Identification of the Most Potent Odorants in Wild and Farmed Cooked Turbot (*Scophtalamus maximus* L.)

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Potent odorants of wild and farmed turbot (*Scophtalamus maximus* L.) were investigated by an olfactometry global method to point out odorant detection frequency and by aroma extract dilution analysis (AEDA). Thirty-four compounds were detected and 24 identified. Among these compounds, trimethylamine (fishy), 2,3-butanedione (buttery), (*Z*)-4-heptenal (potato-like), 4-methyl-2-pentanol (mushroom-like), (*E*,*Z*)-2,6-nonadienal (cucumber-like), and (*E*,*E*)-2,4-decadienal (cucumber-like) showed a high detection frequency and intensity in turbot. Both methods showed the greater importance of (*E*)-2-nonenal (green, earthy) in wild turbot than in farmed turbot. AEDA highlighted the contribution of 2,3-butanedione and (*E*,*Z*)-2,6-nonadienal to the aroma of wild turbot.

Keywords: *AEDA; detection frequency; fish aroma; sniffing; turbot*

INTRODUCTION

Turbot (*Scophtalamus maximus* L.) is a highly valued marine flatfish, commonly found in northern waters. The European market is almost exclusively satisfied by fish captured in the wild, but commercial fishing has been developing rapidly over the past few years, particulary along the Atlantic coast.

Extensive work has been carried out on the effect of fish diets on the growth and the lipid composition of turbot (Bell et al., 1994; Sheehan et al., 1994; Tocher and Mackinlay, 1990; Leger et al., 1979). Although 280 volatile compounds have been identified in freshly harvested and processed fish (Maarse and Visscher, 1991), to our knowledge, no study on the flavor and aroma of turbot has been published.

Studies have been done on the influence of diet on fish sensory properties on catfish (Maligalig et al., 1973) and on plaice (Hume et al., 1972). In the same way, Hirano et al. (1992) have compared the volatile compounds from wild and cultured ayu fish. They showed that (*E*,*Z*)-2,6-nonadienal, (*E*)-2-nonenal, and 3,6-nonadien-1-ol play a significant role in the characteristic aroma of ayu.

The volatile fraction of a food consists of many compounds, but only a small number is significant in determining the flavor. As recently reviewed, the CHARM method (Acree et al., 1984) and aroma extract dilution analysis (AEDA) (Grosch, 1994) are suitable to screen the potent odorants of foods. In AEDA, an aroma extract is analyzed by gas chromatography/olfactometry (GC/O), and this process is repeated for several serial dilutions of the extract until no more odors are detected. The aroma intensity unit, usually expressed as the flavor dilution (FD) factor, is defined as the ratio of the concentration of a compound in the initial extract and the concentration of the most diluted extract in which the odor was detected by GC/O (Blank and Grosch, 1991). Ott et al. (1997) and Van Ruth et al. (1995) used a different procedure called the olfactometry global method, by which numerous panel members sniffed the nondiluted extracts. The sniffing run is replicated by all of the assessors under the same conditions, and individual aromagrams are summarized by a computer. Peak intensities are not related to flavoring intensities but to their detection frequencies. Such a treatment offers the advantage of smoothing differences within or between individuals (Ott et al., 1997).

Sensory analysis performed on wild and farmed turbot meat by 10 assessors trained in odor description showed that turbot has a potato-like odor and that wild turbot is characterized by amine and rancid odor, whereas farmed turbot is characterized by a milk odor. Therefore, we have carried out a comparative study of the volatile fraction of the cooked muscle of wild and farmed turbot to understand which compounds contribute to the flavor of turbot. The objective of the present study is to determine the most potent odorants of turbot by the olfactometry global method and AEDA.

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MATERIALS AND METHODS

Fish and Fish Preparation. Wild turbot (*Scophtalamus maximus* L.) captured in the Gascogne Gulf (France) was purchased at Marché d'intérêt National of Nantes (France). Weight was between 1.2 and 1.5 kg.

Farmed turbot (*Scophtalamus maximus* L.) was obtained from Aquaculture Society (France). Weight was between 1 and 1.2 kg. Fish were fed on a diet of fish oil, fish meal, and cereal seeds. The diet contained proteins (56%), lipids (11%) [saturated fatty acids (28%), monounsaturated fatty acids (38.8%), polyunsaturated fatty acids (33%)], ashes (10.4%), water (10%), cellulose (1.2%), and vitamins A, C, D_3, and E.

Filets were removed and vacuum packed in polyethylene bags stored at −20 °C for a maximum of 1 week. Just before extraction, fish filets (150 g) cut into pieces of 2 cm × 2 cm were boiled for 5 min with 800 mL of distilled water and ground with an Ultraturrax T25 IKA (7500 t/min).

Chemicals. Dichloromethane (GC quality) was purchased from Aldrich Chemical Co. and collidine (2,4,6-trimethylpyridine) from Sigma.

Simultaneous Steam Distillation−Solvent Extraction (SDE). SDE was done in a Likens−Nickerson (1964) apparatus as described by Tanchotikul and Hsieh (1989).

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A 2-L round-bottom flask was used as the sample flask to contain the fish preparation and purified water to achieve a volume of 1 L; 200 μg of an aqueous solution of 25 mg/L of collidine was added as an internal standard (IS). A 100-mL conical bottom flask containing 35 mL of distilled dichloromethane was attached to the solvent arm of the SDE head. Contents in the sample and solvent flasks were heated to boiling point, and distillation/extraction was continued for 2 h. The volume of SDE extracts was dried over 2 g of anhydrous sodium sulfate and reduced to 3 mL in a Kuderna-Danish concentrator to exactly 2 mL under a gentle stream of nitrogen.

The SDE extracts were stored at −20 °C in glass vials equipped with Teflon-lined caps. Seven extractions were carried out for the volatile quantification of wild and farmed turbot.

Gas Chromatography/Mass Spectrometry (GC/MS). GC/MS consisted of an HP5890 II gas chromatograph and an HP5971 mass selective detector (Hewlett-Packard Co., Palo Alto, CA). Each SDE extract (1 μL) was injected in the splitless mode (250 °C injector temperature, 30 s valve delay) into a capillary column (DB-Wax, 30 m length × 0.32 mm i.d. × 0.5 μm film thickness, J&W Scientific, Folsom, CA). The flow rate of carrier gas (helium) was 1.5 mL/min. Oven temperature was programmed from 50 to 180 °C at 3 °C/min. Oven temperature was further increased to 250 °C at 5 °C/min and then maintained at 250 °C for 15 min.

MSD conditions were as follows: ion source temperature, 180 °C; ionization energy, 70 eV; mass range, 40−300 amu; electron multiplier voltage, 1700 V; and scan rate, 1.60 s^{-1}.

Identification and relative amounts of volatile compounds were based on comparison of GC retention indices (RI) (Van den Dool and Kratz, 1963), mass spectra, and odor properties. Identifications were based on standard MS library information (NBS 75K and internal library of the laboratory).

Gas Chromatography/Flame Ionization Detector/Olfactometry (GC/FID/O). Gas chromatograph Star 3400 (Varian, Palo Alto, CA) was used for analysis purposes. GC effluent was split 1:1 (by volume) into an FID at 250 °C and a sniffing port supplied with humidified air at 40 °C using deactivated but uncoated fused silica capillaries (30 cm × 0.3 mm). GC conditions were the same as above. The relative amounts of each compound were expressed by the ratio of total peak area to that of the internal standard. Wild and farmed cooked turbot results are the average of seven extractions. Estimated concentrations of cooked muscle of wild and farmed fish were compared using an *F* test.

Olfactometry Global Analysis. A panel of 10 judges [according to the guidelines of Pollien et al. (1997), who recommend a minimum of 8−10 panelists] was trained for odor detection by use of numerous standard compounds with various odor descriptors and thresholds. Sniffing of the chromatogram was divided into two parts of ∼23 min. Each person participated in the sniffing of both parts of the chromatogram but during two distinct sessions to remain alert.

GC sniffing of samples revealed that detection of an odor at the sniffing port by ≤3 of 10 assesssors can be considered as noise (Van Ruth and Roozen, 1994). Response values are the number of assessors, up to three, who detect an odor at each time of the GC effluent. Difference of perception of more than three assessors at the same retention index between two samples allowed us to affirm that the volatile compound is differently perceived in the two samples.

AEDA. The AEDA method described by Grosch (1994) was used to access the contribution of individual volatile compounds to the aroma of turbot. Serial dilutions were made from the 1-mL concentrated extracts diluted 3-fold in dichloromethane. The olfactometry procedure was repeated as many times as necessary until no more odor could be detected. Response value is the flavor dilution factor: (FD factor) = 3^{n-1} with *n* the number of coincident responses. Two analysts, chosen because of their high sensitivity during the olfactometry global method, were retained.

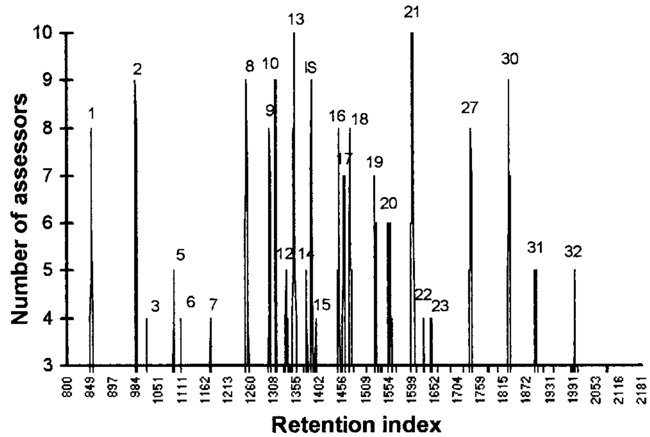

Figure 1. Sniffing chromatograms of volatile compounds of wild turbot meat. Numbers refer to the compounds in Table 1. IS, internal standard.

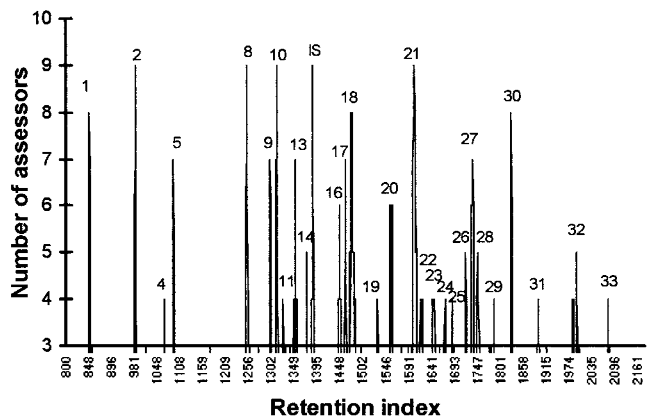

Figure 2. Sniffing chromatograms of volatile compounds of farmed turbot meat. Numbers refer to the compounds in Table 1. IS, internal standard.

RESULTS AND DISCUSSION

Olfactometry Global Analysis. Volatile compounds in wild and farmed turbot were extracted according to the SDE procedure. Both extracts had a strong fishy aroma typical of cooked turbot. Olfactometry global analyses applied for both extracts were similar for dominanting odorants (Figures 1 and 2). This agreed with the results of Hirano et al. (1992) on ayu, who showed that GC patterns and odor quality of wild ayu were similar to those of cultured ayu. Odor descriptions for compounds detected by GC/O and quantitative results for wild and farmed turbot obtained by GC/FID are given in Table 1. Overall estimated concentrations of volatile compounds are higher in wild turbot than in farmed turbot. Thirty-four compounds were perceived and 24 identified. For both turbot, trimethylamine (**1**), 2,3-butanedione (**2**), (*Z*)-4-heptenal (**8**), 4-methyl-2-pentanol (**10**), unknown **18** (mushroom odor), (*E*,*Z*)-2,6-nonadienal (**21**), and (*E*,*E*)-2,4-decadienal (**30**) were detected by ≥8 assessors of 10. These eight compounds contribute actively to turbot aroma. Unknown **13** and (*E*)-2-nonenal (**19**) are the only compounds that are really differently perceived in wild and farmed turbot. Unknown **13**, with an odor of rotting fish, perceived by only 7 assessors in farmed turbot, is perceived by all 10 panel assessors in wild turbot. (*E*)-2-Nonenal (**19**), with a green-earthy odor, is perceived by seven assessors in wild turbot but only four assessors in the farmed one. Nevertheless, the

Table 1. Odor-Active Compounds in Wild and Farmed Turbot Meat

peak no.[a]	compound	methods of identification	RI[b]	odor description[c]	estimated concentration (% IS)[f] wild turbot	farmed turbot	F test[g]
1	trimethylamine	MS, RI, odor	849	fishy			
2	2,3-butanedione	MS, RI, odor	982	buttery	23.14	17.47	**
3	1-penten-3-one	MS, RI	1018	–[e]	tr	tr	
4	2,3-pentanedione	MS,RI	1066	–[e]	6.38	6.33	
5	hexanal	MS, RI, odor	1090	cut grass, green	29.97	23.19	*
6	unknown		1108	rubber, plastic	tr	tr	
7	dodecane	MS,RI	1194	cheese	tr	tr	
8	(*Z*)-4-heptenal	MS, RI, odor	1251	potato, boiled fish	2.42	2.40	
9	2 pentenylfuran	MS, RI	1299	orange, citrus fruits	7.97	6.45	
10	4-methyl-2-pentanol	MS, RI	1312	mushroom	tr	tr	
11	(*E*)-2-penten-1-ol	MS, RI	1325	melted butter	3.04	3.23	
12	(*Z*)-2-penten-1-ol	MS, RI	1332	grilled hazel nut	19.57	11.26	**
13	unknown		1336	rotting fish	0.79	0.71	
14	unknown		1371	sulfur	tr	tr	
15	2-nonanone	MS, RI, odor	1394	fruity, rot	1.43	1.33	
16	(*E*)-2-octenal	MS, odor	1447	lemon, cucumber	13.68	9.74	**
17	methional + heptanol	MS, RI, odor	1475	potato	2.93	1.93	
18	unknown		1528	mushroom	tr	tr	
19	(*E*)-2-nonenal	MS, RI, odor	1555	green, earthy	2.77	1.90	
20	2,4-octadienal[d]	MS, RI, odor	1557	pine, resin	1.37	0.70	
21	(*E*,*Z*)-2,6-nonadienal	MS, RI, odor	1600	grass, cucumber	13.73	6.09	**
22	2-undecanone	MS, RI, odor	1617	fruity	3.12	2.86	
23	unknown		1627	grass	tr	tr	
24	2-octen-1-ol	MS, RI	1645	grass	2.24	2.13	
25	unknown		1643	toasted bread	tr	tr	
26	unknown		1686	amine	tr	tr	
27	thiophenecarboxaldehyde	MS, RI, odor	1718	burnt	2.1	0.8	
28	unknown		1735	woody, flower	4.35	4.49	
29	unknown		1746	spicy	tr	tr	
30	(*E*,*E*)-2,4-decadienal	MS, RI, odor	1828	grass, cucumber	0.79	0.67	
31	benzyl alcohol	MS, RI, odor	1896	walnut	3.48	5.01	
32	unknown		1985	grass	tr	tr	
33	unknown		1995	cucumber	tr	tr	

[a] Numbers correspond to those in Figures 1 and 2. [b] Retention index on DB-WAX column. [c] Odor description as perceived by panelists during olfactometry global analysis. [d] Configuration of isomer not determined. [e] Odor detected without a common descriptor for most of the panelists. [f] IS, internal standard; tr, traces. [g] *F* Test, significance level: **, <5%; *, <10%.

Table 2. Potent Odorants (FD Factor ≥ 9) in Wild and Farmed Turbot for Judge 1

RI[a]	compound	odor description[b]	FD Factor wild turbot	farmed turbot
848	trimethylamine	fishy	9	81
982	2,3-butanedione	buttery	729	243
1249	(*Z*)-4-heptenal	potato, boiled fish	729	243
1297	2-pentenylfuran	orange	729	81
1311	4-methyl-2-pentanol	mushroom	81	81
1346	unknown	green apple	243	243
1552	(*E*)-2-nonenal	woody	243	27
1599	(*E*,*Z*)-2,6-nonadienal	cucumber	2187	729

[a] Retention index on DB-Wax column. [b] Odor description assigned during AEDA.

quantitative results (*F* test, Table 1) of these two compounds are not significatively different in wild and farmed turbot.

Results of the Two Panel Members Retained for AEDA. Eight compounds appeared with FD factors ≥9 by judge 1 and 13 compounds by judge 2 in farmed and wild turbot. Trimethylamine, 2,3-butanedione, (*Z*)-4-heptenal, 4-methyl-2-pentanol, (*E*)-2-nonenal, and (*E*,*Z*)-2,6-nonadienal were common for both judges (Tables 2 and 3).

Judge 2 highlighted the importance of hexanal, benzaldehyde, 2-undecanone, unknown (**28**, RI = 1736), (*E*,*E*)-2,4-decadienal, and benzyl alcohol (Table 3). These compounds appear with a relatively low FD factor but may contribute some background note to the characteristic aroma of turbot.

Table 3. Potent Odorants (FD Factor ≥ 9) in Wild and Farmed Turbot for Judge 2

RI[a]	compound	odor description[b]	FD factor wild turbot	farmed turbot
848	trimethylamine	fishy	27	27
982	2,3-butanedione	buttery	243	81
1090	hexanal	cut grass	27	27
1251	(*Z*)-4-heptenal	potato	243	243
1312	4-methyl-2-pentanol	mushroom	81	27
1538	benzaldehyde	almond	27	<9
1553	(*E*)-2-nonenal	green, earthy	243	81
1599	(*E*,*Z*)-2,6-nonadienal	cucumber	729	81
1614	2-undecanone	fruity	243	27
1736	unknown	flower	81	243
1829	(*E*,*E*)-2,4-decadienal	cucumber	27	27
1894	benzyl alcohol	walnut	81	9
1984	unknown	grass	27	9

[a] Retention index on DB-Wax column. [b] Odor description assigned during AEDA.

Both judges agreed to give greater importance to 2,3-butanedione, (*E*)-2-nonenal, and (*E*,*Z*)-2,6-nonadienal in wild turbot than in the farmed one. Among these compounds, 2,3-butanedione, with a buttery odor, may contribute to the characteristic rancid odor of wild turbot determined by previous sensory analysis.

Identification of Potent Odorants. Compounds **1**, **8**, **13**, **17**, and **26** (Table 1) were associated with potato and amine-like odor by the olfactometry global method. These compounds with descriptors previously pointed out by sensory analysis may contribute actively to the aroma of turbot.

Trimethylamine (TMA; **1**) was described as fishy and ammonia-like and was detected by eight judges during the olfactometry global method in both wild and farmed turbot. Since the volatility of TMA is high, this odorant was the earliest to elute during GC/O. Eluted at the same time as dichloromethane, this compound was not quantified and had been detected only by olfactometric methods. Its odor threshold is between 0.37 and 2.40 ppb (Leffingwell and Leffingwell, 1991; Devos et al., 1990). The presence of high levels of TMA in seafoods is undesirable (Lundstrom and Racicot, 1983); however, at low levels TMA might add a pleasant crustacean-like odor (Cadwallader et al., 1995). Formation of TMA (**1**) is the characteristic feature for the deterioration of fish belonging to the gadoid species (Miller et al., 1972; Krzymien and Elias, 1990), but we have no information about flatfish species.

One of the most intense odorants was 2,3-butanedione (**2**), with a buttery odor. This Maillard reaction product (Hodge, 1967) had a higher FD factor in wild turbot than in farmed turbot for both judges (Tables 2 and 3). This agreed with its higher abundance in wild turbot than in farmed turbot. 2,3-Butanedione is indeed one of the compounds that has a concentration significatively higher in wild turbot than in farmed turbot (*F* test, Table 1).

TMA and 2,3-butanedione were reported as the most potent odorants with 2-acetyl-1-pyrroline in cooked spiny lobster tail meat by AEDA after extraction by SDE (Cadwallader et al., 1995).

1-Penten-3-one (**3**) and 2,3-pentanedione (**4**) were detected by only four assessors during the olfactometric global method and were not associated with specific descriptors. 1-Penten-3-one was previously identified in crayfish (Tanchotikul and Hsieh, 1989) and was associated with a green grassy odor by these authors. 2,3-Pentanedione may contribute to the buttery flavor of turbot and was also identified in crayfish (Tanchotikul and Hsieh, 1989), in fresh baked sockeye salmon (Josephson et al., 1991), and in boiled trout with an FD-factor of 16 (Milo and Grosch, 1996).

Some of the odorants, for example, **5**, **8**, **16**, **19**−**21**, **24**, and **30**, were formed by the peroxidation of polyunsaturated fatty acids (PUFA) and were likely to be involved in the green, cucumber, and potato odor. Hexanal (**5**), (*E*)-2-octenal (**16**), (*E*)-2-nonenal (**19**), and (*E*,*E*)-2,4-decadienal (**30**) are the results of ($n-6$) PUFA oxidation and (*Z*)-4-heptenal (**8**), 2-pentenylfuran (**9**), and (*E*,*Z*)-2,6-nonadienal (**21**) of ($n-3$) PUFA oxidation (Grosch, 1987). These compounds are known to be involved in oxidized fish flavor because of their low odor thresholds (Josephson, 1991).

Recent works performed in our laboratory (Serot et al., 1998) have shown that muscle of farmed turbot had a higher lipid content than that of wild turbot. The ratio of $n-3$ to $n-6$ PUFA was higher in all of the lipid fractions of wild turbot than in farmed turbot. Wild turbot has the highest content of 20:4($n-6$) and 22:5($n-3$), precursors of (*E*)-2-octenal, (*E*)-2-nonenal, and (*E*,*Z*)-2,6-nonadienal, respectively. These results are in correlation with the greatest amount of these volatile compounds found in wild turbot (Table 1).

Hexanal (**5**) was significatively more abundant in wild turbot than in farmed turbot (*F* test, Table 1), but olfactometric methods did not show significant difference of perception in either turbot. Five assessors perceived this compound in wild turbot and seven in farmed turbot. The occurrence of hexanal in turbot might be undesirable since its odor was described as green and cut grass-like. Hexanal has been previously reported to be an odor-active component in cooked spiny lobster tail meat (Cadwallder et al., 1995).

(*Z*)-4-Heptenal (**8**) had potato-like and fishy background aroma. Some investigators have suggested the accumulation of (*Z*)-4-heptenal in cod was undesirable (McGill et al., 1974) and that in freshly cooked crab meat it might be desirable (Chung and Cadwallader, 1994). Its high FD factor is confirmed by its low odor threshold (0.04 ppb; McGill et al., 1974). First, McGill et al. (1974) suggested that (*Z*)-4-heptenal may contribute to the off-flavor in cod which develops during frozen storage, and then McGill cited by Lindsay (1990) showed that cooking was an important factor in the production of this compound in cod. (*Z*)-4-Heptenal could have been generated from (*E*,*Z*)-2,6-nonadienal via water-mediated retro-aldol condensation (Josephson and Lindsay, 1987), which was most likely enhanced during the distillation of volatiles through the combined effect of time and temperature.

(*E*)-2-Nonenal (**19**) was also an important compound as revealed by the olfactometric global and AEDA methods. (*E*)-2-Nonenal was detected by seven assessors in wild turbot (Figure 1) and by only four assessors in farmed turbot (Figure 2). Indeed, both judges gave it a higher FD factor in wild turbot than in the farmed one. Nevertheless, quantitative results (*F* test, Table 1) are not significatively different in wild and farmed turbot.

2,4-Octadienal (**20**) was for the first time reported as a fish volatile by Triqui and Reineccius (1995) in anchovy (*Engraulis encrasicholus* L.).

(*E*,*Z*)-2,6-Nonadienal (**21**) was very well perceived in olfactometry global analysis and showed the highest FD factor in wild and farmed turbot (Tables 2 and 3). This agreed with olfactometric results of Milo and Grosch (1996), who showed that (*E*,*Z*)-2,6-nonadienal and other compounds such as (*E*)-2-nonenal, 1-octen-3-one, and (*Z*)-1,5-octadien-3-one belong to the most important odorants of freshly boiled trout. On the basis of its high FD factor, (*E*,*Z*)-2,6-nonadienal has been previously reported to contribute to the flavor of ripened anchovy (Triqui and Reineccius, 1995), in ayu fish (Hirano et al., 1992), and in boiled salmon and cod (Milo and Grosch, 1996) through its characteristic cucumber-like aroma and a very low odor threshold (0.001 ppb, Leffingwell and Leffingwell, 1991).

(*E*,*E*)-2,4-Decadienal (**30**) is generally considered to contribute to the aromas of a variety of freshly prepared foods (Tanchotikul and Hsieh, 1989) and was previously reported as the main impact odorant of boiled cod (Milo and Grosch, 1996). It can be further degraded to other carbonyl compounds such as hexanal and (*E*)-2-octenal which are also potent odorants in turbot.

2-Pentenylfuran (**9**) has not been previously reported as a seafood volatile. Detected in both samples by the olfactometric global method (Figures 1 and 2), it was associated with high factor dilution by judge 1 in wild turbot (Table 2). The occurrence of this compound in turbot might be desirable because its odor was described as nice and orange-like.

4-Methyl-2-pentanol (**10**), present in trace quantities, was still detected by 9 of 10 assessors by the olfactometric global method and showed a significant FD factor for both judges (Tables 2 and 3), which indicated its low odor threshold. This alcohol, associated with an odor of mushroom, was previously identified in crayfish (Tanchotikul and Hsieh, 1989).

(*E*)-2-Penten-1-ol (**11**), with an odor of melted butter, was detected by the olfactometric global method in farmed turbot (Figure 2) and (*Z*)-2-penten-1-ol (**12**), with an odor of grilled hazelnut, in wild turbot (Figure 1). Although the two compounds are present in both turbot samples olfactometric results can be explained by a higher concentration of (*E*)-2-penten-1-ol in farmed turbot and of (*Z*)-2-penten-1-ol in wild turbot (Table 1). Both compounds were previously identified in menhaden fish oil (Lin, 1994).

2-Nonanone (**15**) and 2-undecanone (**22**) were previously reported in clam (Kubota et al., 1991) and in crayfish (Tanchotikul and Hsieh, 1989). 2-Nonanone (**15**), with a fruity odor, was detected by the olfactometric global method in wild turbot by four assessors but not in farmed turbot. 2-Undecanone (**22**), a nice fruity-like compound, had a significatively higher FD factor in wild turbot than in farmed turbot (Table 3) and may positively contribute to wild turbot flavor.

Benzaldehyde, with an almond-like odor, was detected by judge 2 in AEDA with a higher FD factor in wild turbot than in farmed turbot. As it was detected by fewer than three assessors by the olfactometric global method, it does not appear in Table 1. Benzaldehyde was previously identified in fresh-baked sockeye salmon (Josephson et al., 1991), and Sugisawa et al. (1990) showed by olfactometric analysis that benzaldehyde contributes to the sweet odor of algae.

There were many unidentified compounds with different odor properties (e.g., **6**, **13**, **14**, **18**, **23**, **25**, **26**, **28**, **29**, **32**, **33**). For most of them no peak was observed. Only **13**, and **28** were quantified (Table 1).

Unknown compounds **13** and **18** with, respectively odors of rotting fish and a mushroom odor, were detected by the olfactometry global method by a minimum of 7 of 10 assessors. The mass spectrum of compound **13** was similar to that of *N*,*N*-dimethylformamide previously identified in sardine (Kawai, 1996), but injection of this pure compound showed that *N*,*N*-dimethylformamide is not an odorant.

Unknown **28** (RI = 1736, flower-like) and unknown **32** (RI = 1984, grassy-like) were detected by judge 2 by AEDA. Judge 2 gave to unknown (**28**) an FD factors of 81 in wild turbot and 243 in farmed turbot, which is the highest FD factor he gave in farmed turbot. This unknown with a flower-like odor may contribute positively to the aroma of farmed turbot. An attempt to identify the chemical structure for this component was not successful. The mass spectrum of unknown **28** is as follows: mass/charge (% intensity), 41 (26), 43 (50), 45 (28), 55 (33), 69 (36), 83 (75), 85 (19), 98 (100), 111 (46), 167 (7).

CONCLUSION

Comparison of the aromas of wild and farmed turbot by analytical methods is not sufficient to show differences between the two samples. Consequently, olfactometric methods such as the olfactometry global method showed the detection frequency of volatile compounds. AEDA showed the intensity of these compounds. These two methods point out potent odorants of turbot.

On the basis of the two methods, the aroma of turbot could be primarily attributed to five odorants including TMA (fishy odor), 2,3-butanedione (buttery-odor), (*Z*)-4-heptenal (potato-like odor), 4-methyl-2-pentanol (mushroom-like odor), and (*E*,*Z*)-2,6-nonadienal (cucumber-like odor). The olfactometry global method showed also the high detection frequency of (*E*,*E*)-2,4-decadienal (grass, cucumber-like odor) and AEDA the importance of (*E*)-2-nonenal (green, woody odor).

Further investigations are required to elucidate the endogenous mechanisms of generation of specific turbot aroma. Objectives of further studies will be the origin of most of these compounds by studying lipid and amino acid compositions of wild and farmed turbot.

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