# Studies on Meat Flavor. 2. A Quantitative Investigation of the Volatile Carbonyls and Hydrocarbons in Uncured and Cured Beef and Chicken

Narasimhan Ramarathnam,* Leon J. Rubin, and Levente L. Diosady

Department of Chemical Engineering and Applied Chemistry, University of Toronto, Toronto, Ontario, Canada M5S 1A4

The aroma concentrates from uncured and cured beef and chicken were isolated by the continuous steam distillation–extraction (SDE) method. 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 beef and chicken was carried out by using GC–MS. The investigation indicated that hexanal was found to be present in uncured beef and chicken at concentrations of 8.15 ± 0.17 and 9.84 ± 0.17 mg/kg, respectively, while the concentrations in cured product were 0.05 ± 0.02 and 0.11 ± 0.04 mg/kg, respectively. Also, the concentrations of nonanal and 16-octadecenal were higher in uncured chicken, while in uncured beef they were present in lower amounts, and they were not detected in the cured meat of the two species. D-Limonene was detected in uncured and cured beef and was absent in chicken. Of the hydrocarbons identified, the concentrations of pentadecane, hexadecane, and heptadecane were found to be higher in chicken than in beef. Hexadecanoic acid and 9-octadecenoic acid (oleic acid) were present only in uncured beef and absent in chicken. Comparison of carbonyl components in the aroma concentrates of beef, chicken, and pork has been attempted, and species-specific carbonyls have been identified.

## INTRODUCTION

The acceptance of meat products depends to a major extent on their flavor quality. Several factors, both preslaughter and post-mortem, such as animal feed, storage and sanitation conditions, and processing methods, influence the final flavor quality of the cooked meat. It is estimated that over 70% of pork is cured with nitrite. Meat curing as practiced today involves the addition of sodium nitrite along with other additives such as salt, sugar, certain reducing agents, phosphates, and, where appropriate, seasonings to impart characteristic properties to the end product. Nitrite is a unique and critical ingredient in this curing system. It imparts the characteristic pink color to the cured meat (Eakes et al., 1975; Giddings, 1977) and provides oxidative stability to meat by preventing lipid oxidation (Pearson et al., 1977; Fooladi et al., 1979; MacDonald et al., 1980; Shahidi et al., 1987; Yun et al., 1987). This effect is complex, but it is believed to be associated with bringing forth the cured-meat flavor and prevention of the warmed-over flavor (WOF) in meat (Mottram and Rhodes, 1974; Skjelkvale and Tjaberg, 1974; Rubin and Shahidi, 1988). Nitrite has an antimicrobial effect, which is particularly important in preventing the outgrowth of *Clostridium botulinum* and the formation of a deadly toxin (Hauschild et al., 1982; Pierson and Smoot, 1982; Wood et al., 1986).

It is generally agreed that raw meat has very little odor, although rich in nonvolatile compounds with taste and tactile properties, as well as flavor enhancers and aroma precursors (Crocker, 1948; Bender and Ballance, 1961). The desirable meat flavor is developed upon cooking, the "meaty" flavor being believed to originate from the lean and "species-specific" flavor from the fat tissue (Sink, 1979; Rubin and Shahidi, 1988). Although the composition of aroma generated during cooking of meat has been exhaustively studied (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) and over 700 components in beef and half that number in chicken have been characterized, the search for individual character-impact components possessing notes specific for pork, beef, chicken, or lamb has remained largely unsuccessful.

Hornstein and Crowe (1960) were among the first to report that the fat, and more specifically the carbonyl compounds, contributed to differences in flavor among species. When volatile constituents from nitrite-treated and untreated ham, beef, or chicken were passed through a solution of 2,4-dinitrophenylhydrazine, the effluent stream in all of the systems had a characteristic cured-ham aroma (Cross and Ziegler, 1965; Minor et al., 1965). This preliminary observation on volatiles from uncured and cured meat emphasizing the importance of carbonyls in causing species-specific differences did not receive the attention it deserved. Attempts were, however, made to resolve the controversy relating to the role of lipids in meat flavor systems. Hirai et al. (1973) have demonstrated the formation of a number of carbonyl compounds when lean beef, carefully trimmed to fat, was boiled. Those carbonyl compounds were shown not to possess meaty flavor notes. However, no attempt was made to prevent the formation of such carbonyl compounds, by use of antioxidants such as nitrite or other specific reagents, and to study the organoleptic properties of the resulting aroma mixture. Thus, the nature of cured-meat flavor, which is assumed to be due to suppression of lipid oxidation by nitrite, the basic flavor of cooked meat (Rubin and Shahidi, 1988), remains a mystery so far.

We have characterized the flavor components in uncured and cured pork and have reported the qualitative and quantitative differences therein (Ramarathnam et al., 1991). Comparison of the two flavor isolation techniques, conventional steam distillation and simultaneous steam distillation–extraction (SDE), indicated that the latter was more effective in isolating volatiles from cooked pork. In continuation of our efforts to elucidate the true chemical nature of meat flavor, we now report the qualitative and quantitative differences in uncured and cured cooked beef and chicken. Comparison of the data for carbonyls in

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beef and chicken flavor volatiles will be made with the data of pork already reported by us (Ramarathnam et al., 1991), followed by a brief discussion on species differences.

## MATERIALS AND METHODS

**Meat.** Fresh ground beef (lean meat from shoulder) and chicken breasts with skin on were purchased from a local market and used immediately. Care has always been taken to ensure that the meat bought from this outlet was made available within a day after its arrival from the slaughterhouse. Beef was from Canadian Grade A and B animals probably raised on pasture to a weight of 700 lb and finished in the feed lot to about 1000 lb. Chicken was the standard North American broiler brought to market weight (≈4 lb) in 7 weeks. Until its sale at the retail counter, the post-mortem temperature of the meat was maintained at 4 °C. The skin and excess fat in chicken were removed, the pieces were deboned manually, and the meat was then ground on a Oster meat grinder (0.476-cm grind plate, Model 990-68).

**Proximate Analysis.** The fat content of cooked meat samples was determined according to 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 67.7 ± 0.5% water in beef and 75.8 ± 0.4% water in chicken, while the fat contents were 6.5 ± 0.2% and 2.4 ± 0.3% for beef and chicken (skin off), respectively.

**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 (spectral grade) was purchased from Caledon Laboratoties, Ltd. Gas chromatographic standards hexanal (99%) and decanal (95%) were purchased from Aldrich Chemical Co.

**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) (Ramarathnam et al., 1991), 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 then was 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), on the basis of meat-to-water ratio of 4:1, and sodium nitrite (150 ppm; meat weight basis).

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 the removal of volatiles, distilled water was added to the cooked-meat samples (1:1 w/w) that were then ground to a homogeneous mixture by using a Braun MR 30 hand blender.

**Continuous Steam Distillation–Extraction (SDE) Technique.** Aroma concentrates were prepared by using a modified Likens–Nickerson steam distillation–extraction apparatus (Schultz et al., 1977) from 250–450 g of ground beef and chicken samples. The flavor components were extracted into *n*-pentane (50 mL). 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 Chromatography–Mass Spectrometric (GC–MS) Analysis.** A Hewlett-Packard Model HP 5880A gas chromatograph equipped with a DB-5 capillary column [0.13 mm (i.d.) × 30 m] and coupled to a Hewlett-Packard Model HP 5987A mass spectrometer was used. Analysis was carried out by using helium as the carrier gas, 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 an 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 according to 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 preliminary gas chromatographic results (Ramarathnam et al., 1991) 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 according to the SDE method, followed by concentration and subsequent analysis of the concentrate using GC–MS, was carried out according to procedures already described above.

## RESULTS AND DISCUSSION

**Gas Chromatography–Mass Spectrometric (GC–MS) Analysis.** The total ion chromatograms (TIC) of separated constituents in aroma concentrates of beef and chicken, analyzed on GC–MS, are shown in Figures 1 and 2. It was observed that the aroma concentrates isolated from uncured and cured beef had 59 and 40 components, respectively (parts A and B of Figure 1), while those of chicken resolved into 48 and 36 components (parts A and B of Figure 2). Of the separated constituents, 31 hydrocarbons, 26 carbonyls, 3 alcohols, and 2 acids were identified in uncured and cured beef (Table I). The corresponding figures for chicken (Table II) were 29 hydrocarbons, 26 carbonyls, and 2 alcohols. Our earlier work on the characterization of pork volatiles showed that aroma concentrates from cooked uncured and cured pork resolved into 77 and 72 components, respectively (Ramarathnam et al., 1991). Of these, 50 hydrocarbons, 37 carbonyls, 6 acids, and 2 alcohols were identified. The differences in the total number of components and individual carbonyls identified among the three species could be attributed to the differences in their fat content and also to a great extent to the differences in their fatty acid compositions. Pork used in our previous investigation had a fat content of 10.4 ± 0.1% (Ramarathnam et al., 1991), while beef and chicken, as reported earlier, had fat contents of 6.5 ± 0.2% and 2.4 ± 0.3%, respectively. It is also well-known that the composition of polyunsaturated fatty acids (PUFA) differs widely among the three species (Fogerty et al., 1990).

The separated constituents in beef and chicken volatiles are reported in Tables I and II, respectively. Of the components identified in the present work, carbonyl compounds were found to be present as major components in the aroma concentrates of cooked uncured beef and chicken. Similar observations were also made by us previously in the aroma concentrate of uncured pork (Ramarathnam et al., 1991). Also, among the carbonyl components identified in beef and chicken, a distinct difference was observed in the content of hexanal of uncured and cured meat. Hexanal content in uncured beef was 8.15 ± 0.17 mg/kg (peak 15, Table I), whereas the content of this lipid oxidation product in uncured chicken was 9.84 ± 0.17 mg/kg (peak 14, Table II). The corresponding values for cured beef and chicken were 0.05 ± 0.02 and 0.11 ± 0.04 mg/kg, respectively. A comparison of differences in the contents of carbonyl components in the three species, beef, chicken, and pork, is summarized

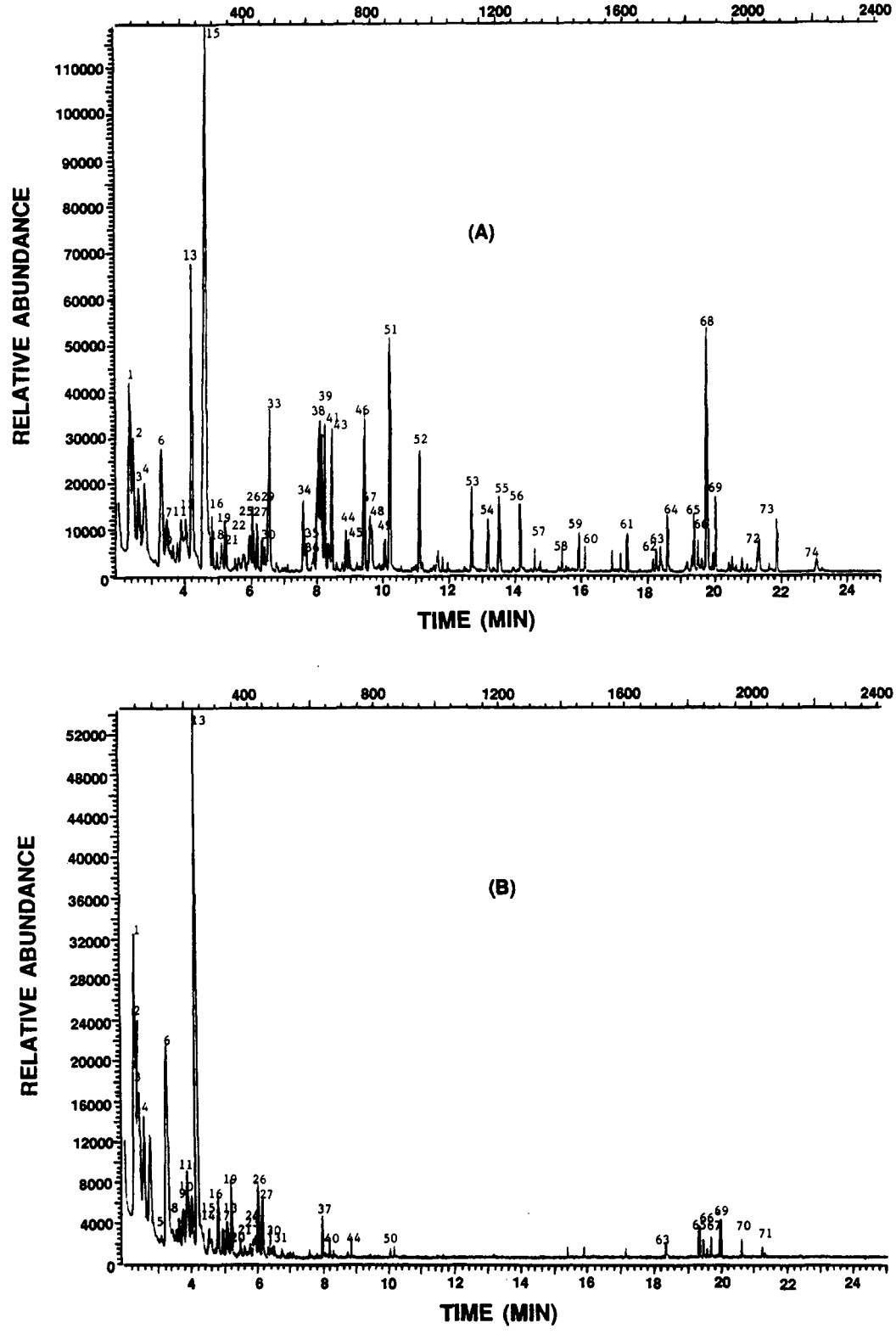


**Figure 1.** Total ion chromatograms (TIC) of (A) uncured-beef and (B) cured-beef flavor concentrates isolated by the SDE method.

in Table III. The concentration of 3-hexanone in uncured and cured beef was 1.08 ± 0.09 and 0.57 ± 0.02 mg/kg, respectively (peak 4, Table I), while the corresponding levels in cooked uncured and cured chicken were 5.78 ± 0.13 and 1.45 ± 0.07 mg/kg, respectively (peak 4, Table II). This component was found in uncured pork at a level of 0.42 ± 0.06 mg/kg, while in cured pork it was present in small traces (Table III). 2-Hexanone, detected only in uncured beef, was present at a concentration of 0.38 ± 0.06 mg/kg (peak 7, Table I). This component was absent in cured beef and was not detected in cooked pork and chicken. The absence of 4-methyl-2-pentanone in the uncured meat of all three species and its presence in small amounts, 0.03 ± 0.01 mg/kg in cured beef (peak 8, Table I), 0.06 ± 0.02 mg/kg in cured chicken (peak 7, Table II), and traces in cured pork (Table III), indicate that this component may be one of the typical constituents of the "cured-meat" volatiles. Whether it is a constituent of the spectrum of volatiles which forms the cured-meat flavor remains to be established experimentally. The fact that 4-methyl-2-pentanone is absent in uncured meat and present in small amounts in the cured product indicates

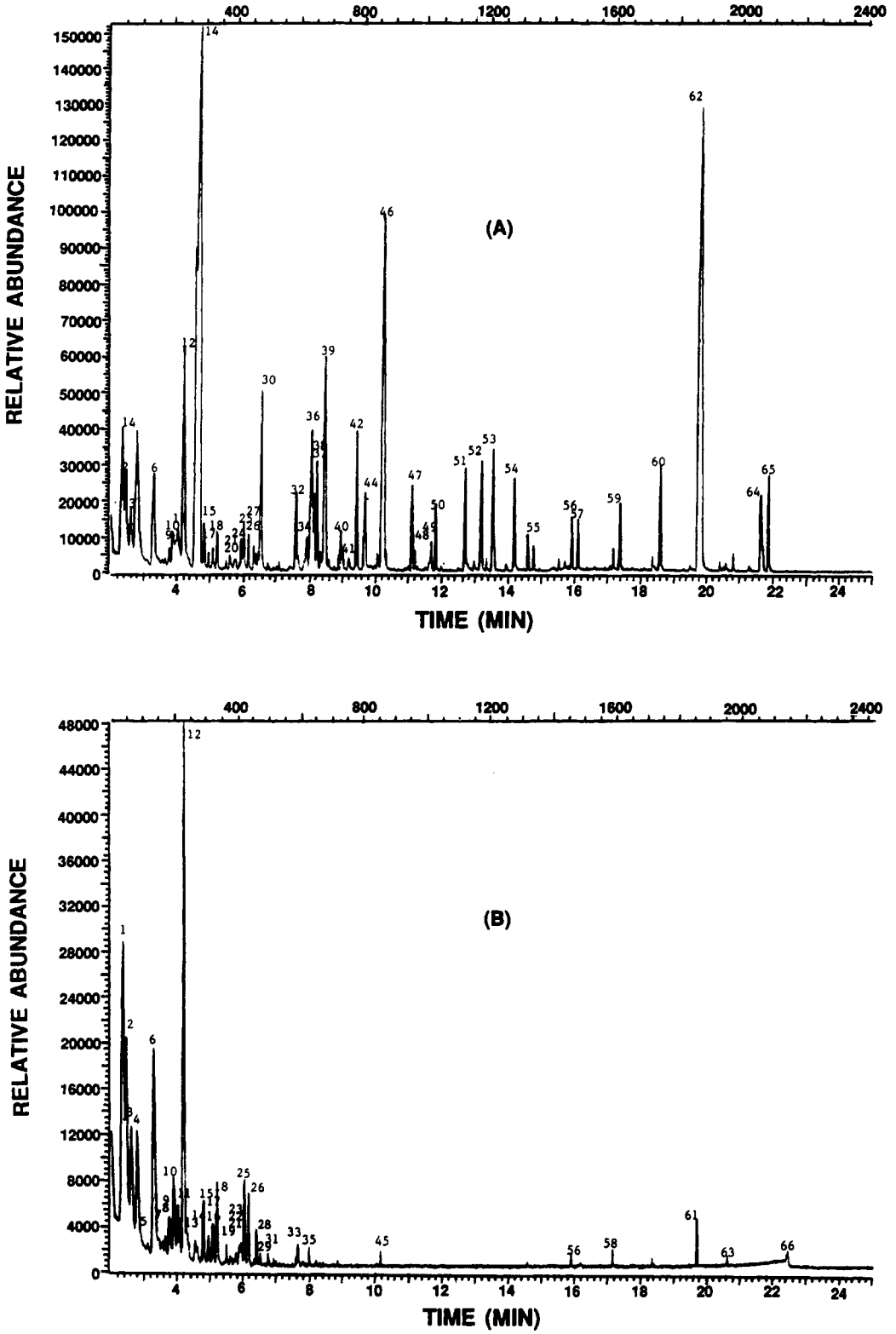


**Figure 2.** Total ion chromatograms (TIC) of (A) uncured-chicken and (B) cured-chicken flavor concentrates isolated by the SDE method.

that this compound is not derived from lipid oxidation. It may be formed as a result of a Maillard reaction.

The unsaturated aldehyde 2-hexenal was detected only in uncured chicken (peak 20, Table II) at a level of 0.40 ± 0.04 mg/kg, while it was absent in cured chicken and cooked beef and present in small traces in cooked pork. 3,3-Dimethylhexanal (peak 21, Table I) was present in uncured and cured beef at concentrations of 0.11 ± 0.04 and 0.03 ± 0.02 mg/kg, respectively, and was not detected in chicken or pork. In low concentrations, 3-methyl-4-heptanone may be an important component of the cured-meat flavor in all three species, while at a higher level of 0.44 ± 0.05 mg/kg this component may be one of the key factors in uncured cooked chicken flavor (peak 21, Table II). The concentration of 3-methylhexanal (peak 30, Table II) was relatively higher in uncured chicken (4.22 ± 0.04 mg/kg), while in uncured beef (peak 33, Table I) it was found to be present only to the extent of 1.09 ± 0.07 mg/kg. The concentration of this component in uncured pork was 0.65 ± 0.14 mg/kg, and it was not detected in the

**Table I. Components in the Aroma Concentrates of Uncured and Cured Beef[a]**

| peak no. | RT, min | component | content, mg/kg | |
|---|---|---|---|---|
| | | | uncured | cured |
| 1 | 2.35 | 2-methylhexane | 1.82 ± 0.12 | 1.58 ± 0.09 |
| 2 | 2.45 | 3-methylhexane | 1.11 ± 0.08 | 0.94 ± 0.04 |
| 3 | 2.60 | 2,2-dimethylhexane | 0.71 ± 0.07 | 0.60 ± 0.03 |
| 4 | 2.79 | 3-hexanone | 1.08 ± 0.09 | 0.57 ± 0.02 |
| 5 | 3.12 | unidentified | –[b] | 0.04 ± 0.02 |
| 6 | 3.30 | 2,4-dimethylhexane | 1.46 ± 0.12 | 1.22 ± 0.11 |
| 7 | 3.47 | 2-hexanone | 0.38 ± 0.06 | – |
| 8 | 3.57 | 4-methyl-2-pentanone | – | 0.03 ± 0.01 |
| 9 | 3.65 | 3,3-dimethylhexane | 0.12 ± 0.04 | 0.10 ± 0.02 |
| 10 | 3.77 | 4-methylheptane | 0.13 ± 0.05 | 0.12 ± 0.02 |
| 11 | 3.89 | 2,5-dimethylhexane | 0.42 ± 0.09 | 0.04 ± 0.02 |
| 12 | 4.03 | 3-methylheptane | 0.36 ± 0.08 | 0.14 ± 0.04 |
| 13 | 4.21 | 2,2,5-trimethylhexane | 2.27 ± 0.12 | 1.91 ± 0.09 |
| 14 | 4.55 | 2,2,4-trimethylhexane | – | 0.12 ± 0.04 |
| 15 | 4.65 | hexanal | 8.15 ± 0.17 | 0.05 ± 0.02 |
| 16 | 4.81 | 2,3,5-trimethylhexane | 0.27 ± 0.08 | 0.19 ± 0.08 |
| 17 | 4.96 | 2,3,4-trimethylhexane | 0.11 ± 0.05 | 0.07 ● 0.02 |
| 18 | 5.09 | 2,6-dimethylheptane | 0.20 ± 0.11 | 0.12 ± 0.05 |
| 19 | 5.21 | 2,5-dimethylheptane | 0.37 ± 0.15 | 0.24 ± 0.09 |
| 20 | 5.50 | 1,2,4-trimethylcyclohexane | – | 0.05 ± 0.02 |
| 21 | 5.61 | 3,3-dimethylhexanal | 0.11 ± 0.04 | 0.03 ± 0.02 |
| 22 | 5.75 | unidentified | 0.10 ± 0.01 | – |
| 23 | 5.80 | 3-methyl-4-heptanone | – | 0.04 ± 0.01 |
| 24 | 5.87 | 1,3-dimethylbenzene | – | 0.04 ± 0.02 |
| 25 | 5.95 | 2,5-dimethyloctane | 0.30 ± 0.05 | 0.10 ± 0.04 |
| 26 | 6.04 | 4-ethyl-2,2-dimethylhexane | 0.33 ± 0.11 | 0.19 ± 0.07 |
| 27 | 6.17 | 2,2,4-trimethylhexane | 0.28 ± 0.12 | 0.15 ± 0.07 |
| 28 | 6.33 | 1,2-dimethylbenzene | – | 0.03 ± 0.01 |
| 29 | 6.34 | 2-heptanone | 0.21 ± 0.07 | – |
| 30 | 6.41 | 3,3,5-trimethylheptane | 0.10 ± 0.02 | 0.07 ± 0.02 |
| 31 | 6.47 | unidentified | – | 0.03 ± 0.01 |
| 32 | 6.53 | unidentified | – | 0.04 ± 0.01 |
| 33 | 6.56 | 3-methylhexanal | 1.09 ± 0.07 | – |
| 34 | 7.60 | (*E*)-2-heptenal | 0.45 ± 0.04 | – |
| 35 | 7.67 | benzaldehyde | 0.20 ± 0.02 | – |
| 36 | 7.90 | 3-methyloctane | 0.14 ± 0.05 | – |
| 37 | 8.00 | 1,3,5-trimethylbenzene | – | 0.11 ± 0.02 |
| 38 | 8.10 | 1-hepten-3-ol | 1.73 ± 0.15 | – |
| 39 | 8.16 | 2,3-octanedione | 0.65 ± 0.11 | – |
| 40 | 8.21 | 3,6-dimethyloctane | – | 0.04 ± 0.02 |
| 41 | 8.24 | unidentified | 0.75 ± 0.06 | – |
| 42 | 8.35 | 3-ethoxy-2-methyl-1-propene | 0.11 ± 0.04 | – |
| 43 | 8.46 | octanal | 0.69 ± 0.07 | – |
| 44 | 8.87 | D-limonene | 0.18 ± 0.05 | 0.04 ± 0.02 |
| 45 | 8.95 | 3-ethyl-2-methyl-1,3-hexadiene | 0.15 ± 0.11 | – |
| 46 | 9.45 | (*E*)-2-octenal | 1.07 ± 0.15 | – |
| 47 | 9.62 | 2-octen-1-ol | 0.38 ± 0.09 | – |
| 48 | 9.66 | unidentified | 0.23 ± 0.05 | – |
| 49 | 10.07 | 3,7-dimethylnonane | 0.17 ± 0.04 | – |
| 50 | 10.18 | unidentified | – | 0.03 ± 0.01 |
| 51 | 10.23 | nonanal | 1.44 ± 0.07 | – |
| 52 | 11.13 | 2-nonenal | 0.68 ± 0.11 | – |
| 53 | 12.71 | 2-undecenal | 0.44 ± 0.05 | – |
| 54 | 13.19 | tridecane | 0.31 ± 0.03 | – |
| 55 | 13.53 | (*E*,*E*)-2,4-decadienal | 0.42 ± 0.08 | – |
| 56 | 14.18 | 2-dodecenal | 0.35 ± 0.06 | – |
| 57 | 14.60 | tetradecane | 0.10 ± 0.02 | – |
| 58 | 15.43 | unidentified | 0.10 ± 0.05 | – |
| 59 | 15.92 | pentadecane | 0.17 ± 0.08 | – |
| 60 | 16.12 | tridecanal | 0.12 ± 0.04 | – |
| 61 | 17.38 | tetradecanal | 0.17 ± 0.03 | – |
| 62 | 18.25 | unidentified | 0.12 ± 0.02 | – |
| 63 | 18.37 | 2-pentadecanone | 0.19 ± 0.08 | 0.05 ± 0.02 |
| 64 | 18.60 | hexadecanal | 0.28 ± 0.07 | – |
| 65 | 19.38 | 1,14-tetradecanediol | 0.27 ± 0.09 | 0.07 ± 0.01 |
| 66 | 19.50 | octadecane | 0.15 ± 0.09 | 0.05 ± 0.02 |
| 67 | 19.73 | 17-octadecenal | – | 0.04 ± 0.01 |
| 68 | 19.79 | 16-octadecenal | 1.81 ± 0.14 | – |
| 69 | 20.02 | unidentified | 0.37 ± 0.15 | 0.09 ± 0.02 |
| 70 | 20.65 | pentadecanenitrile | – | 0.04 ± 0.01 |
| 71 | 21.27 | 15-octadecenal | – | 0.03 ± 0.02 |
| 72 | 21.35 | hexadecanoic acid | 0.32 ± 0.04 | – |
| 73 | 21.87 | octadecanal | 0.26 ± 0.11 | – |
| 74 | 23.06 | 9-octadecenoic acid | 0.15 ± 0.03 | – |

[a] Reported values are mean ± SD, $n = 3$. [b] –, not detected.

**Table II. Components in the Aroma Concentrates of Uncured and Cured Chicken[a]**

| peak no. | RT, min | component | content, mg/kg | |
|---|---|---|---|---|
| | | | uncured | cured |
| 1 | 2.36 | 2-methylhexane | 4.27 ± 0.28 | 3.03 ± 0.04 |
| 2 | 2.46 | 3-methylhexane | 2.55 ± 0.06 | 1.80 ± 0.11 |
| 3 | 2.61 | 2,2-dimethylhexane | 1.57 ± 0.08 | 1.17 ± 0.14 |
| 4 | 2.80 | 3-hexanone | 5.78 ± 0.13 | 1.45 ● 0.07 |
| 5 | 3.13 | unidentified | –[b] | 0.09 ± 0.02 |
| 6 | 3.30 | 2,4-dimethylhexane | 3.76 ± 0.12 | 2.78 ● 0.09 |
| 7 | 3.58 | 4-methyl-2-pentanone | – | 0.06 ± 0.02 |
| 8 | 3.66 | 3,3-dimethylhexane | – | 0.11 ± 0.05 |
| 9 | 3.78 | 4-methylheptane | 0.38 ± 0.11 | 0.29 ± 0.04 |
| 10 | 3.89 | 2,5-dimethylhexane | 0.94 ± 0.08 | 0.70 ± 0.06 |
| 11 | 4.04 | 3-methylheptane | 0.92 ± 0.12 | 0.48 ± 0.08 |
| 12 | 4.22 | 2,2,5-trimethylhexane | 5.81 ± 0.16 | 4.37 ± 0.09 |
| 13 | 4.55 | 2,2,4-trimethylhexane | – | 0.20 ± 0.02 |
| 14 | 4.60 | hexanal | 9.84 ± 0.17 | 0.11 ± 0.04 |
| 15 | 4.82 | 2,3,5-trimethylhexane | 0.67 ± 0.05 | 0.42 ± 0.04 |
| 16 | 4.95 | 2,3,4-trimethylhexane | – | 0.17 ± 0.05 |
| 17 | 5.10 | 2,6-dimethylheptane | 0.46 ± 0.07 | 0.29 ± 0.03 |
| 18 | 5.22 | 2,5-dimethylheptane | 0.78 ± 0.08 | 0.63 ± 0.06 |
| 19 | 5.50 | 1,2,4-trimethylcyclohexane | – | 0.11 ± 0.02 |
| 20 | 5.62 | 2-hexenal | 0.40 ± 0.04 | – |
| 21 | 5.79 | 3-methyl-4-heptanone | 0.44 ± 0.05 | 0.09 ± 0.04 |
| 22 | 5.88 | 1,3-dimethylbenzene | – | 0.11 ± 0.03 |
| 23 | 5.92 | unidentified | – | 0.11 ± 0.02 |
| 24 | 5.96 | 2,5-dimethyloctane | 0.86 ± 0.07 | 0.13 ± 0.05 |
| 25 | 6.04 | 2,2,3-trimethylhexane | 0.83 ± 0.06 | 0.51 ± 0.07 |
| 26 | 6.17 | 2,2,4-trimethylheptane | 0.65 ± 0.05 | 0.40 ± 0.03 |
| 27 | 6.34 | 2-heptanone | 0.54 ± 0.05 | – |
| 28 | 6.41 | 3,3,5-trimethylheptane | – | 0.20 ± 0.02 |
| 29 | 6.53 | unidentified | – | 0.09 ± 0.02 |
| 30 | 6.58 | 3-methylhexanal | 4.22 ± 0.04 | – |
| 31 | 6.76 | 3,5-dimethyloctane | – | 0.11 ± 0.05 |
| 32 | 7.60 | (*E*)-2-heptenal | 1.78 ± 0.05 | – |
| 33 | 7.66 | benzaldehyde | – | 0.12 ± 0.04 |
| 34 | 7.93 | 3-methyloctane | 0.96 ± 0.09 | – |
| 35 | 8.00 | unidentified | – | 0.11 ± 0.04 |
| 36 | 8.10 | 1-hepten-3-ol | 4.91 ± 0.05 | – |
| 37 | 8.15 | 2,3-octanedione | 1.23 ± 0.11 | – |
| 38 | 8.23 | unidentified | 1.98 ± 0.12 | – |
| 39 | 8.49 | octanal | 5.08 ± 0.14 | – |
| 40 | 8.96 | 3-ethyl-2-methyl-1,3-hexadiene | 0.64 ± 0.06 | – |
| 41 | 9.20 | 4,4,5-trimethyl-2-hexene | 0.37 ± 0.03 | – |
| 42 | 9.46 | (*E*)-2-octenal | 3.07 ± 0.11 | – |
| 43 | 9.65 | 2-octen-1-ol | 0.69 ± 0.07 | – |
| 44 | 9.72 | unidentified | 1.60 ± 0.09 | – |
| 45 | 10.18 | unidentified | – | 0.08 ± 0.02 |
| 46 | 10.28 | nonanal | 11.59 ± 0.12 | – |
| 47 | 11.13 | 2-nonenal | 1.46 ± 0.09 | – |
| 48 | 11.21 | 4-ethylbenzaldehyde | 0.36 ± 0.04 | – |
| 49 | 11.69 | dodecane | 0.45 ± 0.05 | – |
| 50 | 11.83 | decanal | 1.05 ± 0.06 | – |
| 51 | 12.72 | 2-undecenal | 1.94 ± 0.09 | – |
| 52 | 13.20 | tridecane | 2.21 ± 0.11 | – |
| 53 | 13.56 | (*E*,*E*)-2,4-decadienal | 2.48 ± 0.15 | – |
| 54 | 14.20 | 2-dodecenal | 1.90 ± 0.09 | – |
| 55 | 14.60 | tetradecane | 0.52 ± 0.07 | – |
| 56 | 15.92 | pentadecane | 0.82 ± 0.09 | 0.07 ± 0.01 |
| 57 | 16.12 | tridecanal | 0.85 ± 0.08 | – |
| 58 | 17.17 | hexadecane | – | 0.09 ± 0.03 |
| 59 | 17.40 | tetradecanal | 1.14 ± 0.08 | – |
| 60 | 18.61 | hexadecanal | 2.13 ± 0.05 | – |
| 61 | 19.73 | 17-octadecenal | – | 0.23 ± 0.03 |
| 62 | 19.89 | 16-octadecenal | 5.86 ± 0.18 | – |
| 63 | 20.65 | pentadecanenitrile | – | 0.06 ± 0.04 |
| 64 | 21.67 | 9-octadecenal | 1.85 ± 0.09 | – |
| 65 | 21.90 | octadecanal | 1.88 ± 0.04 | – |
| 66 | 22.46 | unidentified | – | 0.18 ± 0.04 |

[a] Reported values are mean ± SD, $n = 3$. [b] –, not detected.

cured meat of all three species (Table III). A similar trend was also observed in the concentration of 2-alkenals such as (*E*)-2-heptenal, (*E*)-2-octenal, 2-nonenal, 2-undecenal, and 2-dodecenal. The concentration of such components in uncured chicken was nearly 2–5 times more than that of uncured beef and pork. Octanal was not detected in cured beef, cured chicken, and cured and uncured pork; in uncured chicken (peak 39, Table II) it was present as a major component (5.08 ± 0.14 mg/kg), and in uncured beef it was detected only to the extent of 0.69 ± 0.07 mg/kg (peak 43, Table I).

Striking differences were also observed in the contents of nonanal and 16-octadecenal. Nonanal was absent in uncured pork (Table III), while it was present in uncured

Table III. Carbonyls in the Aroma Concentrates of Uncured and Cured Beef, Chicken, and Pork[a]

| component | content, mg/kg | | | | | |
|---|---|---|---|---|---|---|
| | beef | | chicken | | pork[b] | |
| | uncured | cured | uncured | cured | uncured | cured |
| 3-hexanone | 1.08 ± 0.09 | 0.57 ± 0.02 | 5.78 ± 0.13 | 1.45 ± 0.07 | 0.42 ± 0.06 | tr[c] |
| 2-hexanone | 0.38 ± 0.06 | –[d] | – | – | – | – |
| 4-methyl-2-pentanone | – | 0.03 ± 0.01 | – | 0.06 ± 0.02 | – | tr |
| hexanal | 8.15 ± 0.17 | 0.05 ± 0.02 | 9.84 ± 0.17 | 0.11 ± 0.04 | 12.66 ± 0.08 | 0.03 ± 0.05 |
| 2-hexenal | – | – | 0.40 ± 0.04 | – | tr | tr |
| 3,3-dimethylhexanal | 0.11 ± 0.04 | 0.03 ± 0.02 | – | – | – | – |
| 3-methyl-4-heptanone | – | 0.04 ± 0.01 | 0.44 ± 0.05 | 0.09 ± 0.04 | – | tr |
| 2-heptanone | 0.21 ± 0.07 | – | 0.54 ± 0.05 | – | 0.20 ± 0.06 | – |
| 3-methylhexanal | 1.09 ± 0.07 | – | 4.22 ± 0.04 | – | 0.65 ± 0.14 | – |
| (*E*)-2-heptenal | 0.45 ± 0.04 | – | 1.78 ± 0.05 | – | 0.34 ± 0.04 | – |
| benzaldehyde | – | – | – | – | 0.11 ± 0.01 | 0.04 ± 0.05 |
| 2,3-octanedione | – | – | – | – | 0.88 ± 0.09 | – |
| octanal | 0.69 ± 0.07 | – | 5.08 ± 0.14 | – | – | – |
| (*E*)-2-octenal | 1.07 ± 0.15 | – | 3.07 ± 0.11 | – | 0.99 ± 0.10 | – |
| nonanal | 1.44 ± 0.07 | – | 11.59 ± 0.12 | – | – | – |
| 2-nonenal | 0.68 ± 0.11 | – | 1.46 ± 0.09 | – | 0.39 ± 0.05 | – |
| 4-ethylbenzaldehyde | – | – | 0.36 ± 0.04 | – | tr | – |
| decanal | – | – | 1.05 ± 0.06 | – | tr | tr |
| 2-undecenal | 0.44 ± 0.05 | – | 1.94 ± 0.09 | – | 0.39 ± 0.07 | – |
| (*E*,*E*)-2,4-decadienal | 0.42 ± 0.08 | – | 2.48 ± 0.15 | – | 0.69 ± 0.16 | – |
| (*E*,*Z*)-2,4-decadienal | – | – | – | – | 0.41 ± 0.15 | – |
| 2-dodecenal | 0.35 ± 0.06 | – | 1.90 ± 0.09 | – | 0.43 ± 0.08 | – |
| tridecanal | 0.12 ± 0.04 | – | 0.85 ± 0.08 | – | 0.25 ± 0.05 | 0.09 ± 0.01 |
| tetradecanal | 0.17 ± 0.03 | – | 1.14 ± 0.08 | – | 0.40 ± 0.14 | 0.03 ± 0.01 |
| 2-pentadecanone | 0.19 ± 0.08 | 0.05 ± 0.02 | – | – | tr | 0.06 ± 0.02 |
| hexadecanal | 0.28 ± 0.07 | – | 2.13 ± 0.05 | – | 0.65 ± 0.05 | 0.06 ± 0.02 |
| 17-octadecenal | – | 0.04 ± 0.01 | – | 0.23 ± 0.03 | tr | – |
| 16-octadecenal | 1.81 ± 0.14 | – | 5.86 ± 0.18 | – | 8.34 ± 0.35 | 2.20 ± 1.26 |
| 15-octadecenal | – | 0.03 ± 0.02 | – | – | 0.70 ± 0.04 | 0.14 ± 0.04 |
| 9-octadecenal | – | – | 1.85 ± 0.09 | 1.85 ± 0.09 | 0.81 ± 0.06 | 0.14 ± 0.02 |
| octadecanal | 0.26 ± 0.11 | – | 1.88 ± 0.04 | – | 1.19 ± 0.11 | 0.19 ± 0.09 |

[a] Reported values are mean ± SD, $n = 3$. [b] Ramarathnam et al. (1991). [c] tr, trace amount (<0.01 mg/kg). [d] –, not detected.

chicken (peak 46, Table II) at the very high concentration of 11.59 ± 0.12 mg/kg; in uncured beef the level of this compound was only 1.44 ± 0.07 mg/kg (peak 51, Table I). 16-Octadecenal (peak 62, Table II) was present in uncured chicken at a concentration of 5.86 ± 0.18 mg/kg. This component was present in uncured beef (peak 68, Table I) at a concentration of only 1.81 ± 0.14 mg/kg, while in uncured pork the concentration of 16-octadecenal was found to be 8.34 ± 0.35 mg/kg (Table III). Nonanal was absent in the cured meat of all three species, while 16-octadecenal was detected in cured pork at a concentration of 2.20 ± 1.26 mg/kg (Table III).

Among the aromatic compounds, 4-ethylbenzaldehyde was present at a concentration of 0.36 ± 0.04 mg/kg in uncured chicken (peak 48, Table II) and was not detected in the other meat samples (Table III). A similar observation was made in the case of decanal, which was present at a level of 1.05 ± 0.06 mg/kg in the uncured meat of chicken (peak 50, Table II). (*E*,*Z*)-2,4-Decadienal may be one of the components responsible for the cooked-pork flavor, as it was detected in uncured pork at a concentration of 0.41 ± 0.15 mg/kg (Table III) and was absent in all other meat samples.

Thus, the presence and absence of certain carbonyls, or the differences in their concentrations in the volatiles among the three species, can be a major contributory factor to the differences in the aroma nuances observed in them. Carbonyl compounds, which are formed due to the oxidation of unsaturated lipids and during the nonenzymatic amino–carbonyl reactions, have been implicated as significant contributors to the flavor of uncured meat but not in cured meat. Since the aroma concentrates of cured pork, beef, and chicken are similar and the concentrations of the individual carbonyls, with the exception of 3-hexanone and 16-octadecenal, are less than 1 mg/kg, it is therefore evident that the cured-meat flavor or the basic flavor of cooked meat, which is devoid of any lipid oxidation product, should originate from non-triglyceride precursors. Removal of carbonyls by the use of carbonyl-specific reagents should result essentially in a simplified basic meat flavor mixture (Cross and Ziegler, 1965; Minor et al., 1965). Although the nature of such a mixture seems to be much simpler than that of uncured meat, the elucidation of the compounds responsible for the cured-meat flavor is not easy. This simplified mixture still has the second major group of volatiles, the hydrocarbons, that make practically no contribution to the "meaty note" detectable in cured meat. Minute traces of aroma-effective heterocyclic components having very low flavor threshold values can present enormous difficulties in their isolation and identification steps (MacLeod and Ames, 1986). The TIC profiles have clearly shown that the flavor spectrum of cured meat is indeed simple (Figures 1B and 2B). The components identified, however, do not show the presence of sulfur and nitrogenous substances. Suitable modifications to the existing isolation and analytical techniques should be helpful in overcoming this problem. Preliminary experiments on the isolation of volatiles from the three meat species using the purge-and-trap technique, which is milder than the SDE method, have been successful in identifying certain heterocyclic compounds (data not shown). It is also believed that the heterocyclic compounds could be preferentially extracted from cooked meat by use of supercritical carbon dioxide at relatively low temperatures and in a completely inert atmosphere. Work is currently being planned in this direction.

Among the hydrocarbons identified, cured and uncured chicken had the highest concentration of low-boiling ho-

mologues of branched hexane, heptane, and octane (Table II), while the levels of such components in cured and uncured beef were only slightly higher than those of pork (Ramarathnam et al., 1991). Hydrocarbons of specific interest, which were absent in the uncured meat of all three species but present in the cured meat, include the following: 2,2,4-trimethylhexane, which was present in cured beef to the extent of 0.12 ± 0.04 mg/kg (peak 14, Table I), 0.20 ± 0.02 mg/kg in cured chicken (peak 13, Table II), and 0.09 ± 0.06 mg/kg in cured pork (Ramarathnam et al., 1991); 1,2,4-trimethylcyclohexane, detected in cured beef to the extent of 0.05 ± 0.02 mg/kg (peak 20, Table I), 0.11 ± 0.02 mg/kg in cured chicken (peak 19, Table II), and 0.03 ± 0.01 mg/kg in cured pork (Ramarathnam et al., 1991); and 1,3-dimethylbenzene, present in cured beef to the extent of 0.04 ± 0.02 mg/kg (peak 24, Table I), 0.11 ± 0.03 mg/kg in cured chicken (peak 22, Table II), and in small traces in cured pork (Ramarathnam et al., 1991). D-Limonene (peak 44, Table I) was detected both in uncured beef (0.18 ± 0.05 mg/kg) and in cured beef (0.04 ± 0.02 mg/kg) and was absent in chicken. This compound was also absent in uncured pork, while in cured pork it was present to the extent of 0.02 mg/kg (Ramarathnam et al., 1991). The concentration of less volatile hydrocarbons such as pentadecane, hexadecane, and heptadecane was relatively higher in chicken (Table II) than in beef (Table I). Hydrocarbons are formed due to the breakdown of unsaturated fatty acids during autoxidation of lipids. The differences in the concentrations of most of the hydrocarbons detected in chicken and beef can be attributed to the differences in the content of total fat and unsaturated fatty acids. Carboxylic acids such as hexadecanoic acid (peak 72, Table I) and 9-octadecenoic acid (peak 74, Table I) present in uncured beef at concentrations of 0.32 ± 0.04 and 0.15 ± 0.03 mg/kg, respectively, were not seen in cooked chicken.

In the first phase of this major study we have deliberately concentrated on the carbonyl spectrum of both uncured and cured meat from the three important species on the North American continent—beef, pork, and chicken. The quantitative information on carbonyls, and hydrocarbons, which we provide here using the SDE technique has not been hitherto reported. We have kept the cooking conditions mild, which in itself would limit the formation of heterocyclic sulfur and nitrogen compounds, and the sample rather modest in size. This simplified system threw the emphasis on the carbonyls, and many new data are presented here. We now plan to proceed to the isolation of heterocyclic meat flavor components using the purge-and-trap and supercritical fluid extraction techniques. Cooking conditions will be kept mild, e.g., heating in water as opposed to roasting, to keep the system in the first instance as simple as possible.

## CONCLUSION

In the study of meat flavor volatiles, much attention has been focused on the characterization of the key components responsible for the flavor of different types of meat products. Though higher in fat content, the number of volatiles detected in pork is far fewer than in beef, in which more than 700 components have been detected in the past 2 decades (Shahidi et al., 1986). This could be due to the extensive investigations carried out on beef mainly because of its commercial importance and consumer preference (Baines and Mlotkiewicz, 1984). Nevertheless, the current literature available on meat flavor does not provide a clear path to the formulation of essences that could impart meaty or cured-meat-type flavor notes.

Our approach to this problem, at this stage, is a fundamental one. The first step, that of providing quantitative information for carbonyls and hydrocarbons present in the three main species of meat consumed in most parts of the world, has now been achieved. Of the various components identified in the present investigation in the three meat species, 4-methyl-2-pentanone, 2,2,4-trimethylhexane, 1,2,4-trimethylcyclohexane, and 1,3-dimethylbenzene could be contributing either directly as individual constituents or indirectly as synergists in the formation of the cured-meat aroma. Although these components were detected in small amounts in the cured-meat flavor concentrates of all three species, they were, however, absent in the cooked uncured meat. 16-Octadecenal, benzaldehyde, 2,3-octanedione, and (*E*,*Z*)-2,4-decadienal may be responsible for the species-specific flavor notes in pork, while 2-hexanone and 3,3-dimethylhexanal have been uniquely identified in beef. The characteristic "chicken-like" flavor perhaps includes a complex mixture of 3-hexanone, 2-hexenal, 3-methyl-4-heptanone, 3-methylhexanal, (*E*)-2-heptenal, octanal, (*E*)-2-octenal, nonanal, 16-octadecenal, 4-ethylbenzaldehyde, and decanal. The preparation of such a "nature-identical" chicken flavor will involve a sophisticated methodology, both in the formulation and in the sensory evaluation.

What remains to be done next is to avoid the formation of such carbonyls and also the hydrocarbons in cured-meat aroma concentrates, so that the minor components such as those beloning to the heterocyclic family can be more readily isolated and made detectable by the instrumentation currently available. Work is in progress in this direction, and the results will be published in due course.

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