

Volatile Components in Crabmeats of *Charybdis feriatus*

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The volatile components of different meats (legs with claws, body, and carapace) of a popularly consumed edible crab in Asia, *Charybdis feriatus*, were investigated. Samples were extracted by simultaneous steam distillation–solvent extraction and analyzed by gas chromatography/mass spectrometry. Among 177 compounds detected, 130 were positively identified. Seventy-six compounds were previously reported in other crab species. A greater number of naphthalenes were detected in this crab compared with other crabs in the literature. Aromatic compounds, alcohols, and sulfur-containing compounds were the three predominant groups with > 15 components. Carapace tissue contained a greater number of volatile components in each group, except for sulfur-containing compounds. Most of the common components in the leg meat and the body meat were found at similar levels ($p > 0.05$). Carapace tissue generally had the highest quantity of common components among the meats. The higher levels of volatile components present in the carapace tissue might account for its stronger flavor compared with the other meats. Furthermore, the higher number of aldehydes and lower number of sulfur-containing compounds detected in the carapace meat might contribute to its unique flavor.

Keywords: *Volatiles; crabmeat; Charybdis feriatus; composition; Asia*

INTRODUCTION

The delicate flavor of crab is favored by many consumers. The volatile components of crabs, particularly blue crab (Hsieh et al., 1989; Matiella and Hsieh, 1990; Chung and Cadwallader, 1993, 1994; Chung et al., 1995) and other crabs (Rayner et al., 1981; Ando and Osawa, 1988; Flament, 1990; Cha et al., 1993), have been extensively studied. A number of compounds contributing to the flavor of blue crab have been identified including 2,3-butadione, pyrrolidine, (*Z*)-4-heptenal, 2-acetyl-1-pyrroline, and 3-(methylthio)propanal (Chung and Cadwallader, 1994).

The crab, *Charybdis feriatus*, is often caught and consumed in Southeast Asia. It has a reddish exoskeleton, and the crabmeat is very tasty and desirable. The crab is available throughout the year. Some connoisseurs consume not only the crabmeats from claws, walking legs, and body but also the soft tissue in the carapace, which they claim to have a very interesting and desirable flavor. It would be informative to investigate the volatile components of this edible crab and to contribute additional information to the literature on the volatile components of different crab species. The objectives of this experiment were to identify and to compare the volatile components of the various edible meats (legs with claws, body, and carapace) of *C. feriatus* and to explain the uniqueness of the carapace meat.

MATERIALS AND METHODS

Sample Collection and Preparation. Live crabs (*C. feriatus*), 3.7 kg, were bought three times from a seafood outlet in Hong Kong in the fall of 1996 and steamed within 1 h of

purchase. Crabs were steamed for 20 min in a large stainless pot and cooled overnight (12 h) in a refrigerator (6 °C) before meats were picked manually. Three types of meat were picked including the leg meat (LC, walking legs with claws), the body meat (B), and the carapace soft meat (C). Standard compounds for verification and quantification were purchased from Aldrich Chemical Co. (Milwaukee, WI), Tokyo Kasei Kogyo Co., Ltd. (Tokyo, Japan), and Fluka (Buchs, Switzerland).

Moisture Determination. Percentage moisture of each cooked sample was determined by an oven-drying method (AOAC, 1980).

Simultaneous Distillation and Extraction of Volatile Components. Extraction was carried out with a simultaneous distillation and extraction (SDE) apparatus (model 523010-0000, Kontes, NJ) as described in Chung and Cadwallader (1993). Sample (LC or B, 500 g; C, 250 g) was mixed with boiled, double-distilled water (ddw) in the ratio of 1 g of sample to 2 mL of ddw. Ten micrograms of 2,4,6-trimethylpyridine, internal standard (IS), was added to each sample. Redistilled dichloromethane (50 mL) was used as solvent. Boiling stones were added. SDE was timed for 2 h when sample solution started to boil. Extracts were concentrated to 15 mL in the solvent flask by a gentle steam of nitrogen (99.995% purity) and were further concentrated to 0.1 mL after passing through anhydrous sodium sulfate (2.5 g).

Identification of Volatile Components by Gas Chromatography/Mass Spectrometry (GC/MS). Qualitative analyses of samples were carried out with an HP 6890 GC/HP 5973 mass selective detector (MSD) (Hewlett-Packard Co., Palo Alto, CA). GC and MS conditions were similar to those described by Chung and Cadwallader (1993). GC conditions were as follows: pulse splitless valve delay for 30 s; injector temperature at 220 °C; and helium carrier gas at 30 cm/s. Temperature program was as follows: initial temperature of 35 °C for 5 min; ramp rate at 2 °C/min; and final temperature of 195 °C for 90 min. MSD conditions were as follows: ion source temperature at 230 °C; MS quadrupole temperature at 106 °C; interface temperature at 150 °C; ionization voltage at 70 eV; mass range at 33–450 amu; scan rate at 6.52 scans/s; and electron multiplier voltage at 1106 V. Separations were performed on a Supelcowax 10 column (60 m length × 0.25

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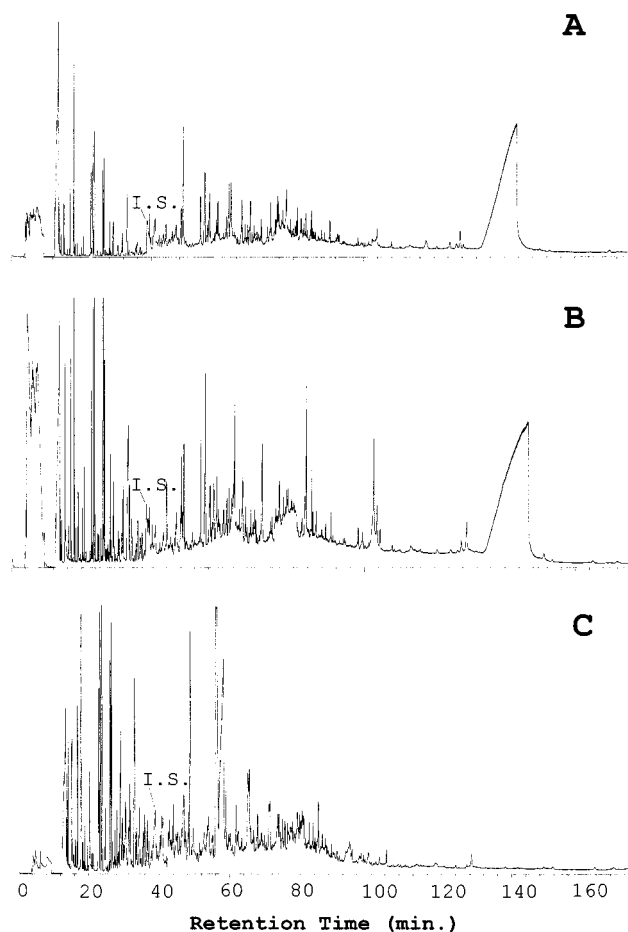


Figure 1. Typical total ion chromatograms of the meats of *C. feriatius*. (A) claws with walking legs; (B) body; (C) carapace.

mm. i.d. \times 0.25 μ m d_f , Supelco, Inc., Bellefonte, PA). Five microliters of concentrated extract was injected to a GC/MS.

Compound Identification and Quantification. Identity of compounds was confirmed by comparison of their retention time or retention indices (RI) (van den Dool and Kratz, 1963) and mass spectra with those of authentic standards under identical analytical conditions. Tentative identifications were based on matching mass spectra of unknown compounds with those in the Wiley library of mass spectral database (Hewlett-Packard Co., 1995). Quantification of each compound was determined by an internal standard method using the area ratio of a specific fragment area of a compound to that of the 2,4,6-trimethylpyridine (IS, fragment chosen is m/z 121). Relative abundance of a tentatively identified compound was estimated by the ratio of the relative area of a specific fragment of the tentatively identified compound to that of the internal standard.

Statistical Analysis. Moisture content and compounds from triplicate samples were analyzed by one-way analysis of variance (ANOVA) and compared by the Tukey test at the $p < 0.05$ level of significance (Ott, 1988).

RESULTS AND DISCUSSION

A combined total of 177 compounds were identified in the cooked meats of *C. feriatius*. Parts A, B, and C of Figure 1 show the typical chromatograms of the leg (claws with walking legs), body, and carapace meats, respectively. These compounds were divided into 14 groups including acids, aldehydes, alkanes, alcohols, aromatics, esters, furans, ketones, pyrazines, naphthalenes, pyridines, sulfur-containing compounds, terpenes, and miscellaneous compounds. Both leg and body meats contain similar numbers of compounds. The carapace

meat has many fewer sulfur-containing compounds than the other two meats. When the numbers of compounds in each group among the meats were compared, carapace meat generally had the largest number, except it had a lower count of sulfur-containing components as shown in Table 1. Table 2 shows the moisture contents of the three cooked meats, which are statistically insignificant. Table 3 shows the average yield of each type of meat recovered from the crab.

Acetic acid was the only acid identified in the acid group. The origin of this acid is unknown. This acid was not found in blue crab. Carapace meat contained almost all of the aldehydes identified among the various meats. Six aldehydes reported in blue crab were detected in the carapace meat of this crab. Generally much higher levels of aldehydes were found in the carapace meat. The quantity of phenylacetaldehyde in the carapace tissue was the highest among the meats and was 205 and 105 times higher than in the leg and body meats, respectively. This compound has a harsh, hawthorn aroma (Aldrich, 1996). Seven of the 15 aldehydes detected were unsaturated and may impart more important organoleptic properties than the saturated aldehydes (Mottram, 1991). Lipid autoxidation might be responsible for the formation of some of these aldehydes such as (*E*)-2-hexenal and (*E,Z*)-2,6-nonadienal (Josephson and Lindsay, 1986).

All compounds in the alkane group were previously detected in blue crab (Chung and Cadwallader, 1993). *n*-Alkanes generally do not contribute much to the overall flavor of foods (Grosch, 1982). However, 2,6,10,14-tetramethylpentadecane, a branched alkane, was reported to contribute a floral, woody aroma to crayfish processing byproduct (Tanchotikul and Hsieh, 1989).

Aromatic compounds comprised the largest group of compounds detected in *C. feriatius*. Thirteen of these compounds were previously identified in blue crab (Matiella and Hsieh, 1990; Chung and Cadwallader, 1993). Statistical analysis indicated that the quantity of each of these volatile compounds was generally significantly higher in the carapace meat than in the other meats. Alkylbenzenes were reported in a number of crustaceans such as shrimp and crayfish (Shye et al., 1987; Matiella and Hsieh, 1990), and some are known to contribute aromas to food. For example, 1,2,4-trimethylbenzene was reported to have a slight green aroma (Min et al., 1977). Phenolic compounds, such as phenol and 4-methylphenol, contributed characteristic sheepy and piggy aroma in some perinephric fats (Ha and Lindsay, 1991).

Twenty naphthalenes were detected in the *C. feriatius*. Compared with blue crab, the level of naphthalenes detected in this experiment was quite substantial. In the present study, most naphthalenes were detected for the first time in the crab, except naphthalene which was detected in both cooked blue crab meat and its processing byproduct (Matiella and Hsieh, 1990; Chung and Cadwallader, 1993). 1-Methylnaphthalene was reported in lobster (Cadwallader et al., 1995). Both naphthalene and 1-methylnaphthalene impart a mothball-like odor (Budavari, 1996; Cadwallader et al., 1995). *C. feriatius* might have acquired and accumulated these compounds from food sources or the environment (McElroy et al., 1989).

Nine of 11 pyrazines identified in *C. feriatius* were previously found in blue crab meat (Chung and Cadwallader, 1993). Pyrazines are regarded as thermally

Table 1. Volatile Components of Leg Meat (Claws and Walking Legs), Body Meat, and Carapace Meat of *C. feriatius*

compound ^a	RI ^b	m/z ^c	sig ^d	refs ^e	leg		body		carapace	
					concn ^f ($\mu\text{g/kg}$)	SD ^g	concn ^f ($\mu\text{g/kg}$)	SD ^g	concn ^f ($\mu\text{g/kg}$)	SD ^g
acid (1)										
acetic acid	1472	45	---		74.4	43.0	85.9	31.5	50.1	3.0
aldehydes (15)										
pentanal	1000>	44	~	1, 3	nd ^h	nd	nd	nd	264.1	42.3
hexanal	1086	56	**	1, 3, 6, 8	16.0 ^A	6.5	14.3 ^A	2.1	257.5 ^B	8.0
2-methyl-(<i>E</i>)-2-butenal	1097	84	**	8	2.3	1.3	nd	nd	9.3	0.7
(<i>E</i>)-2-pentenal	1132	55	**		nd	nd	2.8	0.8	79.7	9.1
cyclopentanecarboxaldehyde*	1171	69	~		nd	nd	0.8	0.5	nd	nd
3-methyl-2-butenal	1200	84	**		1.2 ^A	0.4	2.0 ^A	0.5	28.7 ^B	7.4
(<i>E</i>)-2-hexenal	1223	69	**	8	1.1 ^A	0.6	2.0 ^A	0.3	60.8 ^B	19.8
nonanal	1399	98	**	6	6.1 ^A	4.4	4.0 ^A	1.2	58.7 ^B	11.9
2-furancarboxaldehyde	1473	96	**		0.5 ^A	0.3	0.9 ^A	0.2	10.2 ^B	0.7
(<i>E,E</i>)-2,4-heptadienal	1500	81	~	6, 8	nd	nd	nd	nd	192.4	68.5
benzaldehyde	1530	105	---	2, 3, 6, 8	64.0	11.4	31.3	5.7	703.0	447.5
(<i>E</i>)-2-nonenal	1542	122	~		nd	nd	nd	nd	168.3	129.1
(<i>E,Z</i>)-2,6-nonadienal	1593	70	~		nd	nd	nd	nd	83.5	34.0
phenylacetaldehyde	1652	91	---		3.5	3.1	6.8	1.1	718.9	562.7
3,4-dimethylbenzaldehyde*	1790	105	~		0.6	0.3	nd	nd	nd	nd
alkanes (3)										
decane	1000	57	---	1, 6, 8	0.5	0.2	0.3	0.1	26.0	18.4
2,6,10,14-tetramethylpentadecane	1671	183	**	6	6.9 ^A	9.1	6.2 ^A	3.8	974.0 ^B	522.8
heptadecane	1700	57	**	8	nd	nd	0.3	0.0	1600.9 ^B	738.0
aromatics (34)										
benzene	1000>	78	---	1, 8	6.4	2.6	3.4	0.4	33.8	19.1
toluene	1041	91	---	1, 2, 6, 8	80.0	8.8	56.9	16.0	350.0	256.5
ethylbenzene	1130	91	**	8	22.4 ^A	1.7	17.0 ^A	6.0	143.3 ^B	29.4
<i>p</i> -xylene	1137	91	**	1, 3, 6, 8	36.0 ^A	2.8	26.2 ^A	9.1	234.6 ^B	65.1
<i>m</i> -xylene	1144	91	**	1, 3, 8	53.8 ^A	4.3	40.1 ^A	12.4	329.4 ^B	75.5
<i>o</i> -xylene	1188	91	---	1, 3, 6, 8	31.4	1.6	23.6	7.1	199.7 ^B	119.7
isopropylbenzene	1177	105	---		0.4	0.1	0.3	0.1	33.2	44.2
propylbenzene	1212	91	**	1, 3, 8	2.8 ^A	0.5	1.2 ^A	0.3	18.7 ^B	6.2
1-ethyl-3-methylbenzene	1226	105	**	1, 3, 6, 8	10.8 ^A	3.2	7.0 ^A	2.9	135.0 ^B	37.5
1,3,5-trimethylbenzene	1248	105	**	1, 3, 8	5.6 ^A	0.7	3.7 ^A	0.6	33.3 ^B	8.0
styrene	1262	104	**	1, 6, 8	4.4 ^A	1.6	7.3 ^A	5.1	27.0 ^B	4.0
1-ethyl-2-methylbenzene	1265	105	**	1, 8	2.7 ^A	0.3	2.3 ^A	0.4	20.0 ^B	7.8
1,2,4-trimethylbenzene	1285	105	**	6, 8	26.4 ^A	2.1	18.2	3.3	171.8 ^A	52.7
1,2,3-trimethylbenzene	1341	105	**	1, 3, 6, 8	5.1 ^A	0.9	4.1	0.9	45.0 ^B	19.4
1,4-dichlorobenzene*	1450	146	**	6, 8	0.5 ^A	0.3	0.6	0.1	5.1 ^B	1.2
C4-benzene*	1272	119	~		0.5	0.1	nd	nd	nd	nd
C4-benzene*	1274	119	*		0.2 ^A	0.1	0.2	0.0	1.1 ^B	0.4
C4-benzene*	1306	119	---		1.0	0.4	0.6	0.3	2.9	2.0
1,3-diethylbenzene*	1314	119	~		nd	nd	nd	nd	2.1	1.8
1,4-diethylbenzene*	1315	119	---		0.8	0.4	0.6	0.4	3.3	1.6
4-ethyl-1,2-dimethylbenzene*	1330	119	**		2.7 ^A	1.4	1.6	0.4	8.4 ^B	2.3
1-methyl-2-isopropylbenzene*	1358	119	**		2.4 ^{AB}	1.2	1.3	0.3	5.0 ^B	1.0
1-methyl-4-isopropylbenzene*	1359	119	~		nd	nd	nd	nd	10.1	4.7
1-ethyl-2,3-dimethylbenzene*	1364	119	---		2.8	1.3	1.7	0.4	15.6	8.5
1-ethyl-2,4-dimethylbenzene*	1373	119	**		5.8 ^A	2.0	3.9 ^A	1.2	22.1 ^B	0.6
1-methyl-4-isopropylbenzene*	1415	119	**		0.7 ^A	0.1	0.6 ^A	0.2	5.9 ^B	2.4
C4-benzene*	1430	119	**		2.7 ^A	0.6	2.0 ^A	0.6	26.3 ^B	13.3
C4-benzene*	1441	119	**		3.8 ^A	1.2	2.5 ^A	0.5	22.7 ^B	3.9
C4-benzene*	1494	119	**		3.0 ^A	0.1	3.3 ^A	1.1	18.7 ^B	4.3
3-methyl-1,1'-biphenyl	2104	167	**		0.7 ^A	0.2	0.5 ^A	0.1	6.9 ^B	3.3
4-methyl-1,1'-biphenyl	2117	167	**		0.8 ^A	0.2	0.5 ^A	0.1	5.2 ^B	2.3
(1-methyldodecyl)benzene*	2164	105	**		1.3 ^{AB}	0.5	0.9 ^A	0.0	4.5 ^B	1.9
3,3'-dimethyl-1,1'-biphenyl	2208	167	**		0.3 ^{AB}	0.2	0.2 ^A	0.1	1.3 ^B	0.5
4,4'-dimethyl-1,1'-biphenyl	2221	167	**		0.4 ^A	0.2	0.3 ^A	0.1	2.6 ^B	0.9
esters (4)										
<i>n</i> -butyl acetate	1078	43	---		0.9	0.3	0.8	0.1	1.5	0.4
methyl (<i>E,E</i>)-farnesate*	2210	169	**		2.0 ^A	0.6	2.5 ^A	0.3	19.1 ^B	6.0
diethyl phthalate	2372	149	---		0.4	0.2	0.2	0.1	1.1	0.6
dibutyl phthalate	>2600	149	---		2.3	0.8	1.9	0.7	2.8	1.6
furans (3)										
2-ethylfuran	1000>	81	**	1, 3, 8	1.3 ^A	0.7	1.9 ^A	0.4	78.0 ^B	18.8
2-pentylfuran	1237	81	---	1, 3, 6, 8	0.9	0.3	1.3	0.1	55.9	21.0
5-hexyldihydro-2(3 <i>H</i>)-furanone	2151	85	**		0.8 ^A	0.4	1.0 ^A	0.2	15.2 ^B	5.4
pyridines (5)										
pyridine	1180	79	---	2, 6, 8	165.9	76.7	89.2	34.5	286.4	71.6
2-methylpyridine	1214	93	---	8	5.5	2.5	2.6	0.7	4.5	1.2
3-methylpyridine	1291	93	**	8	11.6 ^B	6.3	7.5 ^A	3.0	14.6 ^A	4.7
2,4,6-trimethylpyridine (internal standard, IS)	1365	121	~		nd	nd	nd	nd	nd	nd
3-phenylpyridine	2243	155	---		0.4	0.1	0.2	0.0	9.5	7.0
2-methyl-5-phenylpyridine*	2282	169	---		2.8	3.2	0.2	0.1	nd	nd

Table 1 (Continued)

compound ^a	RI ^b	m/z ^c	sig ^d	refs ^e	leg		body		carapace	
					concn ^f ($\mu\text{g}/\text{kg}$)	SD ^g	concn ^f ($\mu\text{g}/\text{kg}$)	SD ^g	concn ^f ($\mu\text{g}/\text{kg}$)	SD ^g
naphthalenes (20)										
naphthalene	1748	128	**	1, 6	11.7 ^A	1.4	8.4 ^A	0.4	66.6 ^B	22.6
2-methylnaphthalene	1860	142	**		404.4 ^A	232.7	344.3 ^A	72.1	4800.5 ^B	1617.3
1-methylnaphthalene	1895	142	**		2.7 ^{AB}	1.9	0.8 ^A	0.3	13.1 ^B	5.9
2-ethylnaphthalene	1965	141	~		0.5	0.1	nd	nd	nd	nd
C2-naphthalene*	1954	141	**		1.4 ^A	0.5	0.4 ^A	0.2	5.1 ^B	1.4
2,7-dimethylnaphthalene	1970	156	**		4.2 ^A	1.6	1.8 ^A	1.0	33.3 ^B	13.0
1,7-dimethylnaphthalene	2000	156	**		2.2 ^A	0.5	1.0 ^A	0.5	17.5	8.1
1,6-dimethylnaphthalene	2007	156	**		1.9 ^{AB}	0.8	1.1 ^{AC}	0.6	18.9 ^{BC}	10.5
2,3-dimethylnaphthalene	2009	156	**		1.0 ^A	0.3	0.3 ^A	0.1	5.2 ^B	2.3
1,4-dimethylnaphthalene	2041	141	~		0.7	0.2	nd	nd	nd	nd
1,3-dimethylnaphthalene	2045	156	**		0.4 ^A	0.1	0.2 ^A	0.1	3.9 ^B	1.7
1,5-dimethylnaphthalene	2048	156	**		0.2 ^{AB}	0.1	0.1 ^{AC}	0.1	1.8 ^{BC}	1.0
C3-naphthalene*	2063	170	**		0.5 ^A	0.3	0.4 ^A	0.2	2.5 ^B	1.1
C3-naphthalene*	2069	170	**		0.1 ^{AB}	0.0	0.1 ^A	0.0	0.5 ^B	0.2
1,2-dimethylnaphthalene	2073	156	**		0.2 ^A	0.1	0.2 ^A	0.1	2.1 ^B	0.9
C3-naphthalene*	2111	170	**		0.9 ^A	0.4	0.6 ^A	0.3	4.8 ^B	1.7
C3-naphthalene*	2118	170	---		1.3	0.4	0.8	0.6	4.1	2.4
C3-naphthalene*	2143	170	---		0.6	0.1	0.6	0.1	2.2	1.3
C3-naphthalene*	2153	170	**		1.0 ^A	0.1	0.6 ^A	0.3	3.5 ^B	1.3
1,3,5-trimethylnaphthalene	2183	170	**		0.6 ^A	0.4	0.4 ^A	0.2	3.8 ^B	1.7
pyrazines (11)										
pyrazine	1213	80	---	1, 6	40.2	12.5	26.4	8.3	45.1	7.5
methylpyrazine	1266	94	**	1, 6, 8	38.6 ^A	12.3	17.8 ^A	4.7	73.7 ^B	14.2
2,5-dimethylpyrazine	1322	108	---	1, 6, 8	24.6	3.4	3.6	0.8	52.5	33.3
2,6-dimethylpyrazine	1329	108	**	1, 6, 8	12.4 ^{AB}	2.3	5.9 ^A	1.8	21.5 ^B	4.3
2-ethylpyrazine	1336	108	---	6, 8	0.6	0.0	0.7	0.2	nd	nd
2,3-dimethylpyrazine	1346	108	**	1, 6, 8	10.1 ^A	1.2	6.5 ^A	1.5	27.9 ^B	2.4
2,3,5-trimethylpyrazine	1403	122	**	1, 6, 8	17.2 ^{AB}	6.3	5.7 ^A	1.4	68.8 ^B	32.5
2,3,5,6-tetramethylpyrazine	1474	136	---	1, 6	0.4	0.2	0.3	0.1	1.7	1.5
2-isopropylpyrazine*	1498	119	---		1.5	0.5	11.8	11.5	nd	nd
2-acetyl-3-methylpyrazine*	1630	136	---		11.5	4.6	6.7	3.8	11.4	5.7
acetylpyrazine	1633	122	---	6, 8	4.4	1.9	4.8	2.1	27.4	17.9
alcohols (23)										
2-methyl-1-propanol	1094	43	---		1.9	0.2	1.2	0.3	nd	nd
2-propen-1-ol*	1116	57	**		0.3 ^A	0.1	0.1 ^B	0.0	nd	nd
2-pentanol	1122	45	**		0.3 ^A	0.1	0.3 ^A	0.1	0.7 ^B	0.2
1-penten-3-ol	1155	57	**	6, 8	6.1 ^A	3.0	7.3 ^A	1.3	62.7 ^B	11.8
3-buten-1-ol	1171	42	---		5.1	2.6	1.9	0.9	3.3	1.5
3-methyl-1-butanol	1209	42	---	2	1.6	0.4	1.2	0.4	6.3	3.5
1-hexanol	1356	56	**	3, 4, 6, 8	6.4 ^A	3.8	2.5 ^A	0.3	20.2 ^B	6.5
1-octen-3-ol	1454	57	---	6, 8	3.9	1.8	3.9	0.5	48.8	8.5
6-methyl-5-hepten-2-ol	1466	95	---		0.4	0.0	0.4	0.1	nd	nd
2-cyclohexen-1-ol	1473	70	**		1.1 ^A	0.5	1.1 ^A	0.4	3.3 ^B	0.1
2-ethyl-1-hexanol	1493	57	**	4	2.5 ^A	1.4	2.2 ^A	1.0	26.7 ^B	12.9
2-chlorocyclohexanol	1659	57	---		1.5	0.6	1.4	0.2	6.8	3.5
1-phenylethanol	1819	107	**		4.3 ^{AB}	1.1	3.6 ^{AC}	0.8	22.9 ^{BC}	11.0
benzyl alcohol	1882	79	**	4, 8	4.4 ^A	1.5	3.8 ^A	1.3	71.7 ^B	33.4
2,6-bis(1,1)-dimethylethyl-4-methylphenol (BHT)	1920	205	---		5.8	3.4	4.0	0.9	10.4	3.7
4-methylbenzyl alcohol	1977	122	---		nd	nd	3.2	1.9	38.5	18.7
2-methylbenzyl alcohol	1996	122	---		nd	nd	0.5	0.4	5.0	2.4
phenol	2015	94	**	2, 3, 6	9.1 ^A	2.6	12.0 ^A	1.8	78.8 ^B	28.6
nerolidol	2044	69	---	6	3.2	1.2	2.9	0.4	5.8	2.2
2,5-dimethylphenol	2086	107	---		3.3	1.1	1.8	0.7	23.0	12.8
2,4-dimethylphenol	2090	122	---		1.0	0.4	0.2	0.0	1.2	0.7
2-(1,1'-dimethylethyl)-4-methylphenol	2235	149	**		0.7 ^A	0.3	2.2 ^B	0.5	1.1 ^{AB}	0.3
2,4-bis(1,1'-dimethylethyl)phenol	2317	191	---		3.3	1.7	2.4	1.0	5.7	3.4
ketones (15)										
3-buten-2-one*	1000>	55	**	1, 3, 6	0.1 ^A	0.1	0.1 ^A	0.0	6.7 ^B	2.5
2,3-butadione	1000>	43	**	1, 3, 6-8	95.7 ^A	30.4	129.0 ^A	45.2	563.2 ^B	187.3
3-hexanone	1053	57	**	6	0.2 ^A	0.1	0.5 ^A	0.1	4.1 ^B	1.4
2,3-pentanedione	1065	43	**	6	27.7 ^A	9.8	29.6 ^A	6.5	74.2 ^B	11.7
2-hexanone	1083	43	---	6	0.5	0.3	1.0	0.9	3.6	1.8
1-methoxy-2-propanone	1104	45	---		4.3	2.2	1.6	0.5	7.8	2.9
2-heptanone	1186	43	**	3, 6, 8	5.4 ^A	4.3	4.8 ^B	0.7	36.0 ^A	9.4
3-hydroxy-2-butanone	1289	45	---	2, 6, 8	418.6	493.5	110.3	38.9	130.5	5.1
1-hydroxy-2-propanone	1304	74	---	2	10.2	7.2	136.1	81.8	34.8	2.0
2-nonanone	1394	58	**	6, 8	0.9 ^A	0.7	1.6 ^A	0.2	31.7 ^B	4.9
2-cyclohexen-1-one	1438	68	---	6	4.1	1.7	2.7	1.2	4.5	0.4
(E,E)-3,5-octadien-2-one*	1576	95	**	8	0.4 ^A	0.2	0.2 ^A	0.0	12.3 ^B	5.3
2-undecanone	1604	58	~	6	0.6	0.3	nd	nd	nd	nd
2-pentadecanone	2027	58	**		0.9 ^A	0.4	nd	nd	10.8 ^B	3.8
2-heptadecanone	2243	58	---		0.6	0.3	0.6	0.2	8.3	5.0

Table 1 (Continued)

compound ^a	RI ^b	m/z ^c	sig ^d	refs ^e	leg		body		carapace	
					concn ^f ($\mu\text{g}/\text{kg}$)	SD ^g	concn ^f ($\mu\text{g}/\text{kg}$)	SD ^g	concn ^f ($\mu\text{g}/\text{kg}$)	SD ^g
sulfur-containing compounds (27)										
hydrogen sulfide*	1000>	34	---		105.0	78.6	95.8	60.8	45.7	29.3
carbon disulfide*	1000>	76	---	6	217.2	89.7	203.9	89.9	29.8	12.6
3-(methylthio)-1-propene	1000>	88	---		6.5	2.2	3.7	1.7	8.3	2.2
dimethyl disulfide	1077	94	---	1-3, 5, 6, 8	5.6	6.4	1.6	0.4	11.1	0.9
2-methylthiophene	1097	97	**	1, 3, 6	10.1 ^A	3.0	8.3 ^A	0.2	0.6 ^B	0.2
3-methylthiophene	1124	97	**		8.1 ^A	4.2	0.7 ^{AB}	0.2	0.3 ^B	0.0
δ -3-isopentenylmethyl sulfide*	1191	61	---		2.9	1.2	1.5	0.5	1.8	0.8
2-methylthiazole*	1239	99	---		0.3	0.1	0.3	0.1	nd	nd
thiazole	1252	85	**	8	1.6 ^A	0.5	2.5 ^A	0.2	22.6 ^B	3.6
2,4,5-trimethylthiazole	1378	127	**	6	15.3 ^A	2.1	7.4 ^B	1.7	nd	nd
dimethyl trisulfide	1386	126	---	2, 6, 8	179.0	185.0	68.7	40.7	9.5	2.5
7-thiabicyclo[4.1.0]heptane	1390	81	---		3.1	1.9	2.5	1.4	nd	nd
5-ethyl-3,4-dimethylthiazole*	1443	126	---		0.1	0.1	0.2	0.2	nd	nd
3-(methylthio)propanal	1463	48	**	7	nd	nd	1.1 ^A	0.1	166.6 ^B	62.7
dimethyl sulfoxide	1563	63	---		6.6	3.4	8.3	2.7	44.2	41.9
3,5-dimethyl-1,2,4-trithiolane* (an isomer)	1610	59	---	2	2.0	0.9	1.7	1.0	nd	nd
3,5-dimethyl-1,2,4-trithiolane* (an isomer)	1631	59	---	2	3.1	1.3	2.3	1.2	nd	nd
2-acetylthiazole	1655	127	**	2, 5, 6, 8	19.6 ^A	5.0	16.5 ^A	1.8	162.4 ^B	79.2
3-thiophenecarboxaldehyde	1687	111	---	8	8.2	3.0	15.6	4.2	nd	nd
2-thiophenecarboxaldehyde	1702	111	**	6, 8	1.5 ^A	0.6	0.2 ^B	0.1	nd	nd
3-methyl-2-thiophenecarboxaldehyde*	1736	125	---		5.4	1.7	6.3	1.3	nd	nd
1,2,4-trithiolane*	1760	124	---		10.0	3.2	7.5	3.3	nd	nd
<i>N,N</i> -dimethylmethanethioamide	1830	89	---		18.9	7.4	8.7	2.5	11.0	2.8
<i>N,N</i> -dimethylethanethioamide*	1917	103	---		8.4	5.1	6.8	4.0	nd	nd
4,6-dimethyl-1,2,3,5-tetrathiacyclo- hexane* (an isomer)	2016	184	---		3.2	1.5	1.3	0.8	nd	nd
4,6-dimethyl-1,2,3,5-tetrathiacyclo- hexane* (an isomer)	2061	184	---		3.8	1.5	1.6	0.9	nd	nd
3-phenylthiophene*	2140	160	---		0.4	0.2	0.2	0.0	nd	nd
2-methyl-4-phenylthiazole*	2279	134	---		0.2	0.1	0.1	0.0	9.6	4.5
2-(methylthio)benzothiazole	2422	181	---		0.3	0.3	0.2	0.1	0.7	0.3
terpenes (3)										
limonene	1201	68	**	1, 3, 6, 8	2.0 ^{AB}	0.2	1.1 ^{AC}	0.4	7.6 ^{BC}	3.7
camphor	1520	81	---		15.7	9.9	16.4	9.9	nd	nd
β -ionone	1944	77	---		nd	nd	0.8	0.2	32.2	17.7
miscellaneous (13)										
trimethylamine	1000>	58	---	5-7	869.1	474.7	966.0	630.4	457.4	492.9
bromochloromethane	1054	130	**		17.5 ^{AB}	6.8	7.0 ^A	1.4	24.9 ^B	3.3
trimethyloxazole*	1193	111	---	2, 6	1.0	0.3	0.9	0.2	0.4	0.2
(dimethylamino)acetonitrile	1244	83	---		1.4	0.9	1.0	0.4	nd	nd
2,3-dihydro-5-methyl-1 <i>H</i> -indene*	1480	117	**		3.0 ^A	1.1	2.0 ^A	0.3	20.6 ^B	3.6
2,3-dihydro-4-methyl-1 <i>H</i> -indene*	1506	117	**		1.4 ^A	0.1	1.1 ^B	0.2	16.2 ^{AB}	7.7
1 <i>H</i> -pyrrole	1525	67	---	1, 2, 6, 8	18.9	4.8	11.7	2.6	56.6	29.2
<i>N,N</i> -dibutylformamide	1773	72	---		14.8	9.2	31.4	19.6	43.3	13.6
phenylacetonitrile	1919	117	**		0.2 ^A	0.1	0.3 ^A	0.0	8.0 ^B	3.4
1-chloro-octadecane	2306	57	~		nd	nd	nd	nd	11.5	7.6
9 <i>H</i> -fluorene	2338	166	**		0.4 ^A	0.1	0.2 ^A	0.0	1.7 ^B	0.7
1 <i>H</i> -indole	2445	117	**	2, 6	5.0 ^A	3.3	5.1 ^A	1.4	46.9 ^B	10.1
3-methyl-1 <i>H</i> -indole	2492	130	**		0.3 ^A	0.1	0.3 ^A	0.0	4.2 ^B	1.7

^a *, compound tentatively identified by mass spectrum. ^b Retention indices calculated on the basis of van den Dool and Kratz (1963). ^c Mass/charge value, fragment used for amount calculation. ^d **, statistically significant difference ($p < 0.05$) among samples in a row; ---, statistically insignificant difference ($p > 0.05$); ~, not determined. Values of the amount in the same row with different superscripts (A-C) are significantly different (Tukey, $p < 0.05$). ^e References: 1, Matiella and Hsieh, 1990; 2, Ando and Osawa, 1988; 3, Hsieh et al., 1989; 4, Flament, 1990; 5, Rayner et al., 1981; 6, Chung and Cadwallader, 1993; 7, Chung and Cadwallader, 1994; 8, Cha et al., 1993. ^f Average concentration of a compound (μg per kg of dry sample), from three batches of samples. ^g SD, standard deviation. ^h nd, not determined.

Table 2. Moisture Contents of the Meats from Claws and Walking Legs, Body, and Carapace of *C. feriatius*

meat	moisture content ^a (w/w %)	SD ^b
leg	66.73	1.45
body	66.83	1.28
carapace	66.58	2.45

^a Each moisture content was calculated from three batches of cooked crabs, each with three replicates. No statistical difference among the meats at $p < 0.05$. ^b SD, standard deviation.

generated products in the reaction between reducing sugars and amino acids (Ho and Carlin, 1989). Pyra-

Table 3. Percentage Recovery of Meats from Cooked *C. feriatius*

meat	tissue recovered ^a (w/w %)	SD ^b
leg	20.18	1.96
body	18.63	0.14
carapace	7.91	1.17

^a Each meat was calculated from three batches of cooked crabs. ^b SD, standard deviation.

zines generally impart a nutty and desirable aroma notes to food (Fors, 1983). The levels of four pyrazines,

namely, methylpyrazine, 2,6-dimethylpyrazine, 2,3-dimethylpyrazine, and 2,3,5-trimethylpyrazine, were found to be significantly higher ($p < 0.05$) in the carapace meat than in the other crab meats. No differences were observed for the other compounds in this group.

Sulfur-containing compounds are another large group composed of 27 compounds. These compounds generally have very low odor threshold values (e.g., dimethyl trisulfide, 0.008 mg/L; Milo and Grosch, 1996) and characteristic odor, making them quite important in the overall aroma of crabmeat. 3-(Methylthio)propanal, which has a soy sauce-like aroma note, was important in blue crab meat (Chung and Cadwallader, 1994). Compounds such as dimethyl disulfide, dimethyl trisulfide, and 1,2,4-trithiolane were important sulfurous volatile components in shiitake mushroom (Chen et al., 1986). Fifteen components of this group were detected in the carapace tissue, whereas 26 and 27 were detected in the leg meat and body meat, respectively.

Three terpenes were detected in the samples. Limonene was previously reported in blue crab meat (Hsieh et al., 1989; Matiella and Hsieh, 1990; Chung and Cadwallader, 1993) and was detected in all three meats of *C. feriatus*. Camphor and β -ionone were not detected in the leg and carapace meats, respectively. Terpenes might originate from plant materials that the crabs consumed.

Twenty-three alcohols were detected, and 22 of them were positively identified. Eight of these alcohols were previously found in the blue crab, the snow crab effluent, and other crab samples (Flament, 1990; Cha et al., 1993; Chung and Cadwallader, 1993). Most of the common alcohols did not differ in quantity between the leg and body meats ($p > 0.05$). However, the average amount of each alcohol was much higher in the carapace tissue than in any of the other two meats. Among these alcohols, the amount of benzyl alcohol in carapace tissue was 16 and 19 times greater in the carapace tissue than in the leg and body meats, respectively. Benzyl alcohol, having a sharp burning taste and faint aromatic odor, is often found in essential oils (Aldrich, 1996; Bauer et al., 1997). 1-Alkanols have odor threshold values ranging from 0.5 to 20 mg/kg and are considered to have only a minor role in the overall aroma of food (Siek et al., 1971). Unsaturated alcohols such as 1-octen-3-ol generally have much lower threshold values than the saturated ones and may have a greater impact on the overall flavor (Mottram, 1991).

Fifteen ketones were detected, and 12 of them were found in other crab species (Ando and Osawa, 1988; Hsieh et al., 1989; Matiella and Hsieh, 1990; Cha et al., 1993; Chung and Cadwallader, 1993, 1994). 2,3-Butanedione was indicated as an important odorant in the blue crab meat and had a sour/creamy aroma (Chung and Cadwallader, 1994). Six 2-alkanones were identified and contributed little to the meat flavor (Flament et al., 1978), especially when their concentrations were low. Alicyclic ketones, such as 2-cyclohexen-1-one, were able to enhance the flavor of meat (Flament et al., 1978). Ketones were probably products of lipid oxidation (Mottram, 1991).

Four esters were detected in the samples. *n*-Butyl acetate was described as having a fruity, burning, and sweet odor (Burdock, 1995). Acetic acid detected in this experiment might contribute to the acidic moiety of the ester, whereas the butanol, which was limited in amount, contributed to the alcohol moiety. Methyl (*E,E*-

farnesate was reported in the pawpaw fruit (Shiota, 1991). Both diethyl phthalate and dibutyl phthalate contained the phthalic acid moiety. The former was odorless and described as having a bitter, disagreeable taste (Budavari, 1996). These phthalates might have originated from the diet.

Three furans including 2-ethylfuran 2-pentylfuran, and 5-hexyldihydro-2(3*H*)-furanone were detected in all of the samples. Higher quantities of these compounds were found in the carapace tissue than in the other meats. Both 2-ethylfuran and 2-pentylfuran were reported in blue crab meat (Matiella and Hsieh, 1990; Chung and Cadwallader, 1993). 2-Pentylfuran had an odor threshold value of 0.006 mg/kg and a sweet, spicy, and green odor in crayfish processing waste (van Gemert and Nettenbreijer, 1977; Tanchotikul and Hsieh, 1989). However, the reversion flavor of soybean oil was also caused by the presence of this compound (Krishnamurthy et al., 1967). 5-Hexyldihydro-2(3*H*)-furanone was described as having a fruity, peach aroma (Aldrich, 1996).

Four pyridines of five were positively identified in the crabmeats. Except pyridine, 2- or 3-methylpyridine, and 2,4,6-trimethylpyridine (which was the internal standard), the remaining compounds in the group were identified for the first time in crabmeat. Among the miscellaneous compounds, trimethylamine, trimethylloxazole, 1*H*-pyrrole, and 1*H*-indole were reported in other crab species (Cha et al., 1993; Chung and Cadwallader, 1993). (Dimethylamino)acetonitrile was reported in dried squid (Kawai et al., 1991). A minor quantity of *N,N*-dibutylformamide was reported in green tea (Shimoda et al., 1995). Bromochloromethane was reported as a volatile organic contaminant in the ham lunch meat and sandwich cookies (Heikes et al., 1995).

Among the 177 compounds reported here, 76 compounds (43%) were previously detected in other crab species. Qualitative similarity in the numbers of compounds within each compound group found between other reported crab samples and *C. feriatus* may be revealed by expressing this similarity as a percentage ratio between the number of compounds found in other crab samples and that found in *C. feriatus*. A ratio of 100% means that the numbers of compounds of each compound group found in both samples are the same, and a ratio of 0% means that the compounds identified are found only in *C. feriatus* and not in any other reported crab samples. On the basis of this percentage ratio, qualitative similarity of the positively identified compounds within each compound group between other reported crab samples and *C. feriatus* can be shown in the following order: alkanes, pyrazines (100%) > ketones (77%) > pyridines (75%) > aromatics (68%) > furans (67%) > sulfur-containing compounds (60), aldehydes (54%) > alcohols (36%) > terpenes (33%) > miscellaneous compounds (31%) > naphthalenes (8%) > acid, esters (0%). For both positively and tentatively identified compounds, this similarity may be shown in the following order: alkanes (100%) > pyrazines (82%) > ketones (80%) > furans (67%) > pyridines (60%) > aldehydes (47%) > sulfur-containing compounds (41%) > aromatics (40%) > alcohols (35%) > terpenes (33%) > miscellaneous compounds (30%) > naphthalenes (5%) > acid, esters (0%). Overall, three compound groups, including naphthalenes, acids, and esters, have very low similarity (<10%) between *C. feriatus* and other crab

samples. These compound groups might be partly responsible for the unique and characteristic flavor in *C. feriatius* as many individual compounds from these groups are present only in *C. feriatius* but not in other reported crab samples. The majority of the components among these groups of compounds might have originated from the environment or from the diet rather than from thermal generation. The characteristic flavor of this crab could be partially due to the bioaccumulation of these environmental contaminants in crabmeats. Besides, this experiment detected the presence of 2,3-butadione and 3-(methylthio)propanal in crabmeats. These were considered to be among the most important character-impact aroma compounds in cooked crustaceans (Baek and Cadwallader, 1997). Nevertheless, other character-impact aroma compounds such as 2-methyl-3-furanthiol, 2-acetyl-1-pyrroline, 2-acetyl-2-thiazoline, and bromophenols (Boyle et al., 1992; Baek and Cadwallader, 1997) were not detected in these same extracts, probably due to their minute quantities.

Among the three types of meats in *C. feriatius*, qualitative differences existed between the carapace meat and the other two types of meats, particularly in the number of sulfur-containing compounds. Carapace meat contained many fewer of these compounds. For the aldehyde group, a higher number of compounds was detected in the carapace meat than in either the leg or the body meat. Similar numbers of compounds were found for the rest of the compound groups in these three types of meats. Statistical comparison of the quantity of the common compounds among these three types of meats showed that the differences between the leg and body meats were not as great as that with the carapace tissue. The latter had much higher mean values for most compounds. The desirability and the uniqueness of the flavor of the carapace meat in *C. feriatius* might be contributed by the absence of a large number of sulfur-containing compounds, the presence of a large number of aldehydes, and the overall much higher intensity of each compound in the carapace meat than in the other two types of meats.

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Received for review September 14, 1998. Revised manuscript received March 4, 1999. Accepted March 5, 1999.

JF981027T