Volatiles from Roasted Byproducts of the Poultry-Processing Industry

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Volatiles of roasted chicken breast muscle and byproducts, such as backbones, breastbones, spent bones, and skin, were investigated. Total volatile concentrations ranged from 2030 ppb in the roasted backbones to 4049 ppb in the roasted skin. The major classes of volatile compounds detected in roasted samples were aldehydes (648−1532 ppb) and alcohols (336−1006 ppb). Nitrogen- and/or sulfur-containing compounds were also detected in appreciable quantities (161−706 ppb) in all samples. For all samples, hexanal and 2-methyl-2-buten-1-ol were dominant among the aldehydes and alcohols, respectively. Among the nitrogen- and sulfur-containing compounds, Maillard reaction products, such as tetrahydropyridazines, piperidines, and thiazoles, were the major contributors to the total volatile content in all samples. The composition of volatiles observed in roasted byproducts was markedly different from that of the roasted breast muscle. Therefore, the blending of the byproducts in appropriate proportions or blending of volatile flavor extracts from different byproducts may be necessary to obtain an aroma that mimics roasted chicken aroma.

Keywords: *Volatiles; chicken breast muscle; chicken byproducts; aldehydes; hexanal; Maillard reaction; flavor; aroma*

INTRODUCTION

The poultry-processing industry generates a large volume of byproducts that are, at present, used in fertilizer and animal feed formulations. There are four major types of chicken byproducts, namely, breastbones, backbones, spent bones, and skin. The former three have appreciable amounts of muscle tissues attached to them. These processing industry byproducts may be utilized to develop a natural chicken flavor base. While the flavor components in chicken-processing byproducts remain unknown, it may be assumed that they possess flavor characteristics similar to those of intact chicken muscles. The information available for raw chicken muscles emphasizes bland and metallic flavors, whereas desirable meaty flavor develops only after heating. When heated, the flavor precursors of meat undergo a series of physical and chemical changes that are governed by temperature and moisture content (Wasserman, 1979). The primary reactions occurring upon heating that can lead to meat flavor include pyrolysis of amino acids and peptides, carbohydrate degradation, interaction of sugars with amino acids and peptides, degradation of ribonucleotides, and thermal degradation of lipids (MacLeod and Ames, 1987; Bailey and Einig, 1987).

The thermal decomposition of amino acids and peptides requires temperatures higher than those that are normally encountered during the cooking of meat. At higher temperatures, usually above 125 °C, aldehydes, hydrocarbons, nitriles, and amines are formed due to decarboxylation and deamination of amino acids and peptides. However, these pyrolysis reactions are relatively unimportant in meat flavor because they occur only on the surface of roasted meats where temperature rises significantly above 100 °C (Mottram, 1991). Sugar caramelization is also considered unimportant due to extremely low sugar concentrations found in meat. Nevertheless, sugars, even at low concentrations, can play a major role in the generation of flavor compounds (with threshold values as low as a few parts per trillion) via the Maillard reaction. This reaction does not require the very high temperatures associated with protein pyrolysis and sugar caramelization (Hurrell, 1982; Mauron, 1981). Flavor compounds generated by the Maillard reaction tend to localize in those areas of the roasted meat that have been dehydrated due to heat (van den Ouwenland et al., 1989). The first stage of the Maillard reaction involves the condensation of amino groups of amino acids with carbonyl groups of reducing sugars followed by Amadori and Heyns rearrangements (van den Ouwenland et al., 1989; Shu, 1999). Shibamoto (1989) has reported the major classes of Maillard reaction products in meat as furans, thiophenes, thiazoles, thiazolines, thiazolidines, pyrazines, pyrroles, imidazoles, pyridines, and oxazoles. Among these classes of compounds, pyrazines were well characterized as the compounds which directly contribute to the roast or smoky aroma. Maga and Sizer (1973) have reported that pyrazines, such as 2-isobutyl-3-methoxypyrazine, have odor threshold values as low as 0.002 ppb.

Another important reaction contributing to the formation of volatile flavor compounds during the thermal processing of meat is the heat-induced oxidation of unsaturated fatty acids in triacylglycerols (Elmore et

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al., 1999). The oxidation of unsaturated fatty acids occurs via a self-catalyzed free radical chain reaction, but the reaction is initiated when a hydrogen atom is abstracted from an allyl methylene group of the fatty acid (Kanner et al., 1987). The primary products of this reaction are odorless hydroperoxides. In the final stages of the oxidation process, hydroperoxides are decomposed to produce various aldehydes, ketones, hydrocarbons, alcohols, and acids (Lamikarna and Dupuy, 1990). Alcohols and acids can easily undergo esterification reactions to yield various esters.

Roasted chicken flavor is a result of a large number of compounds, belonging to different chemical classes present in particular quantitative proportions. However, it has been shown that volatile sulfur-containing heterocyclic compounds substituted with sulfur in the 3-position play an important role in the aroma of both cooked and roasted chicken (Workhoff et al., 1990).

The objectives of this study were to isolate, identify, and quantify the volatile flavor components of roasted chicken breast muscle and processing industry byproducts, namely, breastbones, backbones, spent bones, and skin.

MATERIALS AND METHODS

Materials. Three 10 kg batches of fresh chicken backbones, breastbones, spent bones, skin, and breast muscle were obtained from Maple Leaf Poultry Ltd., Edmonton, Alberta, and stored at 4 °C refrigerated until use (~24 h). Methylene chloride and anhydrous sodium sulfate were purchased from Fisher Scientific (Nepean, Ontario) and Sigma Chemical Co. (St. Louis, MO), respectively.

Sample Preparation. Each type of byproduct (3 × 2.5 kg) was ground separately in a commercial meat grinder (Hobart model 84185, Hobart Canada Inc., Don Mills, Ontario) using a 0.79 and then a 0.48 cm plate. For each type of byproduct, the ground samples from three different batches were combined and mixed manually. After further mixing and grinding with a 0.48 cm plate, two representative samples (1 kg each) from each type of byproduct were drawn for roasting. The temperature of all samples was maintained at 4 °C during mixing and grinding. Breast muscle samples were also prepared using the same procedure.

Proximate Composition. For each type of byproduct and muscle, two samples (100 g each) were drawn from three batches (total of six replicates) and were homogenized separately in a blender. The temperature of all samples was maintained at 4 °C during mixing and grinding. The moisture, crude protein, and ash contents of samples were determined according to the AOAC (1990) methods 950.46, 981.10, and 900.02, respectively. The total lipid content was determined using the procedure of Bligh and Dyer (1959).

Roasting. Each type of ground sample (1 kg in duplicate) was roasted in a convection oven (Kenmore Mark 2, Simpson-Sears Ltd., Toronto, Ontario) for 1 h at 190.5 °C.

Distillation of Volatile Compounds. A simple steam distillation procedure was adapted to isolate volatile compounds from the freshly roasted samples. Each type of roasted byproduct/breast muscle (200 g in duplicate) was placed in a three-neck 1 L round-bottom flask, and 20 mL (10%, v/w) of deionized water was added to the flask. Steam was generated in a 4 L Erlynmeyer flask by heating 2 L of deionized water. The steam thus generated was sent through the sample using a glass tube connected to a side neck of the round-bottom flask. The middle neck of the round-bottom flask was connected to a condenser, and the distillate (300 mL) was collected in a 500 mL flask placed in an ice bath. The remaining side neck of the round-bottom flask was used to introduce samples into the flask and kept closed during distillation. The 4 L Erlynmeyer flask used as the steam generator had a 50 cm long open glass tube (vent) fitted to its neck to prevent the buildup of pressure inside the flask.

Extraction of Volatile Compounds from the Distillate. The distillate (300 mL) and 150 mL of methylene chloride were combined in a 500 mL separatory flask, and the contents were mixed vigorously and allowed to stand for 30 min at ambient temperature. The methylene chloride layer was drained off, and the solvent was removed under vacuum using a rotary evaporator (Rotavapor, Buchi, Flawil, Switzerland) at 40 °C. When the contents reached a volume of about 10 mL, they were removed from the evaporator and filtered through 10 g of anhydrous sodium sulfate followed by rinsing of the filter bed with 10 mL of methylene chloride. Extract was then further concentrated under a gentle stream of UHP grade nitrogen gas. Concentrated volatile extracts (150 μL) were kept in screw-capped dark glass vials at −25 °C for 24 h until analysis by GC−MS.

GC−MS Analysis of Volatile Compounds. A 5 μL aliquot of duplicate extracts of each byproduct/breast muscle was injected into a Varian VISTA 6000 gas chromatograph (Varian Associates Inc., Walnut Creek, CA) coupled with a 7070E VG Analytical (V.G. Micromass Ltd., Manchester, U.K.) mass spectrometer. Separation of volatile components was achieved on a fused silica capillary column (DB 225, 30 m × 0.24 mm i.d. × 0.25 μm film thickness, J&W Scientific, Folsom, CA). The linear velocity of the helium carrier gas was 25 cm/s. The oven temperature was programmed from 40 to 200 °C at a rate of 5 °C/min with initial and final hold times of 5 and 14 min, respectively. Injector and flame-ionization detector (FID) temperatures were maintained at 155 and 280 °C, respectively. Of the injector temperatures investigated, 155 °C was found to produce reproducible results. The total run time was 46 min. For the mass spectrometry, the electron ionization energy was set at 70 eV. The mass range, electron multiplier voltage and scan rate were set at *m*/*z* 33−300, 2000 V, and 1.6 scans/s, respectively. Capillary direct interface and ion source temperatures were maintained at 195 and 250 °C, respectively (Vejaphan et al., 1988).

Volatile compounds were tentatively identified by matching mass spectral data of sample components with those of known compounds in a database (Maspec II, Mass Spectrometry Services Ltd., Manchester, U.K.). The concentration of identified compounds (μg/kg of sample or ppb on wet basis) and their percent (w/w) contribution to the total volatile content were determined using samples spiked with 2,4,6-colidine as the internal standard. The peaks originating from contaminants (mainly phthalates) were located using a blank distillate and eliminated from subsequent calculations. The following equations were used to estimate the concentration of the identified compounds and their percent (w/w) contribution to the total volatile content:

$$C_i = (C_s/A_s)A_i$$

where C is the concentration (μg/kg of sample or ppb), A is the peak area counts, and the subscripts i and s represent the component of interest and the standard, respectively, and

$$R_i = (C_i/C_t) \times 100$$

where R is the percent (w/w) contribution to the total volatile content, C is the concentration (μg/kg of sample or ppb), and the subscripts i and t represent the component of interest and the total volatile content, respectively.

Statistical Analysis. The significance ($p < 0.05$) of the differences among mean values obtained from proximate composition analyses (six replicates for a given byproduct) was established using the analysis of variance (ANOVA) followed by Tukey's studentized range test (Snedecor and Cochran, 1980).

RESULTS AND DISCUSSION

Proximate Composition. Table 1 shows the proximate composition of fresh chicken breast muscle and

Table 1. Proximate Composition of Fresh Chicken Breast Muscle and Processing Industry Byproducts[a]

	% (w/w)				
constituent	breast muscle	backbones	breastbones	spent bones	skin
moisture	74.0 ± 3.1^{b}	65.6 ± 3.6^{b}	71.4 ± 4.2^{b}	68.0 ± 4.0^{b}	40.7 ± 1.6^{a}
total lipids	2.3 ± 0.1^{a}	18.3 ± 1.4^{c}	7.2 ± 1.1^{b}	9.9 ± 0.8^{b}	49.0 ± 1.8^{d}
crude proteins	22.3 ± 1.4^{c}	10.6 ± 0.8^{a}	16.2 ± 1.8^{b}	17.8 ± 1.4^{bc}	11.1 ± 0.7^{a}
ash	1.0 ± 0.0^{a}	3.5 ± 0.8^{b}	4.0 ± 0.6^{b}	3.3 ± 0.6^{b}	0.2 ± 0.0^{a}

[a] Results are mean ± standard deviation for data obtained from six replicates. Means sharing the same superscript in a row are not significantly different ($p > 0.05$) from one another.

byproducts. The moisture content of fresh skin was lower by approximately 33% (w/w) than that of fresh breast muscle, whereas those of the other byproducts were not statistically different. The total lipid content of all four types of fresh byproducts was higher than that of fresh breast muscle. Among the byproducts, fresh skin contained a remarkably high level of total lipid (49%, w/w), whereas the breastbones contained the least (7.2%, w/w). The crude protein content of fresh byproducts (~11−18%, w/w) was less than that of the fresh breast muscle, which had approximately 22% (w/w) crude protein. As expected, all bone byproducts contained a high ash content (~3−4%, w/w) compared to the fresh breast muscle containing only 1% (w/w) ash. Fresh skin had the least amount of ash (0.2%, w/w), which was 5 times lower than that of the fresh breast muscle.

Total Volatile Contents. The distillation and extraction technique used in this study was simple and straightforward as it does not require an advanced apparatus. However, the efficacy of extraction of volatiles in our technique may be lower than that of the simultaneous distillate extraction technique. As listed in Table 2, various aldehydes, ketones, alcohols, hydrocarbons, esters, nitrogen- and/or sulfur-containing compounds, and some miscellaneous compounds contributed to the total volatile content of roasted breast muscle, backbones, breastbones, spent bones, and skin. The highest concentration of total volatiles was present in the roasted skin (4049 ppb) while the least was in the roasted backbones (2030 ppb). The total volatile contents of roasted breast muscle, breastbones, and spent bones were 2648, 2712, and 3100 ppb, respectively. For all samples, aldehydes, alcohols, and nitrogen- and/or sulfur-containing compounds were dominant (in both number of compounds and concentration) among the different classes of volatile compounds. The number of individual volatile compounds identified in roasted breast muscle, backbones, breastbones, spent bones, and skin was 135, 60, 68, 50, and 84, respectively. The following sections will focus on the qualitative and quantitative differences among volatiles of various roasted byproducts, how the volatiles of roasted byproducts differ from those of the roasted breast muscle, and the origin of key volatile compounds.

Aldehydes. The total number of aldehydes identified in roasted breast muscle, backbones, breastbones, spent bones, and skin was 12, 10, 10, 9, and 11, respectively. The total concentration of aldehydes in roasted backbones (778 ppb) and breastbones (721 ppb) did not deviate greatly from that of the roasted breast muscle. However, the total concentration of aldehydes in roasted spent bones and skin was approximately 1.9 and 2.4 times higher than that observed in the roasted breast muscle. The contribution of aldehydes to the total volatiles of roasted breast muscle, backbones, breastbones, spent bones, and skin was ~24, 38, 27, 39, and 38% (w/w), respectively. Hexanal was the dominant aldehyde detected in all samples, and its concentrations in roasted breast muscle, backbones, and breastbones were similar. The concentration of hexanal in spent bones and skin was approximately twice that of the roasted breast muscle. Roasted backbones and spent bones contained nonanal at concentrations >100 ppb while roasted skin contained nonanal, benzeneacetaldehyde, and hexadecanal at concentrations >100 ppb. All other aldehydes were present in concentrations <100 ppb. Certain low molecular weight aldehydes, such as butanal, isobutanal, propanal, and pentanal, were not detected in any of the samples. These highly volatile aldehydes are present mainly in cooked muscle (Harkes and Begemann, 1974), but the higher temperatures applied for roasting in this study might have caused their escape from the samples or decomposition and/or rearrangement into other products. Moreover, certain low molecular mass volatiles might have escaped from the extract while the extract was concentrated under vacuum.

Alkanals, alkenals, and alkadienals are formed from oxidizing fatty acids, and thus, their presence could be anticipated in any lipid-containing food. These compounds have low odor threshold values and possess fatty aroma notes (Mottram, 1991). Aldehydes, in particular enals and dienals, are believed to be important in the characteristic aroma of heated chicken fat (Noleau and Toulemonde, 1987). 2,4-Decadienal has been implicated in the characteristic aroma of chicken fat (Pippen et al., 1958). Aldehydes are also known to serve as important intermediates in the formation of other aroma compounds. Unsaturated aldehydes, such as enals and dienals, can be further oxidized to yield other carbonyls, alcohols, and furans (Grosch, 1982). 2,4-Dienals have been reported to undergo oxidation faster than the parent fatty acids such as linoleic acid (Lillard and Day, 1964).

Ketones. The number of different ketones identified in roasted breast muscle, backbones, breastbones, spent bones, and skin was 11, 5, 5, 4, and 8, respectively. The concentration of ketones in all samples was very low, ranging from 46 to 135 ppb in the roasted skin and breast muscle, respectively (Table 2). The relative contribution of ketones to the total volatile content of breast muscle and byproducts ranged from ~2% to ~3% (w/w). The dominant ketone detected in the roasted breast muscle and spent bones was 3-hydroxy-2-butanone, while 1-(4-hydroxyphenyl)-2-phenylethanone was the dominant one in roasted backbones. Roasted breastbones contained three dominant ketones (equal concentrations), namely, 3-hydroxy-2-butanone, 1,5-di-*tert*-butyl-3,3-dimethylbicyclohexan-2-one, and 3,5-dimethyl-4-ethyl-2-hydroxycyclopent-2-en-1-one. The roasted skin contained almost equal concentrations of 3-hydroxy-2-butanone (30 ppb) and 1-(4-hydroxyphenyl)-2-phenylethanone (31 ppb) as major ketones.

Table 2. Volatile Flavor Composition of Roasted Chicken Breast Muscle and Processing Industry Byproducts[a]

RT[b] (min)	M•+ [c]	tentative identity	concentration (ppb)				
			breast muscle	backbones	breastbones	spent bones	skin
		Aldehydes					
7.13	100	hexanal	397 (15.00)	407 (20.05)	372 (13.72)	827 (26.68)	722 (17.83)
10.39	114	heptanal	39 (1.47)	56 (2.76)	40 (1.47)	72 (2.32)	88 (2.17)
13.56	128	octanal	18 (0.68)	33 (1.62)	16 (0.59)	33 (1.06)	64 (1.58)
16.48	106	benzaldehyde	25 (0.94)	18 (0.89)	56 (2.06)	29 (0.93)	88 (2.17)
16.56	142	nonanal	52 (1.96)	184 (9.06)	47 (1.73)	122 (3.94)	144 (3.56)
19.43	156	decanal	4 (0.15)	13 (0.64)	54 (1.99)	16 (0.52)	31 (0.76)
20.21	120	benzeneacetaldehyde	48 (1.81)	13 (0.64)	57 (2.10)	35 (1.13)	110 (2.72)
25.13	138	2,4-nonadienal	2 (0.07)	–	–	–	–
25.52	152	2,4-decadienal	20 (0.75)	5 (0.25)	29 (1.07)	22 (0.71)	55 (1.36)
29.11	212	tetradecanal	2 (0.07)	3 (0.15)	13 (0.48)	–	9 (0.22)
33.14	240	hexadecanal	39 (1.47)	46 (2.27)	37 (1.36)	55 (1.77)	199 (4.91)
36.53	252	heptadecanal	2 (0.07)	–	–	–	22 (0.54)
		Ketones					
8.56	88	3-hydroxy-2-butanone	11 (0.41)	7 (0.34)	18 (0.66)	31 (1.00)	30 (0.74)
17.18	110	2-methyl-4-hexyne-3-one	–	–	–	–	21 (0.52)
19.45	156	2-decanone	4 (0.15)	–	–	16 (0.52)	31 (0.76)
21.32	212	1-(4-hydroxyphenyl)-2-phenylethanone	7 (0.26)	22 (1.08)	14 (0.52)	12 (0.39)	16 (0.39)
21.48	126	2,2,3,3-tetramethylcyclobutanone	4 (0.15)	–	–	–	–
26.42	136	3,5,7-nonatrien-2-one	6 (0.23)	–	–	–	–
27.40	276	2,4,6-tris(1,1-dimethylethyl)-4-methylcyclohexa-2,5-dien-1-one	2 (0.06)	9 (0.44)	16 (0.59)	–	12 (0.30
29.19	218	benzyloxymethyl-4-methyl-2(5*H*)-furanone	1 (0.03)	–	–	–	6 (0.15)
30.03	236	1,5-di-*tert*-butyl-3,3-dimethylbicyclohexan-2-one	4 (0.15)	6 (0.29)	18 (0.66)	5 (0.16)	9 (0.22)
31.23	154	3,5-dimethyl-4-ethyl-2-hydroxycyclopent-2-en-1-one	2 (0.07)	–	18 (0.66)	–	–
37.48	276	4-iodotricyclodecanone	4 (0.15)	10 (0.49)	–	–	10 (0.25)
38.05	236	4-isopropyl-5,10-dimethyldecalindione-(1.3)	1 (0.03)	–	–	–	–
		Alcohols					
5.16	86	2-methyl-2-buten-1-ol	524 (19.79)	197 (9.70)	300 (11.06)	389 (12.55)	328 (8.10)
8.11	88	1-pentanol	101 (3.81)	25 (1.23)	110 (4.06)	166 (5.35)	85 (2.10)
14.34	128	1-octen-3-ol	29 (1.09)	29 (1.43)	60 (2.21)	43 (1.39)	105 (2.59)
15.56	128	2,4-dimethylcyclohexanol	2 (0.07)	–	–	–	11 (0.27)
16.05	130	2-ethyl-1-hexanol	8 (0.30)	13 (0.64)	16 (0.59)	9 (0.29)	10 (0.25)
16.19	98	2-furanmethanol	27 (1.02)	–	–	–	275 (6.79)
17.13	130	3-ethyl-4-methylpentanal	4 (0.15)	–	–	–	–
17.24	182	4-ethyl-4-methyl-3-(1-methylethyl)cyclohexanol	4 (0.15)	–	–	–	–
17.34	130	1-octanol	20 (0.75)	21 (1.03)	41 (1.51)	27 (0.87)	41 (1.01)
18.28	184	5-dodecenol	6 (0.23)	–	–	8 (0.26)	–
22.09	108	benzyl alcohol	7 (0.26)	3 (0.15)	42 (1.55)	13 (0.42)	14 (0.34)
22.26	156	2-*tert*-butyl-2,3-dimethyl-3-buten-1-ol	5 (0.19)	13 (0.64)	31 (1.14)	–	13 (0.32)
23.08	94	phenol	–	–	–	–	8 (0.20)
23.21	140	nona-1,8-dien-4-ol	1 (0.03)	–	–	–	–
25.09	108	4-methylphenol	4 (0.15)	–	20 (0.74)	7 (0.22)	13 (0.32)
25.29	152	2-hydroxy-2-ethynyl-bicyclooctane	2 (0.07)	–	–	–	–
26.30	158	4-ethyl-2-octanol	8 (0.30)	7 (0.34)	29 (1.07)	–	33 (0.81)
27.21	154	3-methylnon-1-yn-3-ol	2 (0.07)	–	–	–	–
28.46	158	3,7-dimethyl-1-octanol	5 (0.19)	–	–	–	–
29.09	170	1-(2-methyl-2-tetrahydrofuryl)-4-penten-1-ol	2 (0.07)	–	–	–	9 (0.22)
29.27	128	α-butylcyclopropanemethanol	4 (0.15)	–	–	–	14 (0.34)
30.55	170	3-methyldec-1-en-4-ol	2 (0.07)	–	–	–	10 (0.25)
31.12	152	2-methyl-6-methyleneocta-1,7-dien-3-ol	2 (0.07)	–	–	–	8 (0.20)
31.22	140	2,6,6-trimethyl-2-cyclohexen-1-ol	2 (0.07)	–	–	10 (0.32)	8 (0.20)
31.34	206	2,4-bis(1,1-dimethylethyl)phenol	–	11 (0.54)	13 (0.48)	–	6 (0.15)
35.05	200	1-tridecanol	–	7 (0.34)	9 (0.33)	11 (0.35)	10 (0.25)
37.40	220	4-nonylphenol	4 (0.15)	10 (0.49)	8 (0.29)	29 (0.93)	5 (0.12)
39.09	170	2-(5,5-dimethyltetrahydrofuran-2-yl)-3-buten-2-ol	2 (0.07)	–	–	–	–
40.28	146	3,4-dimethyl-3,4-hexanediol	11 (0.41)	–	–	–	–
41.15	158	3,4-dimethyl-3-octanol	12 (0.45)	–	–	–	–
		Hydrocarbons					
6.55	70	methylcyclobutane	275 (10.38)	–	–	–	–
8.12	84	2-hexene	39 (1.47)	–	–	–	–
11.35	84	1-hexene	18 (0.68)	12 (0.59)	25 (0.92)	57 (1.84)	35 (0.86)
16.05	170	2,2,2,4,5,5-hexamethylhexane	8 (0.30)	–	–	9 (0.29)	10 (0.25)
17.56	96	2,4-dimethyl-1,4-pentadiene	2 (0.07)	–	–	–	9 (0.22)
19.34	112	3,4-dimethyl-1-hexene	3 (0.11)	–	–	–	–
20.13	126	1-nonene	7 (0.26)	4 (0.20)	7 (0.26)	17 (0.55)	5 (0.12)
22.10	108	1,3,5-octatriene	7 (0.26)	–	–	–	–
24.13	128	3-ethyl-2,4-dimethylpentane	6 (0.23)	4 (0.20)	10 (0.37)	9 (0.29)	30 (0.74)
26.31	140	1-methyl-2-propylcyclohexane	8 (0.30)	–	–	–	33 (0.81)
28.45	126	2,4-dimethyl-1-heptene	5 (0.19)	–	–	–	13 (0.32)
30.55	126	3-nonene	2 (0.07)	–	–	–	–
35.52	192	1-*n*-butyladamantane	2 (0.07)	–	–	–	–
36.03	180	4-methyl-9*H*-fluorene	2 (0.07)	3 (0.15)	10 (0.37)	–	–

Table 2 (Continued)

RT[b] (min)	M•+ [c]	tentative identity	concentration (ppb) breast muscle	backbones	breastbones	spent bones	skin
		Hydrocarbons					
37.19	220	1-*n*-pentyladamantane	3 (0.11)	20 (0.98)	26 (0.96)	–	13 (0.32)
39.38	178	9-methylene-9*H*-fluorene	2 (0.07)	–	–	–	–
41.24	210	1-pentadecene	–	–	–	26 (0.84)	–
		Esters					
10.03	132	propyl ester of 2-hydroxypropanoic acid	25 (0.94)	21 (1.03)	–	48 (1.55)	92 (2.27)
10.48	86	1-propen-2-ol, formate	9 (0.34)	–	–	–	–
12.52	132	butyl glycolate	9 (0.34)	18 (0.89)	15 (0.55)	17 (0.55)	31 (0.76)
16.19	140	cyclohexen-1-ol, acetate	27 (1.02)	18 (0.89)	22 (0.81)	16 (0.52)	–
21.32	180	methyl ester of α-methoxybenzeneacetic acid	7 (0.26)	22 (1.08)	–	12 (0.39)	16 (0.39)
24.37	202	α-methyl-1*H*-indene-1-methanol, acetate	2 (0.07)	–	–	–	–
29.29	216	1-(1,1-dimethyl)-2-methyl-1,3-propanediyl ester of 3-methylpropanoic acid	4 (0.15)	6 (0.29)	12 (0.44)	–	14 (0.34)
32.06	242	3,4-dimethylpentyl-3-ethyl-4-methyl pentanoate	1 (0.03)	–	–	–	–
32.52	258	2-oxo-2-phenylethyl ester of 3-fluorobenzoic acid	10 (0.38)	34 (1.67)	18 (0.66)	26 (0.84)	16 (0.39)
39.08	130	methyl ester of 2-methoxycyclopropane-1-carboxylic acid	2 (0.07)	5 (0.25)	–	–	6 (0.15)
		Nitrogen- and/or Sulfur-Containing Compounds					
8.47	129	pidolic acid	1 (0.03)	–	–	–	–
8.57	86	1-methyl-1-(2-propenyl)hydrazine	11 (0.41)	–	–	–	–
9.14	84	2,3,4,5-tetrahydropyridazine	13 (0.49)	7 (0.34)	–	22 (0.71)	16 (0.39)
9.40	98	5-methyl-1*H*-1,2,4-triazole-3-amine	4 (0.15)	5 (0.25)	7 (0.26)	–	13 (0.32)
9.47	94	methylpyrazine	4 (0.15)	–	8 (0.29)	–	13 (0.32)
10.05	84	tetrahydropyridazine (isomer)	25 (0.94)	16 (0.79)	49 (1.81)	48 (1.55)	92 (2.27)
10.28	181	5-(cyclohexylmethyl)-2-pyrrolidinone	1 (0.03)	–	–	–	–
10.48	58	dimethyldiazene	9 (0.34)	11 (0.54)	13 (0.48)	16 (0.52)	33 (0.81)
11.21	84	2-methylpiperidine	29 (1.09)	4 (0.20)	50 (1.84)	–	83 (2.05)
11.58	67	pyrrole	5 (0.19)	3 (0.15)	11 (0.40)	–	48 (1.18)
12.09	108	2,5-dimethylpyrazine	5 (0.19)	–	27 (0.99)	–	37 (0.91)
12.18	108	2,5-dimethylpyrimidine	1 (0.03)	–	10 (0.37)	–	12 (0.30)
12.29	86	4-fluoroimidazole	7 (0.26)	4 (0.20)	9 (0.33)	–	8 (0.20)
13.36	199	ethyl ester of 1-lactyl-2-piperidinecarboxylic acid	2 (0.07)	–	–	–	–
14.19	81	3-methyl-1*H*-pyrrole	1 (0.03)	–	–	–	5 (0.12)
14.42	84	piperidine	56 (2.11)	22 (1.08)	80 (2.95)	30 (0.97)	131 (3.23)
14.48	122	trimethylpyrazine	8 (0.30)	–	39 (1.44)	–	42 (1.04)
15.03	157	2-methoxy-4,4,5,5-tetramethyl-2-oxazoline	2 (0.07)	–	–	–	–
15.40	169	2-hexyl-1-methylpyrrolidine	1 (0.03)	–	–	–	–
16.16	104	3-(methylthio)propanal	27 (1.02)	18 (0.89)	54 (1.99)	16 (0.52)	–
16.26	136	3-ethyl-2,5-dimethylpyrazine	6 (0.23)	–	6 (0.22)	–	33 (0.81)
18.12	86	1-nitrosoazetidine	3 (0.11)	–	–	–	–
18.27	141	2-azido-2,3,3-trimethylbutane	5 (0.19)	5 (0.25)	8 (0.29)	8 (0.26)	14 (0.34)
18.49	143	methyl ester of 4,5-dihydro-5-methylisoxazole-carboxylic acid	1 (0.03)	–	–	–	–
18.55	127	2-acetylthiazole	7 (0.26)	8 (0.39)	21 (0.77)	12 (0.39)	10 (0.25)
19.03	143	5-(ethoxymethyl)-2-pyrrolidinone	30 (1.13)	18 (0.89)	19 (0.70)	14 (0.45)	16 (0.39)
19.39	112	4*H*-thiopyran-4-one	1 (0.03)	–	–	–	–
19.48	149	2-pentylpyridine	2 (0.07)	–	–	–	–
20.04	74	acetyl hydrazide	3 (0.11)	–	7 (0.26)	–	5 (0.12)
20.30	175	1-benzoylpyrrolidine	4 (0.15)	–	–	–	–
20.55	127	2-propylpiperidine	1 (0.03)	–	–	–	–
21.40	154	1,1′-methylenebis(2-methylazetidine)	1 (0.03)	–	–	–	–
22.25	176	2-(2-pyrrolidine-yl-ethyl)pyridine	5 (0.19)	–	–	–	–
23.07	94	5-methylpyrimidine	1 (0.03)	–	–	–	–
23.22	150	1-methyl-3,1′-bi(1,2,4-triazole)	–	–	–	8 (0.26)	–
23.32	95	1*H*-pyrrole-2-carboxaldehyde	1 (0.03)	–	–	–	9 (0.22)
23.39	109	1-(1*H*-pyrrol-2-yl)ethanone	5 (0.19)	–	12 (0.44)	–	12 (0.30)
23.52	86	1,2,5-thiadiazole	6 (0.23)	–	–	–	–
24.13	143	7-methoxy-8-oxa-1-azabicyclooctane	6 (0.23)	–	–	–	–
24.17	69	1*H*-1,2,4-thiazole	–	–	–	9 (0.29)	–
24.27	84	3-aminotriazole	1 (0.03)	–	–	–	–
24.47	195	*N*-(hept-1-enyl)piperidin-2-one	1 (0.03)	–	–	–	–
25.24	130	1-nitropiperidine	1 (0.03)	–	–	–	–
25.37	135	benzothiazole	22 (0.83)	25 (1.23)	62 (2.29)	51 (1.64)	31 (0.76)
26.59	74	2-methlazetidine	2 (0.07)	–	–	–	–
27.07	141	2,2,4,4-tetramethyl-1-acetidinecarboxaldehyde	2 (0.07)	–	–	–	–
29.11	128	2-methylenebutanediamide	2 (0.07)	–	–	–	–
29.43	163	methyl diethyldithiocarbamate	4 (0.15)	3 (0.15)	6 (0.22)	9 (0.29)	3 (0.07)
29.48	203	2-(3-isoxazolyl)phenol, acetate	4 (0.15)	–	7 (0.26)	–	–
32.18	117	indole	4 (0.15)	3 (0.15)	17 (0.63)	–	26 (0.64)
32.39	143	5-methyl-5-nitrosohexan-2-one	1 (0.03)	–	–	–	–
36.58	206	*N*,*N*′-diacetyl-2-aminobenzylanine	1 (0.03)	–	–	–	–
37.08	169	2-*p*-tolylpyridine	9 (0.34)	7 (0.34)	14 (0.52)	11 (0.35)	8 (0.20)
39.08	143	1-nonanamide	2 (0.07)	2 (0.10)	5 (0.18)	–	6 (0.15)

Table 2 (Continued)

RT[b] (min)	M•+ [c]	tentative identity	concentration (ppb) breast muscle	backbones	breastbones	spent bones	skin
		Miscellaneous Compounds					
6.52	72	tetrahydrofuran	27 (1.02)	100 (4.93)	100 (3.69)	18 (0.58)	170 (4.20)
7.39	72	ethoxyethene	−	24 (1.18)	37 (1.36)	−	33 (0.81)
21.17	86	butyrolactone	5 (0.19)	3 (0.15)	8 (0.29)	17 (0.55)	18 (0.44)
21.48	128	2-(1,1-dimethylethyl)-3-ethyl oxirane	4 (0.15)	−	−	−	11 (0.27)
23.00	220	diethyl-2-methylbuta-2,3-dienyl phosphate	3 (0.11)	−	−	−	−
23.52	124	benzylphosphine	−	−	8 (0.29)	−	−
26.26	116	2-propyl-1,3-dioxolane	4 (0.15)	−	−	−	−
27.00	188	3-hydroxydecanoic acid	−	2 (0.10)	5 (0.18)	−	14 (0.34)
27.21	148	3,3,6,6-tetramethyl-1,2,4,5-tetroxane	−	−	8 (0.29)	−	−
31.29	142	(1-methoxypentyl)cyclopropane	−	−	7 (0.26)	−	−
37.50	156	1-(chloromethyl)-4-methoxybenzene	4 (0.15)	−	−	−	−
40.27	228	tetradecanoic acid	11 (0.41)	22 (1.08)	10 (0.37)	30 (0.97)	34 (0.84)
		Total Volatile Content	2648	2030	2712	3100	4049
		aldehydes	648 (24.47)	778 (38.32)	721 (26.58)	1211 (39.06)	1532 (37.84)
		ketones	46 (1.74)	54 (2.66)	84 (3.10)	64 (2.06)	135 (3.33)
		alcohols	800 (30.20)	336 (16.55)	679 (25.04)	712 (22.97)	1006 (24.84)
		hydrocarbons	389 (14.69)	43 (2.12)	78 (2.88)	118 (3.81)	148 (3.65)
		esters	96 (3.62)	124 (6.11)	67 (2.47)	119 (3.84)	175 (4.32)
		nitrogen- and/or sulfur-containing compounds	356 (13.44)	161 (7.93)	541 (19.95)	254 (8.19)	706 (17.44)
		miscellaneous compounds	58 (2.19)	151 (7.44)	183 (6.75)	65 (2.10)	280 (6.92)
		total identified	2393 (90.37)	1647 (81.05)	2353 (86.76)	2543 (82.03)	3982 (98.34)
		total unidentified	255 (9.63)	383 (18.95)	359 (13.24)	557 (17.97)	67 (1.66)

[a] Results are the average values of two analyses. Values in parentheses represent the percent (w/w) contribution of individual compounds or classes of compounds to the total volatile content. − indicates not detected. [b] RT = retention time. [c] M•+ = molecular radical cation.

In general, aliphatic ketones are less abundant components in meat aroma. The aroma note of 2-decanone, which was detected in the roasted white muscle, spent bones, and skin, has been reported as citrus-like. However, the odor threshold values of 2-alkanones are much higher than those of isomeric aldehydes (Seik et al., 1971). MacLeod and Ames (1987) have reported that the meaty aroma of cooked beef is due to the presence of cyclopentanones and cyclohexanones at high concentrations (>500 ppb). However, these compounds, also detected in roasted chicken, may not be as important as they were in cooked beef, due to the very low concentrations present (2−18 ppb) in chicken.

Alcohols. This class of volatile compounds was the second largest among the major classes of volatile compounds detected in the roasted chicken byproducts. Total alcohol concentration in the roasted byproducts ranged from 336 ppb (∼17%, w/w) in the backbones to 1006 ppb (∼25%, w/w) in the roasted skin. However, alcohols represented the largest group of volatile compounds in roasted breast muscle (800 ppb; 30%, w/w). The highest number of different alcohols (27) was detected in the roasted breast muscle, while the lowest (11) was detected in both backbones and spent bones. Roasted skin also contained a relatively large number of different alcohols (20). 2-Methyl-2-buten-1-ol was the dominant alcohol present in all samples. 1-Pentanol was present in roasted breast muscle, breastbones, and spent bones at concentrations >100 ppb. Furthermore, the roasted skin contained 1-octen-3-ol and 2-furanmethanol at concentrations of 105 and 275 ppb, respectively. 2-Furanmethanol was absent in all types of roasted bones, but present in roasted breast muscle at a concentration of 27 ppb, which is approximately 10 times lower than that detected in the roasted skin. In general, the nature of alcohols present in all types of roasted bones was similar. Alcohols present in the roasted skin showed similarities to those of the roasted breast muscle.

Both saturated and unsaturated fatty alcohols are ubiquitous in meat volatiles. Seik et al. (1971) have reported that the straight-chain saturated alcohols are unimportant in meat aroma due to their very high odor threshold values (500−20000 ppb). Unsaturated alcohols, however, have low odor threshold values and are associated with the mushroom-like or metallic notes of meat aroma (Mottram, 1991). Therefore, it may be assumed that 2-methyl-2-buten-1-ol (the dominant alcohol detected in all roasted samples) contributed more to the aroma of roasted samples than the other alcohols.

Hydrocarbons. The number of hydrocarbons detected in the roasted breast muscle was 16, and methylcyclobutane was the dominant one. The concentration of hydrocarbons in the roasted breast muscle was 389 ppb (∼15%, w/w). None of the hydrocarbons detected in the roasted backbones, breastbones, and skin showed a clear dominance and had low concentrations (3−57 ppb). The dominant hydrocarbon detected in the roasted spent bones was 1-hexene. Methylcyclobutane, the dominant hydrocarbon detected in the roasted breast muscle, was absent in the roasted byproducts.

During lipid oxidation, alkanes and alkenes are readily formed from homolytic scission of saturated and unsaturated alkoxy radicals, respectively (Grosch, 1982). Aliphatic hydrocarbons have high odor threshold values (Champagne and Nawar, 1969) and are, therefore, unlikely to play a major role in meat aroma.

Esters. Similar to that of hydrocarbons, the concentration of esters in all samples was low (<50 ppb) with the exception of the propyl ester of 2-hydroxypropanoic acid, which was detected in the roasted skin at a concentration of 92 ppb. The amount of esters in the samples ranged from 67 to 175 ppb (2−6%, w/w). Esters, which possess fruity aroma notes, are not considered to be important contributors to the roasted meat aroma, possibly due to their low concentrations. It has been reported that esters are responsible for the cured pork aroma (Shahidi et al., 1986). Many esters in meat aroma

are acetates and methyl, ethyl, and 3-methylbutyl esters of C_4-C_{10} fatty acids (Kozma-Kovacs, 1976). Esters of C_1-C_{10} fatty acids have been reported to possess fruity aroma notes, while those of long-chain ($>C_{10}$) fatty acids have been implicated in fatty aroma notes, (Forss, 1972). However, esters, except thio esters, are considered unimportant in chicken aroma.

Nitrogen- and/or Sulfur-Containing Compounds. The number of nitrogen- and/or sulfur-containing compounds detected in roasted breast muscle, backbones, breastbones, spent bones, and skin was 52, 17, 24, 13, and 25, respectively. The lowest and highest concentrations of nitrogen- and/or sulfur-containing compounds were detected in backbones (161 ppb; ~8%, w/w) and skin (706 ppb; ~17%, w/w), respectively. For roasted breast muscle, only piperidine was detected at a concentration >50 ppb. Tetrahydropyridazine, 2-methylpiperidine, 3-(methylthio)propanal, and 5-(ethoxymethyl)-2-pyrrolidinone were detected in roasted breast muscle at concentrations of 25−30 ppb, while a majority of other compounds had concentrations <10 ppb. For roasted backbones, piperidine and benzothiazole were the major nitrogen- and/or sulfur-containing compounds present, but their concentrations were only 22 and 25 ppb, respectively. 2-Methylpiperidine, piperidine, 3-(methylthio)propanal, and benzothiazole were the major nitrogen- and/or sulfur-containing compounds present in the roasted breastbones, and their concentrations ranged from 50 to 80 ppb. Tetrahydropyridazine, 2,5-dimethylpyrazine, and trimethylpyrazine were also detected in the roasted breastbones at appreciable concentrations (27−49 ppb). Roasted spent bones contained tetrahydropyridazine and benzothiazole as major nitrogen- and/or sulfur-containing compounds at a concentration of ~50 ppb. Two compounds, namely, 1-methyl-3,1′-bi(1,2,4-triazole) and 1*H*-1,2,4-thiazole, were only detected in the roasted spent bones, but their concentrations were <10 ppb. The concentration of nitrogen- and/or sulfur-containing compounds in the roasted skin (706 ppb) was twice as much as that present in the roasted breast muscle (356 ppb). Piperidine was the dominant nitrogen-containing compound detected in the roasted skin, and its concentration was 131 ppb. The concentrations of tetrahydropyridazine (both isomers) and 2-methylpiperidine in the roasted skin were 108 and 83 ppb, respectively. Dimethyldiazene, pyrrole, 2,5-dimethylpyrazine, trimethylpyrazine, 3-ethyl-2,5-dimethylpyrazine, benzotiazole, and indole were also present in the roasted skin at concentrations ranging from 26 to 48 ppb.

The heterocyclic nitrogen- and/or sulfur-containing compounds are extremely important contributors of roasted meat flavor profiles. Pyrroles, pyridines, piperidines, and their derivatives are present in heated foods, and they are derived from the pyrolysis of amino acids such as proline, reaction of Amadori products with ammonia, and interaction of furfurals and ammonia (Vernin and Parkanyi, 1982). The aroma notes of these compounds have been reported as burnt and earthy (MacLeod and Coppock, 1977). Pyrazines are reported to be important aroma compounds. Various pyrazines with mono-, di-, or trialkyl substitution have been isolated from meats. Most commonly found alkyl substituents are methyl and ethyl groups, but propyl-, butyl-, and pentyl-substituted pyrazines have also been found in meats. The nutty, earthy, and potato-like aroma notes in cooked and roasted meats have been attributed to alkylpyrazines (Fors, 1983). Pyrazines are a result of the Maillard reaction and known as important contributors to roasted meat flavor (Mussinan et al., 1973).

Thiazoles and thiazolines, found mainly in fried, grilled, or roasted meats, have low odor threshold values and thus are considered as important contributors to the aroma. In general, thiazoles and thiazolines are present as monoalkyl-, dialkyl-, or trialkyl-substituted (mostly methyl or ethyl) derivatives. It is known that these compounds with their dialkyl or trialkyl substitution contribute significantly to the nutty, meaty, and roast characteristics of roasted meats (Tang et al., 1983).

Miscellaneous Compounds. Among the miscellaneous compounds detected in the roasted breast muscle, only tetrahydrofuran was present at an appreciable concentration (27 ppb; ~1%, w/w). All roasted byproducts, except the spent bones, also had tetrahydrofuran at high concentrations (100−170 ppb; ~4%, w/w). Tetrahydrofuran is derived from the dehydration of carbohydrates in the Maillard reaction. Furans carrying functional groups, such as carbonyl, alcohol, and thiol groups, have been related to meat-like and caramel-like aromas in beef. However, tetrahydrofuran, as such, has not been implicated in meat aroma (Shibamoto, 1989). The concentration of ethoxyethene in the roasted breastbones and skin was >25 ppb. Butyrolactone and tetradecanoic acid were also present in all samples.

Conclusions. The volatile flavor profiles of the roasted chicken byproducts were markedly different from that of the roasted chicken breast muscle. The quantitative differences in flavor precursors (mainly lipids and nitrogenous compounds) among samples may be responsible for the observed variations among the volatile compositions. Poultry-processing byproducts show potential for use in the production of flavor concentrates. However, further research is required to formulate a blend of byproducts or flavor extracts to produce palatable flavor concentrates from poultry-processing-industry byproducts.

ABBREVIATIONS USED

ppb, parts per billion; GC−MS, gas chromatography−mass spectrometry; i.d., internal diameter; FID, flame-ionization detector; UHP, ultrahigh purity; w/w, weight over weight.

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