Comparison of Volatile Components in Dried Scallops (*Chlamys farreri* and *Patinopecten yessoensis*) Prepared by Boiling and Steaming Methods

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Comparison of two types of dried scallops, *Chlamys farreri* and *Patinopecten yessoensis*, and effects of preparation methods (boiling and steaming) on the composition of their volatile components were carried out by simultaneous steam distillation and extraction and with analysis by gas chromatography–mass spectrometry. One hundred and seventy-two compounds were identified, three tentatively. Qualitatively, both scallops had similar components. Quantitatively, *C. farreri* contained more components with higher levels in aldehydes, alkanes, naphthalenes, esters, furans, miscellaneous compounds, alcohols, and ketones, whereas *P. yessoensis* had more components with higher levels in aromatics, pyrazines, pyridines, sulfur-containing compounds, and terpenes from both boiling and steaming methods. Comparison between methods for the same scallop showed that similar qualities of components were detected. Overall, more compounds with higher levels were detected from the boiling method.

Keywords: *Scallops; volatiles; preparation; comparison; GC-MS analysis*

INTRODUCTION

Thirty-three species of scallops are commercially or potentially important worldwide (*1*). In China, 21 species of scallop are found (*2*), of which 19 are native and the other 2 are exotic. For cultivation, four major species are raised, including two native species (*Chlamys farreri* and *Chlamys nobilis*) and two exotic species (*Patinopecten yessoensis* and *Argopecten irradianus*). The majority of the scallops are sold in dried form. The remainder is sold fresh or processed into canned products (*2*). Similarly, in Japan, several species of scallops are cultivated, including *P. yessoensis*, *Pecten albicans*, *Chlamys senatoria nobilis*, *Chlamys swiftii*, *C. farreri*, and *Amusium japonicum* (*3*). Scallops in Japan are sold fresh or processed into frozen, dried, canned, or boiled forms. In Hong Kong, the consumption of dried scallops is very popular and the major species sold are *C. farreri* from China and *P. yessoensis* from Japan. Their relative prices vary greatly.

The adductor muscle, consisting of both striated and smooth muscles, is the major edible part of these animals. As a food ingredient, the dried muscle is first soaked in water until it is softened before other thermal treatments such as boiling or steaming are carried out. Boiling is usually used in the preparation of the stewed clear or the all-season soups (*4, 5*). The former type is prepared by cooking foods in a covered container kept inside a larger cooking pot, half filled with boiling water for ∼3 h (*4, 6*). The latter type is prepared by simply simmering foods in a pot of boiled water for 2 h (*5, 6*). On the other hand, steaming of dried scallops may take 2–3 h depending on the amount used (*7*). In the past, the quality of scallop muscle has been assessed on the nonvolatile components present; little attention has been given to the volatile components (*8–10*). Suzuki et al. (*11*) identified 84 components in the boiled adductor muscle of frozen scallops, *P. yessoensis*. Whereas trimethylamine dominated in the boiled scallops, dimethyl sulfide was the major compound identified in fresh, raw scallops. No volatile components that contributed to the flavor of the popular dried adductor muscle were reported. The objectives of our research are to compare the volatile components between the two species of dried scallops and to compare the effects of boiling and steaming methods on the samples.

MATERIALS AND METHODS

Materials. Two types of dried scallops, *C. farreri* (sample C) and *P. yessoensis* of LL grade (sample J) were purchased from a retailer in Hong Kong in 1998. Samples were kept in sealed glass containers at room temperature (22 °C). Chemical standards were purchased from Aldrich Chemical Co., Inc. (Milwaukee, WI) except for 3-octen-2-one, which was obtained from Tokyo Chemical Industry Co., Ltd. (Tokyo, Japan).
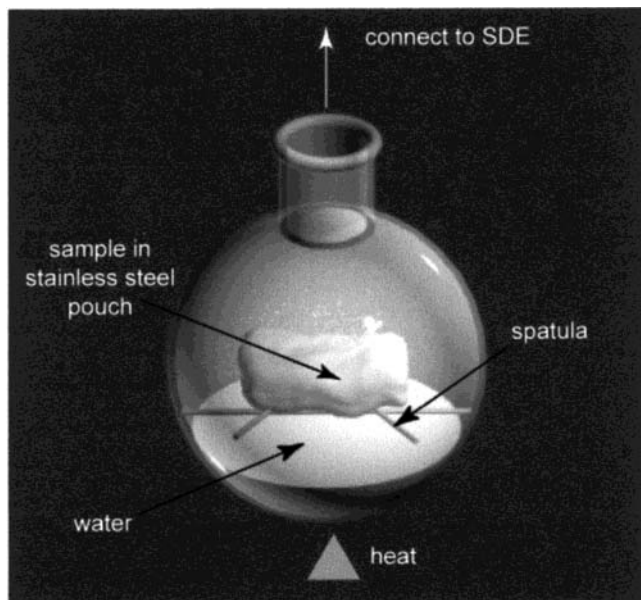
Simultaneous Steam Distillation and Solvent Extraction (SDE) of Volatile Components by Boiling of Samples. Forty-five grams of dried scallop was blended by a domestic blender [National Blender, model MX-T2GN; Matsushita Electric (Taiwan) Co., Ltd., Taipei, Taiwan] and was mixed with boiled double-distilled water [1:11 (w/v)] in a 5-L round-bottom flask. One milliliter of 2,4,6-trimethylpyridine, 9.0783 μg/mL, was added to the sample as an internal standard. Fifty

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Comparison of Volatile Compounds in Dried Scallops

J. Agric. Food Chem., Vol. 49, No. 1, 2001   **193**

Figure 1. A setup of the sample flask and sample for simultaneous steam distillation and solvent extraction (SDE) in the steaming method.

milliliters of distilled dichloromethane was used as solvent. Each sample was extracted for 2 h by boiling it in a Likens and Nickerson (*12*) type SDE apparatus (catalog no. K-523010-0000, Kontes, Vineland, NJ). Four replicated extractions of each sample were carried out. Extracts were concentrated by a stream of ultrahigh purity (99.999%) nitrogen, dried over 5.5 g of anhydrous sodium sulfate, and the concentrates were stored in 15-mL conical tubes sealed with a Telfon-lined screw cap and stored at −80 °C. Before sample injection, extracts were further concentrated to 0.75 mL.

SDE of Volatile Components by Steaming of Samples. An extraction procedure similar to that used for boiling was used for the steaming of samples, but with some modifications in the setup. The blended sample (45 g) was transferred to a stainless steel gauze pouch of U.S. sieve number 70 (size = 6 cm × 16 cm × 2 cm). The pouch was then loaded on a platform formed by three 20 cm long stainless spatulas, which were arranged in a cross position, overlapping each other in a 5-L round-bottom flask as shown in Figure 1. One milliliter of 2,4,6-trimethylpyridine, 9.0783 μg/mL, was again added evenly to the sample as an internal standard. Fifty milliliters of distilled dichloromethane was used as solvent. Each sample was extracted for 2 h in a Likens and Nickerson (*12*) type SDE apparatus (catalog no. K-523010-0000, Kontes, Vineland, NJ). Four replicated extractions of each sample were carried out. Concentration and storage of extracts were the same as previously described.

Gas Chromatography—Mass Spectrometry (GC-MS). A system consisting of an HP 6890 GC coupled with an HP 5973 mass selective detector (MSD) (Hewlett-Packard Co., Palo Alto, CA) was used for both qualitative and quantitative analyses. Five microliters of each extract was injected, in split mode (1:10) with injector temperature at 200 °C, into a fused silica open tubular column (Suplecowax 10, 60 m length × 0.25 mm i.d. × 0.25 μm film thickness; Supelco, Inc., Bellefonte, PA). Helium gas (ultrahigh purity grade, 99.999%) was used as the carrier gas at a constant linear velocity of 30 cm/s. Oven temperature was programmed from 35 to 195 °C at a ramp rate of 2 °C/min. The initial and final hold times were 5 and 90 min, respectively. The MS interface temperature was set at 250 °C, the ion source temperature was 230 °C, the MS quadrupole temperature was 106 °C, and the ionization voltage was 70 eV. The mass range of MS was set at 33−550 amu, the scan rate was 2.94 scans/s, and the electron multiplier voltage was 1494 V.

Compound Identification and Quantification. Identification and quantification were conducted following the procedures of Chung (*13, 14*). Tentative identification of compounds was made by matching the mass spectra of unknowns with those in the Wiley Chemical Database (6th ed., Hewlett-Packard Co., Palo Alto, CA). Positive identifications were based on the comparison between the mass spectra and retention times or retention indices (RI) of unknown compounds in the extracts with the authentic standards under the same experimental conditions (*15*). An internal standard curve was developed for each compound and used to quantify each component. Relative abundance of a tentatively identified compound was estimated from the ratio of the relative area of a specific fragment of the tentatively identified compound to that of internal standard (2,4,6-trimethylpyridine, *m/z* 121).

Proximate Analysis. Moisture, protein, fat, and ash analyses were carried out according to the AOAC official methods (*16*).

Statistical Analysis. Compounds from four replicate samples were analyzed by one-way analysis of variance (ANOVA) and compared by the Tukey HSD at $p < 0.05$ level of significance (*17*).

RESULTS AND DISCUSSION

Table 1 shows the results of proximate analyses from both dried *C. farreri* (C) and *P. yessoensis* (J). Scallop C was much higher in the content of moisture, ash, and fat when compared with scallop J. On the other hand, sample J was higher in protein and carbohydrate. Recalculation of the samples on a dry weight basis gave mean percentages of ash, protein, fat, and carbohydrate of 13.2, 59.5, 1.7, and 25.6 for scallop C and 9.8, 59.7, 0.9, and 29.6 for scallop J, respectively. The percentages of crude protein of these samples were similar.

Table 2 shows the volatile components found in both scallops prepared by either boiling or steaming methods. One hundred and seventy-two compounds were identified (three tentatively) from the combined data. Among them, ketones (32) and aldehydes (25) were the major classes. Other compound classes included aromatics (18), alcohols (15), phenolic compounds (15), miscellaneous compounds (12), naphthalenes (10), sulfur-containing compounds (10), terpenes (8), pyrazines (7), esters (6), alkanes (5), pyridines (4), furans (4), and an acid (1).

Comparison between Scallops *C. farreri* (C) and *P. yessoensis* (J). Qualitatively, both scallops generally contain similar components in almost all classes of compounds in each preparation method, but 22 compounds occurred in only either one or the other of the

Table 1. Proximate Analyses (Percentage by Wet and Dry Weights) of Dried Scallops, *C. farreri* and *P. yessoensis*[a]

sample	percentage wet (dry) weights				
	moisture	ash	protein	fat	carbohydrate[b]
C. farreri	25.2 ± 0.6	9.9 ± 0.0	44.5 ± 0.5	1.3 ± 0.0	19.1
(Chinese scallops)	(0)	(13.2)	(59.5)	(1.7)	(25.6)
P. yessoensis	13.5 ± 0.2	8.5 ± 0.1	51.7 ± 0.7	0.7 ± 0.0	25.6
(Japanese scallops, LL grade)	(0)	(9.8)	(59.7)	(0.9)	(29.6)

[a] Data are expressed as mean ± standard deviation with $n = 3$. [b] Carbohydrate % = 100% − (moisture + ash + protein + fat)% (*41*).

Table 2. Volatile Components in Dried Scallops, *C. farreri* and *P. yessoensis*

							C. farreri scallop C				*P. yessoensis* scallop J			
							boiling		steaming		boiling		steaming	
no.[a]	compd[b]	ref[c]	CAS Registry No.[d]	RI[e]	m/z[f]	sig[g]	concn[h] (ng/g)	SD[i] (ng/g)	concn[h] (ng/g)	SD[i] (ng/g)	concn[h] (ng/g)	SD[i] (ng/g)	concn[h] (ng/g)	SD[i] (ng/g)
	acid (1)													
1	tetradecanoic acid	1	544-63-8	2694	129	**	137a	34	15.8b	1.3	60.3c	20.5	20.0bc	6.3
	aldehydes (25)													
2	pentanal	1	110-62-3	1000>	58	**	901a	27	587a	74	2150b	311	1470c	56
3	2-butenal[j]		4170-30-3	1042	70	**	10.3a	0.4	5.55b	0.44	13.0c	1.9	6.35b	0.99
4	hexanal	1	66-25-1	1086	72	**	571a	20	403b	46	408b	43	325c	20
5	(*E*)-2-methyl-2-butenal		497-03-0	1096	84	**	89.8a	5.6	89.3a	8.1	28.6b	3.6	33.2b	3.6
6	(*E*)-2-pentenal		1576-87-0	1132	69	**	379a	14	142b	12	191c	21	78.2d	17.3
7	2-methyl-2-pentenal		623-36-9	1151	98	**	10.2a	0.3	10.1a	0.8	6.17b	0.85	8.35c	0.75
8	2-methylene-hexanal		1070-66-2	1160	97	**	808a	47	504b	23	35.2c	3.2	64.9c	19.6
9	heptanal	1	111-71-7	1189	70	**	198a	10	130b	15	244c	17	155b	7
10	3-methyl-2-butenal		107-86-8	1202	84	**	5.36a	0.45	5.29a	0.86	10.4b	1.3	5.61a	0.81
11	(*E*)-2-hexenal		6728-26-3	1221	83	**	195a	11	61.6b	2.7	88.0b	57.7	40.1b	2.3
12	(*Z*)-4-heptenal		6728-31-0	1247	84	**	256a	22	158b	16	97.2c	6.7	75.3c	5.0
13	octanal		124-13-0	1293	100	**	261a	24	157b	22	298a	25	204b	17
14	nonanal	1	124-19-6	1398	98	**	28.9a	2.7	23.0a	6.6	44.6b	4.6	21.0a	1.5
15	2-furancarboxaldehyde		98-01-1	1471	96	**	33.9ab	11.2	42.2a	6.8	21.6b	0.7	19.3b	7.6
16	(*E,E*)-2,4-heptadienal	1	4313-03-5	1498	81	**	32.7a	5.1	18.8b	1.4	27.2a	3.2	13.3b	1.6
17	decanal	1	112-31-2	1503	57	**	21.1ab	2.3	17.7b	2.7	27.9a	3.4	18.8b	4.8
18	benzaldehyde	1	100-52-7	1530	106	**	663a	20	741a	54	962b	59	1110c	60
19	(*E,Z*)-2,6-nonadienal		557-48-2	1591	94	**	105a	10	38.5b	3.1	72.6c	6.1	28.8b	5.3
20	3-methylbenzaldehyde[j]		620-23-5	1624	119	**	3.46a	0.08	3.48a	0.27	0.866b	0.049	0.678b	0.155
21	5-ethyl-2-furaldehyde		23074-10-4	1645	124	**	20.9a	0.9	19.0b	0.9	7.07c	0.49	6.27c	0.74
22	phenylacetaldehyde		122-78-1	1651	91	**	2.90a	0.68	3.07a	1.78	7.60b	0.73	7.36b	0.92
23	4-methylbenzaldehyde		104-87-0	1654	119	- -	6.18a	0.25	5.74a	0.39	nd	nd	nd	nd
24	4-ethylbenzaldehyde		4748-78-1	1714	134	**	22.3a	0.7	20.0b	0.9	4.67c	0.42	3.93c	1.09
25	4-methoxybenzaldehyde		123-11-5	2032	135	**	nd	nd	nd	nd	10.2a	4.3	5.00b	0.76
26	2-naphthalenecarbox-aldehyde		66-99-9	2407	156	**	11.0a	0.5	5.15b	0.24	nd	nd	nd	nd
	alkanes (5)													
27	7-oxabicyclo[4.1.0]-heptane		286-20-4	1158	83	**	88.8a	11.6	71.0ab	7.3	58.1b	15.5	81.7a	6.8
28	tridecane		629-50-5	1300	85	- -	6.32	1.24	8.90	0.80	7.93	1.02	8.42	2.20
29	tetradecane		629-59-4	1399	85	- -	25.2	33.1	19.0	3.6	6.46	0.99	10.8	2.8
30	pentadecane		629-62-9	1499	85	**	6.40ab	0.83	17.8c	4.8	4.61a	0.56	12.5bc	3.7
31	2,6,10,14-tetramethyl-pentadecane		1921-70-6	1669	85	- -	nd	nd	22.2a	9.4	nd	nd	16.1a	6.2
	aromatics (18)													
32	benzene	1	71-43-2	1000>	78	**	10.1a	1.0	9.79a	0.72	5.49b	0.64	5.91b	0.40
33	toluene	1	108-88-3	1041	91	**	25.4a	1.8	51.7b	20.4	53.4b	12.4	43.5ab	4.3
34	ethylbenzene		100-41-4	1129	106	**	9.04a	0.90	12.3ab	2.0	17.6c	3.4	16.1bc	1.6
35	1,4-dimethylbenzene		106-42-3	1137	106	**	4.48a	0.81	5.71ab	0.92	7.51b	1.45	6.47ab	0.45
36	1,3-dimethylbenzene		108-38-3	1143	106	**	14.5a	2.3	18.7ab	2.2	22.3b	3.9	20.2b	1.3
37	1,2-dimethylbenzene		95-47-6	1187	106	**	15.5ab	1.6	17.7b	1.4	14.2a	2.2	14.4ab	1.0
38	1-ethyl-3-methylbenzene		620-14-4	1228	105	**	3.96a	0.41	4.42a	0.41	7.20b	0.88	6.43b	0.15
39	styrene		100-42-5	1262	104	**	3.93a	0.46	3.66a	0.28	8.69b	0.92	7.99b	0.60
40	1-methyl-4-(1-methyl-ethyl)benzene		99-87-6	1274	119	**	2.62a	0.09	2.24a	0.24	26.4b	2.5	21.4c	2.2
41	1,2,4-trimethylbenzene		95-63-6	1285	105	**	10.6a	0.7	11.4a	1.2	17.5b	1.7	15.7b	0.6
42	1,2,3-trimethylbenzene		526-73-8	1340	105	**	7.39a	0.37	7.29a	0.77	11.0b	0.9	9.63b	0.71
43	1,4-dichlorobenzene		106-46-7	1449	146	**	19.5a	0.7	18.2a	1.2	29.1b	2.3	27.6b	1.5
44	1,2-dichlorobenzene		95-50-1	1492	146	**	1.25a	0.08	1.11a	0.05	43.8b	0.5	38.7c	3.0
45	1-methoxy-4-(2-propenyl)-benzene		140-67-0	1677	148	**	0.722a	0.207	nd	nd	19.1b	5.5	17.6b	1.1
46	1-methoxy-4-(1-propenyl)-benzene		4180-23-8	1834	148	**	11.8a	0.9	9.50a	0.25	253b	122	225b	73
47	1,1'-biphenyl		92-52-4	1996	154	**	74.0a	1.9	52.9b	3.4	4.26c	0.81	3.54c	0.48
48	3-methyl-1,1'-biphenyl		643-93-6	2102	168	**	18.1a	0.5	9.34b	0.44	1.84c	0.35	1.14c	0.24
49	3,3'-dimethyl-1,1'-biphenyl		612-75-9	2209	182	**	6.41a	0.23	2.55b	0.27	1.16c	0.30	0.824c	0.282
	naphthalenes (10)													
50	naphthalene		91-20-3	1747	128	**	390a	4	349b	14	112c	20	97.7c	5.0
51	2-methylnaphthalene		91-57-6	1859	142	**	74.9a	2.4	57.6b	0.7	11.8c	2.8	8.62c	0.29
52	1-methylnaphthalene		90-12-0	1894	142	**	33.0a	0.9	24.7b	0.1	5.51c	1.30	3.94c	0.26
53	2-ethylnaphthalene		939-27-5	1953	156	**	7.77a	0.41	4.70b	0.26	1.74c	0.54	1.12c	0.13
54	2,6-dimethylnaphthalene		581-42-0	1970	156	**	36.2a	1.1	20.6b	0.6	5.99c	1.49	3.60d	0.45
55	1,7-dimethylnaphthalene		575-37-1	2000	156	**	18.6a	0.8	10.8b	0.4	3.01c	0.73	1.85c	0.21
56	1,6-dimethylnaphthalene		575-43-9	2006	156	**	23.8a	1.1	13.8b	0.4	6.06c	2.10	2.72d	0.29
57	2,3-dimethylnaphthalene		581-40-8	2008	156	**	14.0a	0.5	7.89b	0.65	2.10c	0.53	1.37c	0.21
58	1,2-dimethylnaphthalene		573-98-8	2072	156	**	8.21a	0.52	4.65b	0.10	1.23c	0.35	0.730c	0.159
59	2,3,5-trimethylnaphthalene		2245-38-7	2182	170	**	11100a	404	4690b	341	1570c	472	802c	214

Comparison of Volatile Compounds in Dried Scallops

J. Agric. Food Chem., Vol. 49, No. 1, 2001 **195**

Table 2 (Continued)

| | | | | | | | *C. farreri* scallop C | | | | *P. yessoensis* scallop J | | | |
| | | | | | | | boiling | | steaming | | boiling | | steaming | |
no.[a]	compd[b]	ref[c]	CAS Registry No.[d]	RI[e]	m/z[f]	sig[g]	concn[h] (ng/g)	SD[i] (ng/g)	concn[h] (ng/g)	SD[i] (ng/g)	concn[h] (ng/g)	SD[i] (ng/g)	concn[h] (ng/g)	SD[i] (ng/g)
	esters (6)													
60	2-ethoxyethyl acetate		111-15-9	1299	72	**	12.5[a]	0.9	11.5[a]	1.1	2.80[b]	0.56	2.47[b]	0.30
61	ethyl benzoate		93-89-0	1673	105	**	7.87[a]	0.41	5.72[b]	0.15	11.5[c]	0.5	9.76[d]	0.85
62	methyl hexadecanoate		112-39-0	2217	143	- -	48.4[a]	34.1	nd	nd	13.3[a]	5.7	nd	nd
63	1,2-dimethyl phthalate		131-11-3	2303	149	- -	nd	nd	nd	nd	0.442[a]	0.062	1.75[a]	1.65
64	1,2-diethyl phthalate		84-66-2	2370	149	**	5.31[a]	0.48	4.41[ab]	0.50	1.58[c]	0.25	3.69[b]	0.46
65	diisobutyl phthalate		84-69-5	2536	149	**	8.00[a]	0.69	4.63[ab]	3.11	2.42[b]	0.69	2.72[b]	1.29
	furans (4)													
66	2-ethylfuran		3208-16-0	1000>	96	**	3270[a]	84	2730[b]	187	486[c]	39	509[c]	101
67	2-pentylfuran		3777-69-3	1236	138	**	147[a]	2	102[b]	4	29.6[c]	2.0	25.2[c]	5.8
68	5-methylfurfural		620-02-0	1580	110	- -	16.5	11.4	16.9	4.1	15.3	0.5	25.0	26.7
69	2-acetyl-5-methylfuran		1193-79-9	1620	109	**	4.20[a]	0.39	4.24[a]	0.29	0.909[b]	0.081	0.940[b]	0.509
	miscellaneous compounds (12)													
70	trimethylamine	1	75-50-3	1000>	58	**	7430[a]	684	3230[b]	2350	3190[b]	1480	2440[b]	1430
71	chloroform		67-66-3	1026	83	**	274[a]	13	343[b]	41	233[a]	22	274[a]	35
72	2,4,5-trimethyloxazole		20662-84-4	1193	111	**	2.86[ab]	0.33	1.29[b]	0.13	3.24[a]	1.24	2.11[ab]	0.39
73	dimethylaminoacetonitrile		926-64-7	1243	83	**	986[a]	42	474[b]	20	675[c]	69	660[c]	100
74	*N,N*-dimethylformamide		68-12-2	1326	73	**	195[a]	84	129[ab]	22	104[ab]	21	75.5[b]	25.4
75	1*H*-pyrrole		109-97-7	1523	67	**	13.7[a]	1.8	20.9[a]	5.2	52.8[b]	10.1	57.6[b]	14.7
76	9*H*-fluorene		86-73-7	2337	166	**	80.6[a]	3.5	36.2[b]	2.0	1.78[c]	0.34	1.07[c]	0.28
77	1*H*-indole		120-72-9	2444	117	**	nd	nd	nd	nd	13.0[a]	2.5	6.18[b]	3.70
78	1-methyl-9*H*-fluorene		1730-37-6	2475	165	**	20.2[a]	0.9	7.42[b]	0.60	nd	nd	nd	nd
79	phenanthrene		85-01-8	2673	178	**	525[a]	27	161[b]	12	nd	nd	nd	nd
80	anthracene		120-12-7	2676	178	**	19.4[a]	2.3	5.71[b]	0.57	nd	nd	nd	nd
81	9*H*-fluoren-9-one		486-25-9	2697	180	**	40.3[a]	2.3	15.0[b]	0.9	nd	nd	nd	nd
	alcohols (15)													
82	2-methyl-1-propanol		78-83-1	1092	74	**	6.64[a]	0.31	5.90[a]	0.96	32.2[b]	3.6	28.8[b]	2.2
83	1-butanol		71-36-3	1144	56	**	23.5[a]	1.0	23.0[a]	1.5	32.0[b]	2.1	31.3[b]	2.1
84	1-penten-3-ol	1	616-25-1	1161	71	**	447[ab]	274	552[b]	27	126[c]	12	165[ac]	10
85	3-methyl-1-butanol		123-51-3	1208	70	**	2.65[a]	0.29	2.73[a]	0.64	5.89[b]	0.48	5.46[b]	0.47
86	1-pentanol	1	71-41-0	1251	70	**	122[a]	4	125[a]	8	71.7[b]	4.4	73.5[b]	6.5
87	cyclopentanol		96-41-3	1314	86	**	42.2[a]	1.4	46.7[a]	4.1	8.40[b]	0.59	9.43[b]	0.75
88	1-hexanol		111-27-3	1354	56	- -	26.1	1.2	27.8	1.8	28.3	2.4	26.4	2.0
89	1-octen-3-ol	1	3391-86-4	1453	85	**	131[a]	5	131[a]	7	32.6[b]	1.3	44.6[c]	6.9
90	1-heptanol		111-70-6	1456	83	**	163[ab]	5	171[a]	8	147[b]	6	146[b]	13
91	2-cyclohexen-1-ol		822-67-3	1471	70	- -	19.0	2.4	19.6	2.6	14.6	3.5	20.0	4.6
92	2-ethyl-1-hexanol		104-76-7	1491	83	**	10.8[a]	0.3	10.8[a]	0.7	18.2[b]	3.3	17.3[b]	1.2
93	1-octanol		111-87-5	1559	70	**	16.6[a]	0.7	16.2[ab]	3.0	12.7[bc]	0.7	9.47[c]	1.38
94	2-chlorocyclohexanol		1561-86-0	1658	98	**	15.7[a]	0.8	25.1[b]	2.2	13.5[a]	3.4	14.2[a]	3.2
95	2-furanmethanol		98-00-0	1665	98	**	19.4[a]	2.9	17.4[a]	2.1	7.28[b]	0.36	13.7[ab]	8.2
96	benzenemethanol		100-51-6	1876	108	**	14.4[a]	1.1	12.7[a]	1.2	15.5[a]	0.9	19.2[b]	2.2
	phenolic compounds (15)													
97	2-methoxyphenol		90-05-1	1867	109	**	7.29[a]	0.10	5.64[ab]	0.63	6.67[ab]	1.00	5.28[b]	1.45
98	2,6-dimethylphenol		576-26-1	1917	108	**	43.1[a]	1.3	30.7[b]	2.4	nd	nd	nd	nd
99	2,6-bis(1,1-dimethylethyl)-4-methylphenol		128-37-0	1919	205	**	49.1[a]	1.0	20.3[b]	2.9	40.7[c]	3.0	23.5[b]	4.6
100	2-methylphenol		95-48-7	2011	108	**	254[a]	13	187[b]	10	6.25[c]	0.55	4.79[c]	0.49
101	phenol		108-95-2	2014	94	**	653[a]	16	465[b]	24	18.6[c]	3.6	19.6[c]	4.1
102	2-ethylphenol		90-00-6	2079	108	**	27.9[a]	0.9	20.0[b]	1.2	nd	nd	nd	nd
103	2,5-dimethylphenol		95-87-4	2085	108	**	129[a]	10	96.2[b]	5.9	nd	nd	nd	nd
104	4-methylphenol		106-44-5	2089	108	**	2750[a]	154	1880[b]	95	85.8[c]	6.1	78.6[c]	9.1
105	3-methylphenol		108-39-4	2097	108	**	76700[a]	4500	50700[b]	2640	437[c]	47	424[c]	68
106	2,3-dimethylphenol		526-75-0	2155	108	**	72.6[a]	10.4	46.1[b]	10.2	nd	nd	nd	nd
107	4-ethylphenol		123-07-9	2182	108	**	141[a]	7	86.1[b]	2.8	nd	nd	nd	nd
108	3-ethylphenol		620-17-7	2189	108	**	36.3[a]	3.0	22.3[b]	1.2	nd	nd	nd	nd
109	3,4-dimethylphenol		95-65-8	2225	108	**	82.0[a]	8.8	49.9[b]	2.6	nd	nd	nd	nd
110	2,3,5-trimethylphenol		697-82-5	2228	121	**	30.2[a]	1.6	17.3[b]	0.9	nd	nd	nd	nd
111	2,4-bis(1,1-dimethylethyl)-phenol		96-76-4	2316	191	**	108[a]	12	32.5[b]	4.2	16.7[c]	2.0	7.24[c]	1.01
	ketones (32)													
112	2-propanone		67-64-1	1000>	58	**	479[a]	61	717[ab]	71	999[b]	440	813[ab]	104
113	3-buten-2-one[j]		78-94-4	1000>	70	**	2.35[ab]	0.42	1.61[b]	0.78	2.66[ab]	0.34	3.63[a]	1.10
114	2-pentanone		107-87-9	1000>	86	**	61.8[a]	7.7	70.3[a]	3.5	30.5[b]	7.9	45.8[c]	6.5
115	2,3-butanedione	1	431-03-8	1000>	86	**	26200[a]	2980	15400[b]	1690	18400[b]	1100	10800[c]	2350
116	1-penten-3-one		1629-58-9	1024	55	**	58.4[a]	11.7	12.2[b]	9.7	19.0[b]	3.4	12.2[b]	2.4
117	3-hexanone		589-38-8	1053	100	**	27.6[a]	1.4	24.2[a]	2.2	13.8[b]	2.3	14.2[b]	1.9
118	2,3-pentanedione	1	600-14-6	1065	100	**	353[a]	11	240[b]	22	464[c]	15	239[b]	40
119	2-hexanone		591-78-6	1083	100	- -	12.9	2.7	13.7	0.6	10.4	2.4	9.80	1.71
120	1-methoxy-2-propanone		5878-19-3	1104	88	**	70.7[a]	3.7	37.9[b]	5.6	nd	nd	nd	nd
121	3-penten-2-one		625-33-2	1128	84	**	89.0[a]	8.9	40.5[b]	6.5	49.6[b]	6.1	24.7[c]	2.8

Table 2 (Continued)

no.[a]	compd[b]	ref[c]	CAS Registry No.[d]	RI[e]	m/z[f]	sig[g]	*C. farreri* scallop C boiling concn[h] (ng/g)	SD[i] (ng/g)	steaming concn[h] (ng/g)	SD[i] (ng/g)	*P. yessoensis* scallop J boiling concn[h] (ng/g)	SD[i] (ng/g)	steaming concn[h] (ng/g)	SD[i] (ng/g)
	ketones (continued)													
122	2,3-hexanedione		3848-24-6	1136	114	**	27.9a	2.9	19.9a	1.0	74.0b	5.8	49.0c	5.4
123	2-heptanone		110-43-0	1185	114	**	74.2a	5.9	81.4a	8.3	38.8b	3.5	48.7b	7.6
124	3-octanone		106-68-3	1258	99	**	156a	3	153a	11	24.5b	14.1	33.0b	4.1
125	2-methyltetrahydrofuran-3-one		3188-00-9	1268	100	**	16.0a	1.2	15.0a	1.7	27.9b	3.4	33.4b	8.0
126	3-hydroxy-2-butanone	1	513-86-0	1288	88	**	1600a	217	1150b	50	1210b	61	774c	204
127	cyclohexanone		108-94-1	1291	98	**	8.36a	1.44	109b	18	56.7c	1.6	47.3c	5.4
128	1-hydroxy-2-propanone		116-09-6	1303	74	**	191a	37	93.0b	4.1	177a	12	97.4b	23.0
129	2-methyl-2-cyclopenten-1-one		1120-73-6	1371	67	- -	13.7	2.9	17.7	2.0	9.24	1.24	16.7	13.8
130	2-nonanone	1	821-55-6	1393	142	**	226a	10	220a	11	171b	3	197ab	26
131	3-octen-2-one		1669-44-9	1411	111	**	20.4a	1.2	9.36b	0.32	6.32c	0.72	3.56d	0.52
132	2-cyclohexen-1-one		930-68-7	1437	68	**	53.5a	3.7	57.8a	6.9	32.9b	1.3	56.1a	6.8
133	2-decanone		693-54-9	1497	156	**	43.6a	3.2	35.3b	3.3	18.7c	1.4	19.1c	4.5
134	1-(2-furanyl)ethanone		1192-62-7	1511	95	- -	25.4	7.2	29.2	7.7	17.1	3.7	36.6	52.8
135	2-undecanone		112-12-9	1602	85	**	46.4a	8.0	33.6ab	9.3	37.3ab	8.1	23.9b	4.6
136	1-(2-pyridinyl)ethanone		1122-62-9	1608	93	- -	nd	nd	nd	nd	17.8a	4.7	19.5a	4.4
137	dihydro-2(3H)furanone		96-48-0	1635	86	- -	55.2	50.1	80.4	22.6	98.3	20.2	87.4	73.6
138	1-phenylethanone	1	98-86-2	1657	105	**	15.3ab	0.5	17.5a	1.5	14.1b	1.4	15.4ab	1.0
139	1-(1-methyl-1H-pyrrol-2-yl)ethanone		932-16-1	1660	108	- -	48.4	1.8	31.2	4.3	27.1	0.6	31.7	14.6
140	2-tridecanone		593-08-8	1813	58	**	23.0a	1.2	9.62b	1.39	21.4a	1.6	13.9b	3.4
141	1-phenyl-1,2-propanedione		579-07-7	1818	105	**	10.9a	0.4	6.82b	0.60	10.3a	0.6	6.21b	0.63
142	1-(1H-pyrrol-2-yl)ethanone		1072-83-9	1977	109	**	340a	22	247b	16	296ab	40	269ab	51
143	1-(2-aminophenyl)ethanone		551-93-9	2222	120	**	6.90ab	1.85	10.1b	2.7	2.87c	0.19	5.20ac	0.71
	pyrazines (7)													
144	methylpyrazine		109-08-0	1266	94	**	14.0a	4.6	11.8a	1.5	17.9ab	1.7	25.3b	4.9
145	2,5-dimethylpyrazine		123-32-0	1321	108	**	35.7a	30.3	26.4a	10.1	91.9b	4.3	172c	13
146	2,6-dimethylpyrazine	1	108-50-9	1328	108	**	27.6a	9.2	32.2a	5.1	39.7a	2.0	66.6b	14.2
147	2,3-dimethylpyrazine	1	5910-89-4	1346	108	- -	16.5	11.2	15.5	3.3	13.8	1.3	21.8	6.1
148	2-ethyl-3-methylpyrazine		15707-23-0	1403	122	**	300a	203	347a	71	402a	25	899b	225
149	2,3,5,6-tetramethylpyrazine	1	1124-11-4	1473	136	**	24.9a	9.1	33.6ab	4.8	60.6b	4.6	116c	23
150	2-acetylpyrazine	1	22047-25-2	1631	122	**	6.50a	0.64	8.38a	1.89	17.1b	1.3	15.7b	2.3
	pyridines (4)													
151	pyridine	1	110-86-1	1179	79	**	363a	77	514a	59	923a	58	1700b	604
152	2-methylpyridine		109-06-8	1213	66	**	5.58a	0.70	7.12a	0.36	59.5b	5.8	97.6c	18.4
153	3-methylpyridine		108-99-6	1290	93	**	11.3a	1.5	12.9a	1.5	24.2ab	3.4	43.4b	25.1
154	3-ethylpyridine		536-78-7	1378	107	- -	1.20	0.09	1.35	0.13	1.03	0.25	2.21	2.77
	sulfur-containing compounds (10)													
155	dimethyl disulfide	1	624-92-0	1077	94	**	164a	43	238a	45	264a	57	644b	187
156	2-ethylthiophene		872-55-9	1177	97	**	4.69a	0.26	5.39b	0.43	0.731c	0.069	0.848c	0.143
157	4,5-dimethylthiazole		3581-91-7	1374	113	**	8.50a	1.02	4.43b	0.40	6.91ab	1.77	4.86b	1.36
158	methional	1	3268-49-3	1461	104	**	41.9a	11.5	90.3bc	31.1	70.7ab	9.8	121c	23
159	2-acetylthiazole		24295-03-2	1654	85	**	12.5a	0.9	12.1ab	1.2	7.35c	0.45	8.96bc	2.59
160	3-(methylthio)-1-propanol		505-10-2	1720	106	- -	nd	nd	nd	nd	18.6a	1.4	19.2a	2.9
161	1-(2-thienyl)ethanone		88-15-3	1782	111	**	1.58a	0.25	3.41b	0.24	4.92c	0.46	5.54c	0.97
162	N,N-dimethylthioformamide		758-16-7	1829	89	**	43.0a	15.8	84.8a	22.2	79.7a	6.2	223b	71
163	benzothiazole		95-16-9	1961	135	**	4.22a	0.31	4.53a	0.20	8.93b	0.62	7.66c	0.67
164	2-(methylthio)benzothiazole		615-22-5	2422	181	**	nd	nd	15.4b	6.5	1.14b	0.33	10.0a	2.5
	terpenes (8)													
165	α-pinene		80-56-8	1019	93	**	1.76a	0.13	1.36a	0.16	5.93b	1.10	3.83c	0.27
166	l-limonene		5989-54-8	1199	93	**	13.8a	0.8	10.2a	1.4	157b	17	114c	15
167	camphor		76-22-2	1518	108	**	4.05a	0.29	37.1b	15.4	10.4a	0.5	10.9a	0.6
168	linalool		78-70-6	1551	71	**	2.17a	0.27	3.36a	0.31	5.87b	1.43	6.46b	1.06
169	(E)-6,10-dimethyl-5,9-undecadien-2-one		3796-70-1	1859	136	- -	nd	nd	nd	nd	15.1a	2.4	13.0a	3.2
170	(Z)-jasmone		488-10-8	1947	164	**	2.77a	0.27	1.88b	0.26	1.50b	0.24	1.73b	0.27
171	nerolidol		7212-44-4	2003	107	**	nd	nd	nd	nd	7.27a	0.90	3.55b	0.87
172	farnesol		4602-84-0	2352	93	**	209a	15	34.6b	6.5	215a	38	52.6b	9.0

[a] Compound number in each class. [b] Compounds in order of their elution sequences. [c] Articles in which the compounds were reported in 1: (*11*). [d] Chemical Abstracts Service Registry Number (supplied by the author). [e] Retention indices calculated from the average of all replicates (*15*). [f] Specified fragment for calculation of compound amount. [g] **, concentration (ng/g) of a compound in a row is statistically significant ($p < 0.05$); - -, concentration (ng/g) of a compound in a row is statistically insignificant ($p > 0.05$). Values of the amount in the same row with different superscripts (a−d) are significantly different (Tukey, $p < 0.05$). [h] Mean concentration (ng/g) from four replicates; nd, not detected. [i] Standard deviation; nd, not determined. [j] Tentatively identified compound by MS database (6th edition, *Wiley Chemical Database*; Hewlett-Packard: Palo Alto, CA).

scallops analyzed. Table 2 shows that the majority of them were found to be in the miscellaneous and phenolic compound classes. These two classes have four or more components detected, whereas for other minor classes, they have two or fewer components detected in only one kind of scallop.

Comparison of Volatile Compounds in Dried Scallops

J. Agric. Food Chem., Vol. 49, No. 1, 2001 **197**

Table 3. Compounds Identified Only in *C. farreri* with Their Published Threshold Values and Odor Descriptors

no.[a]	compd	CAS Registry No.[b]	RI[c]	threshold value[d] (g/L)	odor descriptors[e]	occurrence[e]
23	4-methylbenzaldehyde	104-87-0	1654		bitter almond[2]	
98	2,6-dimethylphenol	576-26-1	1917		medicinal, phenolic[1]	
102	2-ethylphenol	90-00-6	2079		burnt, guaiacol, indole-like[1,4]	fats of equine, ram, lamb, goat[4]
103	2,5-dimethylphenol	95-87-4	2085	$1.45 \times 10^{-7;1}$	creosote, sweet, medicinal[1]	frankfurters[3]
106	2,3-dimethylphenol	526-75-0	2155	$5.89 \times 10^{-8;1}$	chemical, phenolic, stale, musty[4]	swine fat[4]
107	4-ethylphenol	123-07-9	2182	$6.00 \times 10^{-4;2}$	medicinal, phenolic, pungent[1,4]	fats of ovine-wool, beef, equine, swine[4]
108	3-ethylphenol	620-17-7	2189		phenolic, sheepy, medicinal[4]	fats of ovine-wool, beef, equine, swine[4]
109	3,4-dimethylphenol	95-65-8	2225	$3.89 \times 10^{-9;1}$	flat dry odor[4]	fats of goat, lamb, ovine-wool, equine, swine, cervine[4]
80	anthracene	120-12-7	2676		weak aromatic odor[5]	

[a] Compound number as in Table 1. [b] Chemical Abstracts Service Registry Number (supplied by the author). [c] Linear retention index (15). [d] References on threshold values: [1]Devos et al. (42); [2]Ha and Lindsay (19). [e] References: [1]Aldrich (28); [2]Burdock (43); [3]Chevance and Farmer (44); [4]Ha and Lindsay (19); [5]Montgomery and Welkom (45).

Table 4. Compounds Identified Only in *P. yessoensis* with Their Published Threshold Values and Odor Descriptors

no.[a]	compd	CAS Registry No.[b]	RI[c]	threshold value[d] (g/L)	odor descriptors[e]	occurrence[e]
136	1-(2-pyridinyl)ethanone	1122-62-9	1608	$1.9 \times 10^{1;3}$	popcorn, heavy, oily, fatty[1]	liquid sage smoke;[8] thermal degradation products of glucosamine[4]
160	3-(methylthio)-1-propanol	505-10-2	1720		raw potato[9]	Cabernet Sauvignon wine;[9] Merlot wine[9]
169	(*E*)-6,10-dimethyl-5,9-undeca-dien-2-one	3796-70-1	1859	$6.0 \times 10^{-5;1}$	hay-like[10]	Japanese green tea[10]
171	nerolidol	7212-44-4	2003		rose, apple green, citrus, woody, waxy[1]	Iberian ham;[11] crabmeats[5]
25	4-methoxybenzaldehyde	123-11-5	2032	$1.9 \times 10^{-7;2}$	sweet, balsamic, floral[1]	red fermented soybean curds[7]
63	1,2-dimethylphthalate	131-11-3	2303		slight aromatic odor[3]	Iberian ham[11]
77	1*H*-indole	120-72-9	2444	$1.5 \times 10^{-10;2}$	fecal, putrid, floral when diluted[1,2]	crabmeat;[5] fermented soybean products[6,7]

[a] Compound number as in Table 1. [b] Chemical Abstracts Service Registry Number (supplied by the author). [c] Linear retention index (15). [d] References on threshold values: [1]Buttery et al. (46); [2]Devos et al. (42); [3]Fors (36). [e] References: [1]Aldrich (28); [2]Bauer and Garbe (47); [3]Budavari (29); [4]Chen and Ho (48); [5]Chung (13); [6]Chung (14); [7]Chung (49); [8]Guillén and Manzanos (50); [9]Kotseridis and Baumes (51); [10]Kumazawa and Masuda (52); [11]Ruiz et al. (53).

In scallop C, the miscellaneous compound class was dominated by four polycyclic aromatic hydrocarbons (PAHs) including 1-methyl-9*H*-fluorene, anthracene, phenanthrene, and 9*H*-fluoren-9-one, whereas the phenol class mainly consisted of eight alkylphenols including 2,6-dimethylphenol, 2-ethylphenol, 2,5-dimethylphenol, 2,3-dimethylphenol, 4-ethylphenol, 3-ethylphenol, 3,4-dimethylphenol, and 2,3,5-trimethylphenol. In addition, 4-methylbenzaldehyde, 2-naphthalenecarboxaldehyde, and 1-methoxy-2-propanone were found only in scallop C.

PAHs are considered to be contaminants, and their origins in the scallop could be the result of accumulation from either environmental or food sources (18). Most of their odor qualities are not known. Alkylphenols were reported to contribute to the characteristic species-related flavor in red meats, and it has been suggested that these compounds could be derived from phenol-containing feeds or intestinal microbial fermentation in the animals, with the latter being most likely (19). In dried scallops, both conditions might exist. Plankton and benthos algae in the ocean could serve as sources of alkylphenols when live scallops consume and accumulate them (20), whereas during handling and drying of scallops, contaminating microbes could metabolize suitable amino acid substrates to phenolic products (19). Table 3 shows selected components in this group of compounds with their published threshold values, odor descriptors, and foods in which they were reported.

Seven compounds including 4-methoxybenzaldehyde, 1,2-dimethylphthalate, 1-(2-pyridinyl)ethanone, 1*H*-indole, 3-(methylthio)-1-propanol, (*E*)-6,10-dimethyl-5,9-undecadien-2-one, and nerolidol were found only in scallop J. Table 4 shows their reported odors, threshold values, and food items in which they were identified.

In the aldehyde class, a total of 25 compounds was found. Scallop C has more components with higher levels than those of sample J. Most *n*-aldehydes were in higher levels in scallop J, whereas most alkenals were in higher levels in scallop C. Aldehydes could be generated from lipid degradation or oxidation (21).

Five alkanes were identified and might be derived from lipid degradation (22, 23). Generally, higher levels were detected in scallop C. Alkanes do not contribute much to the odor of foods (24). For branched aromatic compounds, the majority of them were found with higher levels in scallop J, except for 1,2-dimethylbenzene. These compounds could be formed from thermal degradation of sugars and/or amino acids (25−27). Several environmental contaminants including all biphenyls (3), several naphthalenes (10), and some specific miscellaneous compounds (4) were detected with higher levels in scallop C. 1,1′-Biphenyl has a pleasant, pungent, green, mild, geranium, and peculiar odor (28, 29). Naphthalenes could be products from microbial degradation of plant materials or environmental contaminants (18). Three of six esters identified were phthalates and were considered to be contaminants. Dimethyl phthalate has a slight aromatic odor and is used as insect repellent, solvent, and plasticizer (29).

Four furans were detected, and most were in higher levels in scallop C. Furans could be thermally generated

198 *J. Agric. Food Chem.,* Vol. 49, No. 1, 2001

Chung et al.

in the Maillard reactions or from lipid oxidation (*21*). Nine of 15 alcohols were at higher levels in scallop C. Alcohols might be formed from lipid degradation or oxidation (*21*−*23*). Similarly, almost all 15 phenolic compounds were dominating in scallop C. Phenolic compounds could originate from phenol-containing feeds or intestinal microbial fermentation in the animals (*19*). Thirty-two ketones were found comprising the major class among all classes found in the samples. The levels were generally higher in scallop C. Ketones could be formed from lipid degradation and oxidation and Maillard reaction (*21*).

Both pyrazines and pyridines are mostly thermally produced (*30*). In both classes, sample J had more of these components at higher levels. Ten sulfur-containing compounds were found. Very high concentrations were found in dimethyl disulfide, methional, and *N*,*N*-dimethylthioformamide compared with the components within the same class. They were in higher levels in scallop J. Sulfur-containing compounds could originate from the degradation of sulfur-containing amino acids, which further provide additional substrates for reactions to form various sulfur-containing components (*31*). Terpenes are generally found in plant materials (*32*). The presence of this class of compound in dried scallops probably suggests dietary intake by the living scallops.

Aldehydes, alkanes, naphthalenes, esters, furans, miscellaneous compounds, alcohols, phenols, and ketones dominated in scallop C, whereas aromatic compounds, pyrazines, pyridines, sulfur-containing compounds, and terpenes were predominant in scallop J. Overall, more compounds with higher levels were detected in scallop C than those in scallop J, and such observations were generally true for almost all compounds found in both methods of preparation. From these results, the flavor quality of the dried scallops could be contributed partly by the conditions of their dwelling environment and partly by the content of the diets consumed by the live animals. Some representative classes included naphthalenes and terpenes. Apparently, the environment where scallop C lived might contain an abundant source of naphthalenes, whereas the environment in which scallop J dwelled had an available source of terpenes. The detection of 1*H*-indole and trimethylamine might indicate a microbial contribution to the flavor quality of the final products (*33, 34*). Because these compounds are less likely to be found in living animals, their presence could suggest microbial effects during drying process.

In fresh, raw scallop J, Suzuki et al. (*11*) identified dimethyl sulfide, unsaturated alcohols, and ketones. In boiled samples, they found various thermally generated products that belonged to the classes of N- or S-containing compounds, both saturated and unsaturated alcohols, aldehydes, ketones, and fatty acids. A large amount of trimethylamine was also identified. Eighty-three components were reported for their boiled samples (*11*). In our investigation, many more compounds were found in dried scallops. By comparison, only 26 compounds identified in the samples of Suzuki et al. (*11*) were found in the present samples. Such differences in quality among various scallops are probably due to the composition of the species, the forms (e.g., raw, boiled, or dried) of the samples, and the methods used for the collection of volatile components.

During the preparation of dried scallops, drying operations such as solar drying are required to dehy-

drate the adductor muscle (*35*). In the presence of both protein and carbohydrate (Table 1), and under suitable conditions (moisture and temperature) during drying (*35*), Maillard reaction could take place (*36*). Some components that could be formed from this reaction include pyrazines, pyridines, and sulfur-containing compounds (*30*). In addition, lipid oxidation could be facilitated by the presence of warm temperature and open-air conditions during drying (*37*). Some of the components such as carbohydrates, amino acids, and lipids found in the raw and boiled scallops could be degraded into smaller components, which could interact during processing to form additional components in the final dried products (*38*).

Additionally, the methods used to prepare samples might have some effect on the numbers and amounts of components found. Both boiling and steaming of samples could create additional thermally generated components in terms of numbers and amounts. However, such methods are still practiced in preparing dried scallops for oriental soups and dishes (*4*−*7*). Although the extraction method (SDE) used here has an inherent weakness, such as the creation of high quantities of thermal degradation and generation products, it is one of the most efficient extraction methods in recovering volatile components (*39*).

Because both scallops C and J have similar qualities of components, the chemical reactions and changes that they underwent during processing and extraction should be quite similar. Therefore, major differences in the overall flavor could be due to differences in the concentration in each component, their threshold value, and the presence or absence of unique components that the other dried scallops did not have.

In Tables 3 and 4, threshold values of eight compounds among other components found only in scallops C and J, respectively, reported in the literature are shown. Their calculated odor activity values (OAV), that is, ratio of concentration to threshold value, are shown in Table 5 for the two scallops prepared by different methods (*40*). 1*H*-Indole had the highest value, followed by 3,4-dimethylphenol, 2,3-dimethylphenol, 2,5-dimethylphenol, and 4-methoxybenzaldehyde. 4-Methylphenol, 1-(2-pyridinyl)ethanone, and (*E*)-6,10-dimethyl-5,9-undecadien-2-one were among the lowest. For compounds that were found only in one type of scallop, the odor effects of the phenolic compounds and the odor characteristics of 1*H*-indole seemed to be quite significant and important in scallops C and J, respectively.

On the basis of the calculated OAVs in Table 5, the 10 most potent components in boiled scallop C from strong to weak were found in the following order: 3-methylphenol > 2,3-butanedione > (*E,Z*)-2,6-nonadienal > trimethylamine > 4-methylphenol > pentanal > 1-octanol > 2-methylphenol > 3,4-dimethylphenol > 2,3-pentanedione. In boiled scallop J, the order was as follows: 2,3-butanedione > (*E,Z*)-2,6-nonadienal > trimethylamine > 3-methylphenol > pentanal > 1*H*-indole > 1-octanal > 2,3-pentanedione > heptanal > 4-methylphenol. Although the same 10 compounds were found in the steamed method for each corresponding scallop, their orders in magnitude were different as follows: for steamed scallop C, 3-methylphenol > 2,3-butanedione > trimethylamine > (*E,Z*)-2,6-nonadienal > 4-methylphenol > pentanal > 2-methylphenol > octanal > 3,4-dimethylphenol > 2,3-pentanedione; for steamed scallop J, 2,3-butanedione > trimethylamine > (*E,Z*)-2,6-nona-

Comparison of Volatile Compounds in Dried Scallops

J. Agric. Food Chem., Vol. 49, No. 1, 2001 **199**

Table 5. Reported Detection Thresholds and Calculated Odor Activity Values of Selected Compounds in Dried Scallops, *C. farreri* and *P. yessoensis*

| | | | | | calcd OAV | | | |
| | | | | | *C. farreri* | | *P. yessoensis* | |
no.[a]	compd	CAS Registry No.[b]	RI[c]	threshold value[d] (g/L)	boiling	steaming	boiling	steaming
2	pentanal	110-62-3	1000>	$2.19 \times 10^{-8;\,1}$	41.19	26.8	98.3	67.2
32	benzene	71-43-2	1000>	$1.20 \times 10^{-5;\,1}$	0.00[e]	0.00	0.00	0.00
66	2-ethylfuran	3208-16-0	1000>	$8.00 \times 10^{-3;\,3}$	0.00	0.00	0.00	0.00
70	trimethylamine	75-50-3	1000>	$5.89 \times 10^{-9;\,1}$	1260	549	542	414
112	2-propanone	67-64-1	1000>	$3.47 \times 10^{-5;\,1}$	0.01	0.02	0.03	0.02
114	2-pentanone	107-87-9	1000>	$5.50 \times 10^{-6;\,1}$	0.01	0.01	0.01	0.01
115	2,3-butanedione	431-03-8	1000>	$1.58 \times 10^{-8;\,1}$	1650	972	1160	681
165	α-pinene	80-56-8	1019	$3.89 \times 10^{-6;\,1}$	0.00	0.00	0.00	0.00
116	1-penten-3-one	1629-58-9	1024	$4.00 \times 10^{-4;\,4}$	0.00	0.00	0.00	0.00
70	chloroform	67-66-3	1026	$3.30 \times 10^{-3;\,2}$	0.00	0.00	0.00	0.00
33	toluene	108-88-3	1041	$5.89 \times 10^{-6;\,1}$	0.00	0.01	0.01	0.01
118	2,3-pentanedione	600-14-6	1065	$2.14 \times 10^{-8;\,1}$	16.51	11.2	21.7	11.2
155	dimethyl disulfide	624-92-0	1077	$2.00 \times 10^{-5;\,2}$	0.01	0.01	0.01	0.03
119	2-hexanone	591-78-6	1083	$7.08 \times 10^{-7;\,1}$	0.02	0.02	0.01	0.01
4	hexanal	66-25-1	1086	$5.75 \times 10^{-8;\,1}$	9.92	7.00	7.09	5.64
82	2-methyl-1-propanol	78-83-1	1092	$2.57 \times 10^{-6;\,1}$	0.00	0.00	0.01	0.01
121	3-penten-2-one	625-33-2	1128	$1.50 \times 10^{-6;\,4}$	0.06	0.03	0.03	0.02
34	ethylbenzene	100-41-4	1129	$1.29 \times 10^{-8;\,1}$	0.70	0.95	1.36	1.25
6	(*E*)-2-pentenal	1576-87-0	1132	$2.30 \times 10^{-3;\,2}$	0.00	0.00	0.00	0.00
35	1,4-dimethylbenzene	106-42-3	1137	$2.14 \times 10^{-6;\,1}$	0.00	0.00	0.00	0.00
36	1,3-dimethylbenzene	108-38-3	1143	$1.41 \times 10^{-6;\,1}$	0.01	0.01	0.02	0.01
83	1-butanol	71-36-3	1144	$1.51 \times 10^{-6;\,1}$	0.02	0.02	0.02	0.02
84	1-penten-3-ol	616-25-1	1161	$1.48 \times 10^{-6;\,1}$	0.30	0.37	0.09	0.11
151	pyridine	110-86-1	1179	$2.75 \times 10^{-7;\,1}$	1.32	1.87	3.35	6.17
123	2-heptanone	110-43-0	1185	$6.76 \times 10^{-7;\,1}$	0.11	0.12	0.06	0.07
37	1,2-dimethylbenzene	95-47-6	1187	$3.80 \times 10^{-6;\,1}$	0.00	0.00	0.00	0.00
9	heptanal	111-71-7	1189	$2.29 \times 10^{-8;\,1}$	8.63	5.67	10.67	6.76
72	2,4,5-trimethyloxazole	20662-84-4	1193	$5.00 \times 10^{-6;\,3}$	0.00	0.00	0.00	0.00
166	*l*-limonene	5989-54-8	1199	$2.45 \times 10^{-6;\,1}$	0.01	0.00	0.06	0.05
85	3-methyl-1-butanol	123-51-3	1208	$1.62 \times 10^{-7;\,1}$	0.02	0.02	0.04	0.03
152	2-methylpyridine	109-06-8	1213	$1.66 \times 10^{-7;\,1}$	0.03	0.04	0.36	0.59
11	(*E*)-2-hexenal	6728-26-3	1221	$1.32 \times 10^{-7;\,1}$	1.48	0.47	0.67	0.30
67	2-pentylfuran	3777-69-3	1236	$9.12 \times 10^{-8;\,1}$	1.61	1.12	0.32	0.28
12	(*Z*)-4-heptenal	6728-31-0	1247	$8.00 \times 10^{-7;\,4}$	0.32	0.20	0.12	0.09
86	1-pentanol	71-41-0	1251	$1.70 \times 10^{-6;\,1}$	0.07	0.07	0.04	0.04
124	3-octanone	106-68-3	1258	$3.24 \times 10^{-7;\,1}$	0.48	0.47	0.08	0.10
39	styrene	100-42-5	1262	$7.30 \times 10^{-4;\,2}$	0.00	0.00	0.00	0.00
144	methylpyrazine	109-08-0	1266	$1.00 \times 10^{-1;\,3}$	0.00	0.00	0.00	0.00
40	1-methyl-4-(1-methylethyl)benzene	99-87-6	1274	$1.20 \times 10^{-8;\,1}$	0.22	0.19	2.19	1.78
41	1,2,4-trimethylbenzene	95-63-6	1285	$7.76 \times 10^{-7;\,1}$	0.01	0.01	0.02	0.02
126	3-hydroxy-2-butanone	513-86-0	1288	$8.00 \times 10^{-4;\,4}$	0.00	0.00	0.00	0.00
127	cyclohexanone	108-94-1	1291	$2.88 \times 10^{-6;\,1}$	0.00	0.04	0.02	0.02
13	octanal	124-13-0	1293	$7.24 \times 10^{-9;\,1}$	36.0	21.7	41.1	28.1
60	2-ethoxyethyl acetate	111-15-9	1299	$1.00 \times 10^{-6;\,1}$	0.01	0.01	0.00	0.00
28	tridecane	629-50-5	1300	$1.66 \times 10^{-5;\,1}$	0.00	0.00	0.00	0.00
87	cyclopentanol	96-41-3	1314	$1.95 \times 10^{-4;\,1}$	0.00	0.00	0.00	0.00
145	2,5-dimethylpyrazine	123-32-0	1321	$1.50 \times 10^{-3;\,2}$	0.00	0.00	0.00	0.00
146	2,6-dimethylpyrazine	108-50-9	1328	$2.00 \times 10^{-4;\,3}$	0.00	0.00	0.00	0.00
147	2,3-dimethylpyrazine	5910-89-4	1346	$4.00 \times 10^{-4;\,3}$	0.00	0.00	0.00	0.00
88	1-hexanol	111-27-3	1354	$1.86 \times 10^{-7;\,1}$	0.14	0.15	0.15	0.14
157	4,5-dimethylthiazole	3581-91-7	1374	$4.70 \times 10^{-4;\,3}$	0.00	0.00	0.00	0.00
130	2-nonanone	821-55-6	1393	$2.29 \times 10^{-7;\,1}$	0.99	0.96	0.75	0.86
14	nonanal	124-19-6	1398	$1.35 \times 10^{-8;\,1}$	2.15	1.70	3.31	1.55
148	2-ethyl-3-methylpyrazine	15707-23-0	1403	$1.30 \times 10^{-4;\,3}$	0.00	0.00	0.00	0.01
43	1,4-dichlorobenzene	106-46-7	1449	$2.95 \times 10^{-7;\,1}$	0.07	0.06	0.10	0.09
89	1-octen-3-ol	3391-86-4	1453	$1.62 \times 10^{-8;\,1}$	8.06	8.08	2.01	2.75
90	1-heptanol	111-70-6	1456	$1.20 \times 10^{-7;\,1}$	1.36	1.42	1.22	1.22
158	methional	3268-49-3	1461	$2.00 \times 10^{-7;\,2}$	0.21	0.45	0.35	0.60
15	2-furancarboxaldehyde	98-01-1	1471	$3.16 \times 10^{-6;\,1}$	0.01	0.01	0.01	0.01
149	2,3,5,6-tetramethylpyrazine	1124-11-4	1473	$7.10 \times 10^{1;\,2}$	0.00	0.00	0.00	0.00
92	2-ethyl-1-hexanol	104-76-7	1491	$1.32 \times 10^{-6;\,1}$	0.01	0.01	0.01	0.01
44	1,2-dichlorobenzene	95-50-1	1492	$4.47 \times 10^{-7;\,1}$	0.00	0.00	0.10	0.09
133	2-decanone	693-54-9	1497	$5.25 \times 10^{-8;\,1}$	0.83	0.67	0.36	0.36
16	(*E,E*)-2,4-heptadienal	4313-03-5	1498	$1.91 \times 10^{-8;\,1}$	1.72	0.99	1.43	0.70
17	decanal	112-31-2	1503	$5.89 \times 10^{-9;\,1}$	3.59	3.01	4.73	3.20
134	1-(2-furanyl)ethanone	1192-62-7	1511	$1.10 \times 10^{2;\,2}$	0.01	0.11	0.03	0.03
167	camphor	76-22-2	1518	$3.24 \times 10^{-7;\,1}$	0.01	0.11	0.03	0.03
75	1*H*-pyrrole	109-97-7	1523	$4.96 \times 10^{-2;\,4}$	0.00	0.00	0.00	0.00
18	benzaldehyde	100-52-7	1530	$1.86 \times 10^{-7;\,1}$	3.56	3.98	5.17	5.96
168	linalool	78-70-6	1551	$6.00 \times 10^{-6;\,2}$	0.00	0.00	0.00	0.00

200 *J. Agric. Food Chem.,* Vol. 49, No. 1, 2001

Chung et al.

Table 5 (Continued)

| | | | | | calcd OAV | | | |
| | | | | | *C. farreri* | | *P. yessoensis* | |
no.[a]	compd	CAS Registry No.[b]	RI[c]	threshold value[d] (g/L)	boiling	steaming	boiling	steaming
93	1-octanol	111-87-5	1559	$3.16 \times 10^{-8; 1}$	0.52	0.51	0.40	0.30
68	5-methylfurfural	620-02-0	1580	$2.00 \times 10^{-2; 3}$	0.00	0.00	0.00	0.00
19	(*E,Z*)-2,6-nonadienal	557-48-2	1591	$7.41 \times 10^{-11; 1}$	142	520	979	389
135	2-undecanone	112-12-9	1602	$1.55 \times 10^{-7; 1}$	0.30	0.22	0.24	0.15
136	1-(2-pyridinyl)ethanone	1122-62-9	1608	$1.90 \times 10^{1; 3}$	nd[f]	nd	0.00	0.00
150	2-acetylpyrazine	22047-25-2	1631	$6.20 \times 10^{-5; 3}$	0.00	0.00	0.00	0.00
137	dihydro-2(3*H*)furanone	96-48-0	1635	$2.00 \times 10^{2; 2}$	0.00	0.00	0.00	0.00
22	phenylacetaldehyde	122-78-1	1651	$4.00 \times 10^{-6; 2}$	0.00	0.00	0.00	0.00
159	2-acetylthiazole	24295-03-2	1654	$1.00 \times 10^{-5; 3}$	0.00	0.00	0.00	0.00
138	1-phenylethanone	98-86-2	1657	$1.82 \times 10^{-6; 1}$	0.01	0.01	0.01	0.01
95	2-furanmethanol	98-00-0	1665	$3.00 \times 10^{1; 2}$	0.00	0.00	0.00	0.00
61	ethyl benzoate	93-89-0	1673	$1.74 \times 10^{-7; 1}$	0.05	0.03	0.07	0.06
50	naphthalene	91-20-3	1747	$7.94 \times 10^{-8; 1}$	4.91	4.40	1.41	1.23
161	1-(2-thienyl)ethanone	88-15-3	1782	$8.00 \times 10^{-8; 3}$	0.02	0.04	0.06	0.07
140	2-tridecanone	593-08-8	1813	$1.82 \times 10^{2; 2}$	0.00	0.00	0.00	0.00
46	1-methoxy-4-(1-propenyl)benzene	4180-23-8	1834	$4.47 \times 10^{-8; 1}$	0.26	0.21	5.66	5.03
51	2-methylnaphthalene	91-57-6	1859	$1.00 \times 10^{-5; 2}$	0.01	0.01	0.00	0.00
169	(*E*)-6,10-dimethyl-5,9-undecadien-2-one	3796-70-1	1859	$6.00 \times 10^{-5; 4}$	nd	nd	0.00	0.00
97	2-methoxyphenol	90-05-1	1867	$5.25 \times 10^{-9; 1}$	1.39	1.07	1.27	1.01
96	benzenemethanol	100-51-6	1876	$5.50 \times 10^{-3; 2}$	0.00	0.00	0.00	0.00
98	2,6-dimethylphenol	576-26-1	1917	$3.89 \times 10^{-9; 1}$	11.08	7.89	nd	nd
163	benzothiazole	95-16-9	1961	$4.50 \times 10^{-1; 2}$	0.00	0.00	0.00	0.00
142	1-(1*H*-pyrrol-2-yl)ethanone	1072-83-9	1977	$2.00 \times 10^{2; 2}$	0.00	0.00	0.00	0.00
100	2-methylphenol	95-48-7	2011	$7.76 \times 10^{-9; 1}$	32.7	24.1	0.81	0.62
101	phenol	108-95-2	2014	$4.27 \times 10^{-7; 1}$	1.53	1.09	0.04	0.05
25	4-methoxybenzaldehyde	123-11-5	2032	$1.86 \times 10^{-7; 1}$	nd	nd	0.05	0.03
103	2,5-dimethylphenol	95-87-4	2085	$1.45 \times 10^{-7; 1}$	0.89	0.67	nd	nd
104	4-methylphenol	106-44-5	2089	$8.32 \times 10^{-9; 1}$	331	226	10.3	9.44
105	3-methylphenol	108-39-4	2097	$3.55 \times 10^{-9; 1}$	21600	14300	123	119
106	2,3-dimethylphenol	526-75-0	2155	$5.89 \times 10^{-8; 1}$	1.23	0.78	nd	nd
107	4-ethylphenol	123-07-9	2182	$6.00 \times 10^{-4; 5}$	0.00	0.00	nd	nd
109	3,4-dimethylphenol	95-65-8	2225	$3.89 \times 10^{-9; 1}$	21.08	12.84	nd	nd
172	farnesol	4602-84-0	2352	$2.00 \times 10^{-5; 4}$	0.01	0.00	0.01	0.00
164	2-(methylthio)benzothiazole	615-22-5	2422	$5.00 \times 10^{-6; 3}$	nd	0.00	0.00	0.00
77	1*H*-indole	120-72-9	2444	$1.55 \times 10^{-10; 1}$	nd	nd	84.0	39.9

[a] Compound number as in Table 1. [b] Chemical Abstracts Service Registry Number (supplied by the author). [c] Linear retention index (*15*). [d] References on threshold values: [1]Devos et al. (*42*); [2]Fazzalari (*54*); [3]Fors (*36*); [4]Leffingwell and Associates (*55*); [5]Ha and Lindsay (*19*). [e] Value <0.01. [f] Not detected.

dienal > 3-methylphenol > pentanal > 1*H*-indole > octanal > 2,3-pentanedione > 4-methylphenol > heptanal. Overall, the medicinal, aromatic, woody, and ether-like odor character (*28*) of 3-methylphenol dominated in strength among other compounds in scallop C for both methods. Other phenolic compounds such as 2-methylphenol (musty, phenolic aftertaste), 4-methylphenol (medicinal, heavy), and 3,4-dimethylphenol (flat dry odor) also contributed to the overall flavor in scallop C (*28*). Although similar compounds were found in scallop J, their magnitudes were usually lower. In scallop J, the powerful buttery flavor of 2,3-butanedione was more dominant. Also, the cucumber, violet, green, waxy-like odor of (*E,Z*)-2,6-nonadienal and the fishy, oily, rancid, sweaty-like odor of trimethylamine contributed to the characteristic overall flavor in scallop J in both methods (*28*). When only those components found in only one type of scallop and with high value of OAV were considered, 3,4-dimethylphenol and 1*H*-indole were again identified in scallops C and J, respectively (Table 5). These two compounds were some of the more important characteristic odor contributors to the respective dried scallops.

Comparison between Boiling and Steaming Methods. The number of the same compounds identified in different preparation methods for the same scallop is higher than that of different scallops prepared by the same method. In scallop C, four compounds, including 2,6,10,14-tetramethylpentadecane, 1-methoxy-4-(2-propenyl)benzene, methyl hexadecanoate, and 2-(methylthio)benzothiazole, were detected in only one method, whereas in scallop J, three compounds including 2,6,10,14-tetramethylpentadecane, methyl hexadecanoate, and 2-(methylthio)benzothiazole were found in only one preparation method. However, when any one method was considered, 23 compounds were found only in one or the other type of scallop. The results were reasonable because the former involved the same species but the latter dealt with different species. More variations in the identity of compounds detected were expected to be found across species than within the same species.

Quantitatively, extracts prepared by the boiling method generally had more components at higher levels than those by the steaming method. For example, 109 and 93 of 165 and 157 combined components with higher mean concentrations in scallops C and J, respectively, were detected in the boiling method. When the statistical results were considered, similar observations were found. For scallop C prepared by different methods, a total of 75 components was significantly different (*p* < 0.05), and 68 of these compounds with higher mean values were found in the boiling method. Similarly, among 52 compounds showing significant difference in

Comparison of Volatile Compounds in Dried Scallops

J. Agric. Food Chem., Vol. 49, No. 1, 2001 **201**

scallop J, 33 compounds with higher mean values belonged to the boiling method.

The following classes were found to contain more than half of their components with higher mean concentration levels in the boiling than in the steaming methods in each scallop: acids, aldehydes, aromatics, naphthalenes, miscellaneous compounds, phenolic compounds, ketones, and terpenes. However, for classes such as alkanes, furans, alcohols, pyrazines, pyridines, and sulfur-containing compounds, the number of components with higher concentration levels was mainly found in the steaming method. Such distributions of common components among the classes showed that differences did exist in the boiling and steaming methods, but consistency in the distributions was observed for the two samples. On the basis of the recovery of components that were relatively stable and high-boiling such as naphthalenes and some known contaminants (e.g., phenanthrene, anthracene, and 1,1′-biphenyl), the recovery efficiency of the boiling method seemed to be higher than that of the steaming method.

The present procedures for boiling and steaming of scallops were similar to the actual cooking preparation of dried scallops for food (*4*− *7*). Instead of releasing the volatile components into the open environment during cooking, they were collected by the extraction solvent in the SDE apparatus. As discussed previously, analyses of the extracts prepared from different methods showed that data collected from the boiling method generally had mean levels of each component in the extracts higher than or similar to those from steaming. This might suggest that the kind of preparation method could greatly affect the retention of the volatile components in the cooked dried scallops ready to be consumed. From the present data, the boiling method was likely to release more volatile components than the steaming method and thus to lose more of them during food preparation when other conditions were kept constant. This further indicated that more volatile components at higher concentration levels were retained in the samples when the steaming method was used during cooking. If these volatile components contain important contributors to the overall flavor of dried scallops, steaming was more desirable than boiling because much stronger flavor would be retained in the steamed scallops. This was particularly important for those components that were heat stable and odorous such as naphthalenes and miscellaneous compounds. Other components identified might not have the same effect because they could be thermally generated during boiling or steaming. Future experiments using a model system may help to clarify the relationship between the preparation methods and levels of various components generated.

In summary, both scallops C and J had similar qualities except for a few classes of compounds. Concentration levels of common components in scallop C were higher than those in scallop J. On the basis of the calculated OAV, 8 of 10 of the most potent odorants found were identical for the two different scallops, but their orders of concentration were different. However, for the same scallop, their orders were similar in both boiling and steaming methods. Overall, the methods did not affect much the quality of the volatile components in each sample. The magnitude of the volatile components collected by the boiling method was generally higher than that by the steaming method.

These compounds were often found in classes such as acid, aldehydes, aromatics, naphthalenes, miscellaneous compounds, phenolic compounds, ketones, and terpenes.

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202 *J. Agric. Food Chem.*, Vol. 49, No. 1, 2001

Chung et al.

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