Flavor Compounds of Dry-Cured Ham†

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Volatile compounds of dry-cured Parma ham, the most representative among those of Italian style, were extracted by means of the dynamic headspace technique followed by adsorption onto Tenax traps. GC-FID and GC-FPD were used to obtain the aromatic profiles of the samples; gas chromatography–mass spectrometry was also used to identify the structure of the volatile components. One hundred twenty-two compounds were identified in this study, several of which have not been previously reported. Hydrocarbons (22), aldehydes (16), alcohols (25), and esters (28) were the prevalent volatiles. The mechanism of formation of some classes of compounds is also discussed.

INTRODUCTION

The characterization of the volatile components in dry-cured Parma ham is part of a study dealing with the definition of the quality level of food on the basis of analytical data. Flavor is one of the most important quality attributes contributing to the acceptability of meat.

Up to now, there have been few studies on the aroma components of raw ham. Much of the research concerning volatile compounds of raw ham was carried out before the development of updated sophisticated instrumentation such as gas chromatography–mass spectrometry.

Ockerman et al. (1964) studied the volatile components of dry-cured hams using a vacuum distillation system equipped with cold traps. In their work, aldehydes, ketones, acids, bases, and sulfur-containing compounds were identified, most of which had been found also in uncured meat. Cross and Ziegler (1965) determined the relative amounts of aroma compounds in cured and uncured ham; although the volatile components were qualitatively similar, there were quantitative differences. Branched-chain aldehydes such as 2-methylpropanal, 2-methylbutanal, and 3-methylbutanal occurred in both kinds of ham in the same quantity but at lower levels than the straight-chain aldehydes. Moreover, the most relevant differences were found for pentanal and hexanal, which were present in considerable quantities in the uncured ham and almost absent in the cured meat. Lillard and Ayres (1969) extracted volatile compounds from country-style cured ham by means of vacuum distillation and collection of the volatiles in cold traps: numerous carbonyl compounds, alcohols, and esters were identified. Piotrowski et al. (1970) studied different parts of hams with the aim of isolating and identifying the flavor of cured ham; they also followed changes in meat during curing, cooking, and smoking. The extraction of the volatile compounds was carried out with a mixture of chloroform–methanol, thus obtaining the total lipid fractions; the extract had a cured aroma, indicating that cured ham flavor compounds were essentially in the lipid phase. Recently, Baloga et al. (1990) extracted volatile compounds from a cured, precooked ham using a Likens–Nickerson apparatus; they used gas chromatography with atomic emission detection (AED) to obtain the selective detection of nitrogen-, oxygen-, and sulfur-containing compounds. More than 60 heteroatomic compounds were identified in this study. Berdagué et al. (1991a) extracted the aroma compounds from dry-cured ham by dynamic headspace and analyzed them by gas chromatography–mass spectrometry; more than 60 compounds were identified, including a number of aldehydes, ketones, alcohols, esters, aromatic hydrocarbons, and heterocycles. The volatile fraction of the same French product was studied by Berdagué et al. (1991b) using vacuum distillation and GC–MS analysis; the authors also carried out flavor tests to determine the compounds which were responsible for its aroma. The flavor of aged Iberian hams, processed in the traditional way, has been studied by Garcia et al. (1991). The aromatic substances were collected in cold traps after high vacuum distillation, extracted with dichloromethane, and analyzed by gas chromatography–mass spectrometry; 77 components were identified in the ham flavor, most of which were alkanes, aldehydes, and aliphatic alcohols.

In this work, the aroma components of dry-cured Parma ham, at different stages of aging, were extracted using the dynamic headspace technique to obtain a GC profile of the volatile fraction of different samples and to identify the compounds; using HRGC–MS, 122 compounds were identified in the volatile fraction. Hypotheses on the mechanism of formation of some classes of compounds are also provided.

MATERIALS AND METHODS

Materials. Twenty raw hams supplied by different producers (Parma, Italy) were examined. The samples were taken from biceps femoris of raw ham at different stages of maturity, being in every case more than 12 months old. The samples were kept vacuum-packed at 0 °C until analysis.

Extraction Procedure for Volatile Components. The volatile compounds of raw ham were isolated by the dynamic headspace technique using a polymeric material as adsorbing trap.

Nearly 400 g of ham, just sliced, were frozen under liquid nitrogen, ground in a domestic blender, and frozen again. To 25 g of ham treated in this way was added 8 μg of linalool to check the reproducibility of the sampling procedure. The sample (20 g), thermostated at 40 °C, was flushed with purified helium for 5 min at a flow rate of 60 mL/min; the volatile substances were then stripped out with the same flow of helium and adsorbed on a Tenax trap for 35 min. The trap was flushed with helium for 10 min to eliminate the adsorbed water, which could interfere in

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the GC analysis. The aroma compounds were thermally desorbed and injected into the gas chromatograph using a TCT thermal desorption cold trap (Chrompack, Middelburg, The Netherlands); the trap was heated at 240 °C for 10 min under a helium flow (flow rate 10 mL/min). The desorbed substances, cryofocused in a silica capillary cooled at −108 °C, were directly injected into the GC column by quickly heating the silica capillary to 200 °C and maintaining this temperature for 15 min. The traps for adsorption, purchased from Chrompack, consisted of glass tubes (16 cm × 4 mm i.d.) filled with Tenax TA (90 mg, 20–35 mesh) and preconditioned at 300 °C for 8 h.

Capillary Gas–Liquid Chromatography–Mass Spectrometry Analysis. For GC analysis a Chrompack CP9000 chromatograph, a multicanal interface HP3500, and a HP Vectra QS/165 computer (Hewlett-Packard, Palo Alto, CA) were used. A flame ionization detector (FID) and a flame photometric detector (FPD) were used, both held at 250 °C; the injector temperature was 230 °C.

GC–MS analysis was carried out using an AUTO/HRGC/MS system consisting of an MFC gas chromatograph, a QMD 1000 quadrupole mass spectrometer, an RS500 interface (Carlo Erba, Milan, Italy), and a Quadram computer (Slough, U.K.). The mass spectra were obtained by electron impact at 70 eV. The gas chromatograms were recorded by monitoring the total ion current in the 35–300-amu range. Interface and ion source were maintained at 220 and 190 °C, respectively.

Chromatographic separations were performed with DB-Wax bonded-phase columns (J&W Scientific, Folsom, CA; 30 m × 0.25 mm i.d., film thickness 0.25 μm). The oven temperature was held at 20 °C for 6 min and then programmed from 20 to 120 °C at 4 °C/min and from 120 to 220 °C at a rate of 15 °C/min. The same columns and the same temperature program were used for both GC-FID and GC–MS analyses.

The substances used as references in the gas chromatographic analysis were purchased from Aldrich Chimica (Milan, Italy).

RESULTS AND DISCUSSION

Using the dynamic headspace technique, more than 150 compounds were detected and 122 compounds identified, 40 of which have not been previously reported. The substances identified in the 20 samples of dry-cured ham by means of GC–MS are given in Table I. This table lists the bibliographic references of the papers in which these compounds were previously reported, the occurrence of identification in the samples, and the method of identification. The identity of the compounds, obtained by mass spectrometry, was confirmed by injection of authentic substances as references where possible. The identified substances were 10 aliphatic hydrocarbons, 12 aromatic hydrocarbons, 16 aldehydes, 11 ketones, 25 alcohols, 5 carboxylic acids, 28 esters, 3 furans, 4 pyrazines, 2 nitrogen compounds, 4 sulfur compounds, and 2 miscellaneous components. Figure 1 shows chromatograms obtained with flame ionization detection of the volatile ham components for two samples having different aromatic profiles. Six chromatographic profiles by FID and FPD detection were obtained for each ham sample: CV% values of the area of most peaks were less than 15%. Figure 2 shows a gas chromatogram obtained using GC–MS by plotting the total ion current.

One of the most important reactions involved in the formation of volatile substances in meat products is the autoxidation of unsaturated fatty acids. Phospholipid constituents of meats are normally rich in polyunsaturated fatty acids and thus are generally prone to autoxidation. It is known that hydrocarbons are secondary products of the lipid autoxidation along a radical pathway together with alcohols, ketones, and aldehydes (Shahidi, 1989); in fact, the intermediate hydroperoxides that form in the chain reaction are not very stable with a high tendency to decompose. The proportions of these oxidation products vary significantly according to the composition of the fatty acids in lipids; moreover, such products can themselves undergo further oxidation and degradation, yielding a large number of new products such as short-chain hydrocarbons, aldehydes, dialdehydes, ketones, acids, and furans. It is believed that xylenes derive from the unsaponifiable fat fraction, whereas toluene seems to be a catabolism product of phenylalanine (Berdagué et al., 1991a). However, saturated and unsaturated hydrocarbons do not seem to contribute significantly to the meat flavor (Shahidi et al., 1986).

Sixteen aldehydes and 11 ketones, both linear and branched (13.5 and 7.2% of the relative chromatogram area, respectively), were identified; benzaldehyde was the only aromatic aldehyde identified. Straight-chain alkanals, alkenals, and alkadienals might be produced by scission of the hydroperoxides arising from oxidation of C_{18} polyunsaturated fatty acids such as linoleic and linolenic and the C_{20} arachidonic acid (Shahidi et al., 1986). Hexanal is a predominant breakdown product of lipid peroxidation of ω_6 fatty acids in meat; it is known to impart unpleasant, rancid, and pungent flavor notes to meats (Shahidi, 1989). Cross and Ziegler (1965), in the study of the volatile carbonyl compounds of both cured and uncured meats, found that some aldehydes, in particular hexanal, were present to a much greater extent in uncured than in cured ham; the content of hexanal, which is the major component of uncured meat volatile compounds, has been found to be directly proportional to the amount of 2-thiobarbituric acid (TBA) and thus may be considered a useful indicator of the degree of lipid oxidation (Shahidi et al., 1987). Previous works reported a high relative abundance of hexanal among the volatile products of the low-temperature oxidation process; at the higher temperature, however, 2,4-decadienal forms in larger amounts (Nawar, 1989). Both aldehydes are typical scission products of linoleate hydroperoxides. Other types of aldehydes may form as degradation products of lipids, proteins, or reaction products between proteins and carbohydrates. Branched-chain aldehydes identified, such as 2- and 3-methylbutanal, might arise from the oxidative deamination–decarboxylation of amino acids via Strecker degradation (Garcia et al., 1991) along a pathway that yields to an aldehyde or ketone having one carbon less than the amino acid involved in the initial reaction. Although this reaction generally occurs at temperatures near 90 °C and in alkaline medium, conditions different from those of the aging process of Parma ham, it should be noted that a very high free amino acid content deriving from the intense proteolysis and the low water activity value as a consequence of the salting process may facilitate Strecker degradation.

On the other hand, butanal and 2- and 3-methylbutanal can be formed as byproducts during the biosynthesis of valine, leucine, and isoleucine (Belitz and Grosch, 1987). Scheme I shows that α-ketobutyric acid, derived from threonine, can be converted into isoleucine. Butanal and 2-methylbutanal are formed from side-reaction pathways.

Among the identified ketones, 3-hydroxy-2-butanone (acetoin), the precursor of diacetyl, may arise as a byproduct from the decarboxylation of 2-acetolactic acid (Belitz and Grosch, 1987); the latter compound can be formed from the condensation of two pyruvate molecules as an intermediary product in the biosynthetic pathways of valine and leucine. Furthermore, during leucine biosynthesis, 3-methylbutanal forms from decarboxylation of α-keto-4-methylvaleric acid, as is shown in Scheme II (Belitz and Grosch, 1987). Acetoin occurs frequently in food aromas, and it is considered to provide a buttery note to cooked meat.

A large number of alcohols were identified in this work; these components accounted for 6.9% of the relative

Table I. Volatile Components of Raw Ham

peak[a]	compound	ID[b]	frequency[c]	ref[d]	peak[a]	compound	ID[b]	frequency[c]	ref[d]
1	*n*-pentane	RT, MS	19	3	62	2-hexanol	MS	10	
2	2,2,3-trimethylpentane	MS	20	4	63	*tert*-butylbenzene	MS	9	
3	*n*-heptane	RT, MS	20	1, 3	64	1,2,4-trimethylbenzene	RT, MS	20	1, 4
4	1-heptene	RT, MS	20	3	65	3-methyl-3-buten-1-ol	MS	20	3
5	acetone	RT, MS	18	1	66	methyl 3-hexenoate	MS	17	
6	*n*-octane	RT, MS	20	1, 3	67	1-pentanol	RT, MS	20	1, 3–5
7	methyl acetate	RT, MS	20	1	68	cyclohexanone	RT, MS	3	1
8	1-octene	RT, MS	20	1, 3	69	2-methylpyrazine	RT, MS	19	1, 2
9	?-octene (a)	MS	20		70	acetoin	RT, MS	20	1, 3–5
10	?-octene (b)	MS	20		71	octanal	RT, MS	19	1, 4, 5
11	ethyl acetate	RT, MS	20	1, 2, 5	72	methyl heptanoate	RT, MS	20	
12	butanal	RT, MS	4	1, 5	73	4-octen-3-one	MS	20	
13	2-butanone	RT, MS	20	1–5	74	methylvinylbenzene	MS	20	1
14	methyl propanoate	RT, MS	19	1	75	1-hydroxy-2-propanone	MS	20	1
15	2-methylbutanal	MS	19	1–3, 5	76	(*E*)-2-heptenal	RT, MS	20	
16	3-methylbutanal	RT, MS	20	1, 3–5	77	2-penten-1-ol	MS	11	
17	methyl 2-methylpropanoate	MS	20		78	1,2-propanediol	MS	20	
18	3-methyl-2-butanone	RT, MS	20	4, 5	79	4,6,8-trimethylnonene	MS	4	
19	benzene	MS	20	1	80	2-methyl-2-buten-1-ol	MS	10	
20	2-ethylfuran	RT, MS	20	1, 3	81	2,6-dimethylpyrazine	RT, MS	20	1, 3, 4
21	1-methoxyhexane	MS	20		82	6-methyl-5-hepten-2-one	RT, MS	20	
22	ethyl propanoate	MS	14	1	83	1-hexanol	RT, MS	20	1, 3–5
23	pentanal	RT, MS	20	1, 3, 5	84	dimethyl trisulfide	MS	20	1, 2
24	2-pentanone	RT, MS	20	1, 3	85	1-butoxy-2-propanol	MS	11	
25	methyl butanoate	RT, MS	20		86	methyl octanoate	RT, MS	20	1
26	methyl 2-methylbutanoate	RT, MS	17		87	methyl 6-methylheptanoate	MS	14	
27	methyl 3-methylbutanoate	RT, MS	19		88	2-butoxyethanol	MS	20	3, 5
28	toluene	RT, MS	20	1, 3, 4	89	trimethylpyrazine	MS	14	1
29	2-butanol	RT, MS	20	1	90	(*E*)-2-octenal	RT, MS	20	1
30	ethyl butanoate	RT, MS	20	1, 3	91	ethyl octanoate	MS	20	5
31	1-propanol	RT, MS	20	1	92	methyl 3-octenoate	MS	7	
32	2-methyl-3-buten-2-ol	RT, MS	20	1	93	acetic acid	RT, MS	20	1
33	ethyl 2-methylbutanoate	RT, MS	17	5	94	1-octen-3-ol	RT, MS	20	1, 3–5
34	dimethyl disulfide	MS	20	1, 3	95	1-heptanol	RT, MS	20	1, 5
35	2,3-pentanedione	MS	16	1, 5	96	epoxydihydrolinalool	MS	16	
36	ethyl 3-methylbutanoate	MS	19		97	3-vinylpyridine	MS	20	
37	hexanal	RT, MS	20	1–5	98	(*E*,*E*)-2,4-heptadienal	MS	6	1
38	methyl pentanoate	RT, MS	20		99	2-ethyl-1-hexanol	MS	12	1
39	2-methyl-1-propanol	RT, MS	20	1, 3	100	pyrrole	MS	20	
40	ethylbenzene	RT, MS	20	1, 4	101	methyl nonanoate	MS	12	
41	*p*-xylene	RT, MS	20	1, 3, 4	102	decanal	MS	3	1, 3–5
42	*m*-xylene	RT, MS	20	1, 3, 4	103	benzaldehyde	RT, MS	20	1–4
43	(*E*)-2-pentenal	MS	17		104	2-hepten-1-ol	MS	14	
44	methyl 4-methylpentanoate	MS	17		105	methyl 3-(methylthio)propanoate	MS	18	
45	isopropylbenzene	MS	20	1	106	(*Z*)-2-nonenal	MS	20	1, 3, 5
46	2-pentanol	RT, MS	20		107	propanoic acid	RT, MS	15	1
47	*o*-xylene	RT, MS	20	1, 3, 4	108	3,7-dimethyl-1-octen-3-ol	MS	15	
48	1-butanol	RT, MS	20	1	109	1-octanol	RT, MS	20	1, 4
49	1-penten-3-ol	RT, MS	20		110	benzonitrile	MS	20	1
50	heptanal	RT, MS	20	1, 3, 5	111	methyl decanoate	RT, MS	20	1
51	methyl hexanoate	RT, MS	20	1	112	2-undecanone	MS	4	1
52	limonene	RT, MS	20		113	methyl benzoate	MS	16	
53	1-ethyl-2-methylbenzene	MS	19	1	114	(*Z*)-2-octen-1-ol	MS	17	
54	2-hexenal	MS	16	1	115	(*E*)-2-octen-1-ol	MS	12	
55	pyrazine	MS	13	1	116	butanoic acid	RT, MS	18	1
56	3-methyl-1-butanol	RT, MS	20	1, 3–5	117	(*Z*)-2-decenal	MS	6	1
57	2-pentylfuran	MS	20	1, 3	118	ethyl decanoate	RT, MS	13	5
58	methyl 5-hexenoate	MS	20		119	methyl 4-decenoate	MS	16	
59	ethyl hexanoate	RT, MS	20	1, 5	120	dimethyl tetrasulfide	MS	20	2
60	styrene	MS	20	1	121	pentanoic acid	MS	18	1
61	methyl 4-methylhexanoate	MS	19		122	hexanoic acid	RT, MS	20	1, 4

[a] Peak sequence in the gas chromatogram. [b] RT, identified by comparison with retention time of authentic reference substances; MS, identified by means of mass spectrometry. [c] Occurrence of identification in the 20 samples. [d] Already detected in (1) Shahidi et al. (1986), (2) Baloga et al. (1990), (3) Berdagué et al. (1991a), (4) Berdagué et al. (1991b), or (5) Garcia et al. (1991).

chromatogram area. With regard to the formation of these molecules, alcohols are mostly oxidative decomposition products of lipids (Shahidi et al., 1986). Alcohol dehydrogenases can reduce the aldehydes derived from the metabolism of fatty acids and amino acids into the corresponding alcohols:

$$RCH_2OH + NAD^+ \rightarrow RCHO + NADH + H^+$$

Alcohol formation is strongly favored by the predominance of the concentration of NADH over that of NAD^+. In most cases aldehydes > C_5 are only slowly reduced. Thus, when aldehydes form by oxidative breakdown of unsaturated fatty acids, a mixture of alcohols and aldehydes results (Belitz and Grosch, 1987). The straight-chain primary alcohols identified in raw ham are considered to provide greenish, woody, and fatty-floral notes in general and may be significant in the overall aroma of ham. 1-Penten-3-ol, which gives a penetrating, grassy, and ethereal note, was identified in pork meat for the first time in this work. Not insignificant amounts of 1-octen-3-ol, which is responsible for a mushroom note, were found;

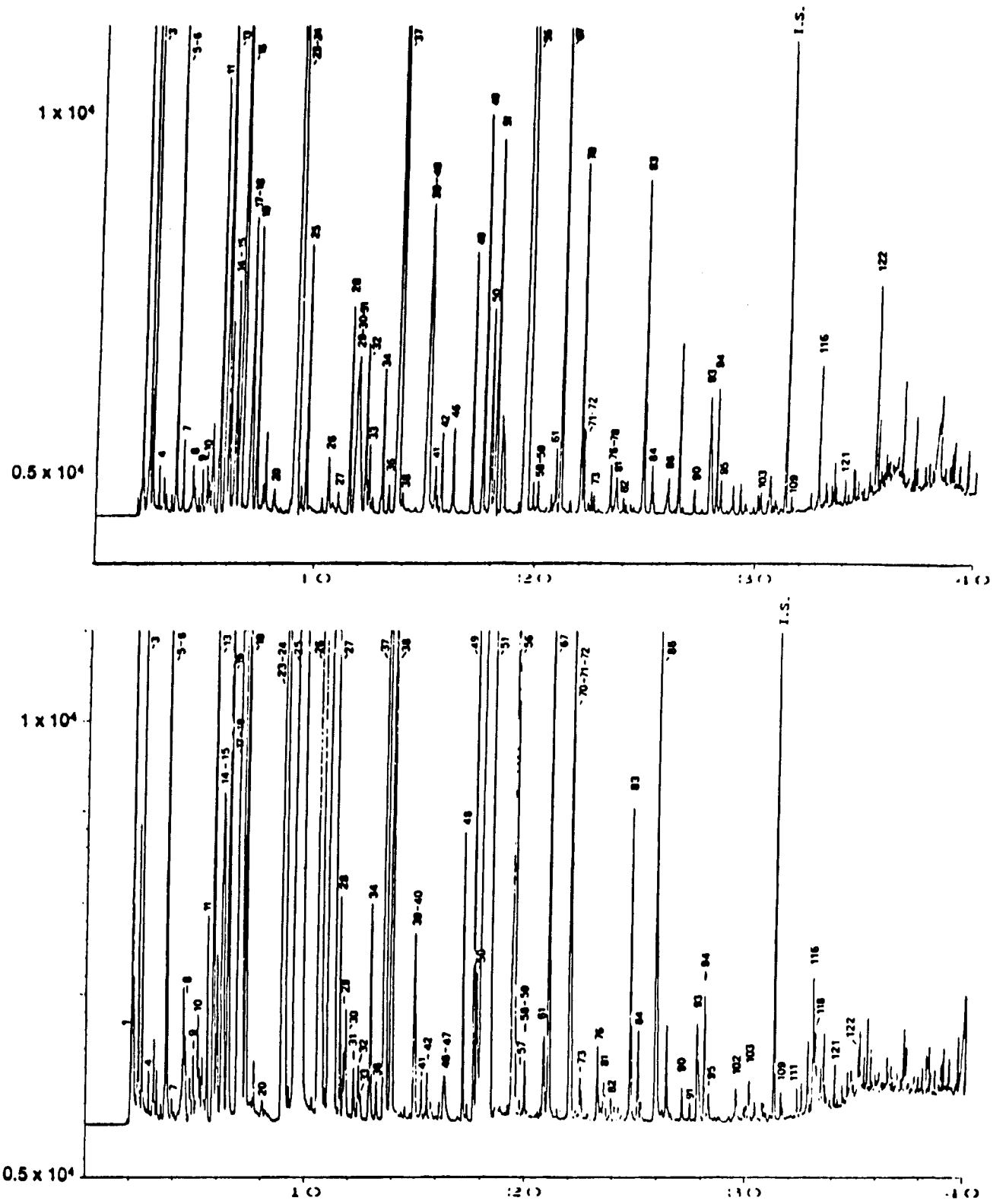


Figure 1. Gas chromatograms of volatile components of two dry-cured ham samples obtained by using the FID. For peak numbers, see Table I.

this component is believed to derive from lipids as an enzymatic reaction product.

Few carboxylic acids ranging from C_1 to C_6 were identified in raw ham volatiles, but all with high occurrence; these compounds derive from the hydrolysis of the triglycerides and phospholipids in the ham.

Numerous esters were isolated and identified in this study, most of which have not been previously reported, as is shown in Table I; they are predominant both in number and in intensity since they constitute a high percentage of the total area (65.9%). They included a series of acetates, propanoates, butanoates of different alcohols, and various methyl and ethyl esters of longer chain acids, both linear and branched. Among the volatiles, esters seem to be present to a much higher extent in Parma ham compared with similar products of different origin (Baloga et al., 1990; Berdagué et al., 1991b; Garcia et al., 1991). Esters strongly affect the flavor of ham as a typical aged meat product; in particular, the methyl-branched short-chain esters were found to be positively related to the attribute of aged meat (Careri et al., 1992). Esters that impart a fruity sweet note to pork meat

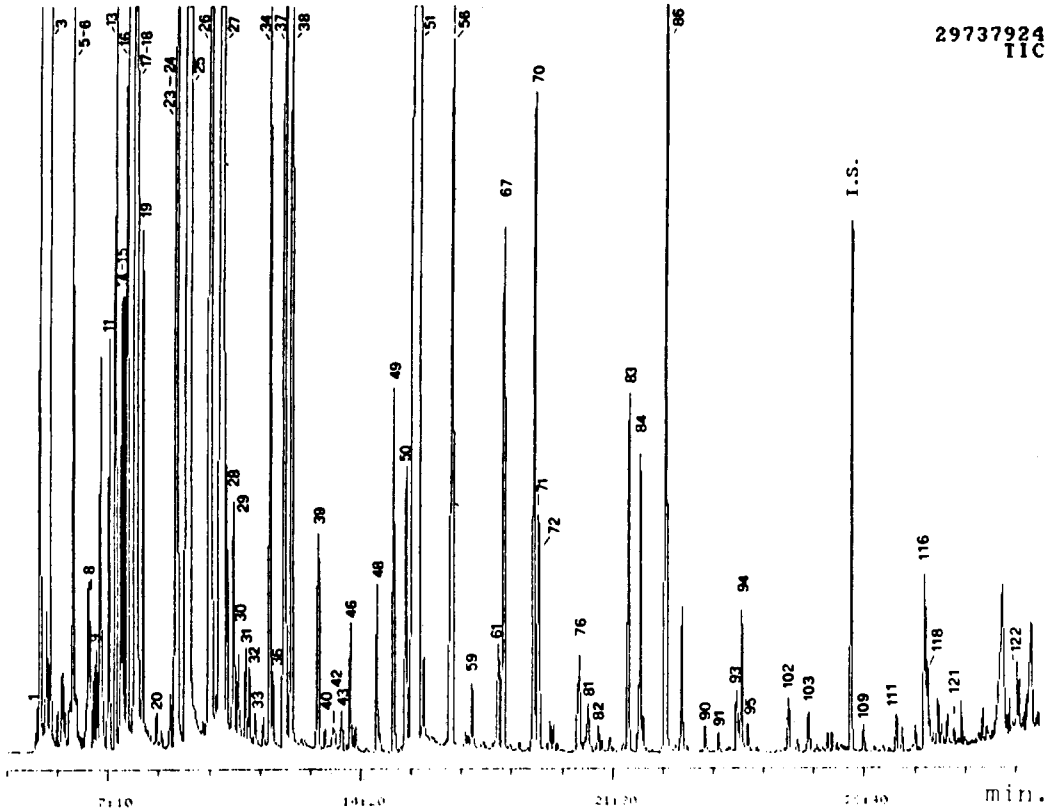
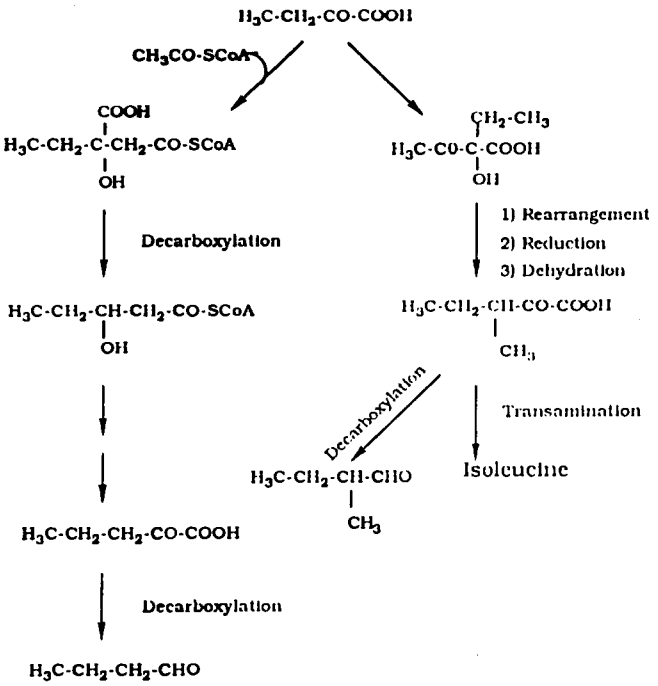
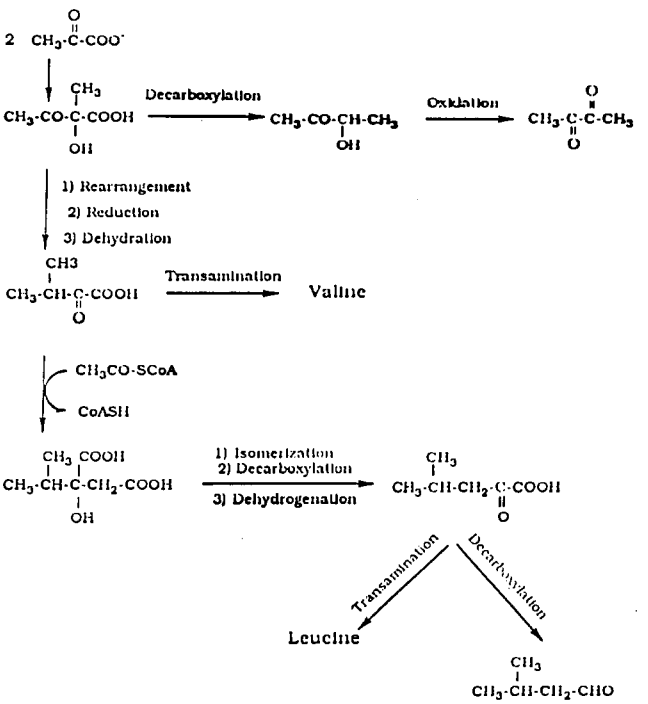


Figure 2. Gas chromatogram of volatile components of a dry-cured ham sample obtained by plotting the total ion current of the GC–MS signal. For peak numbers, see Table I.

Scheme I



Scheme II

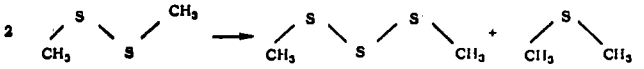


probably derive from esterification of the various alcohols and carboxylic acids (Shahidi et al., 1986).

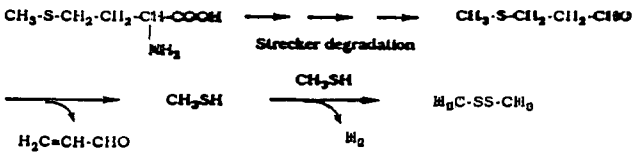
As a consequence of the use of the headspace sampling method for extraction, lactones were not isolated; these substances have been isolated by other authors who used a different sampling technique (Berdagué et al., 1991b; Garcia et al., 1991).

Of the heterocyclic compounds, pyrrole, 3-vinylpyridine, three furans, and four pyrazines were identified. Heterocyclic compounds relating to meat flavor can be produced in different ways, i.e., by reactions of reducing sugars and amino acids, by thermal degradation of Amadori rearrangement compounds in the Maillard reaction, by pyrolysis of α-amino acids, or by reaction of α-dicarbonyl compounds and aldehydes with ammonia (Bailey and Einig, 1989). In accordance with other authors (Baines and Mlotkiewicz, 1983), only a few pyrazines, i.e., pyrazine, methylpyrazine, 2,6-dimethylpyrazine, and trimethylpyrazine, were identified in the headspace of raw ham (<0.2% total relative area), these compounds being typical of thermally treated products. Pyrazines are normally considered to be key flavor components in many foods because they impart nutty, roasted, or toasted aromas.

The headspace volatiles of raw ham showed the presence of four sulfur compounds, namely, dimethyl disulfide, dimethyl trisulfide, dimethyl tetrasulfide, and methyl 3-(methylthio)propanoate, few in comparison to those found in pork flavor by other investigators (Shahidi et al., 1986), with 0.5% of relative percentage of total peak area. These sulfur compounds can derive from *S*-amino acids such as cysteine, cystine, and methionine via Strecker degradation to thiols. These compounds are oxidized to disulfides which can disproportionate to trisulfides (Belitz and Grosch, 1987):



In particular, dimethyl disulfide is obtained from methionine degradation following the pathway



This kind of sulfur compound occurs in all protein-containing foods, when they are heated or stored for a prolonged period of time (Belitz and Grosch, 1987). Sulfur compounds were detected by means of both MS and FPD.

CONCLUSIONS

The dynamic headspace technique used led to the isolation of many volatile components having different chemical structures in dry-cured ham. In Parma ham, as well as in various meat products, the typical aroma cannot be ascribed to a few compounds but seems to depend on a large number of volatiles present in proper amounts and proportions; however, a high content of various types of esters appears to be a typical feature of Parma ham with respect to the French and Iberian products, which are characterized by a higher amount of alcohols and aldehydes.

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Registry No. *n*-Pentane, 109-66-0; 2,2,3-trimethylpentane, 564-02-3; *n*-heptane, 142-82-5; 1-heptene, 592-76-7; acetone, 67-64-1; *n*-octane, 111-65-9; methyl acetate, 79-20-9; 1-octene, 111-66-0; octene, 25377-83-7; ethyl acetate, 141-78-6; butanal, 123-72-8; 2-butanone, 78-93-3; methyl propanoate, 554-12-1; 2-methylbutanal, 96-17-3; 3-methylbutanal, 590-86-3; methyl 2-methylpropanoate, 547-63-7; 3-methyl-2-butanone, 563-80-4; benzene, 71-43-2; 2-ethylfuran, 3208-16-0; 1-methoxyhexane, 4747-07-3; ethyl propanoate, 105-37-3; pentanal, 110-62-3; 2-pentanone, 107-87-9; methylbutanoate, 623-42-7; methyl 2-methylbutanoate, 868-57-5; methyl 3-methylbutanoate, 556-24-1; toluene, 108-88-3; 2-butanol, 78-92-2; ethylbutanoate, 105-54-4; 1-propanol, 71-23-8; 2-methyl-3-buten-2-ol, 115-18-4; ethyl 2-methylbutanoate, 7452-79-1; dimethyl disulfide, 624-92-0; 2,3-pentanedione, 600-14-6; ethyl 3-methylbutanoate, 108-64-5; hexanal, 66-25-1; methyl pentanoate, 624-24-8; 2-methyl-1-propanol, 78-83-1; ethylbenzene, 100-41-4; *p*-xylene, 106-42-3; *m*-xylene, 108-38-3; (*E*)-2-pentenal, 1576-87-0; methyl 4-methylpentanoate, 2412-80-8; isopropylbenzene, 98-82-8; 2-pentanol, 6032-29-7; *o*-xylene, 95-47-6; 1-butanol, 71-36-3; 1-penten-3-ol, 616-25-1; heptanal, 111-71-7; methylhexanoate, 106-70-7; limonene, 138-86-3; 1-ethyl-2-methylbenzene, 611-14-3; 2-hexenal, 505-57-7; pyrazine, 290-37-9; 3-methyl-1-butanol, 123-51-3; 2-pentylfuran, 3777-69-3; methyl 5-hexenoate, 2396-80-7; ethyl hexanoate, 123-66-0; styrene, 100-42-5; methyl 4-methylhexanoate, 2177-82-4; 2-hexanol, 626-93-7; *tert*-butylbenzene, 98-06-6; 1,2,4-trimethylbenzene, 95-63-6; 3-methyl-3-buten-1-ol, 763-32-6; methyl 3-hexenoate, 2396-78-3; 1-pentanol, 71-41-0; cyclohexanone, 108-94-1; 2-methylpyrazine, 109-08-0; acetoin, 513-86-0; octanal, 124-13-0; methyl heptanoate, 106-73-0; 4-octen-3-one, 14129-48-7; methylvinylbenzene, 25013-15-4; 1-hydroxy-2-propanone, 116-09-6; (*E*)-2-heptenal, 18829-55-5; 2-penten-1-ol, 20273-24-9; 1,2-propanediol, 57-55-6; 4,6,8-trimethylnonene, 144043-16-3; 2-methyl-2-buten-1-ol, 4675-87-0; 2,6-dimethylpyrazine, 108-50-9; 6-methyl-5-hepten-2-one, 110-93-0; 1-hexanol, 111-27-3; dimethyl trisulfide, 3658-80-8; 1-butoxy-2-propanol, 5131-66-8; methyl octanoate, 111-11-5; methyl 6-methylheptanoate, 2519-37-1; 2-butoxyethanol, 111-76-2; trimethylpyrazine, 14667-55-1; (*E*)-2-octenal, 2548-87-0; ethyl octanoate, 106-32-1; methyl 3-octenoate, 74023-04-4; acetic acid, 64-19-7; 1-octen-3-ol, 3391-86-4; 1-heptanol, 111-70-6; epoxydihydrolinalool, 1365-19-1; 3-vinylpyridine, 1121-55-7; (*E,E*)-2,4-heptadienal, 4313-03-5; 2-ethyl-1-hexanol, 104-76-7; pyrrole, 109-97-7; methyl nonanoate, 1731-84-6; decanal, 112-31-2; benzaldehyde, 100-52-7; 2-hepten-1-ol, 22104-77-4; methyl 3-(methylthio)propanoate, 13532-18-8; (*Z*)-2-nonenal, 60784-31-8; propanoic acid, 79-09-4; 3,7-dimethyl-1-octen-3-ol, 18479-49-7; 1-octanol, 111-87-5; benzonitrile, 100-47-0; methyl decanoate, 110-42-9; 2-undecanone, 112-12-9; methyl benzoate, 93-58-3; (*Z*)-2-octen-1-ol, 26001-58-1; (*E*)-2-octen-1-ol, 18409-17-1; butanoic acid, 107-92-6; (*Z*)-2-decenal, 2497-25-8; ethyl decanoate, 110-38-3; methyl 4-decenoate, 1191-02-2; dimethyl tetrasulfide, 5756-24-1; pentanoic acid, 109-52-4; hexanoic acid, 142-62-1.