Flavor of Green Tea

By TEI YAMANISHI

Food Chemistry Laboratory, Ochanomizu University

The most popular green tea in Japan is Sencha. This is made of young tender leaves by steaming, rolling and firing (oven drying) and is well twisted. By steaming in the first step of the manufacturing process, the green color of the leaves can be well maintained. In Kyushu district, Kamairi-cha is produced. This is made by pan-firing process similar to Chinese green tea.

There are many types and grades of green tea in Japan and other Asian countries. Virtually, every tea has a distinctive aroma and this difference is so pronounced that an organoleptic assessment by a tea taster is sufficient to identify the season, the manufacturing process and even the geographical location in which the tea was grown.

This paper deals with the aroma components of several distinctive green teas and their aroma characteristics.

First of all, aroma compounds identified from green tea up to date are listed in Table 1.[1] Most of the compounds in Table 1 were identified by silicagel column chromatography of the aroma concentrate from tea samples followed by combined gas chromatography—mass spectrometry.[2]

Table 1. Aroma compounds identified from green tea

1. Hydrocarbons	
1. Toluene	C_7H_8
2. Limonene	$C_{10}H_{16}$
3. α-Cubebene	$C_{15}H_{24}$
4. α-Copaene	$C_{15}H_{24}$
5. Caryophyllene	$C_{15}H_{24}$
6. γ-Muurolene	$C_{15}H_{24}$
7. α-Muurolene	$C_{15}H_{24}$
8. δ-Cadinene	$C_{15}H_{24}$
9. Calamenene	$C_{15}H_{24}$
10. α-Humulene	$C_{15}H_{24}$
11. β-Sesquiphellandrene	$C_{15}H_{24}$
2. Alcohols	
1. 2-Methylpropanol	$C_4H_{10}O$
2. Butanol	$C_4H_{10}O$
3. Furfurylalcohol	$C_5H_6O_2$
4. 1-Penten-3-ol	$C_5H_{10}O$
5. *cis*-2-Penten-1-ol	$C_5H_{10}O$
6. 3-Methylbutanol	$C_5H_{12}O$
7. Pentanol	$C_5H_{12}O$
8. *cis*-3-Hexen-1-ol	$C_6H_{12}O$
9. *trans*-2-Hexen-1-ol	$C_6H_{12}O$
10. Hexanol	$C_6H_{14}O$
11. Benzyl alcohol	C_7H_8O
12. Heptanol	$C_7H_{16}O$
13. 2-Phenylethanol	$C_8H_{10}O$
14. 1-Phenylethanol	$C_8H_{10}O$
15. Octanol	$C_8H_{18}O$
16. Nonanol	$C_9H_{20}O$
17. 3s-(+)-3, 7-Dimethyl-1, 5, 7-octatrien-3-ol	$C_{10}H_{16}O$
18. Linalool	$C_{10}H_{18}O$
19. Nerol	$C_{10}H_{18}O$
20. Geraniol	$C_{10}H_{18}O$
21. α-Terpineol	$C_{10}H_{18}O$
22. Linalool oxide I (*cis*, furanoid)	$C_{10}H_{18}O_2$
23. Linalool oxide II (*trans*, furanoid)	$C_{10}H_{18}O_2$
24. Linalool oxide III (liquid, pyranoid)	$C_{10}H_{18}O_2$
25. Linalool oxide IV (solid, pyranoid)	$C_{10}H_{18}O_2$
26. Nerolidol	$C_{15}H_{26}O$
27. α-Cadinol	$C_{15}H_{26}O$
28. Cubenol	$C_{15}H_{26}O$
29. *epi*-Cubenol	$C_{15}H_{26}O$
3. Aldehydes	
1. *trans*-2-Hexenal	$C_6H_{10}O$

2. 5-Methylfurfural $C_6H_6O_2$
3. Benzaldehyde C_7H_6O
4. Heptanal $C_7H_{14}O$
5. Nonanal $C_9H_{18}O$

4. Ketones

1. Acetophenone C_8H_8O
2. *trans*-3, *trans*-5-Octadien-2-one $C_8H_{12}O$
3. 6-Methyl-*trans*, *trans*-3, 5-hepta-dien-2-one $C_8H_{12}O$
4. *trans*-3-Octen-2-one $C_8H_{14}O$
5. *cis*-Jasmone $C_{11}H_{16}O$
6. α-Ionone $C_{13}H_{20}O$
7. β-Ionone $C_{13}H_{20}O$
8. Geranylacetone $C_{13}H_{22}O$
9. 3, 4-Dihydro α-ionone $C_{13}H_{22}O$
10. Theaspirone $C_{13}H_{20}O_2$
11. 6, 10, 14-Trimethylpentadecan-2-one $C_{18}H_{30}O$

5. Esters

1. *cis*-3-Hexenyl butyrate $C_{10}H_{18}O_2$
2. *cis*-3-Hexenyl *trans*-2-hexenoate $C_{12}H_{20}O_2$
3. Neryl acetate $C_{12}H_{20}O_2$
4. α-Terpinyl acetate $C_{12}H_{20}O_2$
5. *cis*-3-Hexenyl hexanoate $C_{12}H_{22}O_2$
6. *cis*-3-Hexenyl benzoate $C_{13}H_{16}O_2$
(7) Methyl jasmonate $C_{13}H_{20}O_3$

6. Lactones

1. Coumarin $C_9H_6O_2$
(2) Jasmine lactone $C_{10}H_{16}O_2$
3. Dihydroactinidiolide $C_{11}H_{16}O_2$

7. Acids

1. Butyric $C_4H_8O_2$
2. Pentanoic $C_5H_{10}O_2$
3. *cis*-3-Hexenoic $C_6H_{10}O_2$
4. *trans*-2-Hexenoic $C_6H_{10}O_2$
5. Hexanoic $C_6H_{12}O_2$
6. Benzoic $C_7H_6O_2$
7. *trans*-Geranic $C_{10}H_{16}O_2$
8. Decanoic $C_{10}H_{20}O_2$

8. Phenols

1. Phenol C_6H_6O
2. *o*-Cresol C_7H_8O
3. *m*-, *p*-Cresol C_7H_8O
4. Salicylic acid $C_7H_6O_3$
5. Methylsalicylate $C_8H_8O_3$
6. 4-Vinylphenol $C_9H_{10}O_2$
7. 4-Ethylguaiacol $C_9H_{12}O_2$
(8) Isoeugenol
(9) Vanillin

9. Miscellaneous oxygenated compounds

1. 1, 4-Dimethoxybenzene $C_8H_{10}O_2$
2. Anethol $C_{10}H_{12}O$

10. Sulfur compounds

1. Hydrogen sulfide H_2S
2. Dimethylsulfide C_2H_6S

11. Nitrogenous compounds

1. 2-Acetylpyrrole C_6H_7ON
2. 1-Ethyl-2-formylpyrrole C_7H_9ON
3. Indole C_8H_7N
4. Benzylcyanide C_8H_7N
5. 1-Ethyl-2-acetylpyrrole $C_8H_{11}ON$
6. Diphenylamine $C_{12}H_{11}N$

Pyrazines

7. Methylpyrazine $C_5H_6N_2$
8. 2, 3-Dimethylpyrazine $C_6H_8N_2$
9. 2, 5-Dimethylpyrazine $C_6H_8N_2$
10. 2, 6-Dimethylpyrazine $C_6H_8N_2$
11. Ethylpyrazine $C_6H_8N_2$
12. 2-Ethyl-5-methylpyrazine $C_7H_{10}N_2$
13. 2-Ethyl-6-methylpyrazine $C_7H_{10}N_2$
14. 2-Ethyl-3-methylpyrazine $C_7H_{10}N_2$
15. Trimethylpyrazine $C_7H_{10}N_2$
16. 2, 5-Diethylpyrazine $C_8H_{12}N_2$
17. 2, 6-Diethylpyrazine $C_8H_{12}N_2$
18. 3-Ethyl-2, 5-dimethylpyrazine $C_8H_{12}N_2$
19. Tetramethylpyrazine $C_8H_{12}N_2$
20. 2, 5-Diethyl-3-methylpyrazine $C_9H_{14}N_2$
21. 2, 6-Diethyl-3-methylpyrazine $C_9H_{14}N_2$
22. 6, 7-Dihydro-5H-cyclo-pentapyrazine $C_7H_8N_2$
23. 2-Methyl-6, 7-dihydro-5H-cyclo-penta-pyrazine $C_8H_{10}N_2$
24. 5-Methyl-6, 7-dihydro-5H-cyclo-penta-pyrazine $C_8H_{10}N_2$
25. 2-(2′-Furyl)-pyrazine $C_8H_6ON_2$
26. 2-(2′-Furyl)-5(or 6)-methylpyrazine $C_9H_8ON_2$

To look over a typical aroma pattern of green tea of the first grade, a diagram was prepared by plotting the fraction number of silicagel column chromatography against the retention time of gas chromatography as shown in Fig. 1. The size of bar in the diagram presents the relative quantity of each component.

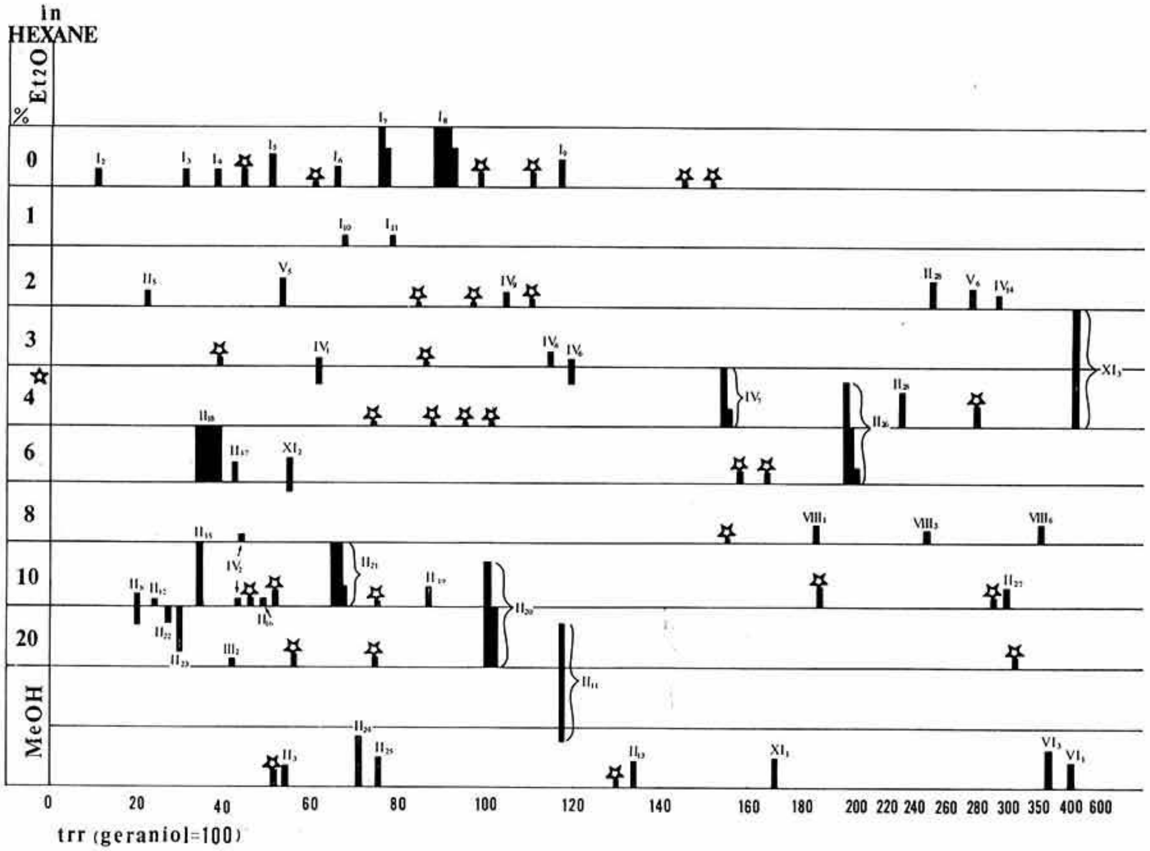

Fig. 1. Diagram of the aroma composition of green tea
Note : Numbers on each bar present compound number in Table 1.
Star marked bar present a unknown compound.

Sen-cha

Aroma of spring green tea which made from the tea flush harvested in spring is especially favorite in Japan, because of its briskness. The components responsible to the briskness are *cis*-3-hexen-1-ol along with it's hexanoate and *trans*-2-hexenoate[3] and also dimethylsulfide.[4]

Sen-cha from special variety Sayamamidori (registered in 1953) and effects of pre-withering[5]

Sen-cha made from var. Sayamamidori has a distinctive aroma when compared with that from var. Yabukita (a popularized variety for green tea). Especially when the tea flush is subjected to slight withering before steaming, the excellent flavor is pronounced.

By comparison of the aroma patterns of Sencha from var. Sayamamidori and var. Yabukita, it was recognized that nerolidol and indole are of greater quantities in var. Sayamamidori than in var. Yabukita and on the contrary monoterpene alcohol such as linalool and α-terpineol are in less amounts.

When pre-withering process was employed, *cis*-3-hexenyl hexanoate, *cis*-3-hexenyl *trans*-2-hexenoates and some esters are increased while the amount of indole was reduced to a proper quantity. Such chemical changes seemed to make the aroma of var. Sayamamidori Sen-cha more attractive.

Kamairi-cha

Flavor of Kamairi-cha is a little bit different from that of Sen-cha. The difference seemed to be caused by the difference of heating process, i.e. pan-firing heating is stronger than steaming, with higher temperature than steaming.

Hexanol, *cis*-3-hexen-1-ol, *trans*-2-hexen-1-ol were in less amount while hexanoic acid, α-ionone, β-ionone and nerolidol were in larger quantities when compared with Sen-cha.

Hoji-cha (Roasted green tea)[6]

Hoji-cha is usually made from lower grade of green tea, i.e. Ban-cha (a coarse tea, made from coarser leaves, or by being separated from raw Sen-cha in the refining process), by roasting at around 200°C for a few minute. Roast flavor makes Ban-cha much more acceptable.

Aroma concentrate from Hoji-cha had a strong typical roast flavor and its yield was much larger than that of original Sen-cha, i.e. 45 mg% (yield from original Sen-cha, 17.5 mg%).

Table 2. Furans and pyrroles in the aroma concentrates from Hoji-cha and its original Sen-cha

	Hoji-cha	Original Sen-cha
Furans	%	%
Furfurylalcohol	13.7	0.5
Furfural	9.3	—
2-Acetylfuran	4.7	—
5-Methylfurfural	2.9	0.2
Pyrroles		
Pyrrylmethylketone	5.4	0.9
2-Formylpyrrole	2.6	—
1-Ethylformylpyrrole	4.7	0.9
a pyrrole compound	9.1	0.9

The numbers of % were obtained by measuring the area of each peak as a percentages of the total area of all the peaks on the gas chromatograms of aroma concentrates from Hoji-cha and original Sen-cha.

It is known that the main components of roast flavor of various foods are pyrazines. Therefore, the aroma concentrate from Hoji-cha was separated into basic, acidic and neutral fractions. The propotion of the three fractions was as follows; basic fraction 29% (in the original green tea, only a trace amount), acidic fraction 24% and neutral fraction 47%.

The constituents identified in the basic fraction were all pyrazines listed in Table 1.

Besides pyrazines, furans and pyrroles increased remarkably as shown in Table 2.

On the other hand, most alcohols i.e. butanol, pentanol, *cis*-2-penten-1-ol, *cis*-3-hexen-1-ol, linalool, benzylalcohol and 2-phenyl-ethanol were reduced significantly by roasting.

Vietnamese green tea (Bach-Mao tea, the best quality of Vietnamese green tea) and Lotus tea[7]

Tea plant grown in Vietnam belongs to the family of Theacease originated from Shan district. Manufacturing process of green tea is pan firing. Lotus tea is an exclusive Vietnamese special tea, scented with natural lotus pollen (600 flowers were used for 1 kg of pan-fired green tea). Lotus tea is said to be the best liked and the most expensive tea in Vietnam.

The aroma composition of Bach-Mao tea is shown in Table 3. The large contents of pyrazines and pyrroles in the volatiles must be produced by pan-firing process of stronger heating conditions, compared with Japanese Kamairi-cha.

Aroma concentrate from lotus tea contained a large amount of 1,4-dimethoxybenzene which was obtained as a crystalline form when the aroma concentrate was kept in the refrigerator. 1,4-Dimethoxybenzene was found in amount to 93% of aroma concentrate prepared from dry lotus pollen and 30% of that from fresh lotus pollen. Organoleptically, it was

Table 3. Aroma components and their compositions in Bach-Mao tea volatiles

Compound	Compositon (in peak area % of GC)
Limonene	0.27
Pentanol	2.71
cis-2-Penten-1-ol	1.57
2,5- or 2,6-Dimethylpyrazine	10.91
cis-3-Hexen-1-ol	0.55
2-Methyl-5-ethylpyrazine	5.58
trans-Linalool oxide (furanoid)	5.87
cis-Linalool oxide (furanoid)	6.52
2-Acetylfuran	2.58
Linalool	20.68
trans, *trans*-3,5-Octadien-2-one 5-Methylfurfral	}5.28
3,7-Dimethyl-1,5,7-octatrien-3-ol	10.96
1-Ethyl-2-formylpyrrole	13.58
2-Acetylpyrrole	3.21
Anethole	1.28
α-Terpineol	4.18

clear that 1,4-dimethoxybenzene was the key substance of the characteristic aroma of lotus tea.

Pouchong tea and jasmine tea

Pouchong tea is a kind of Chinese tea and is known for its characteristic floral aroma. The highest quality of Pouchong tea is made only from the variety Chin-shin-oolong, and manufactured by special processing technique; the tea flush is subjected first to withering by sun-light for 5~20 minutes, then withering indoors for 2~4 hrs, before the usual process of manufacturing of pan-fired green tea is practiced.

Jasmine tea is a pan-fired green tea, scented by blending with jasmine flower.

The gas chromatograms of the aroma concentrate from Pouchong tea, jasmine tea and Japanese spring green tea are shown in Fig. 2. As to be seen, Pouchong tea contained

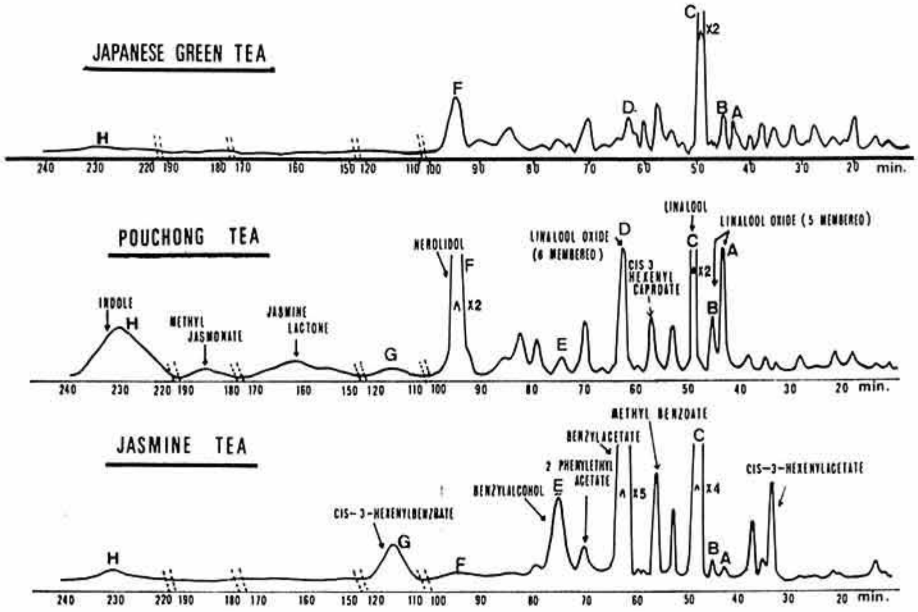

Fig. 2. Comparison of the Gas chromatograms of the aroma concentrates from pouchong tea, jasmine tea and Japanese green tea (GC-MS)

Gas chromatographic condition :

Column : Carbowax 20M 23% on Chromosorb w 60/80 mesh stainless steel 3 mm (i. d.)× 3 m

Helium flow rate : 30 ml/min

Temperature program ; 70~200℃ (2℃/min)

Detector : Total ion current of MS

significant amount of jasmine lactone, methyl jasmonate benzyl cyanide and indole. This is noteworthy. Moreover, nerolidole is in much larger amount than in Japanese green tea. In addition to these components, linalool-oxides, 3,7-dimethyl-1,5,7-octatriene-3-ol and nerolidol are found in greater quantity than Japanese green tea. This, therefore, seems to explain the aroma characteristics of Pouchong tea which is more heavier and has a superior floral sweet aroma.

The pattern of the gas chromatogram of jasmine tea was much different from that of Pouchong tea. Benzylalcohol and benzyl acetate were predominant in jasmine tea while jasmine lactone and methyl jasmonate were in much smaller amount when compared with Pouchong tea. Also, from organoleptic stand point, jasmine tea was quite different from that of Pouchong tea.

References

1) Yamanishi, T.: Tea aroma. *J. Agr. Chem. Soc. Japan*, **49**, R_1-R_9 (1975) [In Japanese].
2) Yamanishi, T., Nose, M. & Nakatani, Y.: Studies on the flavor of green tea. VIII. Further investigation of flavor constituents in manufactured green tea. *Agr. Biol. Chem.*, **34**, 599-608 (1970)
3) Takei, Y., Ishiwata, K. & Yamanishi, T.: Aroma components characteristic of spring green tea. *Agr. Biol. Chem.*, **40**, 2151-2157 (1976).
4) Kiribuchi, T. & Yamanishi, T.: Studies on the flavor of green tea. IV. Dimethyl sulfide and its precursor. *Agr. Biol. Chem.*, **27**, 56-59 (1963).
5) Yamanishi, T. et al.: Comparison of aroma pattern between green teas from var. Sayama-midori and var. Yabukita. *Tea Research J.*, **41**, 48-53 (1974).
6) Yamanishi, T. et al.: Aroma of roasted green tea (Hoji-cha). *Agr. Biol. Chem.*, **37**, 2147-2153 (1973).
7) Nguyen, T.T. & Yamanishi, T.: Flavor componets in Vietnamese green tea and Lotus tea. *Agr. Biol. Chem.*, **39**, 1263-1267 (1975).
8) Yamanishi, T., Maeda, R. & Kosuge, M.: The aroma characteristics of Pouchong tea. presented at the 7th International Congress of Essential Oils (1977).