass (*Dicentrarchus labrax*) (Nieva-Echevarría et al., 2018). According to results, pyrroles, alkylpyrazines, alkylthiophenes and 2-ethylpyridine compounds were detected only in oven-baked samples. In addition, it was determined that farmed sea bass had richer aromatic compounds than wild samples.

Similarly, in the study of Zhang et al. (2019), the effect of the two major tuna-fish canning operations (steam boiling and canning) on the volatile and non-volatile compounds of tuna was determined. Regarding to the result of the study, 35, 35 and 34 volatile compound have been detected in raw, cooked, and canned tuna patterns respectively. Among these volatiles hydrocarbons and aldehydes have been identified as the most common compounds in all processes. The main contributors to raw tuna flavors were found to be decanal, nonanal, octanal, and *(E)*-2-nonenal, with their green and fatty properties. Another remarkable finding of this study was the release of 2-pentylfuran (green beans), 2-ethylfuran (rubber, baking) and heptanal (dry fish) during the steam cooking process. Moreover, 2-methyl-3-furanthiol, which contains a fleshy aromatic note also known as an important aromatherapy component, only found in canned tuna (Zhang et al., 2019). Another published study focused on the relationship between the composition of volatile compounds in the bigeye tuna (*Thunnus obesus*) and the variability through processing temperatures. In this study, Sun et al. (2013) examined the volatile compounds of tuna fish by means of HS-SPME-GC-MS" before and after exposure to temperatures of 70°C to 150°C. Researches mentioned that the relative amount of aldehydes, ketones, alcohols, hydrocarbons and heterocyclic compounds increased rapidly with increasing heating temperature. In another study, the oxidation of fish under thermal processing has been investigated using a static head-space gas chromatographic system to determine their volatile production.

Various process temperatures and periods have been analysed to simulate the conditions in industrial fish treatment. According to results, acetaldehyde, propanal, heptane, 2-ethylfuran, pentanal and hexanal were the most important volatile compounds. The results showed that 2-ethylfurane can be considered as a marker aroma compound to identify the oxidative stability of fish muscle during heat treatments (Medina et al., 1999).

2.1.3. Effect of smoking

Heat treatments decrease the water activity of fish flesh and this provides an excellent preservation via deactivation of microbial organisms. Thus, minimization of spoilage increases the conservation and so availability of fish for consumers. The smoking is also known as a kind of preservation method providing heat and antimicrobial smoke chemicals such as formaldehydes and phenols, which act as antimicroorganisms providing and opportunity for the fish to produce a unique colour and excellent flavour (Longwe & Kapute, 2016). Changes that arise from the smoking of fish are hard to maintain, especially for heat sensitive nutrient (Adenike, 2014). The smoking does not only give food a particular taste, color and flavor, but also improves its conservation due to the dehydrating, bactericidal and antioxidant properties. The smoking technique is commonly applying to fish as either in cold (28-32°C) or hot (70-80°C) conditions (Alasalvar et al., 2011).

Salmon is the most common fish subjected to smoking process in the fish industry. Many aromatic compounds of smoked salmon can be traced back to smoke from wood. A further part of the smoked salmon flavour can either be attributed to the combination of odors of raw fish and an evolution of fish flesh flavoring according to the conditions of the smoking process. In an earlier study the volatile compounds in raw and smoked salmon were studied using two gas chromatography-olfactometry (frequency detection and odorant intensity) and gas chromatography mass spectrometry. For fresh salmon, 49 odorous compounds were identified, and 74 for smoked salmon. In particular, phenolic compounds may be used as indicators of smoke development and process intensity. Once smoked salmon aromatic characteristics and their origin are known, it will become easier to adapt the method of smoking (Varlet, et al., 2006). In another study, Mansur et al. (2002) detected that smoked and baked salmon had twice as many volatile compounds as raw salmon. Among all the processes, smoking is considered the highest aroma components followed by baking, canning, surimi samples (kamaboko and chikuwa), drying and finally salting. In another study, Cardinal et al. (2006) investigated the association between odor characteristics and smoking parameters on smoked herring. The impact of three smoking temperatures (16, 24 and 32 °C) on both traditional as well as liquid smoke atomization has been tested. The findings highlight clear discrimination between products, as some of the odor characteristics are particularly related to smoking. A further study aimed to determine that volatile compounds in cold-smoked salmon products is identified by using gas chromatography in order to determine their suitability for the identification of these compounds quickly as indicators to forecast sensory quality. Smoked salmon odor contributed to guaiacol, cooked potato, and mushroom odors characteristic of degradation of fish fats, and sweet odors associated with the microbial metabolites 3-methylbutanal and 3-hydroxybutanone were the strongest odors. Studies show that smoke-related compounds like furfural, phenol, guaiacol and 4-methyl guaiacol are useful indicators for differentiating between products made by different manufacturers that implement different handling and smoking techniques (Jónsdóttir et al., 2008). In another study, Stołyhwo et al. (2006) showed that the typical smoke taste was largely linked with the phenolic compounds in the smoke. Wood smoking compounds that are most active in traditional smoking are pyrogallol, resorcine, 4-

methylguaiacol, and less active are syringol and guaiacol.

2.1.4. Effect of freezing

Freezing is one of the commonly used preservation methods in fresh fish and other seafood. If fish are freezing, however, the result may be physical, chemical and enzymatic changes which ultimately lead to the tissue being in an undesirable state (Magnusse et al., 2008). Texture, flavour and color are some of the effects on quality that are present in frozen foods. Freezing rates, methods of thawing, and different temperatures are some of the factors affecting the magnitude of quality loss (Pourshamsian et al., 2012). The effect that freezing and thawing have on the muscles of frozen fish is a matter for the researchers to consider in order to determine the preservation conditions and textural characteristics of fish products (Díaz-Tenorio et al., 2007). The processing of frozen fish might result in a protein deformity. As soon as protein is denatured, the muscle structure, water holding capacity, color and aroma of frozen fish and fish products are affected, because muscle protein is the main factor for its structural properties (Sriket et al., 2007; Chavan et al., 2008). The freezing of fish results in the loss of important characteristics of quality, with increasing toughness and the formation of large ice crystals. Fish size, shape, and location (extra-cellular or intracellular) are known to have an influence on food quality (Mackie, 1993; Howgate, 1977).

Biochemical modifications (mainly in lipids) due to frozen storage are likely to have a significant impact on the sensory properties of fish. In salmon the formation of volatile lipid oxidation products is demonstrated during deep-freeze storage, and free fatty acids derived from lipid hydrolysis are more important for the decay during deep-freeze storage of trout when compared to lipid oxidation (Milo & Grosch, 1996; Refsgaard et al., 1998; Ingemansson et al., 1995). According to study of Iglesias et al. (2009), volatile profile of fresh and frozen-thawed from Italian and Spanish cultured gilthead sea bream fish during 266 days of deep freeze storage were investigated by using SPME-GC-MS methodology. The results showed that aldehydes exhibited the highest peak ranges during deep refrigeration. On the other hand, the volatile composition of Italian fish started to increase after just 6 days of refrigeration. However, after 62 days of frozen storage, the first significant increase in volatility was observed in Spanish samples. In a prior study by Refsgaard et al. (1998) reported that the quantities of free fatty acids and lipid hydroperoxides present in fresh salmon could be used to forecast the sensory quality during the storage process. According to the study of Milo & Grosch (1996), the amount of *(E,Z)* -2.6-nonaddienal, *(Z)* -3-hexenal, and *(Z,Z)* -3, 6-nodienal compounds increased as a result of storage of salmon at -13°C for 26 weeks. Similar study by Farmer et al. (1997) showed that there has been no significant change in salmon smell or taste stored at -24°C for 33 weeks. In another research by Refsgaard et al. (1998)reported that not only volatile oxidation products account for significant sensory changes during deep-freeze storage of salmon, but other less volatile compounds could also contribute to the increased intensity of off-flavor compounds. In the previous study, Alasalvar et al. (2005) investigated that bream and wild bream were compared for differences in their volatile components a storage period of 23 days in the ice. According to results, a total of 60 volatile compounds have been identified in culture and 78 in wild sea bream. During the whole storage period, the relative concentrations of several compounds (trimethylamine, piperidine, methanethiol, dimethyldisulfide, dimethyl trisulfide, 1-penten-3-ol, 3-methyl-1-butanol and acetic acid) keep increasing and can serve as indicators as to the quality of the bream. The effects of different processes applied to various types of fish found in volatile compounds are depicted in Table 1.

Table 1.Effect of different processing methods on volatile composition of the fish species

No	type of fish	main volatile compounds	dominant group	processed of dominant group (µg/100 g) raw	cooked	canned	ref.[1]
1	Yellowfin Tuna	pentadecane	hydrocarbons	104	436.72	780	Zhang and Dai, (2019)
		pentadecane, 2,6,10,14-tetramethyl-	hydrocarbons	102	159.54	295	
		heptadecane	hydrocarbons	42.37	64.45	121	
		nonanal	aldehyde	74.5	17.53	20.47	
		octanal	aldehyde	39.02	17.42	37.63	

No	type of fish	main volatile compounds	dominant group	processed of dominant group (%) raw	100°C	150°C	ref.
2	Bigeye Tuna	2,4-Pentadienal	aldehyde	31.74	11.95	-	Sun et al., (2013)
		nonanal	aldehyde	5.79	15.44	-	
		octanal	aldehyde	5.63	9.63	-	
		heptanal	aldehyde	4.88	6.14	0.03	
		2-methyl-3-octanone	ketone	5.8	-	-	

No	type of fish	main volatile compounds	dominant group	processed of dominant group (ng/25 g) Salmon 4[2] control	high Cys	high Met	Salmon 5[3] control	low Cys	high Cys	low Met	ref.
3	Salmon	trimethylamine	amine	263	274	277	4	5	3	3	Methven et al., (2007)
		1-octen-3-ol	unsaturated alcohols	87	97	118	54	47	44	44	
		4-heptenal	unsaturated alcohols	132	112	212	53	51	31	49	
		2,4-heptadienal	unsaturated alcohols	87	104	123	45	59	63	52	
		1-penten-3-ol	unsaturated alcohols	23	29	28	225	184	167	150	
		1-pentanol	alcohol	342	487	462	107	54	63	54	
		hexanal	aldehydes	411	486	513	456	352	279	320	
		heptanal	aldehydes	258	336	323	130	91	94	96	
		nonanal	aldehydes	172	192	182	120	105	101	101	
		4-heptenal (Z)	unsaturated aldehyde	132	112	212	53	51	31	49	
		2-butanone	ketone	269	150	275	27	22	33	7	
		2-ethylfuran	furan	274	250	249	241	170	278	258	

[1]ref: Reference. [2]Salmon 4 was a salmon fillet to which water (control), 50 mg/100 g cysteine (high Cys), or 50 mg/100 g methionine (high Met) was added prior to cooking. [3]Salmon 5 was a salmon fillet to which water (control), 5 mg/100 g cysteine (low Cys), 50 mg/100 g cysteine (high Cys), or 5 mg/100 g methionine (low Met) was added prior to cooking.

	type of fish	main volatile compounds	dominant group	Storage time (week) 0	1	2	3	4	ref.
				concentration (ng/g)					
4	Albacore	benzaldehyde	aldehyde	12380	12200	13240	14180	7950	Kim et al., (1992)
		1,4-dimethyl benzene	aromatic hydrocarbon	4850	2960	3103	4130	-	
		1-penten-3-ol	unsaturated alcohol	1760	240	1527	2680	20	
		pentadecane	hydrocarbon	890	1420	1520	830	2700	
		pyridine	N-containing compound	840	310	427	730	40	
		dodecane	hydrocarbon	720	330	420	550	250	

	type of fish	main volatile compounds	dominant group	concentration (mg/kg for STV, mg/L for TS) STV	TS	ref.
5	Skipjack Tuna	3-methylbutanal	aldehyde	140	1395	Cha et al., (1998)
		2-methylpropanal	aldehyde	ND	182	
		2,3-butanedione	ketone	ND	274	
		(E,E)-2,4-heptadienal	aldehyde	41	6	
		2,3,5-trimethylpyrazine	pyrazine	ND	37	

STV: skipjack tuna (*Katsuwonus pelamis*) viscera. TS: tuna sauce

	type of fish	main volatile compounds	dominant group	volatile compounds associated with spoilage in seven grades of tuna and mahi-mahi calculated by internal standard, (ng/g) fish sample T1	T2	T3	T4	T5	T6	T7	ref.
6	Yellowfin Tuna	trimethylamine	amine	12390	16470	15260	23730	36180	28890	33620	Bai et al., (2019)
		dimethylamine	amine	3988	2133	3201	5729	8209	1768	4141	
		acetone	ketone	1389	2839	1399	1902	1268	700	2619	
		tert-butanol	alcohol	646.7	467.6	650	534.4	686.1	559.4	566.1	
		2-ethylhexanol	alcohol	53.73	71.76	53.65	50.11	52.34	52.63	31.47	
	type of fish	**main volatile compounds**	**dominant group**	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	
	Mahi-mahi	trimethylamine	amine	14800	18020	14830	14800	138100	119700	243000	
		dimethylamine	amine	ND	4086	5277	ND	26410	23500	33850	
		methanol	alcohol	1696	2942	2532	3365	1305	1296	1093	
		tert-butanol	alcohol	1045	1129	1003	1014	994.5	996.2	888.9	
		acetone	ketone	206.8	231.8	884.7	1038	907	1011	764.9	

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type of fish	main volatile compounds	dominant group	concentration (mg/kg) group A (dry-cured for 1 day) YDJ	NGW	TS	group B (dry-cured for 5 day) ML	YZD	HWW	ref.
Dry-cured Spanish Mackerel	3-methyl-1-butanal	aldehyde	28.43	24.37	23.99	288.97	294.40	280.28	Wu et al., (2021)
	octanal	aldehyde	88.22	90.69	82.76	242.18	252.45	268.90	
	1-octen-3-ol	alcohol	66.19	53.35	49.64	191.53	176.50	167.75	
	nonanal	aldehyde	116.03	111.06	103.88	150.83	163.53	139.23	
	cis-4-decenal	aldehyde	95.42	98.51	90.89	123.29	129.01	137.10	
	1-heptanol	alcohol	3.25	3.69	2.80	66.78	83.22	77.44	
	3-octanone	ketone	17.05	18.76	16.03	186.58	228.88	173.96	

YDJ (5% sodium chloride, 1 d drying), NGW (5% sodium chloride, 1 d drying), TS (5% sodium chloride, 1 d drying), ML (5% sodium chloride, 5 d drying), YZD (5% sodium chloride, 5 d drying), HWW (5% sodium chloride, 5 d drying)

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type of fish	main volatile compounds	dominant group	the relative levels volatiles of tuna during storage at 30°C/hour 0	12	24	36	48	the relative levels of tuna volatiles during storage in ice/day 0	4	8	12	16	20	ref.
Yellowfin Tuna	hexanal	aldehyde	30.90	21.47	2.18	0.17	0.33	30.90	8.85	5.83	2.14	1.44	1.31	Edirisinghe et al., (2007)
	heptanal	aldehyde	5.99	4.48	0.63	2.00	1.88	5.99	3.5	2.10	0.33	tr	tr	
	3-methyl-1-butanol	alcohol	ND	0.32	13.52	46.5	57.82	ND	34.64	47.09	53.34	59.71	62.73	
	2-nonanone	ketone	28.37	11.15	2.45	tr	ND	28.37	5.54	0.08	tr	tr	tr	

Values are means of five independent determinations (n = 5); tr, trace amounts; ND, not detected. These values do not total to 100 as minor volatiles are not reported.

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type of fish	main volatile compounds	dominant group	percentage area (%) raw	precooked	150 MPa	300 MPa	450 MPa	600 MPa	ref.
Skipjack Tuna	hexanal	aldehyde	19.2	13.9	19,8	17.4	16.5	10.3	Jiranuntakul et al., (2018)
	1-octen- 3-ol	alcohol	8.7	5.7	9.5	7.6	7.4	5.1	

	type of fish	main volatile compounds	dominant group	unwashed sample peak area (%)	washed sample (3% maltodextrin, 30 min) peak area (%)	ref.
10	Skipjack Tuna	(E,E)-2,4- Heptadienal	aldehyde	8010	6928	Junsi et al., (2012)
		Heptanal	aldehyde	4340	1055	
		2-Octenal	aldehyde	2017	ND	
		2-Pentylfuran	furan	4793	1428	
		3,5-Octazdien-2-one	ketone	4236	ND	

ND = not detected

	type of fish	main volatile compounds	dominant group	peak area of each compounds using selected fragment ion 0	1	2	3	4	5	6	7	8[a]	ref.
11	Bonito	propanal	aldehyde	1220	279	95.7	36.8	43.4	252	54.7	34.4	702	Ishiguro et al., (2001)
		acetone	ketone	65.7	58.3	80.8	97.2	79.8	200	168	132	404	
		ethanol	alcohol	2.48	52.3	149	318	185	2900	2121	1070	2770	
		1-penten-3-ol	alcohol	661	433	198	195	194	703	350	182	523	
		2-ethylfuran	furan	167	103	218	144	160	258	282	302	399	

[a]times of smoking (hour)

	type of fish	main volatile compounds	dominant group	changes in volatile of dried Bonito during storage at 30°C ratio of peak area 0	1	3	5	7 days	ref.
12	Powdered Dried Bonito (*Katsuobushi*)	(2E)-hexenal	aldehyde	0.06	0.21	0.25	0.27	0.28	Sakakibara et al., (1988)
		1-penten-3-ol	alcohol	0.13	0.32	0.34	0.36	0.39	
		hexadecanoic acid	acid	3.76	5.02	4.81	2.93	2.95	
		tetradecanoic acid	acid	1.02	1.47	1.52	1.53	1.42	

	type of fish	main volatile compounds	dominant group	0	1	2	3	4	ref.
				the mean value (*n* = 3) of the log 10 transformed peak areas for samples after ice storage; storage time (day)					
13	Jack Mackerel	hexanal	aldehyde	2.9	4.1	5.1	5.7	5.6	Miyasaki et al., (2011)
		4-heptenal	aldehyde	ND	3.2	3.9	4.2	4.4	
		2,4-hexadienal	aldehyde	ND	3.3	3.3	3.7	3.6	
		2,4-heptadienal	aldehyde	ND	3.9	4.5	4.6	4.5	
		octanal	aldehyde	2.9	2.8	3.8	4.0	4.0	
		trimethylamine	amine	ND	ND	4.2	4.7	5.5	
	Skipjack Tuna	hexanal	aldehyde	3.1	3.6	3.7	4.0	just 3 days were preferred	
		4-heptenal	aldehyde	ND	ND	ND	2.8		
		2,4-hexadienal	aldehyde	ND	ND	ND	ND		
		2,4-heptadienal	aldehyde	2.8	3.0	3.2	3.3		
		octanal	aldehyde	2.8	2.8	2.8	3.0		
		trimethylamine	amine	ND	ND	ND	4.9		

ND = not detected

	type of fish	main volatile compounds	dominant group	0	1	2	3	4	0	1	2	3	4	ref.
				peak areas of volatiles produced after incubation of fish muscle at 40 and 60°C										
				at 40°C for days					**at 60°C for days**					
14	Canned Tuna (not specified)	acetaldehyde	aldehyde	321	1125	4405	5561	6779	390	4618	6812	8124	8829	Medina et al., (1999)
		propanal	aldehyde	387	2041	3778	3848	4480	493	5706	7328	10447	12706	
		heptane	aliphatic hydrocarbons	0	0	208	938	1562	0	325	359	428	545	
		pentanal	aldehyde	0	101	340	584	987	0	277	482	916	1357	
		hexanal	aldehyde	0	0	22	75	186	0	60	148	293	442	
		2-ethylfuran	furan	0	0	32	69	136	0	975	4210	12234	23427	

15	**concentration (µg of dodecane / 100 g salmon)**

type of fish	main volatile compounds	dominant group	unsmoked salmon	smoked salmon	ref.
Salmon	8-heptadecene	hydrocarbon	23.96	9.91	Varlet, et al., (2006)
	hexadecanal	aldehyde	18.74	34.82	
	tetradecanoic acid	acid	5.83	-	
	nonanal	aldehyde	5.09	344.98	
	octanal	aldehyde	2.23	-	
	heptanal	aldehyde	2.13	1.32	

Each concentration is the mean of three aromatic extracts injected corresponding to three individual fillets smoked at 32 °C.

				chemical constituents (peak area %) of canned salmon produced from watermarked pink salmon										
				degree of watermarking after 2 month of storage					degree of watermarking after 9 month of storage					
	type of fish	main volatile compounds	dominant group	A	BC	DE	FG	I	A	BC	DE	FG	I	ref.
16	Pink Salmon *(Oncorhynchus gorbuscha)*	dimethyl sulfide	sulfur compound	41.21	37.88	22.55	16.77	45.86	50.29	51.65	26.14	21.38	57.60	Oliveira et al., (2005)
		acetaldehyde	aldehyde	4.06	5.95	7.56	7.19	6.18	4.27	4.95	7.86	7.9	5.28	
		acetone	ketone	5.69	8.40	9.22	7.38	6.89	7.45	8.37	12.07	13.58	8.18	

I = Commercial canned pink salmon

				relative content (%) of individual VOCs detected in salt cured and dried Indian mackerel					
	type of fish	main volatile compounds	dominant group	SCF[a]	SCDF1D	SCDF2D	SCDF3D	SCDF4D	ref.
17	Indian Mackerel	hexanal	aldehyde	ND[b]	29.68	47.80	47.80	1.31	Bhaskaran et al., (2018)
		1-penten-3ol	alcohol	40.30	63.69	45.91	2.32	1.17	
		3-methyl butanol	alcohol	39.24	ND	ND	ND	ND	

[a]SCF: s salt cured fish without drying. SCDF1D: salt cured and 1 day dried fish. SCDF2D: salt cured and 2 day dried fish. SCDF3D: salt cured and 3 day dried fish. SCDF4D: salt cured and 4 day dried fish. [b]ND = not detected.

				peak areas as x 10^5		
	type of fish	main volatile compounds	dominant group	Smoked	baked	ref.
18	Salmon	1-penten-3-ol	alcohol	641	-	Mansur et al., (2002)
		3-methyl-butanal	aldehyde	449	256	
		hexanal	aldehyde	388	579	

acetic acid, anhydride	acid	326	789	
heptanal	aldehyde	213	524	

	type of fish	main volatile compounds	dominant group	the content of volatile stored raw fillets at 4°C					ref.
				0	1	2	3	4 days	
19	Salmon	acetic acid	acid	nd	nd	51.49	104.01	107.58	Mikš-Krajnik et al., (2016)
		ethanol	alcohol	nd	nd	18.64	34.03	57.40	
		trimethylamine	amine	nd	nd	9.15	11.19	12.31	

nd = not detected

	type of fish	main volatile compounds	dominant group	volatile compounds of pre-cooked skipjack tuna bone with sequential treatments						ref.
				original bone	CB	AlB	HxB	B-HxB	Bio-Ca	
20	Skipjack Tuna	heptanal	aldehyde	606.86	39.01	ND	ND	ND	ND	Benjakul et al., (2018)
		octanal	aldehyde	414.30	40.06	16.03	4.03	ND	ND	
		2-hexenal	aldehyde	352.20	12.71	14.37	3.73	ND	ND	
		benzaldehyde	aldehyde	298.4	36.29	21.61	4.44	ND	ND	
		nonanal	aldehyde	246.94	84.27	11.92	9.05	ND	ND	

ND not detectable. Values are expressed as abundance ($\times 10^5$)

3. CONCLUSIONS

Fish is not only a popular nutritious water animal but also a food source. For processing that in compliance with the protocol, it represents a reasonable percentage of the food being consumed. Different kinds of processes have an effect on the aroma compounds of fish. When the effects of all processes applied to fish in general on aroma compounds are examined, it is understood that aldehydes and hydrocarbons are the predominant volatile compounds. As a result, consumer preference for fish rich in aroma compounds depends entirely on the best conditions for processing and storing fish.

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