Studies on Meat Flavor. 1. Qualitative and Quantitative Differences in Uncured and Cured Pork

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The aroma concentrates from uncured and cured pork were isolated by steam distillation and continuous steam distillation–extraction (SDE) methods. While the SDE method was more efficient in isolating the volatiles, the aroma concentrates of uncured meat isolated by either method had more components than those of cured meat. By use of hexanal and decanal in pentane as the respective internal standards for cured and uncured meat, quantitative estimation of the volatile constituents in uncured and cured meat was carried out by using GC–MS. The investigation indicated that hexanal, a major lipid oxidation product, was found to be present in uncured meat at a concentration of 12.66 ± 0.08 mg/kg, while only 0.03 mg/kg was present in the cured product. Also, the concentration of other carbonyl compounds was higher in uncured pork, while they were either present in reduced amounts or not detectable in the cured meat. Similarly, of the hydrocarbons identified, the concentration of 3-methylheptane and methylcyclohexane was found to be higher in the uncured meat. 1-Nonen-3-ol, identified for the first time in uncured pork, was absent in cured pork.

INTRODUCTION

The origin of the use of nitrate and nitrite in the curing of meat is lost in history, but the use of nitrite has been widely put into practice since 1925 when the U.S. Department of Agriculture authorized its use as such for meat curing (Rubin, 1977). Nitrite is a unique ingredient in meat-curing systems because of its ability to produce the characteristic cured-meat color (Eakes et al., 1975; Giddings, 1977) and to generate the typical cured-meat flavor (Cross and Ziegler, 1965; Bailey and Swain, 1973; Gray et al., 1981). Nitrite has an antimicrobial effect that is important in the prevention of *Clostridium botulinum* outgrowth (Hauschild et al., 1982; Pierson and Smoot, 1982), particularly under conditions of product mishandling.

Raw meat has little odor and only a bloodlike taste, whereas cooking develops its flavor. Although a variety of factors is known to influence the flavor of meats, no single group of factors can be assigned the principal role. In their study of cured and uncured ham, Cross and Ziegler (1965) reported that the volatiles of cooked cured and uncured ham were qualitatively similar but quantitatively very different. Striking differences were observed, especially in *n*-pentanal and *n*-hexanal concentrations. They were present in appreciable quantities in the uncured product but were barely detectable in the volatiles of the cured meat.

Shahidi et al. (1987) demonstrated that the flavor acceptability of cooked pork decreased as the TBA number or hexanal content increased. On storage, uncured cooked meats develop an unpleasant warmed-over flavor (WOF) which is not observed in cured meats due to the potent antioxidant effect of nitrite (Pearson et al., 1977; Fooladi et al., 1979; MacDonald et al., 1980).

Oxidation of the unsaturated lipids results in the formation of carbonyl compounds that have been implicated as significant contributors to the flavor of uncured meat, but not in cured meat. Thus, volatile materials derived from cured and uncured ham, beef, or chicken, after passage through a solution of 2,4-dinitrophenylhydrazine, possessed a characteristic cured-ham aroma in the effluent stream in all of these systems (Cross and Ziegler, 1965; Minor et al., 1965). Although the nature of cured-meat flavor seems to be much simpler than that of uncured meat, and is postulated to be the basic flavor of meat regardless of species (Rubin and Shahidi, 1988), the elucidation of the compounds that are responsible for the cured-meat flavor is not easy. Minute traces of compounds can be aroma effective, creating enormous analytical difficulties for their isolation and identification (MacLeod and Ames, 1986).

In a recent review on meat-flavor volatiles, Shahidi et al. (1986) described the qualitative differences in the nature of carbonyl compounds among the different species. The distribution of carbonyls varies with the lipid composition of the original meat—pork, beef, lamb, or poultry. Since the lipids that constitute the fat of different animals are composed of different fatty acids, species differences probably arise by the formation of carbonyl compounds that differ in their qualitative and quantitative composition (Gray et al., 1981).

A large number of components have been isolated and identified in the volatiles of meat in the past two decades, and exhaustive review papers on meat flavor were published (Herz and Chang, 1970; Bailey and Swain, 1973; Dwivedi, 1975; Chang and Peterson, 1977; Wasserman, 1979; Gray et al., 1981; MacLeod and Seyyedain-Ardebili, 1981; Ramaswamy and Richards, 1982; Moody, 1983; Shahidi et al., 1986). Despite the widespread use of nitrite as a meat-curing agent, the literature available on cured-meat flavor is very limited, and none of the papers has attempted to quantitatively differentiate the constituents present in the aroma concentrates of uncured and cured meat.

A comprehensive study to support the conclusion of Cross and Ziegler (1965) that cured-meat flavor comprises the basic meat-flavor components derived from non-triglyceride precursors and to confirm the further postulation by Rubin and Shahidi (1988) that species differences in cooked pork, beef, lamb, or poultry meat probably arise due to the differences in their spectrum of carbonyl compounds has not yet been attempted. It is the objective of the present study, therefore, as a first step, to compare the volatile carbonyls and hydrocarbons of uncured and

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cured pork and to characterize the qualitative and quantitative differences between the components present in these aroma concentrates.

MATERIALS AND METHODS

Meat. Fresh pork loin was purchased from a local market and used immediately. Excess fat was removed, and the meat was then ground in a Oster meat grinder (0.476-cm grind plate, Model 990-68).

Proximate Analysis. The fat content of cooked-meat samples was determined by the Soxhlet extraction method (AOAC, 1984) and their moisture content by oven drying at 102 ± 1 °C for a period of 18 h. The cooked meats in all experiments contained 71.8 ± 0.02% water and 10.4 ± 0.1% fat.

Reagents. Anhydrous sodium sulfate, sodium chloride, and sodium nitrite, all of analytical grade, and sodium ascorbate (USP grade) were purchased from BDH Chemicals. Sodium tripolyphosphate (food grade) was obtained from ERCO Industries, Ltd., while *n*-pentane and diethyl ether (spectral grade) were purchased from Caledon Laboratories, Ltd. Gas chromatographic standards hexanal (99%) and decanal (95%) were purchased from Aldrich Chemical Co., Inc.

Cooking. Ground meat (250–450 g) was placed in a 2-L beaker. Distilled water was added so as to attain a meat-to-water ratio of 4:1 (w/w) (Shahidi et al., 1987), and the contents were heated in a thermostated water bath, maintained at 85 °C, with intermittent stirring to facilitate uniform cooking. Heating was carried out until the meat slurry attained a constant temperature of 73 °C and held at that temperature for 10 min.

Curing of the ground meat was carried out simultaneously in another 2-L beaker by adding sodium chloride (2% w/w), sugar (1.5% w/w, commercial sucrose), sodium ascorbate (0.05% w/w), sodium tripolyphosphate (0.3% w/w), and sodium nitrite (150 ppm).

The cooked-meat (uncured and cured) samples were cooled to room temperature and stored in a refrigerator at 4 °C for 24 h. Prior to extraction, distilled water was added to the cooked-meat samples (1:1 w/w) and ground to a homogeneous mixture by using a Braun Hand Blender MR 30.

Conventional Steam Distillation Method. The slurry of uncured- and cured-meat samples (250–450 g) was placed in a two-necked 2-L distillation flask. Steam was introduced into the flask to heat the slurry and further to distill the volatiles from the cooked meat. Distillation was carried out until about 250 mL of the steam distillate was collected. The distillates were extracted with diethyl ether (2 × 50 mL). The extracts were pooled, dried over anhydrous Na_2SO_4, and evaporated at room temperature to a volume of 500 μL by passing a slow current of nitrogen gas over the solvent. The aroma concentrates of cooked uncured and cured pork, prepared in duplicate, were stored under nitrogen in airtight bottles at −15 °C until further use.

Continuous Steam Distillation–Extraction (SDE) Technique. Aroma concentrates were also prepared by using the modified Likens–Nickerson steam distillation–extraction apparatus (Schultz et al., 1977) from 250–450 g of ground-meat samples. The flavor components were extracted into *n*-pentane (50 mL). Although diethyl ether was tried initially as the solvent for extraction, an emulsion formed at the water–solvent interface in the Likens–Nickerson extraction apparatus which was difficult to clarify. *n*-Pentane was therefore used in subsequent extractions. The pentane extract was dried over anhydrous Na_2SO_4 and concentrated under a slow stream of nitrogen to a final volume of around 500 μL, and the resultant aroma concentrate was stored under nitrogen in airtight bottles at −15 °C until further use. The sample preparations were carried out in duplicate.

Gas Chromatographic Analysis (GC). Gas chromatographic analysis of the aroma concentrates was carried out by using a Hewlett-Packard Model HP 5890 gas chromatograph equipped with a DB-5 [0.13 mm (i.d.) × 60 m] capillary column. The carrier gas was helium, maintained at a flow rate of 1.5 mL/min. The column was initially held at 30 °C for 5 min and then programmed in two stages, from 30 to 60 °C at a rate of 5 °C/min and from 60 to 280 °C at a rate of 10 °C/min. It was finally held at 280 °C for 27 min. The injection port temperature was 250 °C, and the flame ionization detector (FID) temperature was 280 °C. All analyses were carried out in triplicate.

Gas Chromatography–Mass Spectrometric (GC–MS) Analysis. A Hewlett-Packard Model HP 5880A gas chromatograph coupled to a Hewlett-Packard Model HP 5987A mass spectrometer was used. A DB-5 capillary column [0.13 mm (i.d.) × 30 m] was used for GC–MS studies. Analysis was carried out with the column temperature maintained initially at 30 °C for 2 min and then programmed from 30 to 280 °C at a rate of 10 °C/min, where it was held for 3 min. The source, injector, analyzer, and transfer line temperatures were 200, 250, 300, and 300 °C, respectively. The ionization voltage applied was 70 eV. Mass spectra obtained were compared with those of known compounds in the NBS (now NIST) library by using a HP 1000E series computer. Tentative identification of the individual constituents was based on the MS data.

Quantitation of the Individual Components. Quantitative analysis of the individual constituents identified in the aroma concentrates isolated by the SDE method was carried out by spiking the cured meat with hexanal (9.2 mg/mL in *n*-pentane) and the uncured meat with decanal (13.5 mg/mL in *n*-pentane) before the distillation was carried out. Hexanal was used as the internal standard for quantitation of volatiles in cured meat, on the basis of the preliminary gas chromatographic results which revealed that hexanal was present only in trace amounts in cured meat while it was a major constituent in uncured meat. Decanal, another aldehyde having a higher retention time, was used as the internal standard in uncured meat to confirm the quantitative information obtained by use of hexanal.

From the peak areas of different known concentrations of hexanal and decanal, the amount of individual constituents present in uncured and cured meat was calculated and expressed in terms of milligrams per kilogram of meat. Extraction of the volatiles from the spiked-meat samples by the SDE method, followed by concentration and subsequent analysis of the concentrate using GC–MS, was carried out by procedures already described above.

RESULTS AND DISCUSSION

Gas Chromatographic Analysis. Typical gas chromatograms of the uncured and cured pork meat aroma concentrates extracted by the conventional steam distillation method and SDE method using the modified Likens–Nickerson flavor extraction apparatus are given in Figures 1 and 2. It was observed that the aroma concentrate from cured meat, isolated by either technique, had fewer constituents than the uncured-meat sample. This is in agreement with earlier observations (Cross and Ziegler, 1965; Swain, 1972). Also, it was found that many of the volatile constituents present in the aroma concentrate of uncured meat in the retention time range 15–40 min were either absent or present in much lower concentrations in the cured-meat concentrate.

This result is attributable to the suppression of lipid oxidation due to the presence of nitrite in cured meat. The antioxidant effect of nitrite in cured meats, which retards lipid oxidation and the development of warmed-over flavor (WOF) in cooked meat and meat products, is well-known. Sato and Hegarty (1971) were able to inhibit WOF in cooked ground beef, as indicated by the thiobarbituric acid (TBA) values, by adding nitrite at a level of 50 mg/kg of beef. The antioxidant effect of nitrite in the meat-curing process using TBA values and sensory scores was also demonstrated by other workers (Hadden et al., 1975; Love and Pearson, 1976; MacDonald et al., 1980).

Shahidi et al. (1987) proved that the amount of hexanal in nitrite-treated meat decreased drastically to 2% of the level in the uncured control. Under the present analytical conditions, hexanal had a retention time of 18.8 min, and it is evident from Figures 1 and 2 that the level of this lipid oxidation product in the cured meat is indeed very low.

Though the gas chromatograms of the aroma concen-

Table I. Components in the Aroma Concentrates of Uncured and Cured Pork

peak no.	RT, min	component	detected in[a]				content,[b] mg/kg	
			A	B	A+	B+	A	B
1	2.47	2-methylhexane	+	+	+	+	1.20 ± 0.18	1.01 ± 0.06
2	2.56	3-methylhexane	+	+	+	+	0.69 ± 0.04	0.59 ± 0.01
3	2.70	2,2-dimethylhexane	+	+	+	+	0.33 ± 0.04	0.28 ± 0.03
4	2.88	3-hexanone	+	+	–	–	0.42 ± 0.06	tr
5	3.23	unidentified	–	+	–	+		tr
6	3.41	2,4-dimethylhexane	+	+	+	+	0.93 ± 0.08	0.68 ± 0.15
7	3.55	4-methyl,2-pentanone	–	+	–	–		tr
8	3.68	2,3-dimethylhexane	–	+	–	+		tr
9	3.76	3,3-dimethylhexane	–	+	–	+		0.03 ± 0.01
10	3.90	4-methylheptane	–	+	+	+		0.09 ± 0.01
11	4.02	2,5-dimethylhexane	+	+	+	+	0.23 ± 0.09	0.17 ± 0.03
12	4.16	3-methylheptane	+	+	+	+	0.21 ± 0.06	0.09 ± 0.01
13	4.35	2,2,5-trimethylhexane	+	+	+	+	1.27 ± 0.09	1.08 ± 0.06
14	4.44	2,2,4-trimethylhexane	–	+	–	+		0.09 ± 0.06
15	4.69	hexanal	+	+	+	+	12.66 ± 0.08	0.03
16	4.76	unidentified	–	–	–	+		tr
17	4.96	2,3,5-trimethylhexane	+	+	+	+	0.12 ± 0.02	0.10 ± 0.02
18	5.10	2,4-dimethylheptane	–	+	+	+		0.07 ± 0.01
19	5.26	2,6-dimethylheptane	+	+	+	+	tr	0.07 ± 0.02
20	5.35	2,5-dimethylheptane	+	+	+	+	0.17 ± 0.02	0.15 ± 0.03
21	5.63	1,2,4-trimethylcyclohexane	–	+	–	+		0.03 ± 0.01
22	5.76	2-hexenal	+	+	+	+	tr	tr
23	5.92	3-methyl-4-heptanone	–	+	–	+		tr
24	6.02	1,3-dimethylbenzene	–	+	–	+		tr
25	6.09	2,5-dimethyloctane	–	+	–	+		0.04 ± 0.02
26	6.17	4-ethyl-2,2-dimethylhexane	–	+	–	+		0.12 ± 0.02
27	6.20	2,2,3-trimethylhexane	+	–	+	–	0.23 ± 0.11	
28	6.30	2,2,4-trimethylheptane	+	+	+	+	0.12 ± 0.01	0.10 ± 0.03
29	6.46	1,2-dimethylbenzene	–	+	–	–		0.04 ± 0.03
30	6.50	2-heptanone	+	–	+	–	0.20 ± 0.06	
31	6.55	3,3,5-trimethylheptane	–	+	+	+		0.05 ± 0.01
32	6.66	3-methyl-2-nonene	–	+	–	+		0.04 ± 0.01
33	6.74	3-methylhexanal	+	–	+	–	0.65 ± 0.14	
34	6.89	3,5-dimethyloctane	–	+	–	+		tr
35	7.74	2,4,6-trimethyloctane	–	+	–	+		tr
36	7.81	2-heptenal	+	–	+	–	0.34 ± 0.04	
37	7.83	benzaldehyde	+	+	+	+	0.11 ± 0.01	0.04 ± 0.05
38	8.12	3-methyloctane	+	–	–	–	0.11 ± 0.01	
39	8.18	unidentified	+	–	–	–	1.77 ± 0.05	
40	8.33	2,3-octanedione	+	–	–	–	0.88 ± 0.09	
41	8.36	1,3,5-trimethylbenzene	–	+	–	–		tr
42	8.40	1-nonen-3-ol	+	–	+	–	0.75 ± 0.05	
43	8.46	3,6-dimethyloctane	–	+	–	–		tr
44	8.56	unidentified	–	+	–	+		0.04 ± 0.01
45	8.66	3-ethoxy-2-methyl-1-propene	+	–	+	–	0.66 ± 0.1	
46	8.85	2,3,4-trimethyloctane	–	+	–	–		tr
47	9.00	D-limonene	–	+	–	–		0.02
48	9.13	3-ethyl-2-methyl-1,3-hexadiene	+	–	+	–	0.14 ± 0.01	
49	9.40	4,4,5-trimethyl-2-hexene	+	–	–	–	0.13 ± 0.02	
50	9.47	5-methylundecane	–	+	–	–		tr
51	9.57	5,5-dimethyl-2-hexene	–	+	–	–		tr
52	9.65	(*E*)-2-octenal	+	–	+	–	0.99 ± 0.1	
53	9.86	2-octen-1-ol	+	–	+	–	0.69 ± 0.15	
54	10.20	3,7-dimethylnonane	+	+	–	–	tr	tr
55	10.40	methylcyclohexane	+	+	+	+	2.10 ± 0.33	0.33 ± 0.08
56	11.30	2-nonenal	+	–	+	–	0.39 ± 0.05	
57	11.34	4-ethylbenzaldehyde	+	–	+	–	tr	
58	11.45	5-undeca-3(*Z*),5-diyne	+	–	–	–	tr	
59	11.60	5-undeca-3(*E*),5-diyne	+	–	–	–	tr	
60	11.68	naphthalene	+	+	–	–	0.12 ± 0.03	0.04 ± 0.01
61	11.81	dodecane	+	+	+	–	0.28 ± 0.06	tr
62	11.96	decanal	+	+	+	–	tr	tr
63	12.13	2,4-nonadienal	+	–	+	–	tr	
64	12.40	unidentified	+	–	–	–	tr	
65	12.87	2-undecenal	+	–	+	–	0.39 ± 0.07	
66	13.13	unidentified	+	–	–	–	tr	
67	13.27	2-undecanone	–	+	–	–		0.02
68	13.32	4,6-dimethylundecane	–	+	–	–		tr
69	13.40	tridecane	+	+	+	–	0.49 ± 0.04	tr
70	13.49	undecanal	+	–	–	–	tr	
71	13.70	(*E*,*E*)-2,4-decadienal	+	–	+	–	0.69 ± 0.16	
72	13.75	2,4-decadienal	+	–	+	–	0.41 ± 0.15	
73	14.11	unidentified	+	–	+	–	tr	
74	14.22	5-tridecanone	–	+	–	–		tr
75	14.35	2-dodecenal	+	–	+	–	0.43 ± 0.08	
76	14.76	tetradecane	+	–	–	–	0.14 ± 0.04	

Table I (Continued)

peak no.	RT, min	component	detected in[a] A	B	A+	B+	content,[b] mg/kg A	B
77	14.92	dodecanal	+	-	-	-	tr	
78	15.10	2,4-undecadienal	+	-	-	-	tr	
79	15.70	4-pentylbenzaldehyde	+	-	+	-	tr	
80	15.87	1-pentadecene	+	-	-	-	tr	
81	16.07	pentadecane	+	+	+	+	0.19 ± 0.05	0.08 ± 0.07
82	16.29	tridecanal	+	+	+	+	0.25 ± 0.05	0.09 ± 0.01
83	16.97	dodecanoic acid	-	+	-	-		tr
84	17.31	unidentified	-	+	-	-		0.14 ± 0.01
85	17.36	hexadecane	+	+	+	+	tr	0.04 ± 0.01
86	17.49	3-tridecen-1-yne	+	-	-	-	tr	
87	17.55	tetradecanal	+	+	+	+	0.40 ± 0.14	0.03 ± 0.01
88	18.51	heptadecane	+	+	-	-	0.13 ± 0.02	0.11 ± 0.03
89	18.55	2-pentadecanone	+	+	-	+	tr	0.06 ± 0.02
90	18.75	hexadecanal	+	+	+	+	0.65 ± 0.05	0.06 ± 0.02
91	19.37	tridecanoic acid	-	-	+	+		
92	19.48	unidentified	+	-	-	-	0.12 ± 0.02	
93	19.64	1,14-tetradecanediol	+	+	+	+	tr	0.05 ± 0.01
94	19.88	17-octadecenal	+	-	+	+	tr	
95	20.01	16-octadecenal	+	+	+	+	8.34 ± 0.35	2.20 ± 1.26
96	20.56	unidentified	+	-	-	-	0.17 ± 0.03	
97	20.78	pentadecanitrile	+	+	-	+	0.21 ± 0.05	0.12 ± 0.04
98	20.99	15-octadecenal	+	+	+	+	0.70 ± 0.04	0.14 ± 0.04
99	21.52	hexadecanoic acid	+	+	+	+	0.97 ± 0.07	0.14 ± 0.02
100	21.81	9-octadecenal	+	+	+	+	0.81 ± 0.06	0.14 ± 0.02
101	21.86	5-octadecenal	-	+	+	+		0.05 ± 0.01
102	22.05	octadecanal	+	+	+	+	1.19 ± 0.11	0.19 ± 0.09
103	23.17	9,12-octadecadienoic acid	+	+	-	-	tr	0.13 ± 0.03
104	23.22	9-octadecenoic acid	+	+	+	+	0.16 ± 0.05	tr
105	23.37	octadecanoic acid	-	+	-	+		tr

[a] Qualitative information only. +, detected; -, not detected. A and A+ are uncured meat flavor constituents isolated by SDE and steam distillation methods. B and B+ are cured meat flavor constituents isolated by SDE and steam distillation methods. [b] Concentration of constituents in uncured (A) and cured meat (B), isolated by the SDE method. Reported values are mean ± SD, $n = 3$. tr, trace amount (<0.01 mg/kg).

trates of uncured and cured meat, obtained by the two extraction methods, closely resembled each other in terms of the components present, the concentration of individual constituents differed. Detailed quantitative information is given in the following section. It was also observed that the aroma concentrates isolated by the SDE method (Figure 2) had the relative concentrations of the individual components higher than those present in the concentrate obtained by the conventional steam distillation method. This could be due to the partial loss of volatiles during the extraction and concentration steps of the latter method, which involves twice the volume of extraction solvent as the SDE method.

Gas Chromatography–Mass Spectrometric (GC–MS) Analysis. The separated constituents in uncured and cured pork are reported in Table I. In all, 50 hydrocarbons, 37 carbonyls, 6 acids, and 2 alcohols were identified. Table I lists these components and also shows in which of the samples prepared by the two isolation methods the components were identified. The total ion chromatograms (TIC) of the uncured and cured meat aroma concentrates analyzed on GC–MS showed that the aroma concentrates isolated by the SDE method were resolved into 77 and 72 components, respectively. Samples extracted by conventional steam distillation contained only 59 and 51 components, respectively. These differences are mainly due to the minor carbonyl components such as 3-hexanone (peak 4), 4-methyl-2-pentanone (peak 7), dodecanal (peak 77), 2,4-undecadienal (peak 78), and 2-undecenal (peak 65) that were detected only in the aroma concentrates isolated by the SDE method. Hydrocarbons such as 1,2-dimethylbenzene (peak 29), 3-methyloctane (peak 38), 1,3,5-trimethylbenzene (peak 41), 4,4,5-trimethyl-2-hexene (peak 49), 3,7-dimethylnonane (peak 54), naphthalene (peak 60), tetradecane (peak 76), 1-pentadecene (peak 80), and heptadecane (peak 88) were also not observed in the steam-distilled samples. This shows that the Likens–Nickerson flavor extraction apparatus, being a closed system, was more efficient in extracting aroma components than the conventional steam distillation method or that there was considerable loss in minor components during the extraction and concentration steps of the traditional method.

The present results do not show the presence of nitrogenous or sulfur components. Pyridines (Ho et al., 1983) and pyrazines (Watanabe and Sato, 1971) have been identified mainly in fried and roasted meat. Sulfur components are potent flavoring substances and even in small traces can contribute a great deal to the flavor of cured and uncured meat (Golovnja and Rothe, 1980). Sulfur compounds have low flavor thresholds, indicating high aroma effectiveness, and are labile, causing transformation into secondary products as well as active interactions with various organic substances present in the meat system. For some of the sulfur compounds the threshold values are so low that they lie well outside the sensitivity of FID and even of the GC–MS used in the present investigation.

Of the components identified in the present work, carbonyl compounds were found to be present in major quantities in both uncured and cured aroma concentrates (Table I). The concentration values of individual constituents reported in Table I are based on the efficiency of extraction (≈74%) determined for the SDE method (data not shown). The striking difference observed between uncured and cured meat aroma concentrates was in the amount of hexanal (peak 15), which is an oxidation product of lipids. Hexanal was found to be present in uncured meat at a concentration of 12.66 ± 0.08 mg/kg, while in the cured meat it was found to be present as a minor component to the extent of 0.030 ± 0.004 mg/kg, which amounts to only 0.24% of that present in uncured

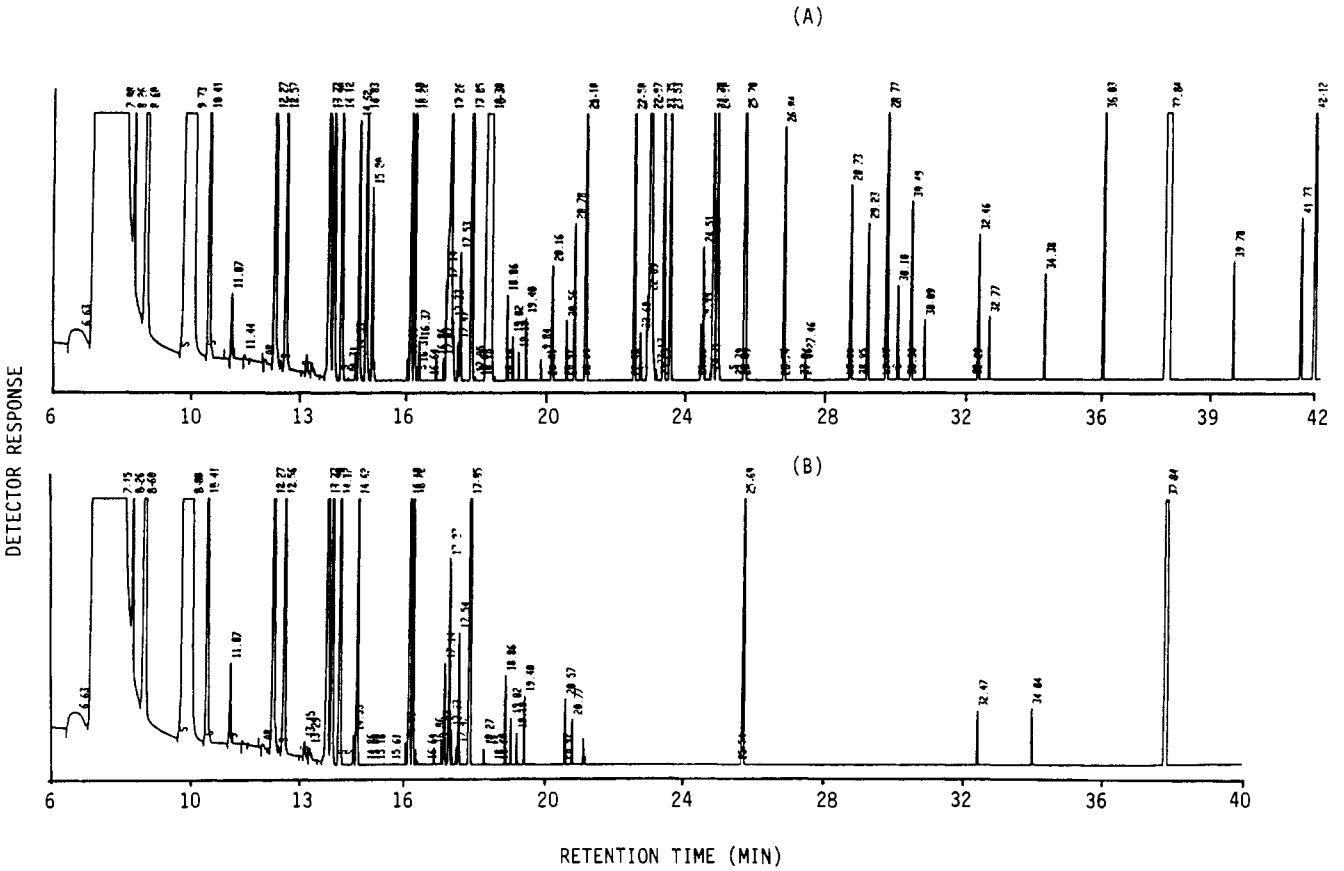

Figure 1. Typical gas chromatograms of (A) uncured-pork and (B) cured-pork flavor concentrates isolated by the steam distillation method.

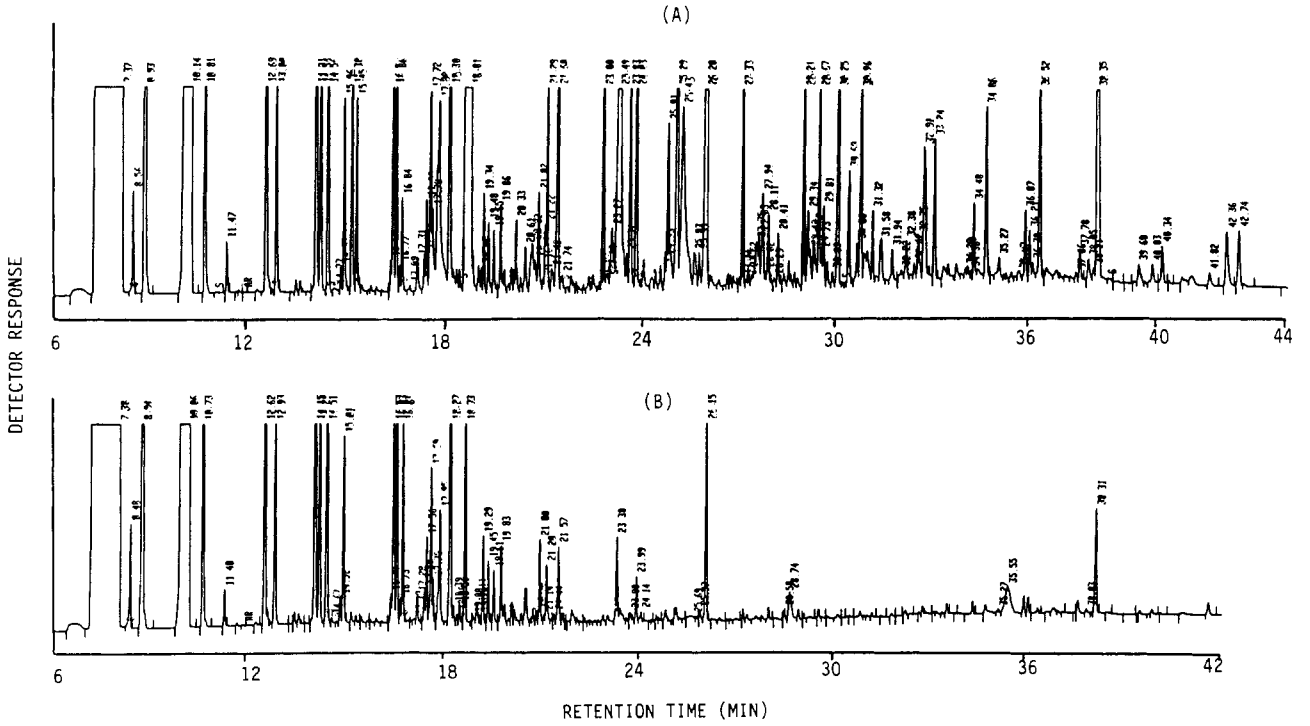

Figure 2. Typical gas chromatograms of (A) uncured-pork and (B) cured-pork flavor concentrates isolated by the SDE method.

meat. Shahidi et al. (1987) found the hexanal content of cured pork to be 2% of the value observed for uncured pork, which is qualitatively similar to the values obtained in the present investigation. The difference in magnitude is probably due to differences in the extraction techniques and sample sizes.

Of the lower carbonyl compounds that were identified, 3-hexanone (peak 4), 2-heptanone (peak 30), 3-methylhexanal (peak 33), 2-heptenal (peak 36), 2,3-octanedione (peak 40), 2-octenal (peak 52), and 2-nonenal (peak 56) were found to be present in appreciable levels in uncured meat, while in the cured meat they either were present in traces or were absent. Similar observations were also found in other higher unsaturated aldehydes such as 2-unde-

cenal (peak 65), stereoisomers of 2,4-decadienal (peaks 71 and 72), and 2-dodecenal (peak 75).

The higher aldehydes such as tridecanal (peak 82), tetradecanal (peak 87), hexadecanal (peak 90), octadecanal (peak 102), and isomeric forms of octadecenal were present in both uncured and cured meat, but the concentration of these components was relatively higher in uncured meat than in cured meat (Table I).

Among the hydrocarbons identified, 3-methylheptane (peak 12) was present in higher amounts in uncured meat (0.21 ± 0.06 mg/kg) than the cured meat (0.090 ± 0.009 mg/kg). The different analogues of dimethylhexane, heptane, and octane were either absent or present in very low concentration in uncured meat, while they were identified in small but measurable amounts in cured meat. Though the exact mechanism of formation of these compounds in cured meat is not clear at this stage, stabilization of the membrane lipid components or inhibition of the natural prooxidants in the muscle by nitrite (Pearson et al., 1977) may be the key factors.

The concentration of methylcyclohexane (peak 55) was higher in uncured meat (2.10 ± 0.33 mg/kg) than in cured meat, where it was present to the extent of 0.33 ± 0.08 mg/kg. 3-Ethyl-2-methyl-1,3-hexadiene (peak 48) was present only in uncured meat (0.14 ± 0.01 mg/kg). The higher hydrocarbons like tridecane (peak 69) and tetradecane (peak 76) were absent in cured meat. 1-Nonen-3-ol (peak 42) was identified for the first time in the volatiles of uncured pork, and this component was found to be absent in cured meat. It could be possible, on the basis of the observation of Bodrero et al. (1981), that this component may play a role in distinguishing cooked-pork flavor from the corresponding cured flavor.

CONCLUSION

The seminal paper of Cross and Ziegler (1965), which concluded that cured-meat flavor comprises the basic meat flavor components, did not receive the attention it deserved. However, work on the chemistry of meat flavor has continued to progress since then, and new contributions, both in isolation techniques and in analytical methods, have been made in the past two decades. Scores of new components have been added to the ever growing list of meat flavor volatiles. Despite these efforts, the "star performers" or "key components" that play the major role in imparting specific notes to the "basic meat flavor" and others which are responsible for species differences have yet to be identified to our satisfaction.

The present investigation quantified the individual constituents present in uncured and nitrite-cured meat. It has been demonstrated that nitrite curing simplifies the flavor spectrum of meat remarkably. Inhibition of the formation, by nitrite, of carbonyl compounds that might contribute to the cooked-pork flavor has been put on a quantitative basis. On the basis of the assumption that the cured-meat flavor is the basic flavor of meat, it may now be possible to point out those carbonyl overtones in meat volatiles which are responsible for species differences in cooked uncured meat. The elaboration of the nature of the cured-meat flavor may prove to be more difficult. Use of more efficient and less destructive techniques such as supercritical fluid extraction may reveal organoleptically important constituents not seen so far. Much more can be accomplished, and if it turns out that the basic meat flavor constituents are limited to a few, then the formulation of a "synthetic" meat flavor, both cured and uncured, will become feasible. Work in this direction is currently in progress and will be reported in due course.

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Registry No. 2-Methylhexane, 591-76-4; 3-methylhexane, 589-34-4; 2,2-dimethylhexane, 590-73-8; 3-hexanone, 589-38-8; 2,4-dimethylhexanone, 589-43-5; 4-methyl-2-pentanone, 108-10-1; 2,3-dimethylhexane, 584-94-1; 3,3-dimethylhexane, 563-16-6; 4-methylheptane, 589-53-7; 2,5-dimethylhexane, 592-13-2; 3-methylheptane, 589-81-1; 2,2,5-trimethylhexane, 3522-94-9; 2,2,4-trimethylhexane, 16747-26-5; hexanal, 66-25-1; 2,3,5-trimethylhexane, 1069-53-0; 2,4-dimethylheptane, 2213-23-2; 2,6-dimethylheptane, 1072-05-5; 2,5-dimethylheptane, 2216-30-0; 1,2,4-trimethylcyclohexane, 2234-75-5; 2-hexenal, 505-57-7; 3-methyl-4-heptanone, 15726-15-5; 1,3-dimethylbenzene, 108-38-3; 2,5-dimethyloctane, 15869-89-3; 4-ethyl-2,2-dimethylhexane, 52896-99-8; 2,2,3-trimethylhexane, 16747-25-4; 2,2,4-trimethylheptane, 14720-74-2; 1,2-dimethylbenzene, 95-47-6; 2-heptanone, 110-43-0; 3,3,5-trimethylheptane, 7154-80-5; 3-methyl-2-nonene, 117365-59-0; 3-methylhexanal, 19269-28-4; 3,5-dimethyloctane, 15869-93-9; 2,4,6-trimethyloctane, 62016-37-9; 2-heptenal, 2463-63-0; benzaldehyde, 100-52-7; 3-methyloctane, 2216-33-3; 2,3-octanedione, 585-25-1; 1,3,5-trimethylbenzene, 108-67-8; 1-nonen-3-ol, 21964-44-3; 3,6-dimethyloctane, 15869-94-0; 3-ethoxy-2-methyl-1-propene, 24309-28-2; 2,3,4-trimethyloctane, 62016-31-3; D-limonene, 5989-27-5; 3-ethyl-2-methyl-1,3-hexadiene, 61142-36-7; 4,4,5-trimethyl-2-hexene, 55702-61-9; 5-methylundecane, 1632-70-8; 5,5-dimethyl-2-hexene, 36382-10-2; (*E*)-2-octenal, 2548-87-0; 2-octen-1-ol, 22104-78-5; 3,7-dimethylnonane, 17302-32-8; methylcyclohexane, 108-87-2; 2-nonenal, 2463-53-8; 4-ethylbenzaldehyde, 4748-78-1; (*Z*)-5-undecen-3-yne, 74744-30-2; (*E*)-5-undecen-3-yne, 74744-31-3; naphthalene, 91-20-3; dodecane, 112-40-3; decanal, 112-31-2; 2,4-nonadienal, 6750-03-4; 2-undecenal, 2463-77-6; 2-undecanone, 112-12-9; 4,6-dimethylundecane, 17312-82-2; tridecane, 629-50-5; undecanal, 112-44-7; (*E*,*E*)-2,4-decadienal, 25152-84-5; 2,4-decadienal, 2363-88-4; 5-tridecanone, 30692-16-1; 2-dodecenal, 4826-62-4; tetradecane, 629-59-4; dodecanal, 112-54-9; 2,4-undecadienal, 13162-46-4; 4-pentylbenzaldehyde, 6853-57-2; 1-pentadecene, 13360-61-7; pentadecane, 629-62-9; tridecanal, 10486-19-8; dodecanoic acid, 143-07-7; hexadecane, 544-76-3; 3-tridecen-1-yne, 91954-34-6; tetradecanal, 124-25-4; heptadecane, 629-78-7; 2-pentadecanone, 2345-28-0; hexadecanal, 629-80-1; tridecanoic acid, 638-53-9; 1,14-tetradecanediol, 19812-64-7; 17-octadecenal, 56554-86-0; 16-octadecenal, 56554-87-1; 2-undecenal, 2463-77-6; pentadecanitrile, 18300-91-9; 15-octadecenal, 56554-93-9; hexadecanoic acid, 57-10-3; 9-octadecenal, 5090-41-5; 5-octadecenal, 56554-88-2; octadecanal, 638-66-4; 9,12-octadecadienoic acid, 2197-37-7; 9-octadecenoic acid, 2027-47-6; octadecanoic acid, 9088-41-9.