Identification of Volatile Flavor Compounds in Roasted Coconut

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Heating of coconut leads to browning and development of fine roasted flavor. Flavor studies were carried out with control and heated samples of coconut. Gas chromatography (GC) and GC/mass spectrometry analyses of the basic, neutral and acid fractions of flavor, isolated by hydrodistillation and selective extraction, showed the presence of pyrazines and other heterocyclic compounds in heated samples. These compounds contribute to the overall roasted flavor. Twenty pyrazines were identified in roasted coconut, which included pyrazine, methyl pyrazine, dimethyl pyrazines, ethyl methyl pyrazines, vinyl pyrazine and isopropyl pyrazine. Pyrazine content increased with temperature. In addition to these compounds, δ-lactones, esters, ketones and fatty acids were present in control and heated samples of coconut.

KEY WORDS: Browning, coconut, flavor, gas-liquid chromatography, Maillard reaction, mass spectrometry, oilseeds, pyrazines, roasting.

The study of formed flavors becomes increasingly important in India because Indian cookery has many intricate steps, such as boiling, broiling, frying and grilling, even for a single preparation. Coconut, which is widely used as a culinary item in India, especially in the state of Kerala, is roasted for certain curry preparations. Heating results in the development of a roasted, nutty aroma, which is inherited by the oil pressed from it. Roasting is also practiced by many oil mill owners in the country. By heating coconut milk—the aqueous extract of the kernel—at high temperatures (≈ 150°C), oil with a pleasant, nutty aroma is obtained. This oil is traditionally used for bathing babies. The chemistry behind these changes in coconut was not investigated earlier. Studies on the development of roasted flavor in coconut oil by heating of coconut were first reported by Jayalekshmy *et al.* (1) in 1981. The flavor compounds of roasted coconut were later reported by Saittagaroon *et al.* (2) and Jayalekshmy *et al.* (3). The detailed gas chromatography-mass spectrometry (GC-MS) analysis of basic, neutral and acid flavor fractions of coconut heated to different temperatures, *viz.* 130, 145 and 160°C, is being reported in this paper.

EXPERIMENTAL PROCEDURES

Gratings of fresh, mature coconut kernels were dried in a cross-flow drier to a final moisture content of 3–5%. Lots of 200 g were roasted in an air oven at 130, 145 and 160°C for 15 min. Unheated, dried coconut gratings were taken as control. The control and heated gratings were hydrodistilled, and flavor compounds were selectively extracted with solvent into basic, neutral and acid fractions after pH adjustment (4). The weight of the different flavor fractions (extracts) were determined gravimetrically. GC and GC-MS analyses of the flavor fractions were carried out. For GC analyses, a Hewlett-Packard 5840 A gas chromatograph (Hewlett-Packard, Palo Alto, CA) equipped with a flame ionization detector (FID) at 300°C was used. Nitrogen, at a flow rate of 20 mL/min, was the carrier gas. The injection port was maintained at 250°C. The basic fraction was analyzed on a packed OV-17 (3%) column of 1.83 m × 3 mm i.d., under the following conditions: Isothermal at 100°C for 5 min and temperature programmed to 200°C at the rate of 5°/min with a final hold of 15 min. The neutral fraction was analyzed on the above-mentioned column under these conditions: Isothermal at 150°C for 1 min and then temperature programmed to 225°C at the rate of 5°/min with a final hold of 15 min. The acid fraction was analyzed on a column under the following conditions: Isothermal at 150°C for 1 min and then temperature programmed to 225°C at the rate of 5°/min, and maintained at the final temperature for 15 min. The acid fraction was methylated with methanol/sulfuric acid (50:1) and was analyzed on a column (1.83 m × 3 mm, i.d.) of di-ethylene glycol succinate (DEGS) at 10% level. The analytical conditions were: Isothermal at 100°C for 1 min and temperature programmed to 190°C at the rate of 5°/min with a final hold of 15 min.

The GC retention time indices (I_E) were calculated according to Van den Dool and Kratz (5), with a series of standard methyl esters.

All GC-MS studies were carried out in a coupled GC-MS instrument (namely Hewlett-Packard 5995 B) with a quadrupole analyzer and provided with a data base system. The MS conditions for the analyses of different samples were maintained as follows: Ionization voltage, 70 ev; source temperature, 150°C; and electron multiplier at 1800 volts. The instrument was initially tuned and calibrated with perfluorotributylamine (PFTBA). All GC-MS analyses were carried out in capillary columns of fused flexible silica, the injection being made in split mode (50:1). The carrier gas used was helium. For analysis of the basic fractions, a capillary Carbowax 20M column (50 m × 0.2 mm i.d.) was used. The conditions were: Isothermal at 90°C for 15 min and temperature programmed to 200°C at the rate of 15°/min and held at final temperature for 15 min. The neutral fraction was analyzed on capillary, cross-linked methyl silicone column (12 m × 0.2 mm i.d.) under the conditions: Isothermal at 90°C for 30 min and then temperature programmed to 250°C at the rate of 5°/min with a final hold of 20 min at 250°C. The methylated acid fraction was analyzed on the methyl silicone column mentioned above under the conditions: Isothermal for 3 min at 90°C and then temperature programmed to 200°C at the rate of 3°/min and final heating at 200°C for 15 min.

The identification of various peaks was carried out by comparing their I_E values with those of authentics and by matching their mass spectra with those of standards as well as with the NBS Library of Flavors and Fragrances in the data base system.

Odor profiles. Odor descriptions of the GC peaks of the

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basic and neutral flavor fractions were recorded. Odor profiles of control and the sample heated at 160°C were prepared. The temperature of 160°C was found to be optimum in earlier experiments (1). For this purpose, a thermal conductivity detector (TCD) was used and hydrogen was used as the carrier gas. The column and GC conditions were maintained as outlined before. A small teflon tube (3-mm i.d.) was connected to the exit port of the GC and the free end of the tube was attached to a small funnel (2 cm i.d.). When each compound was being eluted, *i.e.*, when the peak was being traced, the effluent coming out of the exit port was sniffed and the flavor note was written down descriptively.

RESULTS AND DISCUSSION

From GC analysis, it was possible to find out the relative percent (S) of solvent in the flavor extracts. From this value, the percent of flavor compounds in each fraction was calculated (100-S). This was used in calculating the quantity of flavor compounds in the different fractions from the respective weights. The quantitative distribution of basic, neutral and acid flavor fractions of coconut samples heated to different temperatures is represented in Table 1.

In this study no internal standard was added at the time of distillation—since the hydrodistillate was not extracted as such with solvent—to get the total flavor extract. Instead, the hydrodistillate was subjected to selective extraction after pH adjustment. Under these conditions, it would be impossible to determine what percent of the internal standard was recovered and was extracted into each fraction. As such, no internal standard was added in later stages, either. The FID responses of different peaks within each flavor group, like basic, neutral and acid, were assumed to be equal. Nearly 70–80% of the recorded peaks were identified in the study.

Basic fraction. The basic flavor fraction contributed nearly 30% of the total flavor. The overall odor was earthy, roasted and nutty. The compounds identified in the basic fraction of control and heated samples are listed in Table 2. Pyrazines were present only in heated samples. Pyrazine (unsubstituted), methyl pyrazine, isomers of dimethyl pyrazine, ethyl methyl pyrazines and cyclopentapyrazine were identified. In addition to pyrazines, one pyrrole derivative was also identified. Other compounds like 5-methyl furfural, tetradecane, pentadecane, tetradecanoic acid, 2-butyl benzothiazole and β-terpenyl acetate were also identified. The benzothiazole derivative was found to occur in the control sample also. Odor descriptions of the GC peaks (obtained by sniffing at the exit port) were recorded only for the sample heated at 160°C. This sample also contained all the pyrazines identified in other samples. Figure 1 gives the GC profile of the basic fraction of heated sample for which odor descriptions were made. Table 3 represents the odor descriptions of the peaks.

Most of the pyrazines increased in concentration during roasting, which indicated increased formation of pyrazines with temperature. This also was reflected in the quantitative distribution of the basic flavor fraction of control and heated samples. In total, 20 pyrazines have been identified in the heated samples (160°C). Saittagaroon *et al.* (2) reported only six pyrazines in roasted coconut meat and larger numbers in defatted, roasted coconut meal. Our earlier paper (3) also reported a lower number of pyrazines when a packed column was used for GC-MS studies. In the present study, capillary analysis has enabled identification of more compounds. Methyl pyrazine, 2-ethyl-3-isopropenyl pyrazine and vinyl pyrazine are formed in greater amounts.

Even though it is difficult to pinpoint or identify a particular compound as responsible for roasted flavor of coconut, it is largely contributed by pyrazines. The odor profile indicates that typical, roasted aroma is elicited mostly by methyl and dimethyl pyrazines. The increase in concentration of pyrazines with temperature and the observation of their maximum content in the temperature range from 130°C to 160°C agrees with the results reported in roasted cocoa beans (6) and fried potatoes (7).

The basic fraction of the control sample of coconut shows mainly benzothiazole, which has been reported before in fresh coconut (8). The absence of measurable quantities of pyrazines in the control sample indicates that no advanced flavor-forming reactions (Maillard reaction) have occurred during the isolation procedure. According to previous studies reported by Jayalekshmy *et al.* (1), roasted flavors were found to develop only above a temperature of 120°C during heating of coconut.

Neutral compounds. The neutral fraction of flavor isolates of coconut had the characteristic, coconut-like, sweet, oily, nutty aroma. Corresponding fractions from roasted coconut samples also showed a pronounced nutty, oily, sweet flavor note, reminiscent of coconut, but mixed with a tinge of cooked smell. The neutral compounds occurred almost to the same extent of about 300 ppm in control and heated samples. However, the relative concentration of the neutral fraction in coconut was 90%, whereas that in heated sample (160°C) was only 60%.

Results of the GC and GC-MS analyses of the neutral fraction are represented in Table 4. The GC profile was dominated by δ-lactones in both control and heated samples. Their relative concentration was reduced from 80 to 60% during heating. Another group of compounds that were important from the sensory perspective represented the aliphatic alcohols. n-Octanol was present in considerable quantity (27 ppm), but was partially lost during heating. Most of the alcohols followed the trend,

TABLE 1

Quantitative Distribution[a] of Flavor Fractions of Coconut Isolated by Hydrodistillation and Selective Extraction[b]

	Control	130°C	145°C	160°C
Basic	5	75	125	150
Neutral	300	280	300	310
Acid	25	40	60	80
Total	330	395	485	540

[a]Calculated as follows:

$$\frac{\text{kg/Quantity in mg/g}}{\text{kg}} = \frac{\text{weight of flavor extract (mg)} \times \frac{\text{(100-solvent peak area \% in GC)}}{100}}{\text{weight of dry sample (kg)}}$$

(*i.e.*, in ppm)

[b]Mean of three determinations.

TABLE 2

Compounds Identified in the Basic Fraction of Flavor Isolated from Heated Coconut[a]

Peak No.	I_E value in OV-17 column	RT (min) in capillary Carbowax 20M	Compound	MS fragments (in order of abundance)	130°C		145°C		160°C	
					Relative concentration (%)	Approx. concentration (ppm)	Relative concentration (%)	Approx. concentration (ppm)	Relative concentration (%)	Approx. concentration (ppm)
1	4.70	4.26	Pyridine	79,52,51,50,39	—	—	—	—	1.4	2
2	4.70	4.34	Pyrazine	80,53,81,52	—	—	1.6	2	2.0	3
3	5.40	5.18	Methyl pyrazine	94,67,54,43,53	6.4	5	7.3	9	18.8	28
4	5.86	5.42	Vinyl pyrazine	106,52,53,79,80,105	0.4	trace[b]	3.2	4	4.6	6
5	5.90	6.14	2,5-Dimethyl pyrazine	42,108,82,45,79,80	7.8	6	6.6	8	8.9	13
6	5.94	6.26	2,6-Dimethyl pyrazine	108,42,47,41,109,81	2.6	2	1.5	2	2.9	4
7	6.20	6.40	Ethyl pyrazine	107,108,80,53,52	3.1	2	3.0	2	3.8	6
8	5.60	6.62	2,3-Dimethyl pyrazine	108,67,109,43,42	5.2	4	4.6	6	4.1	6
9	7.60	7.68	2-Ethyl-6-methyl pyrazine	121,122,44,94,56	3.4	3	3.0	4	2.0	3
10	6.40	7.82	2-Ethyl-5-methyl pyrazine	121,122,39,56,94	3.0	2	2.8	3	2.2	3
11	6.40	8.24	2-Ethyl-3-methyl pyrazine	121,122,67,94,81	14.6	11	15.7	20	12.7	19
12	8.30	9.76	2,6-Diethyl pyrazine	135,136,108,53,56,39	11.9	9	9.3	11	6.4	10
13	7.80	10.00	5-Methyl-4-butenyl pyrrole	81,80,121,79,41,53,136	—	—	0.6	1	0.8	1
13	7.80	10.00	5-Methyl-4-butenyl pyrrole	81,80,121,79,41,53,136	—	—	0.6	1	0.8	1
14	8.10	10.32	2,3-Dimethyl-5-ethyl pyrazine	135,136,54,42,53,39 108	2.8	2	2.3	3	2.4	4
15	8.70	12.02	3,5-Dimethyl-2n-propyl pyrazine	149,122,150,135,43, 42,122	3.4	3	3.0	4	1.5	2
16	9.08	17.42	2(*trans*-1-propenyl) pyrazine	119,120,39,67,41,51	1.4	1	0.7	1	1.0	1
17	6.15	17.66	5-Methyl furfural	110,109,53,39,81	1.0	1	2.0	2	1.0	1
18	9.40	17.92	6,7-Dihydro-5H-cyclopenta pyrazine	119,120,39,41,66,65	—	—	—	—	1.4	2
19	9.50	18.80	2,5-Dimethyl-3-vinyl pyrazine	133,134,42,54,91,66,108	—	—	0.8	1	1.0	1
20	—[c]	19.46	2-Methyl-6,7-dihydro-5H-cyclopentapyrazine	134,133,66,39,40,65	—	—	—	—	1.3	2
21	7.20	19.88	2-Ethyl-3-iso-propenyl pyrazine	147,148,133,122,94,67	7.8	6	12.3	15.4	18.3	27
22	11.30	20.38	β-Terpeneol acetate	68,93,43	1.1	1	0.5	trace	0.3	trace
23	5.00	20.40	Tetradecane	43,57,71,85,41	0.3	trace	0.4	trace	0.5	trace
24	24.80	21.54	Tetradecanoic acid	57,85,43,41,55,71, 83,105	—	—	—	—	0.5	1
25	23.68	25.42	2-Butyl benzothiozole	149,41,56,57,150,223	4	3.0	5	3.1	4	4

[a]The unheated control only showed peak #25 at 93.0% or 4 ppm.
[b]Trace, less than 1 ppm.
[c]Not identified.

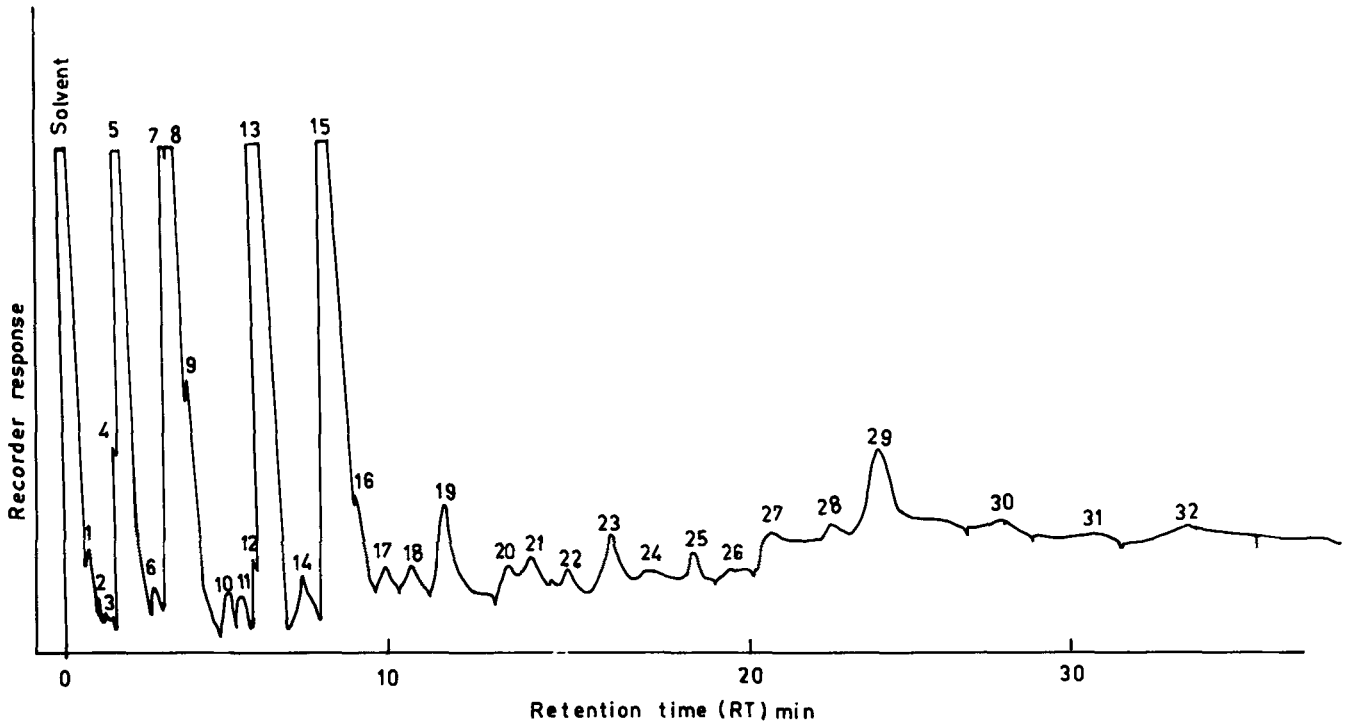

FIG. 1. Gas chromatogram of basic fraction of flavor isolated from heated coconut (160°C/15 min). Column: OV-17 (1.83 m × 3 mm i.d.) (See Table 3).

TABLE 3

Odor Descriptions of the Separated GC Peaks (Aromagram) of the Basic Fraction of Coconut

Peak no.	Odor description	Compound
1	Pungent, greeny, roasted	Pzrazine
2		Unknown
3	Hydrocarbon-like	Tetradecane
4	Hydrocarbon-like	Pentadecane
5	Raw, roasted	Methyl pyrazine
6	Raw, green	Unknown
7	Good roasted	Vinyl pyrazine
8	Fine, roasted	2,5-Dimethyl pyrazine
9	Roasted, nutty	2,6-Dimethyl pyrazine
10	Pleasant, roasted	2,3-Dimethyl pyrazine
11	Green roasted	2-Ethyl pyrazine
12	Cooked aroma	5-Methyl furfural
13	Green, musty, roasted	2-Methyl-3-ethyl and 2-methyl-5-ethyl pyrazine
14	Green, nutty, roasted	2-Methyl-6-ethyl pyrazine
15	Musty, roasted	2-Ethyl-3-isopropenylpyrazine
16	Fragrant but slightly musty	5-Methyl-4-butenyl pyrrole
17	Green beany	2,3-Dimethyl-5-ethyl pyrazine
18	Mildly roasted	3,5-Dimethyl-2-propenyl pyrazine
19	Green, bell pepper-like	2,6-Diethyl pyrazine
20	Pungent, penetrating, mildly roasted	2(*trans*)-1-Propenyl pyrazine
21	Penetrating, musty	Unknown
22	Slightly fermented	2,5-Dimethyl-3-vinyl pyrazine
23	Mildly roasted	6,7-Dihydro-5H-cyclopenta pyrazine
24	Nothing characteristic	Unknown
25	Nothing characteristic	Unknown
26	Pleasant aromatic, mango-like	β-Terpeneol acetate
27	Harsh, oily, burnt smell	Tetradecanoic acid
28	Unpleasant	Unknown
29	Harsh, medicinal	2-Butyl benzothiazole
30	Pungent, irritating (stored oil-like)	Unknown
31	Harsh and pungent	Unknown
32	Harsh pungent smell continues	Unknown

except for 2-heptanol. This compound was most likely formed from triglycerides during heating. Phenyl acetaldehyde was detected only in heated samples. Ethyl esters, methyl ketones and phenyl ethyl alcohol have been reported earlier (8).

Odor characteristics of the various GC peaks (Fig. 2) are explained in Table 5. It indicates that δ-octa-, δ-deca-

TABLE 4

Compounds Identified in the Neutral Fraction Isolated from Heated Coconut

Peak no.	I_E value in OV-17 column	RT (min) in capillary methyl silicone column	Compound	MS fragments (in order of abundance)	Control		130°C		145°C		160°C	
					Relative concentration (%)	Approx. concentration (ppm)	Relative concentration (%)	Approx. concentration (ppm)	Relative concentration (%)	Approx. concentration (ppm)	Relative concentration (%)	Approx. concentration (ppm)
1	5.60	2.30	2-Pentanol	56,41,43,55,83,84	1.7	5	1.2	3	0.4	1	3.1	9
2	5.80	2.60	2-Hexanol	45,69,87,56,57,44	3.0	9	1.1	3	1.1	3	0.9	3
3	6.50	3.10	2-Heptanol	56,70,43,55,42,41, 83,98	1.2	4	3.5	10	1.6	5	1.5	4
4	6.70	3.80	Octanol	56,55,43,70,84,83 41,112	9.0	27	1.4	4	2.0	6	5.4	16
5	7.20	4.06	2-Furyl methyl ketone	95,110,39,43,67,111	—	—	2.0	6	1.0	3	2.0	8
6	7.40	4.32	Octanal	43,44,57,56,69,84, 41,100,110	2.6	7	1.4	4	2.0	6	5.4	16
7	7.80	4.78	Phenyl ethyl alcohol	91,90,122,65,78,104	0.9	3	—	—	0.4	1	—	—
8	8.40	5.03	Phenyl acetaldehyde	119,120,91,77,42,64	—	—	1.3	4	0.6	2	trace	trace
10	9.05	5.10	Nonanal	57,44,56,43,55,70, 82,98,124	—	—	0.5	1	0.8	2	1.0	3
12	9.18	6.18	2-Tridecanone	58,43,40,71,59,88,105	trace	trace	trace	trace	trace	1	trace	trace
13	11.20	5.30	δ-Octalactone	99,71,42,43,70,55,114	27.2	81	48	130	40	120	32	96
14	11.70	5.10	Ethyl octanoate	88,101,57,41,43,55, 114,152	trace	1	—	—	trace	trace	—	—
15	12.10	10.32	δ-Decalactone	99,42,41,71,70,55, 114,152	28	84	30	80	28	77	18	55
16	13.85	8.74	Ethyl decanoate	88,43,41,101,105,70 57	trace	1	trace	1	—	—	—	—
17	14.70	14.72	Ethyl-5-hydroxydecanoate	88,99,71,55,145,43	trace	1	—	—	—	—	—	—
18	14.90	15.39	δ-Dodecalactone	99,41,42,43,55,57, 70,114	9.0	27	3.4	10	3.0	9	2.6	8
19	16.90	13.54	Ethyl dodecanoate	88,43,41,101,105 70,57	2.0	6	—	—	2.8	8	3.5	11
20	16.80	16.40	Ethyl tetradecanoate	88,101,70,157,143, 213,227,256	1.3	4	trace	trace	0.8	2	—	—
21	17.20	17.63	δ-Tetradecalactone	99,42,41,55,70,114	14.4	42	6.6	19	9.5	29	6.0	26
22	20.40	18.80	2-Butyl benzothiazole	149,41,56,57,150	0.6	2	0.3	1	trace	1	trace	1

and δ-tetradeca-lactones exhibited characteristic coconut-like, oily odors. The alcohols had a fresh, green flavor note. The octanal peak gave a strong, citrus-like aroma. The peak corresponding to 2-furyl methyl ketone imparted a cooked smell. On the whole, the aromagram was dominated by the typical coconut-like flavor elicited by δ-octa-, δ-deca- and δ-dodeca-lactones. Probably, the lower alcohols with "fresh" odors and the ethyl esters with "fruity" aroma played auxiliary roles.

As a result of heating, the content of neutral compounds (≈ 300 ppm) does not vary much, but the relative concentration is reduced from 90 to 60% due to the formation of pyrazines and other changes in the overall flavor composition. The presence of δ-lactones, alcohols, esters and other compounds, though present at different relative concentrations, are largely responsible for making the roasted flavor characteristic of coconut. This probably explains why a roasted peanut is different from a roasted coconut or roasted cocoa, especially when some of the pyrazine derivatives are present in all of them. The possible answer is that the native flavor compounds originally present are also important and contribute to the total flavor.

TABLE 5

Odor Descriptions of the Separated GC Peaks (Aromagram) of Neutral Fraction of Coconut

Peak no.	Odor description	Compound
1	Grassy green	2-Pentanol
2	Green, grass-like	2-Hexanol
3	Pleasant, over-ripe fruit-like	3-Heptanol
4	Citrus-like	Octanol
5	Cooked, mildly roasted	2-Furyl methyl ketone
6	Pungent, slightly fragrant	Octanal
7	Fragrant, rose-like	Phenyl ethyl alcohol
8	Aromatic, fragrant	Phenyl acetaldehyde
9	Pleasant, flower-like	Unknown
10	Slightly pungent	Nonanal
11	Oily, pleasant	Unknown
12	Oily, old nut-like, slightly harsh	2-Tridecanone
13	Typical coconut-like	δ-Octalactone
14	Pleasant oily	Ethyl octanoate
15	Coconut-like	δ-Decalactone
16	Oily, nutty, fruity	Ethyl decanoate
17	Pleasant, fruity and nutty	Ethyl hydroxy decanoate
18	Heavy, nutty, oily	δ-Dodecalactone
19	Oily, nutty	Ethyl dodecanoate
20	Coconut-like, oily	δ-Tetradecalactone
21	Pleasant, nutty, oily	Ethyl tetradecanoate
22	Pleasant, medicinal, slightly pungent	2-Butyl benzothiazole

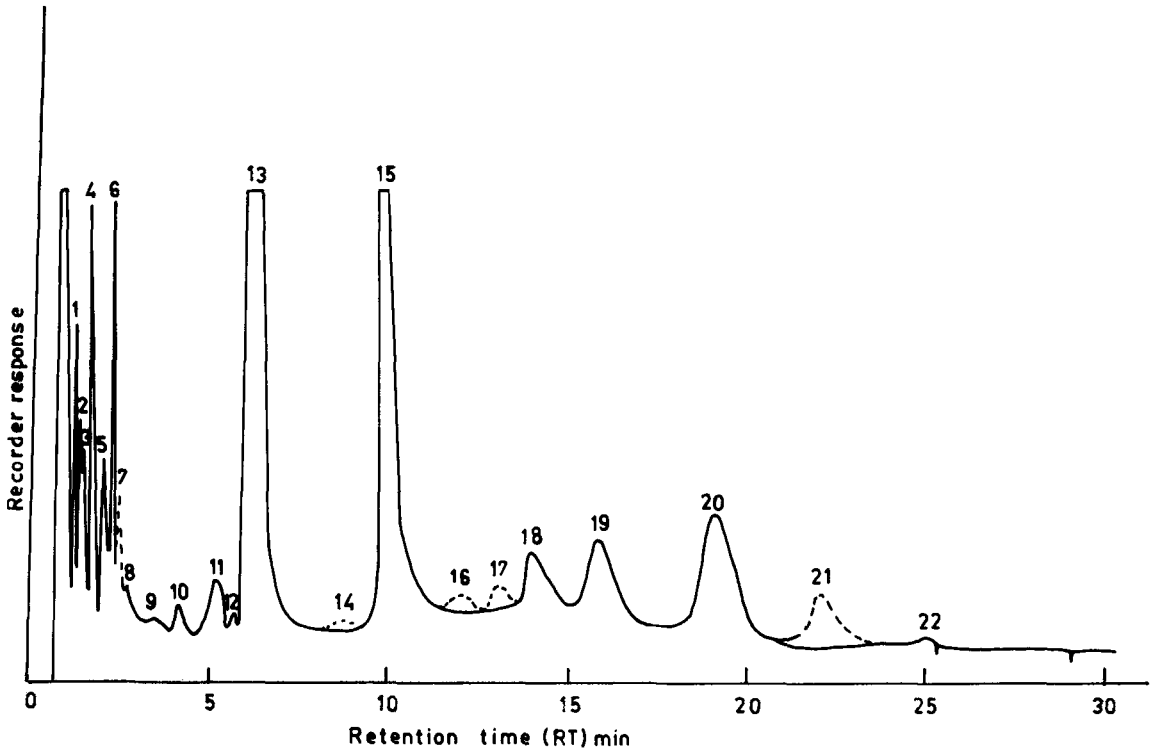

FIG. 2. Gas chromatogram of neutral fraction of flavor isolated from heated coconut (160°C/15 min). Column: OV-17 (1-83 m × 3 mm). (See Table 5). Dotted lines indicate peas which appeared in control and other heated samples.

TABLE 6

Compounds Identified in the Acid Fraction of Flavor Isolated from Heated Coconut

Peak no.	I_E value in DEGS column	RT (min) in capillary, cross-linked methyl silicone column	Compound	MS fragment ions (in order of abundance)	Control		130°C		145°C		160°C	
					Relative concentration (%)	Approx. concentration (ppm)	Relative concentration (%)	Approx. concentration (ppm)	Relative concentration (%)	Approx. concentration (ppm)	Relative concentration (%)	Approx. concentration (ppm)
1	3.80	—	Acetic & propionic acids	Eluted with solvent in GC-MS analysis	46.0	11	65.7	26	28.0	17	3.4	3
2	4.60	—	Butyric	Eluted with solvent in GC-MS analysis	0.7	trace	21.0	8	17.7	11	—	—
3	5.80	—	Pentanoic	Eluted with solvent in GC-MS analysis	6.7	2	1.1	trace	1.0	trace	0.14	trace
4	6.80	0.98	Hexanoic	74,84,51,47,41,88, 49	3.5	1	—	—	0.1	trace	—	—
5	7.40	1.23	Heptanoic	74,87,43,113,55,41	0.1	trace	0.1	trace	0.5	trace	0.5	trace
6	8.30	2.01	Hydroxy octanoic	74,99,130,101,140, 171	trace	trace	0.1	trace	—	—	—	—
7	8.70	3.18	Octanoic	74,87,55,41,69,158	trace	trace	0.8	trace	5.1	3	1.6	1
8	9.10	4.34	Nonanoic	74,87,43,41,55,172	—	—	—	—	0.6	trace	0.8	1
9	10.00	5.60	Hydroxy decanoic	74,99,127,156,202	—	—	—	—	1.7	1	1.7	1
10	10.70	7.50	Decanoic	74,87,143,43,55,186	trace	trace	trace	trace	0.6	trace	4.1	3
11	11.30	8.10	Decenoic	74,87,41,184	—	—	—	—	trace	trace	1.6	1
12	12.00	12.50	Hydroxy dodecanoic	99,74,41,106,230	trace	trace	—	—	5.7	3	11.6	9
13	12.80	12.94	Dodecanoic	74,87,41,55,43,214	0.5	trace	0.6	trace	trace	trace	9.8	8
14	13.40	13.40	Dodecenoic	74,87,41,212	—	—	—	—	trace	trace	3.5	3
15	14.10	17.26	Tetradecanoic	74,87,41,43,55,242	trace	trace	—	—	1.5	1	7.7	6
16	14.60	17.18	Tetradecenoic	74,87,41,240	trace	trace	trace	trace	0.8	trace	9.5	8
17	15.60	18.62	Pentadecanoic	74,87,43,113,41, 55,256	—	—	—	—	1.3	1	—	—
18	15.90	19.34	Pentadecenoic	74,87,41,254	trace	trace	trace	trace	3.2	2	11.1	9
19	16.40	20.58	Hydroxy hexadecanoic	99,74,130,144,41, 286	trace	trace	—	—	3.2	2	11.1	9
20	16.50	20.72	Hexadecenoic	74,87,255,268,43, 41	0.9	trace	trace	trace	2.6	2	—	—
21	17.40	24.16	Hexadecanoic	74,87,43,75,41, 227,270	trace	trace	trace	trace	2.0	1	8.0	6
22	17.90	24.70	Octadecanoic	74,87,43,55,41, 143,255,298	—	—	trace	trace	—	—	—	—
23	18.40	24.10	9-Octadecenoic (oleic)	55,74,69,67,83,43, 81,222	trace	trace	0.5	trace	4.2	2	5.8	5
24	19.40	25.92	9,12-Octadecadienoic (linoleic)	74,87,255,43	4.2	1	0.8	trace	2.9	2	4.1	3
25	20.20	26.30	Eicosanoic	74,87,43,326	5.8	1	2.2	1	5.1	3	3.2	3
26	21.10	27.10	9,12,15-Octadecatrienoic	74,87,43,255	6.7	2	2.0	1	6.5	4	3.1	3

Acid fraction. The acid fraction concentrates had typical odors of short-chain fatty acids, especially of octanoic acid. Quantitatively, acid compounds in the flavor extract of coconut increased with temperature of heating as shown in Table 1 (from 25 to 80 ppm). However, the relative concentration of acid compounds did not alter much (8–10%). Because the acid fraction was methylated before GC analysis, odor descriptions of the individual peaks during GC analysis were not possible. The GC separation was good, and more or less similar in packed and capillary

columns. Compounds identified in the acid fraction include lower acids like acetic, propionic, butyric and most of the straight-chain fatty acids from hexanoic (C_6) to eicosanoic (C_{20}). A few hydroxy fatty acids and unsaturated fatty acids were also identified. These results are presented in Table 6.

The presence of fatty acids, except for dodecanoic (lauric) acid, has not been reported in previous research of Lin and Wilkens (8) on the volatile aroma compounds of coconut meat. Allen (9) and Saittagaroon (2) have not reported the details of acidic flavor compounds in oil or kernel. However, the presence of a few fatty acids was reported by Pai *et al.* (10) in a system of heated coconut oil. Formation of aliphatic acids during roasting has been reported in roasted peanut (11,12), cocoa (13) and cashew nut (14). Thermal hydrolysis of glycerides is supposed to produce the free fatty acids in small amounts (15).

This study suggests that heating of coconut leads to the formation of heterocyclic aroma compounds, especially pyrazines, which are considered to be mainly responsible for roasted flavors. The δ-lactones, alcohols, esters and fatty acids, which are already present in unheated coconut, also contribute to the overall flavor of roasted coconut.

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