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Research Article

Effect of Cooking Methods on the Flavor of Jinhua Ham by GC-MS and Electronic Nose Analysis

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Abstract: Jinhua ham is popular in China because of its characteristic aroma. Unlike dry-cured western ham, it is cooked. The objective of this study was to evaluate the effect of three traditional cooking methods, steaming (B), boiling (C) and stewed ham Soup (S) on the volatiles in Jinhua ham (A). The volatiles were analyzed by Gas Chromatography-Mass Spectrometry (GC-MS) after extraction by Solid Phase Microextraction (SPME). The volatiles mainly consisted of alcohols, sulfur-containing compounds and cyclic compounds. Results from the Principal Components Analysis (PCA) showed A, C1, C3 (13, 18), B1, B2 (13) had the same volatiles, while B3 (22, 24, 36, 12, 30, 19, 23, 26), C2 (28, 33) and S1 (37, 27, 38), S3 (38, 8, 34); S2 (8, 17, 11) showed negative correlation with A, C1, C3, B1 and B2. The compounds generated by cooking the ham were dominated by Maillard reaction and lipid oxidation volatiles. Most importantly, many unsaturated hydrocarbons, such as 3-methyl-2-butenal, 2-heptenal were generating by different types of heating. The electronic nose analysis indicated that the cooking methods had great effect on the flavor profiles of the ham. The C2 appeared to have profile similar to the raw ham. However, C3 had different flavor profile from that for S1 and S2. The main source of the difference was that the profiles appeared to be high in sulfur-containing content in S1 and S2.

Keywords: Boiling, cooked ham, flavor profile, steaming, stewed ham soup

INTRODUCTION

With the increasing demand for convenient foods in China, the market for cooked meat has grown steadily in recent years (Cheng *et al*., 2005). The present study examines the effect of cooking at 3 different levels of heating, steaming, boiling and stewed ham soup on the flavor profile of Jinhua ham and the aromatic compounds responsible for its aroma.

Early work on the flavor of cooked meat found that fatty tissues were responsible for specific flavor and lean tissue provided the precursors of the meaty flavor producing the aroma of cooked meat. A limited number of studies have shown the importance of sulfur-containing compounds in the aroma of cooked meat in the 1950s and 1960s (Hornstein and Crowe, 1960; Kramlich and Pearson, 1960; Wasserman and Gray, 1965; Cross and Ziegler, 1965). The straight-chain hydrocarbons, carbonyls and esters are reported to be responsible for the characteristic cooked pork aroma. Later work was emphasized on the effecting of Warmed-Over Flavor (WOF) on flavor (Pearson *et al*., 1976, 1983). More recent work has been emphasized the relevance of sulfur-containing compounds and cyclic compounds for the aroma of cooked meat.

The characteristic flavor of cooked meat introduced heating, Maillard etc. (Mottram *et al*., 1982; Leod and Ames, 1986). Both types of reactions involve complex pathways leading to an account for the large number of volatile compounds in cooked meat. The compounds formed by the Maillard reaction may also react with other components of meat, making the aroma profile more complex. For example, aldehydes and other carbonyls formed during lipid oxidation react readily with Maillard intermediates. Such interactions give rise to additional aromatic compounds, modifying profile of compounds contributing to the meat. Such interactions may control the formation of sulfur-containing compounds and other volatiles caused by Maillard reaction, at levels which give the desired flavor of cooked meat (Jalbout *et al*., 2007).

MATERIALS AND METHODS

Materials: The visible fat, connective tissue, bones and rind were manually removed from Jinhua ham (ripened

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Table 1: Changes of aldehydes in Jinhua ham by cooking (×10-3 mg/kg)

RI	Compounds	Odor characteristics	A	B1	B2	B3	C1	C2	C3	S1	S2	S3
638	3-methyl-Butanal	Apple, grass flavor	6178.75	5456.73	3105.12	4254.75	3995.95	4034.00	4147.07	1583.50	1221.13	1737.39
775	3-methylcrotonaldehyde	—	0	0	18.50	10.49	20.88	13.17	30.63	28.69	43.25	50.33
801	**Hexanal**	Grass flavor	42.67	923.08	1018.85	1150.58	1418.79	1374.43	1206.42	1091.70	1734.13	1406.02
903	**Heptanal**	Cured ham flavor	104.52	104.05	90.20	128.84	157.23	146.37	147.27	138.13	159.93	116.61
966	Benzaldehyde	Bitter almond, caramel flavor	131.97	196.21	195.44	197.76	239.54	319.09	259.19	91.42	111.65	104.02
1006	Benzaldehyde	Focal and oil flavor	235.96	0.56	0	0	70.02	103.92	75.4	157.48	174.02	102.35
1058	**Phenylacetaldehyde**	Hay flavour, fragrance of flowers	35.96	0.97	146.88	0	124.07	159.54	167.3	0	5.03	294.46
1108	**Nonanal**	Grease, oil flavor	231.93	164.70	181.57	247.19	187.94	216.63	177.9	165.49	184.08	118.29
1207	**Decanal**	—	24.72	0.23	0	29.96	8.6	10.25	8.25	12.68	0	0

A Jinhua ham; B1 steamed for 1 h; B2 steamed for 2 h; B3 steamed for 3 h; C1 boiled for 1 h; C2 boiled for 2 h; C3 boiled for 3 h; S1 steamed soup for1 h; S2 steamed soup for 2 h; S3 steamed soup for 3 h; SD< 5 % (n = 3)

for one year) purchased from Shanghai No. 2 Food Store. The remaining sample included semi-membranous, bicep-femoris and semi-tendinous materials. The ham was vacuum-packaged and stored at -20°C for later analysis. It was thoroughly minced before extraction.

Heating procedures: Three different domestic preparations (steaming, boiling and stewed ham soup) were performed according to the traditional Chinese cookery under the condition of different time and temperature.

The 3 heating procedures are summarized in Table 1. Each session and information on cooking conditions is provided as follows.

Steaming: Muscle samples were cut into pieces (1×1×2.54 cm) and quickly steamed. Steaming was carried out for 1, 2 and 3 h.

Boiling: Cubes of 3×3×3 cm were cut from the sample. The cubes were placed in 20 times their weight of de-ironed water. The heating temperature of 100±2°C was kept for 1, 2 and 3 h, respectively.

Soup-making: Cooking was conducted at three temperature settings; 90, 110 and 160°C using the Electronic Stove. The setting was chosen because of its utilization in domestic work and the temperature was the relatively standard cooking one. The sample was cubed (1×1×2.54 cm) and placed into 1:10 (V:V) water, high heat to boiled at the beginning and then the heat reduced to low, the mixture was covered and simmered for about 1, 2 and 3 h, respectively. The liquid soup was used to make the extract quantified by GC/MS.

After cooking, samples were allowed to cool to 5°C in a refrigerator before analysis.

SPME-GC-MS analysis: Six gram of the cooked ham was placed in a 15 mL vial and it was equilibrated for 10 min at 60°C, which was the serving temperature during sensory analysis in the heating box of the autosampler (CTC analytics, Zwingen, Switzerland). The volatiles were sampled with an SPME fiber (75 mm carboxen/ polydimethylsiloxane) in 1 min. The fiber was then transferred to the injection port of the gas chromatograph and desorbed at 250°C. To ensure the samples were not oxidized during storage before GC-MS, only one sample was analyzed at a time. The quantitative result of each volatile compound was computed by relating the relative peak intensity of the volatile compound to the intensity of the total compounds. The analysis was performed using a gas chromatograph equipped with a flame ionization detector and an olfactometer (Phaser Company, Holland).

Kovats indices (KI) were calculated by using the *n*-alkanes series (C5-C24) under the same chromatographic conditions as samples according to Van Den Dool and Kratz (1963). Compound identification was based on comparison of:

- KIs with those of standards or those reported in the literature (Vallone *et al*., 2013; Meynier *et al*., 1999; Insausti *et al*., 2002).
- Comparison of mass spectra with those in the databases of NIST 98 (National Institute of Standards and Technology, Gaithersburg, Md., U.S.A.) and the Wiley 6.0 (Wiley, New York, N.Y., U.S.A).

For the purpose of quantization, standard solutions of hexanal, 1-octanol and decanoic acid ethyl ester were dissolved in methanol at a concentration of 1 mg/kg. An aliquot of mixed standard solution (6.0 g) was then transferred into a 15 mL headspace vial and sealed for analysis. The amount of individual constituent present was calculated according to Wettasinghe *et al*. (2001).

GC-olfactometry analysis: A panel of nine students experienced in sensory analysis was selected. They were trained to identify the odors in a mixture that consisted of ethyl acetate, 2, 3-pentanedione, hexanal, 3-(methylthio)-propanal, 1-octen-3-ol, nonanal, (*E*, *E*)-

2, 4-decadienal and 2-undecenal, all of which are often found in dry-cured hams and have distinct odors. They were also trained to recognize volatile compounds in the SPME extracts. To obtain verbal descriptions of the aroma, the method of Tønder *et al*. (1998) was used. The panel was instructed to note the time when they first perceived the odor. They were also asked to verbally descript the quality of the odor, using descriptors of their own choice. Two panel members sniffed for 20 min and then they were replaced by two other members. The olfactory voicegram 1.0 directly recorded the description of odors simultaneously at the time the odor was detected.

Electronic nose analysis: Instrumental differentiation of ham aroma was conducted with an Electronic Nose (EN). It was comprised of a headspace auto-sampler unit (HS 100), eighteen different Metal Oxide Sensors (MOS), Alpha M.O.S. αFOX 4000 system and αSOFTV9.1 (Nurjuliana *et al*., 2011; Heidarbeigi *et al*., 2015).

Statistical analysis: All the data were treated for significance by the one-way Analysis of Variance (ANOVA) at $p<0.05$ with the aid of SPSS 13.0 for Windows® software (SPSS Inc. Chicago, IL, USA).

To compare the effect of different cooking methods on volatiles, the Principal Component Analysis (PCA) was relied upon. It was performed using results from GC/MS and selected identified volatile compounds (38) as variables in the SPSS software (11.8, 1996).

Post-hoc analysis for significance was done using Tukey's Honestly Significant Difference (HSD) test. All the curves were fitted with Microsoft® Office Excel (Copyright© 1985-2003 Microsoft Corporation, USA) and the y-axis error bars shown at $p<0.05$. The statistical analysis of electronic nose was performed with the αSOFTV 9.1 program.

RESULTS AND DISCUSSION

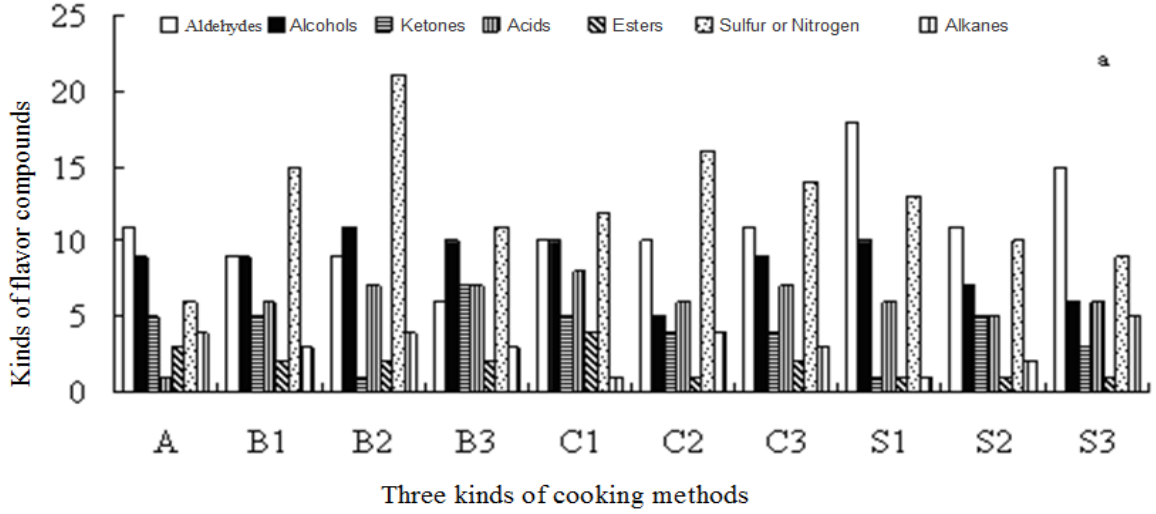
Common volatiles in the raw and cooked Jinhua ham: The volatiles detected by SPME combined with GC-MS were categorized into seven classes, namely aldehydes, alcohols, ketones, acids, esters, sulfur-containing or cyclic compounds and hydrocarbons by the three cooking methods. Figure 1a shows the kinds of volatiles contained the seven classes in the raw ham, steamed ham, boiled ham and stewed ham soup. The profile of the chemical families varied with the three cooking methods. The raw ham (A) showed more kinds of aldehydes and alcohols, while the steamed ham (B) showed more kinds of sulfur-containing or cyclic compounds and ketones. The boiled ham (C) showed more kinds of acids and esters; and stewed ham soup (S) showed more kinds of aldehydes and hydrocarbons.

Figure 1b compared the proportion of each class of volatile in the raw ham, steamed ham, boiled ham and stewed ham soup to the total percent of all volatiles. Cooking decreases the proportion of aldehydes.

The aldehydes such as hexanal, heptanal and nonanal (Table 1) are the predominant volatiles. Cooking reduced the proportion of aldehydes present. The saturated ones dominated the common volatiles. Aldehydes showed the highest proportion in Jinhua ham by each cooking method and then the sulfur-containing or cyclic compounds.

Cooking enhanced the aroma of sulfur-containing volatiles. The proportion of alcohols, hydrocarbons, esters and ketones changed little. Most of the aldehydes had fatty odor, which could be regarded as the characteristic odor of Jinhua ham. Aldehydes especially for those less than ten carbons, such as tenals and ditenals had oil odor (Chang and Peterson, 1977).

The reduction in the proportion of aldehydes could have resulted from the auto-oxidation of unsaturated



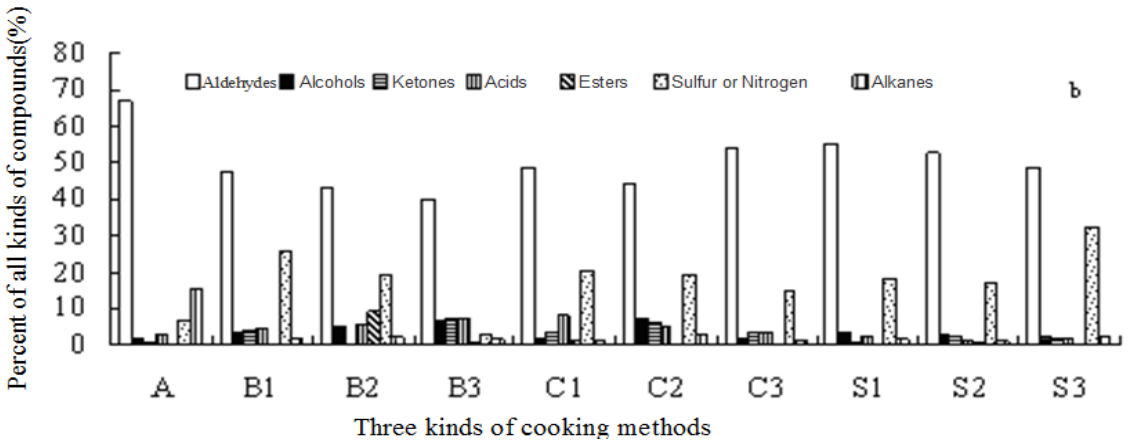


Fig. 1: Changes of kinds and relative content of volatiles in raw and cooked Jinhua ham; (a): Kinds of volatiles; (b): Relative content of volatiles

Table 2: Effect of cooking methods on volatile compounds

	Name	Steamed for 1h, %	Steamed for 2h, %	Steamed for 3h, %	Boiled for 1h, %	Boiled for 2h, %	Boiled for 3h, %	Soup for 1h, %	Soup for 1h, %	Soup for 1h,,%	SDE, %	SPME, %
	Ketone compounds											
1	1-hydroxy-2-acetone			0.52	0.42		0.63		0.21			
2	1-hydroxy-2-butanone						0.02					
3	3-Methyl-2-butanone			0.37		2.75						
4	2-Methyl-3-pentanone			0.32								
5	4-Octen-3-one								0.13			
6	6-Methyl-5-hepten-2-one	0.05		0.12					0.12			
	Peak area	2.24E+08	1.75E+08	1.79E+08	2.40E+08	1.68E+09	7.89E+08	6.62E+07	2.55E+08	3.43E+08		
	Alkanes compounds											
7	3,4-Epoxy-3-Ethyl-2-Butanone			0.04								
8	2-Methyl-Propanyl-3-Oxy-butanoic acid			0.10	0.27							
9	2-Methylcyclopentanone											
10	Cyclohexanone				0.03							
11	4-ethyl-Cyclohexanol			0.40					0.44			
12	2,4-Dimethylcyclohexanol				0.18		0.11					
13	3-Methyl-furanthiol					0.22						
14	1-2-furanyl-ethanon					0.03						
15	2-furanmethanol	0.24	0.23		0.20	0.33	0.29	0.30				
16	:4-Hydroxy-2,5-dimethyl-3(2H)-furanone	0.07		0.03								
17	3-Methylthiopropanol					0.04						
18	Cyclohexanol,4-ethyl-									0.44		
19	Metaldehyde	0.04										
20	2- Sulfur carboxy benzaldehyde									0.20		
21	2-nitropropane	0.26	0.24	0.73		0.43						
22	2- Butene oxygen propane	1.67										
23	Peroxide pentane				0.07							
24	1-Butenylcyclopentane									0.33		
25	2,4,6-trimethyl-1;3,5-trimethyl-s-trioxan		1.09									
26	Phenol	0.03					0.04					
27	3-Methyl butyl aldehyde oxime		0.09									
28	2- Methyl cyclopentanone oxime	0.08		0.07								
29	2- methylpyrazine	0.17	0.18	0.18		0.75		0.21	0.25			
30	3- methylpyrazine		0.07		0.09	0.12	0.08		0.07			
31	Thiazole				0.02		0.05					
32	Pyrrole								0.06			
33	1H-Pyrrolo			0.05			0.08	0.11				
34	1-(1H-pyrrol-2-yl)-Ethanone	0.13		0.09	0.08	0.07	0.07	0.06	0.09	0.09		
35	Phenylethylamine									0.70		
36	:4-Nitro-o-phenylenediaMine							0.28				
	Peak area alcohol	5.47E+09	3.88E+09	1.87E+09	5.58E+09	1.47E+09	1.56E+09	1.16E+09	2.13E+09	1.74E+09		
37	Isoamyl alcohol				0.31							
38	2-methyl-1-propanol			0.10								
39	1-butanol		0.06									
40	2-butanol				0.05		0.05					
41	2- methyl-1-butanol		1.89	0.34		3.74			0.30			
42	2, 3-Butanediol	1.22	0.82	1.84	0.20	0.26	0.17	0.46	0.13			
43	2-pentanol	0.35	0.73	1.04	0.06	2.58	0.09	0.59				

Table 2: Continue

44	:4-Methyl-2-pentanol		1.23							
45	1-heptanol							0.97		
46	2-heptanol		0.05					0.08		
47	3-octanol	0.03								
48	2-octen-1-ol				0.07					
49	2-Nonen-1-ol		0.04							
50	1-nonanol							0.09		
51	1-decanol		0.08							
52	Benzyl alcohol						0.03			
53	Phenethyl alcohol	0.10	0.25	0.20		0.17			0.14	0.05
54	2-Undecanol				0.12					
55	Ethylene-ethanediol	3.43					0.07			0.03
	Peak area	1.11E+09	2.25E+09	5.12E+09	4.09E+08	2.02E+09	3.66E+08	4.38E+08	8.50E+08	4.19E+08
	Acid compounds									
56	1-Propen-2-ol, acetate	7.77	6.04	6.03	5.51	4.64	7.05	0.05		
57	Acetic anhydride	0.76	0.70			0.94		0.23		
58	Heptylic acid		0.06	0.08						0.09
59	2, 2- neopentanoic acid			0.07						
60	2, 4- Azelaic acid									
	Peak area	3.86E+09	2.78E+09	3.86E+09	1.98E+09	4.96E+08	1.91E+08	2.57E+09	9.64E+08	4.38E+08
	Ester compounds									
61	Hexyl acetate									
62	Ethyl hexanoate			0.07	0.12	0.11				
63	2-Propenoic acid, ethyl ester		8.80							
64	Methyl 3-butenoate		0.19		0.72					
65	Butyrolactone					0.08				
66	Decanoic acid ethyl ester							0.14	0.18	
67	Methyl Laurate				0.23					
68	Ethyl laurate		0.04							
69	Ethyl benzoate						0.07			
	Peak area	6.37E+09	2.78E+09	1.62E+08	2.54E+08	5.64E+07	2.59E+07	5.88E+08	3.47E+07	3.11E+07

fatty acids; while the branched aldehydes could have come from the proteolysis or amino acid degradation. For example, 3-methyl-butanal is formed by the Strecker reaction of Leu (Corino *et al*., 2003). The long-chain branched aldehydes were not common though were present in S, such as 2-undecenal and 2, 4-decadienal were possibly formed by the micro flora of the muscle membranes from where they were released during longer cooking (Grosch, 1993). Aldehydes played important roles in the ham flavor because of their low odor thresholds (e.g., hexanal, 4.5×10^{-9} mg/L) (John, 2001).

The proportion of sulfur-containing compounds such as dimethyl disulfide and dimethyl trisulfide increased in most of cooked ham except B3.

Some sixty-nine volatiles present in all the 3 type of the cooked ham were not found in the raw ham. They consisted mainly of sulfur-containing compounds and circle compounds and alcohols. Table 2 presents the content of the volatiles. Sixty-nine generated volatiles were identified and quantified in B, C and S when compared to A. Figure 1b shows that the sulfur-containing or cyclic compounds and alcohols were the most abundant generated volatiles in the three kinds of cooked hams. B1 and C1 had the most abundant sulfur-containing or circle compounds, their contents were 5.58 and 5.47 mg/kg, respectively. Note that the stewed ham soup contained preceding large amount of sulfur-containing and cyclic compounds.

Increased kinds and contents of Maillard-derived compounds including pyrazines, furans and aldehydes were indeed found in S which was processed at higher temperature. This was most likely due to the Maillard reaction or Maillard-generated volatiles, which was occurring at elevated temperatures (Van den Ouweland *et al*., 1978). They found lipid-derived volatiles dominated the boiled ham at least 77-80°C, while those from Maillard reactions mostly prevailed at least 100°C.

The S2 contained the highest alcohols and acids, which implicated most of the volatiles in the S, might be rather hydrophilic. Furthermore, steaming for 2 h could obtain the fullest volatiles.

Esters had fruity odor, mainly formed by the short-chain acids. The concentration of the occurrence was negatively high in the ham. These agree in good agreement with Sabio *et al.* (1998). Due to their low flavor threshold, the esters were important for the flavor of ham. The concentration of the esters and sulfur-containing and circle compounds increased, the concentration of the aldehydes decreased suggested that aldehydes were transformed to the other kinds of volatiles.

The content of hydrocarbons changed little. Due to their high thresholds, they contributed little to the flavor of the ham (Chang and Peterson, 1977).

Sulfur-containing or cyclic compounds generated by cooking were savory, meaty, roast and boiled. The interactions of many odors from the overall aroma profile of the ham. The sulfur-containing compounds were the critical ones for meaty odor in the ham (Zellner *et al*., 2008).

Table 2 also showed the generation of four furan compounds including 3-methylfuran, 1-(2-furan)-alcohol, 2-furan-methanol and 2, 5-dimethyl-4-hydroxy-3 (2 H)-furanone. The furan compounds have indistinct odor that even though their structural formulae suggests they can be a source of odor, they have slight contribution to the flavor of dry-cured ham.

Other kinds of compounds have a nutty odor and roasted nutty odor, which could be considered as a characteristic odor of the cooked ham. The results

Table 3: The common volatiles of ham through different cooking methods

No.	Compounds	No.	Compounds
1	Butane	20	2,6-Dimethylpyrazine
2	2-butanone	21	1-cyclohexyl-2-ol, acetate
3	3-methyl-Butanal	22	Pentanol
4	Hexanal	23	Acetic acid
5	Heptanal	24	2,3-butylene glycol
6	Nonanal	25	2-furan-methanol
7	Benzaldehyde	26	Pentanoic acid
8	2-Pentylfuran	27	Hexanoic acid
9	Octanol	28	2-Methyl-1-butanol
10	3-methylcrotonaldehyde	29	p-limonene
11	Octanal	30	1-Hydroxy-2-propanone
12	Decanal	31	2-nitropropane
13	Phenylacetaldehyde	32	2-pentanol
14	2,3-pentanedione	33	Acetic anhydride
15	3-Hydroxy-2-butanone	34	Pentanal
16	Phenylethane	35	Methylbenzene
17	1,4-Dichlorobenzene	36	1-hexanol
18	Dimethyl disulfide	37	Decylic acid
19	Dimethyl sulfide	38	2-dimethylpropane

indicate that the Maillard reaction and the oxidation of polyunsaturated fatty acids promote the genesis of volatiles including pyrazines, furans and aldehydes.

The esters and acids had fruity odor, mainly formed by the short-chain acids. Esters present were formed by the interaction between carboxylic acids and alcohols (Mottram *et al*., 1991). Note: ham soup had a relative high amount of alcohol (2.25, 5.12 mg/kg) and the highest concentration of esters (6.37, 2.78 mg/kg) (Table 2).

Another reaction occurred during cooking includes lipid degradation. These were concentration of unsaturated aldehydes, such as 3-methyl-2-butenal, 2-heptenal, 2, 4-nonadienal., 2-undecenal and 2, 4-decadienyl, which could be probably result from lipid degradation.

Many kinds of long-chain esters in the soup, such as dodecanoic acid ethyl ester, tetradecanoic acid ethyl ester, hexadecanoic acid ethyl ester, etc. were found in the ham soup. The boiling of meat with large amount of water may probably generate additional thermal decomposition of ham components, in particular, hydrolysis of phospholipids and subsequent oxidation of free fatty acids.

There were some unsaturated alkenes, such as 1-linone and the saturated, such as benzene was not found in the soup. Although most of the fat was removed manually before cooking, there was little in the connective tissue. By this cooking method, the center temperature of ham could amount to 70-80°C, which led to the disruption of muscle membrane structure and the interaction of lipid oxidation catalysts with unsaturated fatty acids, hence the unsaturated aldehydes generated.

Additionally, the volatile compounds in hams may be concentrated or lost during cooking. These losses may occur through evaporation, leaching into the water, degradation during heat treatment and/or to less enzymatic activity. This study to measure such loss is difficult.

Different volatiles in Jinhua ham by three cooking methods: To compare the effect of different cooking methods on volatiles, the Principal Component Analysis (PCA) was carried out using data listed in Table 3. By the first principal component 27.419% of the total variation was explained, 41.770% by the first two components. Figure 2 shows the variable loading of different cooking methods of Jinhua ham on the first

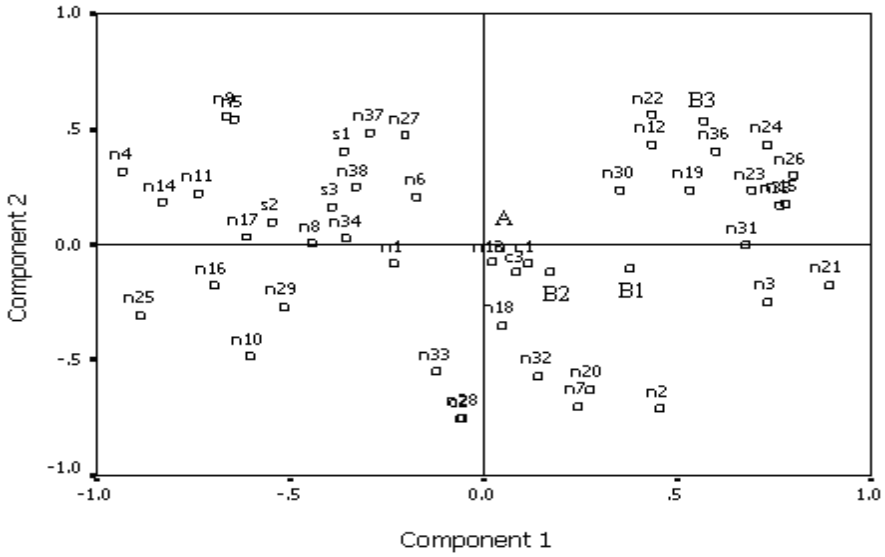


Fig. 2: The principal components involved in the raw and cooked Jinhua ham; Compounds n1, n2, n3…represent the same as Table 3; A represented the raw ham; B1 steamed for 1 h; B2 steamed for 2 h; B3 steamed for 3 h; C1 boiled for 1 h; C2 boiled for 2 h; C3 boiled for 3 h; S1 stewed ham soup for 1 h; S2 stewed ham soup for2 h; S3 stewed ham soup for 3 h

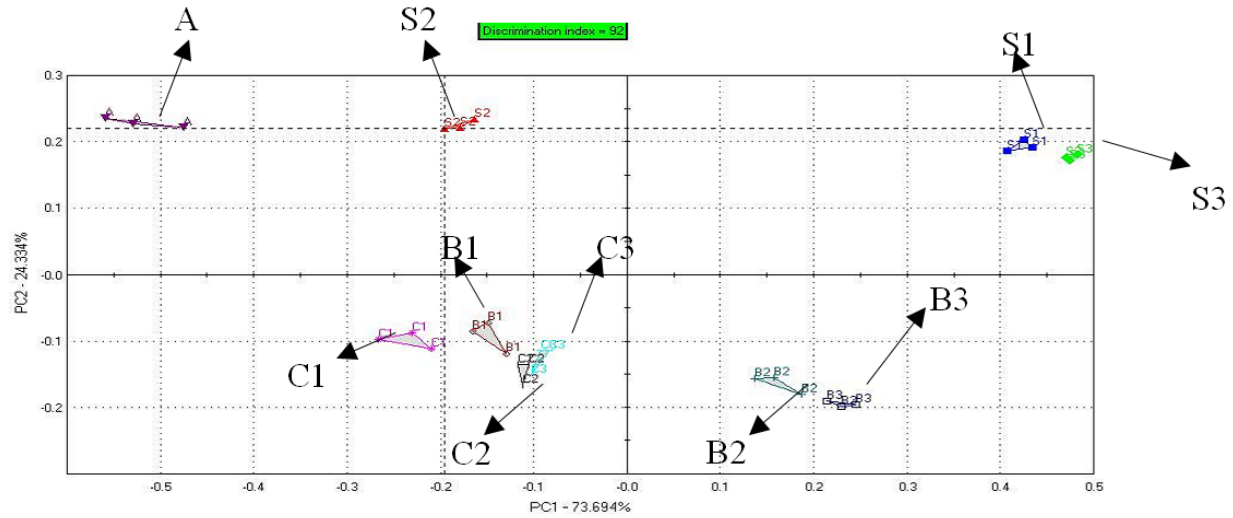


Fig. 3: The principal components analysis of the raw and cooked ham by electronic nose

and second Principal Components (PC). A, B1, B2 (13), C1, C3 (13, 18) showed the same correlation, they have the same volatiles, while B3 (22, 24, 36, 12, 30, 19, 23, 26), C2 (28, 33) and S1 (37, 27, 38), S2 (8, 17, 11); S3 (38, 8, 34) were negatively related with A, B1, B2 and C1, C3. Thus, it seemed that the principle components were not affected by the cooking methods. Furthermore, B3 and C2 had different principle components when compared to A. More obviously, the principle components of S showed the significant difference when compared to A. This was showed in the negative correlation between S1, S2, S3 and A. Such variations between locations may have resulted from the different cooking temperature and time (García-Segovia *et al*., 2007).

Different flavor profiles of Jinhua ham by cooking: A relatively large difference was presented by EN analysis between steamed ham (B), boiled ham (C) and stewed ham soup (S) and the raw ham (A) (Fig. 3). The first two principal components explained 98.02% (PC1 73.69%, PC2 24.33%) of the total variance of the data. Each of the flavor profile of cooked ham (B, C and S) compared to A was shown in Fig. 4. Results showed the effect of cooking time was very significant. With increased cooking time, the difference became significant when compared to A. S2 showed that the flavor profile was the most similar to A and there was no significant difference between S1 and S3. However, it was contrary compared to the flavor profile of A. However, the flavor profile of S2, C1, B1 and C3 was similar to A. In fact, these results indicated the cooking temperature and cooking time may have considerable effects on the volatiles, thus influencing the overall flavor profile. These differences were probably caused by the different thermal stabilities of respective flavor precursors on the one hand and by the different thermal stabilities of the aroma-active compounds on the other hand (Gandemer, 2009). Figure 5 shows the different flavor profiles of the raw and cooked ham. It indicates that the cooking methods had a major effect on the flavor profile of Jinhua ham.

The EN provided a "fingerprint" of the volatiles released from the raw and cooked ham, but it was unable to identify the volatiles involved. The different flavor profiles may be explained by the volatiles isolated from hams by SPME and detected by GC-MS. The relationship between the flavor profile detected by the EN and the volatiles identified by SPME-GC-MS were presented according to the PCA and EN results. It could be inferred that phenyl acetaldehyde (13) appeared to be the main source of the similar profile between B1, B2 and A. On the other hand, Phenyl acetaldehyde (13) and dim-ethyl disulfide (18) appeared to be the main source of the similar profile between C1 and A. They were mainly products of Maillard reaction (Drumm and Spanier, 1991). On the contrary, 1-pentanol (22), 2, 3-butanediol (24), 1-hexanol (36), decanal (12), 2-hydroxy-propanone1 (30), dimethyl trisulfide (19), acetic acid (23) and pentanoic acid (26) were responsible for the difference between B3 and A. 2-Methyl-1-butanol and acetic acid anhydride were responsible for the difference between C2 and A. 2-Pentyl-furan (8), 1, 4-dichlorobenzene (17) and octanal (11) were responsible for the difference between S2 and A. These findings suggested that the specific volatiles could be correlated with the EN analysis for the similar and different flavor profile. These results were in agreement with those reported (McKellar *et al*., 2005). However, the PCA results showed that it was contrary between C3, S1, S3 and A compared to the EN results. It was possible that not only the quantity but the thresholds of the volatiles had great effects on the flavor profile. In order to further study the relationship between specific volatiles and the EN responses.

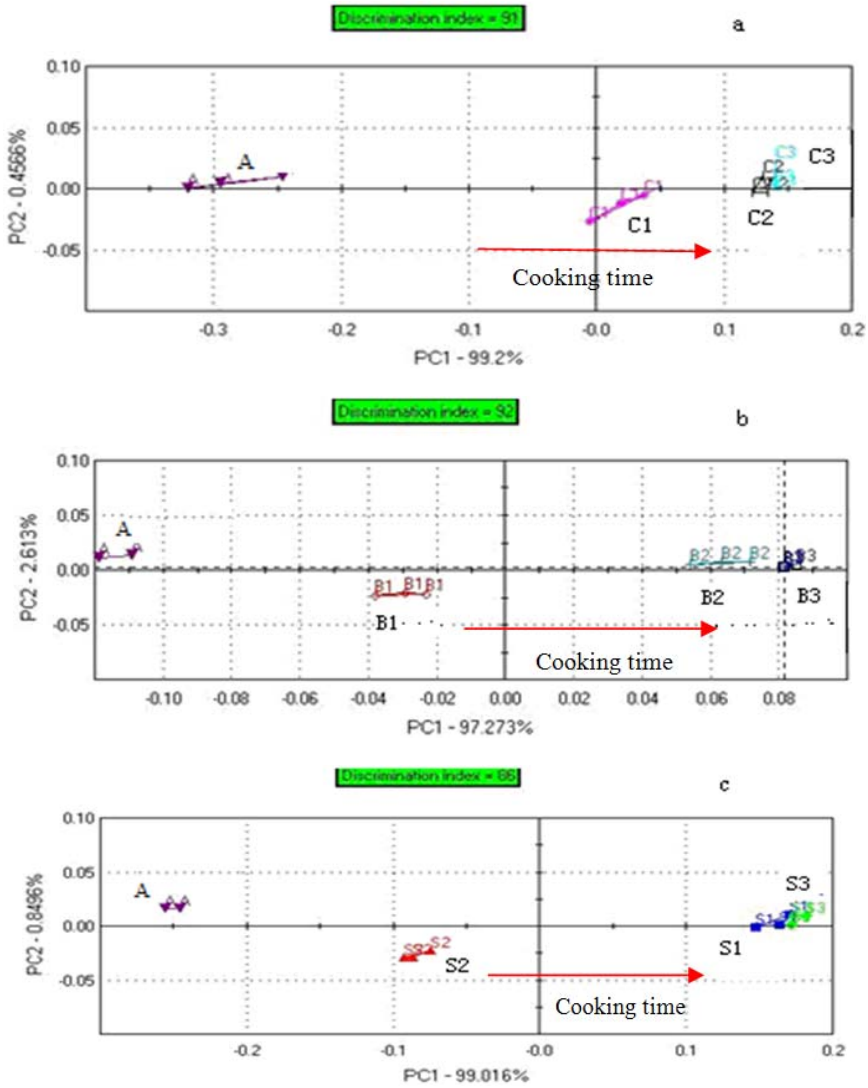


Fig. 4: (a): The principal components analysis between B and A; (b): The principal components analysis between C and A; (c): The principal components analysis between S and A

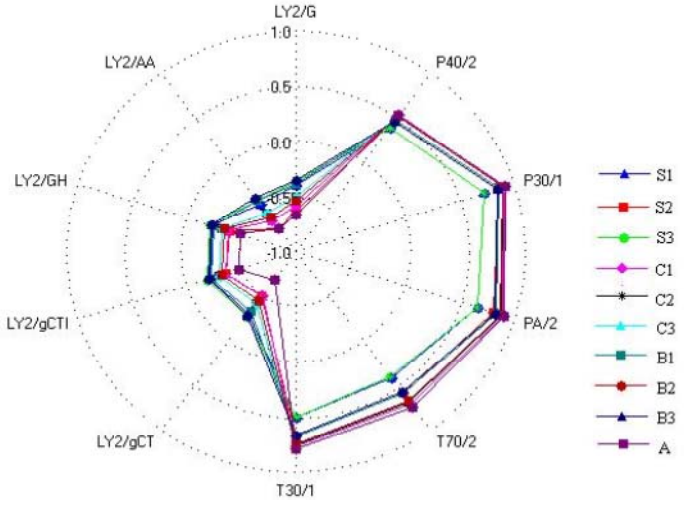


Fig. 5: The flavor profile of the raw and cooked J

From the results of common volatiles, C showed more kinds of acids and esters; S showed more kinds of aldehydes and hydrocarbons; from the result of generated volatiles, aldehydes showed the highest proportion and then the sulfur-containing or cyclic compounds. It was most likely that the different flavor profile between the raw and cooked Jinhua ham depended on a balance of various kinds of volatiles. The sulfur-containing or cyclic compounds were probably the main source due to their low thresholds. Further studies to establish the relation between specific volatiles and the EN responses were warranted.

CONCLUSION

All of the cooking methods were evaluated by the proximate composition of volatiles and the flavor profile of the steamed (B), boiled ham (C), stewed ham soup (S) and the raw ham (A). C2 appeared to be the most similar cooking method whose flavor profile was the most similar to the raw ham. B3 increased much of the content of sulfur-containing or cyclic compounds.

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