Comparison of Volatile Compounds among Different Grades of Green Tea and Their Relations to Odor Attributes

Mitsuya Shimoda,*,† Hiroko Shigematsu,‡ Hideki Shiratsuchi,† and Yutaka Osajima†

Department of Food Science and Technology, Faculty of Agriculture, Kyushu University, 6-10-1 Hakozaki, Higashi-ku, Fukuoka 812, Japan, and Seika Women's Junior College, 2-12-1 Minamihachiman-cho, Hakata-ku, Fukuoka 816, Japan

The contributors to the differences in the odors of different grades of green tea were selected, and the relations to the odors of their infusions are discussed. D-Nerolidol, 6-methyl-α-ionone, methyl jasmonate, coumaran, indole, and coumarin were possible contributors to a typical green tea odor. 3-Hexenoic acid and methyl jasmonate along with aliphatic alcohols and aldehydes provided fresh and brisk odors. 3-Hexenoic acid, 3,5,5-trimethyl-2(5*H*)-furanone, and 5,6,7,7a-tetrahydro-4,4,7a-trimethyl-2(4*H*)-benzofuranone gave deep and mild odors. Linalool, 2,6-dimethyl-1,3,7-octatrien-6-ol, benzeneacetaldehyde, and 3-hexenyl hexanoate afforded floral and fruity odors. 1-Ethyl-1*H*-pyrrole-2-carboxyaldehyde, 3-ethyl-4-methyl-1*H*-pyrrole-2,5-dione, 3-ethyl-3-methyl-2,5-pyrrolidinedione, coumaran, and coumarin provided burnt and sweet odors. 2-Methylbenzonitrile, 2,5-diethylphenol, and 2-ethyl-4,5-dimethylphenol afforded woody and green odors. D-Limonene, acetic acid, linalool, 2,6-dimethyl-1,3,7-octatrien-6-ol, benzeneacetaldehyde, and 3-hexenyl hexanoate gave harsh and sickening odors, while (*E*)-2-hexenal and (*E,Z*)-2,4-heptadienal gave green and sickening odors. 3-Hexenic acid and D-nerolidol provided a deep odor.

Keywords: *Volatile compounds; green tea; Sen-cha; odor attributes*

INTRODUCTION

Steamed green tea is broadly classified into Sen-cha and Gyokuro. The former is commonly consumed, and the latter is one of the highest grades of green tea, which is made from shaded tea leaves. The high acceptability of green tea may be due to many factors, but one of the most contributory factors seems to be its aroma.

On volatile compounds of green tea, many investigations have been carried out to determine important contributors to its aroma (Kawakami et al., 1981; Kosuge et al., 1978; Nguyen and Yamanishi, 1975; Takei et al., 1976; Yamaguchi and Shibamoto, 1981; Yamanishi, 1978) and also to reveal the deterioration of aroma during storage (Hara and Kubota, 1982; Hara et al., 1987; Horita, 1987). A large number of volatile compounds have been identified, and current investigations are concerned with minor or labile components that have not been reported yet in spite of their sensory importance. As described in our previous paper (Shimoda et al., 1995), the adsorptive method of isolating volatile compounds from green tea infusion yielded an aroma concentrate with superior odor attributes.

In the present paper, the important contributors to the differences in the odors of low, medium, and high grade Sen-cha and Gyokuro are shown, and the relationships of the concentrations of contributors and the odor profiles of green tea infusions are discussed.

MATERIALS AND METHODS

Green Tea. Sixty samples of green tea were obtained from The Tea Branch, Agricultural Institute of Fukuoka Prefecture, consisting of 15 samples each of high, medium, and low grade Sen-cha and Gyokuro. The Sen-cha samples were graded into three classes on the basis of market price.

Isolation of Volatile Compounds. Volatile compounds from green tea infusions were separated by a column adsorptive method described in our previous paper (Shimoda et al., 1995). Fifteen samples of green tea of the same grade were successively treated. The concentrated eluates were put together, and further concentration was conducted to about 200 μL.

Gas Chromatography–Mass Spectrometry (GC–MS). Quantification of volatile compounds was carried out on the basis of total ion chromatograms (TIC) in electron impact ionization (EI) mode. The conditions for GC–MS analysis were as described in our previous paper (Shimoda et al., 1995).

Preparative GC and Sniffing. Preparative GC and sniffing were done to evaluate odor attributes of GC peaks according to a method described in our previous paper (Shimoda et al., 1995).

Sensory Test of Green Tea Odor. To reveal the aroma characteristics of green tea samples, a sensory test was performed with respect to all 60 samples. Tea infusions were prepared by pouring about 100 mL of boiling water into a tea cup containing 5 g of green tea and allowing it to stand for 2 min. Panelists were instructed to sniff and taste green tea infusions including tea leaves. The panel was composed of three manufacturers and one professional cup-tester of green tea. Eleven odor descriptive terms in Japanese (Shigematsu et al., 1991) were used for the evaluation of green tea infusion and are interpreted as follows: The term Cha no kaori was used to describe a typical odor of green tea infusion. Sinsen-ka refers to fresh, sharp, strong, and fragrant odors. Mirume-ka refers to fresh, brisk, sharp, strong, and fragrant odors. Ooi-ka refers to deep, mild, fragrant, heavy, fruity, and sweet odors. Ichou-ka refers to floral, fragrant, fruity, sharp, and strong odors. Hi-ka refers to burnt, dry, fragrant, and sweet odors. Mokkei-shu refers to woody, raw, sickening, sharp, and green odors. Mure-shu refers to sickening, raw, wet, heavy, and flat odors. Kowaba-shu refers to harsh, sickening, raw, wet, and sharp odors. Ao-shu refers to raw, green, sharp, and sickening odors. Kaeri-ka refers to an odor feeling in the mouth, deep, aromatic, and floral odors.

Sinsen-ka results from young leaves and Mirume-ka from tea flushes, and both are preferable odor attributes in Sen-

* Author to whom correspondence should be addressed.

† Kyushu University.

‡ Seika Women's Junior College.

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Table 1. Results of the Sensory Test of Green Tea Infusions

	sensory scores[b]			
odor attribute[a]	Gyokuro	high grade Sen-cha	middle grade Sen-cha	low grade Sen-cha
green-tea-like odor	9.60 ± 1.72^{c}	10.6 ± 2.23^{c}	7.93 ± 2.46^{d}	4.33 ± 1.11^{e}
Sinsen-ka	5.07 ± 1.79^{c}	$4.67 \pm 3.18^{c,d}$	3.13 ± 2.45^{d}	1.4 ± 1.45^{e}
Mirume-ka	2.33 ± 1.84^{c}	2.53 ± 2.17^{c}	0.53 ± 0.91^{d}	0.07 ± 0.26^{e}
Ooi-ka	6.33 ± 1.84^{c}	1.20 ± 1.32^{d}	0.29 ± 0.59^{e}	0.07 ± 0.26^{f}
Ichou-ka	1.06 ± 0.98^{c}	1.80 ± 1.14^{c}	2.00 ± 1.13^{d}	1.80 ± 1.08^{d}
Hi-ka	4.33 ± 2.94	5.13 ± 1.69	5.14 ± 2.52	4.46 ± 1.44
Mokkei-shu	0.07 ± 0.25^{c}	$0.33 \pm 0.48^{c,e}$	$0.80 \pm 1.08^{d,e}$	1.60 ± 1.24^{d}
Mure-shu	2.13 ± 1.46	2.54 ± 1.50	1.94 ± 1.71	2.27 ± 1.66
Kowaba-shu	0.40 ± 0.63^{c}	0.47 ± 0.83^{c}	1.54 ± 1.84^{d}	3.20 ± 1.32^{e}
Ao-shu	0.47 ± 0.52^{c}	0.53 ± 1.06^{c}	$0.93 \pm 0.93^{c,d}$	1.60 ± 1.54^{d}
Kaeri-ka	7.4 ± 1.59^{c}	$6.87 \pm 1.85^{c,d}$	5.73 ± 1.91^{d}	3.67 ± 1.54^{e}

[a] Odor-descriptive terms in Japanese are interpreted in text. [b] Each score was the total score of four panelists and the mean of 15 samples of the same grade. Means with different superscript letters in the same row are significantly different at $p < 0.05$.

cha and Gyokuro. Ooi-ka from shaded young tea leaves is the important odor attribute in Gyokuro. Mokkei-shu and Kowaba-shu are unpleasant odor attributes from improperly harvested tea twigs and grown leaves, respectively. Ichou-ka, Hi-ka, Mure-shu, and Ao-shu are unpleasant odor attributes from improper manufacturing conditions.

For all odor attributes the samples were scored on 0−3 scales: 0 indicates "not appreciable"; 1 indicates "slightly appreciable"; 2 indicates "quite appreciable"; and 3 indicates "strongly appreciable".

RESULTS AND DISCUSSION

The results of the sensory test are shown in Table 1. The figures indicate the averages of the total score of the four panelists with respect to 15 samples. Between Gyokuro and high grade Sen-cha, although both teas had superior odor attributes, there was a significant difference in Ooi-ka, an important odor attribute in Gyokuro, and Hi-ka resulted from the heating process. Among the Sen-cha teas, Cha no kaori and Sinsen-ka decreased in lower grade teas. Mirume-ka was slightly observed in medium and low grade teas. Kowaba-shu and Mokkei-shu, which are unpleasant odor attributes resulting from grown tea leaves and tea twigs, respectively, were detected significantly in low grade Sen-cha. Since Ichou-ka, Mure-shu, and Ao-shu were odor attributes caused by improper manufacturing conditions, only small differences were observed among the four tea grades. Small differences in Ichou-ka were observed between Gyokuro and Sen-cha. With respect to Ao-shu, there was a small difference in low grade Sen-cha. No differences in Mure-shu were detected.

The combined concentrates of volatile compounds from 15 tea samples of each of low and high grade Sen-cha and of Gyokuro were applied to GC−MS analysis to obtain a typical composition of volatile compounds in each grade of green tea. The identification and quantification by FID of volatile compounds in medium grade Sen-cha have been reported in a previous paper (Shimoda et al., 1995). Table 2 lists the identified compounds and quantitative values on TIC, which were calculated from peak area ratios to internal standard and related to the weight of tea products. A total of 91 compounds were identified including 17 alcohols, 12 aldehydes, 11 ketones, 4 phenylethanones, 6 esters, 7 acids, 4 furanones and lactones, 2 phenols, 13 hydrocarbons, and 15 miscellaneous compounds.

The total concentration of alcohols in Gyokuro was only half that in low grade Sen-cha, and that in high grade Sen-cha was intermediate between those of low grade Sen-cha and Gyokuro. Two isomers of pentenol, which have a strong stinging green odor (Chen et al., 1992), were contained in Gyokuro in higher levels, but (*E*)-3-hexen-1-ol was contained in almost the same levels. Linalool and linalool oxide, which were both floral and sweet odors (Belitz and Grosch, 1987a; Wintoch, 1993), were found in low grade Sen-cha in higher levels. Hara et al. (1987) reported that 2,6-dimethyl-1,3,7-octatrien-6-ol resulted from 2,6-dimethyl-3,7-octatriene-2,6-diol by a dehydration during the heating process. Concentrations of three isomers of linalool oxides in Gyokuro were lower than those in Sen-cha teas, but their threshold values (3.6−7.0 ppm) were much higher than the quantitative values in green teas (Beritz and Grosch, 1987b). They could play a role in the quality index of green tea; that is, in Sen-cha the higher the ratio of *cis*- to *trans*-pyranoid, the higher the odor quality, and in Gyokuro the concentrations were both low. A large amount of D-nerolidol was contained in high grade Sen-cha and Gyokuro. Judging from its odor attribute (Mosandl, 1992), D-nerolidol seemed to be an important contributor to green tea odor in reasonable levels, but it could deteriorate green tea odor in an extremely high level such as in the SDE concentrate (Shimoda et al., 1995). The absence of 2,6-dimethyl-3,7-octadiene-2,6-diol in Gyokuro should be noticed. It was considered that the absence was due to the fact that it was contained in a glycoside form, which has been isolated and characterized as a natural 2,6-dimethyl-1,3,7-octatrien-6-ol precursor from lulo fruit peelings by Wintoch et al. (1993).

It was shown that the total concentration of aldehydes in low grade Sen-cha was 2 times higher compared to that in high grade Sen-cha. Since aliphatic aldehydes have a greenish and sickening odor (Chen et al., 1992), whether a tea infusion was described as Sinsen-ka or Ao-shu might be determined by the balance in aliphatic aldehydes and alcohols. (*E*,*Z*)-2,4-Heptadienal, which smelled oily green (Chen et al., 1992), was detected in a quite large amount only in low grade Sen-cha. On the other hand, (*E*,*E*)-2,4-heptadienal, whose threshold was much higher than that of (*E*,*Z*)-2,4-heptadienal (Belitz and Grosch, 1987c), was found in all grades of green tea, and a large quantity was contained in low grade Sen-cha and Gyokuro. Benzeneacetaldehyde, with a floral odor (Belitz and Grosch, 1987d), was detected in a high level from low grade Sen-cha.

Aliphatic ketones were found in higher levels in high grade Sen-cha. Cyclohexanone and 6-methyl-α-ionone, both from the oxidation of carotenoids (Kawashima, 1973), were detected in large quantities from high grade Sen-cha. 2-(2-Butoxyethoxy)ethanone might have some contribution to green tea odor. Although this compound is uncommon among natural plant products, 2-butoxyethanol, which was found in mate tea (Kawakami et al., 1991), might be its derivative. 1-(3,4-Dimethylphenyl)-ethanone and 1-(4-ethylphenyl)ethanone were found in low grade Sen-cha in higher levels. 3-Hexenyl butanoate and hexanoate have been considered to be important contributors to the odor of early spring green tea (Takei et al., 1976; Yamanishi, 1978), but they were found in low grade Sen-cha in higher levels. We concluded that the mild flavor of high grade Sen-cha was dependent on the fruity odor of hexenyl esters. Methyl jasmonate, which was reported as a contributor to black tea odor and possessed a sweet floral, tenacious

Table 2. Identification and Quantification of Volatile Compounds in Green Teas

$I^{DB\text{-}Wax}$	compound	approx concn,[a] μg/kg high-grade Sen-cha	low-grade Sen-cha	Gyokuro
	alcohols	1458	1566	970
1166	1-penten-3-ol	84	82	107
1249	*n*-pentanol	46	61	26
1324	2-penten-1-ol	29	97	107
1345	*n*-hexanol	21	17	19
1367	(*E*)-3-hexen-1-ol	42	42	41
1421	2,3-epoxyhexanol	14	8	7
1440	*n*-heptanol	tr[b]	49	tr
1458	linalool oxide (*cis*-furanoid)	29	20	11
1545	linalool	41	71	19
1554	*n*-octanol	16	18	19
1614	2,6-dimethyl-1,3,7-octatrien-6-ol	24	86	7
1724	linalool oxide (*trans*-pyranoid)	59	129	44
1751	linalool oxide (*cis*-pyranoid)	235	207	67
1870	benzenemethanol	222	203	248
1932	3-hexene-2,5-diol	94	44	tr
2023	D-nerolidol	352	193	248
2051	2,6-dimethyl-3,7-octadiene-2,6-diol	150	239	tr
	aldehydes	140	447	306
903	2-methylbutanal	20	44	59
968	*n*-pentanal	20	45	44
1073	*n*-hexanal	17	39	33
1196	(*Z*)-2-pentenal	tr	10	11
1196	(*E*)-2-hexenal	tr	15	7
1385	*n*-nonanal	12	13	15
1457	(*E*,*Z*)-2,4-heptadienal	tr	69	tr
1476	(*E*,*E*)-2,4-heptadienal	24	72	70
1604	5-methylfurfural	tr	tr	tr
1619	β-cyclocitral	tr	10	tr
1623	benzeneacetaldehyde	39	103	37
1719	4-ethylbenzaldehyde	8	27	30
	ketones	606	467	433
978	3,3-dimethyl-2-butanone	7	18	30
1019	1-penten-3-one	12	35	19
1027	3-methylene-2-pentanone	41	59	33
1314	cyclohexanone	247	86	44
1351	4-hydroxy-4-methyl-2-pentanone	7	18	15
1493	(*E*,*Z*)-3,5-octadien-2-one	38	37	11
1512	4-methylheptanone	tr	10	19
1562	(*E*,*E*)-3,5-octadien-2-one	tr	tr	tr
1582	6-methyl-3,5-heptadien-2-one	6	10	7
1740	2,6,6-trimethyl-1,4-cyclohexanedione	tr	tr	tr
1778	2-(2-butoxyethoxy)ethanone	85	66	74
2008	β-ionone 5,6-epoxide (*cis* type)	50	74	107
2068	6-methyl-α-ionone	113	54	74
	phenylethanones	159	498	356
1632	phenylethanone	7	12	7
1831	1-(3,4-dimethylphenyl)ethanone	75	303	215
1867	1-(4-ethylphenyl)ethanone	33	143	104
2239	1-(2,3,4-trimethoxyphenyl)-ethanone	44	40	30
2451	coumarin	110	94	tr
	esters	435	1013	619
863	ethyl acetate	95	134	256
969	methyl butanoate	29	37	56
1882	2,2-dimethyl-1-(2-hydroxy-1-methylethyl)-propyl 2-methylpropanoate	15	57	37
1936	3-hexenyl hexanoate	138	681	159
2006	4-phenyl-2-butyl acetate	15	18	11
2338	methyl jasmonate	143	86	100
	acids	1199	804	1934
1435	acetic acid	171	195	63
1624	4-methylbutanoic acid	11	13	tr
1635	*n*-butanoic acid	tr	7	11
1833	*n*-hexanoic acid	225	173	259
1954	3-hexenoic acid	285	87	667
1734	*n*-heptanoic acid	171	188	130
2157	*n*-nonanoic acid	336	141	804
	furanones and lactones	211	134	337
1254	dihydro-3,5-dimethyl-2(3*H*)-furanone	tr	tr	tr
1689	hexa-4-olide	22	22	tr
2074	3,5,5-trimethyl-2(5*H*)-furanone	16	18	207
2245	7-decen-5-olide	173	94	130
	phenols	280	915	778
1987	2,5-diethylphenol	191	612	522
2009	2-ethyl-4,5-dimethylphenol	89	303	256
	hydrocarbons	1560	1740	1528
800	*n*-octane	277	319	278
823	4-methyloctane	23	34	48
1037	5-ethyl-2-methyloctane	147	180	281
1100	*n*-undecane	93	128	133
1125	ethylbenzene	15	27	19
1130	1,4-dimethylbenzene	8	10	11
1134	1,3-dimethylbenzene	25	17	19
1200	*n*-dodecane	14	37	19
1203	*d*-limonene	70	91	48
1205	1-methyl-2-ethylbenzene	585	645	430
1300	*n*-tridecane	209	200	156
1400	*n*-tetradecane	35	25	30
1700	*n*-heptadecane	59	27	56
	miscellaneous compounds	2568	1858	1286
1375	2,5-dimethylpyrimidine	36	20	7
1479	methylhydrazine	19	27	11
1610	1-ethyl-1*H*-pyrrole-2-carboxaldehyde	35	29	tr
1782	2,3-butanedione monooxime	9	25	37
1831	1-(2-furanyl)-2-butanone	5	24	19
1912	2-methylbenzonitrile	8	47	19
1980	1-(1*H*-pyrrol-2-yl)ethanone	187	173	63
2260	3-ethyl-4-methyl-1*H*-pyrrole-2,5-dione	287	262	144
2325	5,6,7,7a-tetrahydro-4,4,7a-trimethyl-2(4*H*)-benzofuranone	212	339	519
2375	3-ethyl-4-methyl-2,5-pyrrolidinedione	51	30	26
2389	coumaran	136	121	41
2441	indole	1473	667	400

[a] Only approximate concentrations since percent recoveries and TIC (EI mode) response factors were not determined for each compound (assume all response factors of 1). [b] tr represents concentration less than 5 μg/kg.

jasmine-like odor (Yamanishi et al., 1973), was detected in higher level from high grade Sen-cha.

Pronounced increases in (*E*)-3-hexenoic acid and *n*-nonanoic acid were observed in higher grade teas.

Hexan-4-olide was not found in Gyokuro, but 7-decen-5-olide was contained in higher levels in high grade Sencha and Gyokuro than in low grade Sen-cha. Their concentrations, however, were far below their threshold values (1600 and 2000 ppb, respectively) (Engel et al., 1988); therefore, they play only a secondary role in green tea infusion.

In high grade Sen-cha, the concentrations of 2,5-diethylphenol and 2-ethyl-4,5-dimethylphenol with smoky odor attribute (Maga, 1987) were one-third lower compared to those in the other two teas.

Among the miscellaneous compounds, the concentrations of 2,5-dimethylpyrimidine, 1-ethyl-1*H*-pyrrole-2-carboxaldehyde, 1-(1*H*-pyrrol-2-yl)ethanone, 3-ethyl-4-methyl-1*H*-pyrrole-2,5-dione, coumaran, and coumarin in two grades of Sen-cha were much higher than those in Gyokuro. Those compounds, which could be formed during the heating process, might be responsible for Hi-ka as well as the peculiar Sen-cha odor. On the contrary, the concentration of 5,6,7,7a-tetrahydro-4,4,-7a-trimethyl-2(4*H*)-benzofuranone was higher in Gyokuro. Indole, which was regarded as an essential

Table 3. Possible Contributors to the Differences in the Odors of Different Grades of Green Teas and Relations of the Concentrations of Contributors and the Odor Attributes of Green Tea Infusions

$I^{DB\text{-}Wax}$	compound	odor threshold,[a] ppb	concn,[b] ppb				odor attributes[c]
			high grade Sen-cha	medium grade Sen-cha	low grade Sen-cha	Gyokuro	
968	*n*-pentanal	12[d]	20	36	44	59	D, H
1073	*n*-hexanal	4.5[d]	17	26	39	33	D, H
1125	(*Z*)-2-pentenal	S	tr	7	10	11	D, H
1196	(*E*)-2-hexenal	17[d]	tr	9	15	7	H, J
1203	*d*-limonene	10[d]	70	82	91	48	I
1324	2-penten-1-ol	S	29	53	97	107	D
1435	acetic acid	7[d]	171	183	195	63	I
1457	(*E*,*Z*)-2,4-heptadienal	S	tr	17	69	tr	J
1476	(*E*,*E*)-2,4-heptadienal	S	24	41	72	70	D, H
1545	linalool	6[d]	41	57	71	19	E, I
1610	1-ethyl-1*H*-pyrrole-2-carboxaldehyde	S	35	31	29	tr	F
1614	2,6-dimethyl-1,3,7-octatrien-6-ol	S	24	57	86	7	E
1623	benzeneacetaldehyde	4[e]	39	65	103	37	E, I
1912	2-methylbenzonitrile	S	8	35	47	19	G, I
1939	3-hexenyl hexanoate	S	138	295	681	159	E, I
1954	3-hexenoic acid	S	285	230	87	667	B, C, D, K
1987	2,5-diethylphenol	S	191	374	612	522	D, G
2007	*β*-ionone 5,6-epoxide	100[f]	50	61	74	107	D
2009	2-ethyl-4,5-dimethylphenol	S	89	143	303	256	D, G
2023	D-nerolidol	S	352	275	193	248	A, K
2068	6-methyl-α-ionone	S	113	84	54	74	A
2074	3,5,5-trimethyl-2(5*H*)-furanone	S	16	19	18	207	D
2245	7-decen-5-olide	S	173	142	94	130	A, D
2260	3-ethyl-4-methyl-1*H*-pyrrole-2,5-dione	S	287	285	263	144	F
2325	5,6,7,7a-tetrahydro-4,4,7a-trimethyl-2(4*H*)-benzofuranone	S	212	211	339	519	D
2338	methyl jasmonate	S	143	119	86	100	A, B, C
2375	3-ethyl-3-methyl-2,5-pyrrolidinedione	S	51	50	30	26	A, F
2389	coumaran	S	136	124	121	41	A, F
2441	indole	S	1473	912	667	400	A
2451	coumarin	0.02[d]	110	99	94	tr	A, F

[a] S indicates a preparative GC-sniffing was done. [b] The concentrations are calculated on the basis of total ion chromatograms. [c] A, possible contributors to Cha-no-kaori; B, to Sinsen-ka; C, to Mirume-ka; D, to Ooi-ka; E, to Ichou-ka; F, to Hi-ka; G, to Mokkei-shu; H, to Mure-shu; I, to Kowaba-shu; J, to Ao-shu; K, to Kaeri-ka. These odor-descriptive terms in Japanese are interpreted in the text. [d] *Compilation of Odor and Taste Threshold Values Data*, 1978. [e] Belitz and Grosch, 1987d. [f] Kawakami, 1982.

component to green tea odor (Takei et al., 1976), was detected in pronounced high levels from high grade Sen-cha.

Table 2 shows that the compositional features of volatile components of green teas are as follows: high grade Sen-cha was rich in ketones, acids, and lactones but poor in aldehydes, phenylethanones, esters, and phenols; low grade Sen-cha was rich in alcohols, aldehydes, phenylethanones, esters, and phenols but poor in acids and lactones; Gyokuro was rich in acids, lactones, and phenols but poor in ketones.

Table 3 shows the compounds that can be considered as possible contributors to the differences in the odors of high, medium, and low grade Sen-cha and Gyokuro and relations to the odor attributes of green tea infusions (Table 1). Volatile compounds that had only small variances in the quantitative values among the different grades of green teas are not listed in Table 3, even though they have lower threshold values. Judging from their quantitative values and odor attributes by preparative GC-sniffing, D-nerolidol, 6-methyl-α-ionone, methyl jasmonate, coumaran, indole, and coumarin could be considered to be possible contributors to Cha no kaori. In Gyokuro, the odor attributes of Ooi-ka and Kaeri-ka might compensate Cha no kaori by these six compounds. Among these compounds, coumaran, indole, and coumarin might be character impact compounds of Sen-cha, since their concentrations were much higher in high grade Sen-cha, and preparative GC-sniffing also supported this reasoning. 3-Hexenoic acid and methyl jasmonate might be contributors to Sinsen-ka and Mirume-ka. It is considered that C_5 and C_6 aldehydes and alcohols are responsible for Sinsen-ka and Mirume-ka, but the increases in their concentrations weakened the odor attributes, although it is clear that the aldehydes and alcohols play an essential role in the odor attributes. 3-Hexenoic acid, 3,5,5-trimethyl-2(5*H*)-furanone, and 5,6,7,7a-tetrahydro-4,4,7a-trimethyl-2(4*H*)-benzofuranone were included in large amounts in Gyokuro, and their odor attributes by preparative GC-sniffing suggested that they could be principal contributors to Ooi-ka. Linalool, 2,6-dimethyl-1,3,7-octatrien-6-ol, benzeneacetaldehyde, and 3-hexenyl hexanoate could contribute to Ichou-ka, because their sweet, floral, and fruity odors correspond to the odor attributes of Ichou-ka; their low concentrations in Gyokuro also correspond to the scores of Ichou-ka in Table 1. Hi-ka refers to burnt, dry, fragrant, and sweet odors and develops during a final heating process on a pan. The sensory scores were quite high in high and medium grade Sen-cha. Therefore, it was considered that 1-ethyl-1*H*-pyrrole-2-carboxyaldehyde, 3-ethyl-4-methyl-1*H*-pyrrole-2,5-dione, 3-ethyl-3-methyl-2,5-pyrrolidinedione, coumaran, and coumarin might contribute to Hi-ka. 2-Methylbenzonitrile, 2,5-diethylphenol, and 2-ethyl-4,5-dimethylphenol along with aliphatic aldehydes and alcohols might be contributors to Mokkei-shu. It was, however, difficult to select possible contributors to Mure-shu, since no significant differences were observed in Mure-shu. Judging from the odor attributes of compounds in Table 3, *n*-pentanal, *n*-hexanal, (*E*)-2-pentenal, (*E*)-2-hexenal, and (*E*,*E*)-2,4-heptadienal might contribute to Mure-shu. Since Kowaba-shu, which was intensely observed in low grade Sen-cha, has odor attributes of harsh, sickening, raw, and sharp, D-limonene, acetic acid, linalool, 2,6-dimethyl-1,3,7-octatrien-6-ol, benzeneacetaldehyde, and 3-hexenyl hexanoate seemed to be possible contributors. It was difficult to distinguish the compounds contributing to Sinsen-ka and Ao-shu. However, (*E*)-2-hexenal and (*E,Z*)-2,4-heptadienal, which increased in lower grade Sen-cha, might be possible contributors to Ao-shu. Kaeri-ka, which refers to deep, aromatic, and floral odors, was observed intensely in Gyokuro but little in low grade Sen-cha. Therefore, judging from the quantitative values, 3-hexenoic acid and D-nerolidol were possible contributors to Kaeri-ka; D-nerolidol could be an especially important contributor to Kaeri-ka owing to its long-lasting floral odor (Mosandl, 1992).

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