The effect of ginger and garlic addition during cooking on the volatile profile of grass carp (*Ctenopharyngodon idella*) soup

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Abstract Ginger and garlic have long been used in Asian countries to enhance the flavor and to neutralize any unpleasant odors present in fish soup. The purpose of this study was to evaluate the change in the amount of volatile components present in fish soup compared to boiled water solutions of ginger and garlic. The fish soup was prepared by boiling oil-fried grass carp (*Ctenopharyngodon idella*) with or without ginger and/or garlic. Generally, boiling garlic and ginger in water led to a decrease in the amount of the principal volatile constituents of these spices, together with the formation of some new volatiles such as pentanal, hexanal, and nonanal. The results showed that 16 terpenes present in raw ginger, predominantly camphene, β -phellandrene, β -citral, α -zingiberene, and (*E*)-neral, were detected in fish soup with added ginger and thus remained in the solution even after boiling. Similarly, 2-propen-1-ol and three sulfur compounds (allyl sulfide, diallyl disulfide, and diallyl trisulfide) present in raw garlic, were present in trace amounts in the boiled garlic solution, but were present in considerably larger amounts in the boiled fish solution with garlic or garlic plus ginger. In conclusion, the

effect of adding spices on the volatile profile of grass carp soup can be attributed to the dissolution of flavor volatiles mainly derived from raw spices into the solution, with few additional volatiles being formed during boiling. In addition, boiling previously fried grass carp with spices led to enhanced volatile levels compared to boiled spice solutions.

Keywords Spice · Ginger · Garlic · Cooking · Volatile profile · Grass carp (*Ctenopharyngodon idella*) soup

Introduction

Spices, defined as “plant products used for flavoring, seasoning, and imparting aroma in foods” by the International Standards Organization, have been used since antiquity for culinary and medicinal purposes (Dhanya and Sasikumar 2010). The basic effects of spices used in cooking are an enhancement or modification in the flavoring properties, endowing food with pungency, preserving food for longer periods, and modifying color characteristics (Hirasa and Takemasa 1998; Raghavan 2006). In addition, spices have a particularly useful purpose for masking the smell of raw materials when the materials possess an undesirable odor. Fresh fish, especially freshwater fish, have an unpleasant odor, limiting their application in foodstuff (Zakipour Rahimabadi et al. 2011). The masking effect of spices on fish odor has been investigated by a number of studies. Kasahara and Osawa (1998) reported that, according to evaluation through olfactory tests, the combination of Japanese pepper and perilla leaves (1:1) had the strongest effect for suppressing the fish odor of boiled sardines followed by perilla leaves and a formula consisting of a combination of Yuzu and perilla leaves (1:1). Yoshida

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et al. (1984) found that the amount of volatile carbonyl compounds responsible for the fishy odor released from mackerel meat, could be reduced by treating mackerel muscle tissue with spices including pepper, sage, cloves, thyme, and mustard seeds. Kikuchi et al. (1968) found that the fish odor diminished by the addition of 11 spices (caraway, cassia, clove, ginger, laurel, mace, nutmeg, onion, pepper, sage, and thyme), and that addition of onion, laurel, or sage, was more effective than the other eight spices.

The characteristic gustatory and olfactory profile of each spice depends on the balance of the predominating chemical compounds within the spice, granting it characteristic flavor (Raghavan 2006). Ginger (*Zingiber officinale*) and garlic (*Allium sativum*) are two of the most important spices which have been used for thousands of years, both for cooking and medicinal purposes (Raghavan 2006). The volatile components in ginger consist mainly of sesquiterpene hydrocarbons, predominantly zingiberene, curcumenene, and farnesene, and a smaller percentage of monoterpenoid hydrocarbons and some oxidized terpene derivatives. The major volatile components in garlic are sulfur containing compounds, mainly diallyl disulfide and diallyl trisulfide (Kim et al. 2011). It has been consistently found that ginger and garlic have a particularly strong ability to reduce fish odor when blended with mackerel meat (Kikuchi et al. 1968; Yoshida et al. 1984). Throughout some Asian countries, and particularly in China, ginger and garlic have traditionally been used extensively to prepare vegetable dishes, soups, meat dishes, roast meat, and many other foods (Shukla and Singh 2007). Typically, fish soups are prepared by boiling in ginger and/or garlic with a previously oil-fried fish, increasing the flavor and improving the odor characteristics of the soup. The addition of spices may change the profile of volatile compounds within the soup. To the best of our knowledge, no investigations have been published on the effect of spices, namely ginger and garlic, on the composition of volatile compounds in fish soup.

Grass carp is the most important species of the ‘four-major-Chinese-carps’, and commercially is one of the most important freshwater fish species both in China and throughout the world (Zhang et al. 2013). The purpose of this study was to investigate the effect of adding ginger and/or garlic to a previously oil-fried piece of grass carp on the volatile components present in the solution, compared to a boiled solution of the fish without any spices added. The results of this study provide a better understanding of how garlic and/or ginger influence the volatile profile of compounds responsible for removing the unpleasant odor of fish, and how the overall compound profile changes in a boiled solution of a pan-fried grass carp. This information can aid the development of fish products and food additives

containing ginger and garlic for odor control of fish-based products, and to promote the application of spices in the food industry.

Materials and methods

Materials

Standards of camphene, 3-carene, β -myrcene, 1,8-cineole, *p*-cymene, citronellal, linalool, α -terpineol, γ -terpinene, citronellol, geraniol, 1-octen-3-ol, octanal, *trans*-2-heptenal, nonanal, *trans*-2-octenal, decanal, *trans*-2-decenal, vanillin, 3-hydroxy-2-butanone, 6-methyl-5-hepten-2-one, 2,5-dimethylpyrazine, 2-pentylfuran, and 5-methyl-2-furfural were purchased from Sigma-Aldrich (Shanghai, China). Standards of limonene, *p*-cymene, α -farnesene, zingiberone, 2-heptanol, 2-nonanol, *trans,trans*-2,4-heptadienal, allyl sulfide, diallyl disulfide, octanoic acid, *m*-cymene, benzyl alcohol, 1-docosanol, 2-nonanone, phenol, and diallyl trisulfide were purchased from Anpel (Anpel Scientific Instrument Co. Ltd., Shanghai, China). Standards of α -farnesene, 1-butanol, 1-pentanol, 2-ethyl-1-hexanol, 1-dodecanol, 1-octadecanol, hexanal, heptanal, benzaldehyde, *trans,trans*-2,4-decadienal, 2-undecanone, acetophenone, hexadecanoic acid, methyl ester, methyl stearate, *p*-xylene, *m*-xylene, *o*-xylene, 1-methyl-3-(1-methylethyl)-benzene, and 1,2-dichlorobenzene were purchased from Aladdin (Aladdin Reagent Co., Ltd., Shanghai, China). The standard solution containing the *n*-alkane series (C8–C40) was obtained from AccuStandard (DRH-008S-R2, New Haven, CT, USA). All other chemicals and solvents were of analytical grade; water was purified using a Milli-Q system (Millipore Corp., Billerica, Massachusetts).

Grass carps (*Ctenopharyngodon idella*), Ginger (*Zingiber officinale*), garlic (*Allium sativum*), and soybean oil were purchased from a local market in Nanchang (Rainbow Department Store, China).

Sample preparation

Preparation of ginger or garlic boiled solutions

Before boiling, ginger was cut into slices about 1-mm-thick, and garlic was crushed by applying pressure from the flat side of a knife. Then, 1 L of water was added to a non-stick frying pan, half-covered with a glass lid, and heated by an induction cooker (C21-DC005, Joyoung Co., Ltd, Jinan, China) with the power set at 1400 W. When the water began to boil, a 4.5-g slice of fresh ginger or 8.7 g of the previously crushed garlic was immersed in the boiling water and heated for 25 min with the induction cooker set at the same power. During boiling, the solution was

concentrated to about 200 g. After this time, the ginger slice or crushed garlic was removed, and the spiced solution was transferred to a beaker and diluted to 250 g for standard analysis. Since only 2 % of boiled spice solution was used for solid phase microextraction (SPME), 0.09 g of sliced fresh ginger and 0.174 g of crushed garlic was used in a raw control for extraction of volatiles via SPME.

Preparation of grass carp soup

Fresh grass carps, weighing about 1 kg each, were washed with running water several times to remove blood and slime, and then subjected to common household procedures including eviscerating, descaling, and beheading. Next, the fish was rewashed and split along the vertebrae into two equivalent pieces (about 270 ± 10 g each). Each piece was further cut into a 250 g sample and was placed in a frying pan containing 23 g of soybean oil pre-heated for 2 min by the induction cooker at the same power level used for frying fish. The cooker power was set at 1400 W, which raised and maintained the surface temperature of the pan to 180 °C, and each side of the fish piece was fried for 1 min, for a total frying time of 2 min. To prepare the spice added solutions, after adding 1.0 L of water to the pan with the fish present, crushed garlic (8.7 g) and/or ginger slices (4.5 g) were added, and the mixture was held at 97 ± 2 °C for 25 min with the glass lid half-covering the pan. Four kinds of boiled fish samples were prepared: samples with added ginger, added garlic, added ginger plus garlic, and without any spices added. During cooking, the solution was concentrated to about 200 g. The fish and the spices from the solution were filtered with cheesecloth, and the soup was diluted to 250 g for standard analysis.

Extraction of volatiles

Solid-phase microextraction

The solid-phase micro-extraction (SPME) device and fused silica fiber coated with divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS, 1 cm–50/30 µm) were obtained from Supelco (Bellefonte, PA, USA). Prior to use, the SPME fiber was conditioned in the injector of a GC at 270 °C for 30 min according to the manual. Samples (5 g) were placed in a 15 mL sealed head space vial and equilibrated for 30 min at 60 °C. Then, the fiber coating was exposed to the headspace for 30 min at 60 °C (Xiong et al. 2015).

Simultaneous distillation–extraction

Simultaneous distillation–extraction (SDE) extraction was carried out using a Likens-Nickerson apparatus according

to the procedure of Rattan et al. (2015). A 100 g sample of the previously prepared 250 g diluted solution formed after boiling the ginger and/or garlic solution in the presence or absence of fish was further diluted with 500 mL of distilled water and placed in a 1 L round bottomed flask at one end of the apparatus while the other end was fitted with a 500 mL round bottomed flask containing 200 mL dichloromethane. The solution was heated at 100 °C while dichloromethane was kept at 58 °C, and the process was allowed to run for 2 h. The SDE extracts were dried over 25 g of anhydrous sodium sulfate and stored at –20 °C overnight. All samples were concentrated to 2 mL with a Vigreux column before being subjected to GC–MS analysis.

Analysis of volatiles

Volatile extracts were analyzed with an Agilent 7890A gas chromatograph with 5975C mass selective detector (GC–MSD; Agilent Technologies Inc., Palo Alto, CA, USA), equipped with a DB-wax column (30 m × 0.25 mm ID × 0.25 µm film thickness), according to the method reported by Aminifar et al. with some modifications (Aminifar et al. 2014). The GC oven temperature was initially held at 40 °C for 3 min, and increased at a rate of 5 °C/min to 240 °C where it was held for an additional 15 min. For SPME, the injector, heated at 250 °C, was held in the splitless mode for the first 2 min of the analysis and then in split mode (20:1) for the remainder of the analysis. The extract obtained via SDE (1 µL) was injected under the same conditions of as the sample extracted via SPME with a solvent delay time of 3.8 min. Helium was used as the carrier gas with a constant flow rate of 1.0 ml/min. The MS was operated in electron ionization mode (70 eV) and data was acquired in full scan mode from 35 to 400 Da. The temperature of the source and the detector were 150 and 230 °C, respectively, while the MS transfer line was kept at 280 °C. *n*-Alkanes (C8–C40) were examined under identical conditions to determine the linear retention index (LRI) according to the method of Van den Dool and Kratz (1963).

Identification of the components was performed by matching their mass spectra with the NIST 08 mass spectral database and comparing their LRIs with that of authentic standards. When authentic standards were not available, tentative identifications were carried out by matching mass spectra with those in the NIST 08 library and/or comparing LRIs with those reported in literature.

Statistical analysis

All experiments were performed in triplicate. Significant differences analysis among data was performed by paired-

samples *T* test, or one-way Analysis of variance (ANOVA) by the Duncan's multiple range test. $p < 0.05$ was considered statistically significant. Statistical analysis was performed by using SPSS19.0 software (SPSS, IBM Corp, Armonk, NY, USA).

Results and discussion

Effect of boiling on the content of volatiles from ginger

Spices contain both volatile and nonvolatile components. The flavor for most spices is the result of components present in the volatile oil, but some flavors are a result of the release of volatile compounds generated during heating of nonvolatile components (Hirasa and Takemasa 1998). In order to avoid a change in the composition of volatile components during extraction, SPME was used for extraction of volatiles from raw ginger, and SDE and SPME were employed for extraction of volatiles from boiled ginger soup. Volatile compounds detected from raw ginger and boiled ginger soup are shown in Table 1. There were 57 volatile compounds (containing 43 terpenes, 4 aldehydes, 4 ketones, 3 alcohols, and 3 other volatile compounds) directly detected by headspace SPME–GC–MS from the raw ginger. Among these, terpenes were the major components and accounted for 97.1 % of total volatiles (shown as area). The ten most abundant terpenes were camphene, followed by 1,8-cineole, β -phellandrene, β -sesquiphellandrene, α -zingiberene, β -myrcene, α -phellanderene, β -bisabolene, (*E*)-neral, and terpinolene. However, other researchers have obtained slightly different results using different extraction methods. For example, Variyar et al. (1997) used the SDE technique to elucidate the composition of the most abundant volatile compounds present in essential oils obtained from fresh ginger, and found that the major components were the sesquiterpenes zingiberene, zingiberol, α -curcumene, β -sesquiphellandrene, and β -bisabolene, accounting for 70 % of the total chromatographic area. While Bartley and Jacobs (2000) reported that the main compounds extracted from fresh ginger oil extracts with supercritical carbon dioxide were geranial, zingiberene, zingerone, α -farnesene, 6-shogaol, β -sesquiphellandrene, geraniol, geranyl acetate, and β -bisabolene, which accounted for more than 60 % of the chromatographic area. These results highlight the differences in ginger composition that can be obtained from different extraction procedures. Therefore, it is important to use the same extraction technique throughout the study in order to obtain consistent results.

The volatile profile of a boiled ginger solution was significantly different from that of the raw sample. With

the combination of SDE–GC–MS and SPME–GC–MS, 54 compounds were identified from the boiled ginger solution, of these, 46 compounds went undetected in the raw ginger (two terpenes, five aldehydes, three alcohols, fifteen alkanes, fourteen aromatic compounds, one acid, three esters, and three furans) (Table 1). Aldehydes included pentanal, hexanal, heptanal, nonanal, and decanal. The hexanal and decanal detected in this study have been demonstrated to be derived from thermal degradation of non-volatile gingerol compounds during steam distillation (Chu-Chin and Chi-Tand 1987), and were thus likely formed from gingerol during the boiling process. Since aldehydes, alcohols, and furans in food are generated from multiple routes including oxidation of lipids, the Maillard reaction, and thermal decomposition of carbohydrates, further research into these reaction pathways would help to elucidate the origin of these compounds in samples of boiling ginger (Van Lancker et al. 2010; Yaylayan 2006).

The sensitivity of each SPME fiber is different depending on the molecular mass, volatility, and polarity of the analytes being extracted. Early studies showed that DVB-CAR-PDMS fibers were especially effective for polar terpene and sulfur based compounds (Hamm et al. 2003; Wardencki et al. 2004). Since SPME–GC–MS failed to detect the nonpolar or weakly polar compounds detected by SDE–GC–MS in the boiled ginger solution (mostly alkanes and aromatics: fifteen alkanes, fourteen aromatic compounds, and three esters), we could not judge whether the newly detected compounds in the boiled ginger solution were formed as a result of boiling or went undetected as a result of using the DVB-CAR-PDMS fiber in the SPME extraction method. Fortunately, the three groups of volatiles, which are odorless or possess weak odors and have relatively high threshold values, are less important to the overall flavor of ginger solution or fish soup, which will be further illustrated from the results described in this study.

In general, the peak area of volatiles extracted from ginger solution and detected by SPME–GC–MS were far lower than those from fresh ginger, and 30 terpenes, three aldehydes, one alcohol, and two other compounds went undetected in the boiled ginger solution (Table 1). Although it was difficult to accurately compare the volatile content in solid and liquid samples by SPME–GC–MS, the decrease of the peak area and disappearance of a large number of volatiles as a result of boiling ginger in water suggested that the volatiles were susceptible to evaporation or to decomposition and/or side reactions at elevated temperatures. These results were generally in good agreement with earlier studies which reported that high temperature conditions could lead to the loss of compounds with flavor properties due to evaporation, oxidative reactions, or even through the activity of endogenous enzymes (Raghavan 2006; Schweiggert et al. 2007).

Table 1 Volatile compounds identified from raw ginger and boiled ginger soup using SPME (as peak area, 1×10^6) and SDE (as total amount, μg) ($n = 3$)

Name	LRI ^A	Identification ^B	Raw ginger		Boiled ginger soup
			SPME ^C	SDE ^D	SPME ^C
<i>Terpenes</i>					
α -Tricyclene	995	MS + LRI	3.68 $\pm$ 0.68a	nd	0.00 $\pm$ 0.00b
α -Pinene	1015	MS + LRI	14.24 $\pm$ 2.80a	nd	0.00 $\pm$ 0.00b
Camphene	1058	MS + LRI + Std	392.88 $\pm$ 85.98a	0.18 $\pm$ 0.05	0.16 $\pm$ 0.03b
Sabinene	1111	MS + LRI	1.41 $\pm$ 0.30a	nd	0.00 $\pm$ 0.00b
3-Carene	1140	MS + LRI + Std	0.34 $\pm$ 0.17a	nd	0.00 $\pm$ 0.00b
α -Phellanderene	1159	MS + LRI	183.36 $\pm$ 20.04a	nd	0.00 $\pm$ 0.00b
β -Myrcene	1160	MS + LRI + Std	191.77 $\pm$ 27.75a	nd	0.00 $\pm$ 0.00b
α -Terpinene	1171	MS + LRI	5.25 $\pm$ 0.56a	nd	0.00 $\pm$ 0.00b
Limonene	1194	MS + LRI + Std	80.67 $\pm$ 33.56a	nd	0.00 $\pm$ 0.00b
β -Phellandrene	1204	MS + LRI	239.45 $\pm$ 47.77a	nd	0.02 $\pm$ 0.00b
1,8-Cineole	1208	MS + LRI + Std	360.50 $\pm$ 137.00a	nd	2.89 $\pm$ 0.30b
<i>trans</i> -Ocimene	1230	MS + LRI	2.03 $\pm$ 0.28a	nd	0.00 $\pm$ 0.00b
γ -Terpinene	1238	MS + LRI + Std	17.63 $\pm$ 2.10a	nd	0.00 $\pm$ 0.00b
Ocimene	1245	MS + LRI	2.36 $\pm$ 0.52a	nd	0.00 $\pm$ 0.00b
Terpinolene	1275	MS + LRI	133.23 $\pm$ 6.35a	nd	0.00 $\pm$ 0.00b
Allo-Ocimene	1365	MS + LRI	0.43 $\pm$ 0.08a	nd	0.00 $\pm$ 0.00b
α -Cubebene	1452	MS + LRI	1.47 $\pm$ 0.17a	nd	0.00 $\pm$ 0.00b
Citronellal	1472	MS + LRI + Std	3.44 $\pm$ 0.64a	nd	0.11 $\pm$ 0.01b
α -Copaene	1485	MS + LRI	12.77 $\pm$ 2.05a	nd	0.00 $\pm$ 0.00b
Camphor	1507	MS + LRI	14.00 $\pm$ 1.90a	nd	0.00 $\pm$ 0.00b
Linalool	1546	MS + LRI + Std	23.17 $\pm$ 7.38a	nd	0.11 $\pm$ 0.02b
α -Bergamotene	1551	MS + LRI	6.74 $\pm$ 1.36a	nd	0.00 $\pm$ 0.00b
Bornyl Acetate	1573	MS + LRI	9.65 $\pm$ 2.00a	nd	0.00 $\pm$ 0.00b
β -Elemene	1583	MS + LRI	10.71 $\pm$ 1.79a	nd	0.00 $\pm$ 0.00b
L-4-terpineneol	1599	MS	9.23 $\pm$ 0.10a	nd	0.00 $\pm$ 0.00b
Alloaromadendrene	1636	MS + LRI	1.21 $\pm$ 1.11a	nd	0.00 $\pm$ 0.00b
(<i>E</i>)-(β)-Farnesene	1653	MS + LRI	4.48 $\pm$ 0.89a	nd	0.00 $\pm$ 0.00b
Isoborneol	1662	MS + LRI	2.17 $\pm$ 0.19a	nd	0.00 $\pm$ 0.00b
β -Citral	1678	MS + LRI	73.43 $\pm$ 9.86a	nd	1.05 $\pm$ 0.05b
α -Terpineol	1696	MS + LRI + Std	21.97 $\pm$ 5.71a	nd	0.07 $\pm$ 0.01b
Borneol	1698	MS + LRI	44.20 $\pm$ 10.10a	nd	0.27 $\pm$ 0.04b
α -Zingiberene	1730	MS + LRI	188.46 $\pm$ 40.27a	0.30 $\pm$ 0.15	0.00 $\pm$ 0.00b
β -Bisabolene	1733	MS + LRI	149.03 $\pm$ 29.62a	nd	0.00 $\pm$ 0.00b
(<i>E</i>)-Neral	1733	MS + LRI	127.65 $\pm$ 24.30a	0.13 $\pm$ 0.04	1.09 $\pm$ 0.18b
α -Farnesene	1749	MS + LRI + Std	85.92 $\pm$ 19.38a	nd	0.00 $\pm$ 0.00b
δ -Cadinene	1757	MS + LRI	6.44 $\pm$ 0.10a	nd	0.00 $\pm$ 0.00b
α -Curcumene	1762	MS + LRI	8.31 $\pm$ 0.77a	0.11 $\pm$ 0.06	0.01 $\pm$ 0.01b
Citronellol	1762	MS + LRI + Std	7.36 $\pm$ 1.20a	nd	0.00 $\pm$ 0.00b
β -Sesquiphellandrene	1773	MS + LRI	260.20 $\pm$ 46.81a	nd	0.00 $\pm$ 0.00b
Nerol	1799	MS + LRI + Std	22.91 $\pm$ 1.37a	nd	0.00 $\pm$ 0.00b
Geraniol	1848	MS + LRI + Std	47.62 $\pm$ 10.80a	nd	0.00 $\pm$ 0.00b
Nerolidol	2037	MS + LRI	4.14 $\pm$ 1.05a	nd	0.00 $\pm$ 0.00b
Cedrol	2107	MS + LRI	0.00 $\pm$ 0.00a	0.13 $\pm$ 0.01	0.76 $\pm$ 0.21b
Zingerone	2777	MS + LRI + Std	nd	0.11 $\pm$ 0.03	nd
Total			2775.87 $\pm$ 434.77a	0.97 $\pm$ 0.27	6.53 $\pm$ 0.69b

Table 1 continued

Name	LRI ^A	Identification ^B	Raw ginger		Boiled ginger soup
			SPME ^C	SDE ^D	SPME ^C
<i>Aldehydes</i>					
Pentanal	959	MS + LRI	nd	0.09 ± 0.03	nd
Hexanal	1070	MS + LRI + Std	0.00 ± 0.00a	4.00 ± 0.30	1.26 ± 0.06b
Heptanal	1179	MS + LRI + Std	0.00 ± 0.00a	0.07 ± 0.04	0.00 ± 0.00b
Octanal	1283	MS + LRI + Std	1.39 ± 0.10a	0.40 ± 0.05	0.53 ± 0.06b
Nonanal	1387	MS + LRI + Std	0.00 ± 0.00a	1.46 ± 0.44	0.72 ± 0.06b
<i>trans</i> -2-Octenal	1423	MS + LRI + Std	0.72 ± 0.23a	nd	0.00 ± 0.00b
Decanal	1513	MS + LRI + Std	0.00 ± 0.00a	nd	0.65 ± 0.06b
<i>trans</i> -2-Decenal	1637	MS + LRI + Std	2.05 ± 0.07a	nd	0.00 ± 0.00b
<i>trans</i> -2-Dodecenal	1857	MS + LRI	0.18 ± 0.09a	nd	0.00 ± 0.00b
Total			4.34 ± 0.46a	6.03 ± 0.66	3.15 ± 0.25b
<i>Ketones</i>					
2-Heptanone	1178	MS + LRI	2.23 ± 0.48a	0.30 ± 0.11	1.24 ± 0.16a
6-Methyl-5-hepten-2-one	1333	MS + LRI + Std	26.17 ± 9.03a	nd	0.75 ± 0.11b
2-Nonanone	1384	MS + LRI + Std	7.62 ± 1.74a	nd	0.14 ± 0.01b
2-Undecanone	1594	MS + LRI + Std	3.94 ± 1.07a	nd	0.00 ± 0.00b
Total			39.95 ± 12.27a	0.30 ± 0.11	2.13 ± 0.25b
<i>Alcohols</i>					
2-Heptanol	1322	MS + LRI + Std	11.31 ± 1.85a	nd	0.00 ± 0.00b
2-Ethyl-1-hexanol	1485	MS + LRI + Std	0.00 ± 0.00a	0.06 ± 0.00	0.45 ± 0.14b
2-Nonanol	1522	MS + LRI + Std	0.00 ± 0.00a	nd	0.12 ± 0.02b
1-Octanol	1558	MS + LRI	2.50 ± 0.41a	0.34 ± 0.12	0.05 ± 0.01b
1-Dodecanol	1958	MS + LRI + Std	0.00 ± 0.00a	0.13 ± 0.01	0.23 ± 0.02b
1-Octadecanol	2583	MS + LRI + Std	0.07 ± 0.02a	0.31 ± 0.04	14.87 ± 4.15b
Total			13.88 ± 2.12a	0.83 ± 0.09	15.72 ± 4.31a
<i>Alkanes</i>					
Decane	983	MS + LRI + Std	nd	0.58 ± 0.07	nd
Undecane	1097	MS + LRI + Std	nd	0.59 ± 0.09	nd
Dodecane	1198	MS + LRI + Std	nd	2.46 ± 0.68	nd
Tridecane	1298	MS + LRI + Std	nd	2.98 ± 0.14	nd
Tetradecane	1398	MS + LRI + Std	nd	0.89 ± 0.09	nd
Pentadecane	1497	MS + LRI + Std	nd	2.37 ± 0.06	nd
Hexadecane	1598	MS + LRI + Std	nd	4.64 ± 1.29	nd
Heptadecane	1696	MS + LRI + Std	nd	4.78 ± 1.86	nd
Octadecane	1795	MS + LRI + Std	nd	1.97 ± 0.54	nd
Nonadecane	1896	MS + LRI + Std	nd	1.46 ± 0.47	nd
Eicosane	1996	MS + LRI + Std	nd	1.41 ± 0.09	nd
Heneicosane	2095	MS + LRI + Std	nd	0.74 ± 0.04	nd
Tricosane	2294	MS + LRI + Std	nd	0.52 ± 0.06	nd
Tetracosane	2394	MS + LRI + Std	nd	0.88 ± 0.25	nd
Pentacosane	2495	MS + LRI + Std	nd	1.15 ± 0.01	nd
Total			nd	27.44 ± 5.36	nd
<i>Aromatic compounds</i>					
Toluene	1018	MS + LRI	nd	0.12 ± 0.00	nd
Ethylbenzene	1118	MS + LRI	nd	0.31 ± 0.08	nd
<i>p</i> -Xylene	1126	MS + LRI + Std	nd	0.10 ± 0.05	nd
1,3-Dimethylbenzene	1132	MS + LRI + Std	nd	0.17 ± 0.02	nd

Table 1 continued

Name	LRI ^A	Identification ^B	Raw ginger		Boiled ginger soup
			SPME ^C	SDE ^D	
<i>o</i> -Xylene	1175	MS + LRI + Std	0.00 ± 0.00a	0.12 ± 0.08	0.01 ± 0.01a
Styrene	1249	MS + LRI	nd	0.22 ± 0.03	nd
1-Methyl-3-(1-methylethyl)-benzen	1261	MS + LRI + Std	24.04 ± 3.64a	nd	0.00 ± 0.00b
Benzaldehyde	1510	MS + LRI + Std	0.00 ± 0.00a	0.10 ± 0.02	0.09 ± 0.01b
Acetophenone	1636	MS + LRI + Std	nd	0.08 ± 0.04	nd
Benzyl alcohol	1863	MS + LRI + Std	nd	3.49 ± 1.19	nd
Butylated hydroxytoluene	1899	MS + LRI	0.00 ± 0.00a	0.16 ± 0.06	0.02 ± 0.00b
Phenol	2003	MS + LRI + Std	0.00 ± 0.00a	nd	0.07 ± 0.01b
2,4-Di-tert-butylphenol	2312	MS + LRI	0.00 ± 0.00a	nd	1.34 ± 0.31b
Vanillin	2565	MS + LRI + Std	0.00 ± 0.00a	nd	0.05 ± 0.01b
Total			24.04 ± 3.64a	4.86 ± 1.56	1.58 ± 0.31b
<i>Acids</i>					
Acetic acid	1464	MS + LRI	nd	0.06 ± 0.02	nd
Hexadecanoic acid	2942	MS + LRI	0.10 ± 0.02a	2.73 ± 0.48	0.03 ± 0.01b
Total			0.10 ± 0.02a	2.78 ± 0.46	0.03 ± 0.01b
<i>Esters</i>					
Butyl ethanoate	1062	MS + LRI	nd	0.10 ± 0.00	nd
Hexadecanoic acid, methyl ester	2206	MS + LRI + Std	nd	0.22 ± 0.03	nd
Octadecanoic acid, methyl ester	2413	MS + LRI	nd	0.11 ± 0.01	nd
Diisobutyl phthalate	2526	MS + LRI	nd	0.86 ± 0.02	nd
Total			nd	1.29 ± 0.03	nd
<i>Furans</i>					
2-Pentylfuran	1227	MS + LRI + Std	0.00 ± 0.00a	0.25 ± 0.05	0.14 ± 0.04b
Furfural	1453	MS + LRI	nd	1.96 ± 0.46	nd
5-Methyl-2-furfural	1561	MS + LRI + Std	nd	0.05 ± 0.03	nd
Total			0.00 ± 0.00a	2.25 ± 0.54	0.14 ± 0.04b
<i>Others</i>					
Pyridine	1182	MS + LRI	1.12 ± 0.36a	nd	0.00 ± 0.00b
Total			1.12 ± 0.36a	nd	0.00 ± 0.00b
Total			2859.3 ± 452.95a	46.76 ± 7.55	29.28 ± 3.43b

Analyzed by paired-samples *T* test, different letters within a row are significantly different at $p < 0.05$

nd not detected

^A Linear retention indices calculated in relation to the retention time of a series of alkanes (C8–C40) determined by using a DB-Wax column

^B MS + LRI + Std, mass spectrum and LRI agree with those of authentic compound; MS + LRI, mass spectrum identified using the NIST Mass Spectral Database and LRI agrees with the NIST Chemistry WebBook (Linstrom and Mallard 2001)

^C Peak area of the deconvoluted compound extracted by SPME with fiber of DVB/CAR/PDMS, 1×10^6

^D Total amount of volatile compounds extracted by SDE from soup was calculated by using 1,2-dichlorobenzene as internal reference, in μg

Effect of boiling on volatiles content garlic

As in the study with ginger samples, SPME was used for extraction of volatiles from raw garlic, and SDE and SPME were employed for extraction of volatiles from boiled garlic solution. There were 18 volatile compounds detected from crushed garlic directly by headspace SPME–GC–MS, and 48 volatile compounds identified from boiled garlic solution by a

combination of SPME–GC–MS and SDE–GC–MS (Table 2). The headspace volatile components in crushed ginger consisted mainly of sulfur compounds, predominantly diallyl disulphide (37.9 %), allyl methyl disulfide (35.3 %), and methyl propenyl disulfide (10.0 %), with lesser amounts of other sulfides. Alcohols were also present in smaller amounts (with 2-propenol being the most abundant), together with lesser quantities of aldehydes, esters and aromatics.

Table 2 Volatile compounds identified from raw garlic and boiled garlic soup using SPME (as peak area, 1×10^6) and SDE (as total amount, μg) ($n = 3$)

Name	LRI ^A	Identification ^B	Raw garlic		Boiled garlic soup
			SPME ^C	SDE ^D	SPME ^C
<i>Aldehydes</i>					
Pentanal	959	MS + LRI	nd	0.11 ± 0.01	nd
Hexanal	1077	MS + LRI + Std	0.00 ± 0.00a	2.21 ± 0.05	0.12 ± 0.02b
Octanal	1286	MS + LRI + Std	0.00 ± 0.00a	nd	0.07 ± 0.02b
Nonanal	1387	MS + LRI + Std	0.00 ± 0.00a	0.85 ± 0.10	0.66 ± 0.08b
Decanal	1499	MS + LRI + Std	0.12 ± 0.03a	nd	0.74 ± 0.09b
Total			0.12 ± 0.03a	3.16 ± 0.15	1.58 ± 0.17b
<i>Alcohols</i>					
2-Propen-1-ol	1112	MS + LRI	1.21 ± 0.17a	3.08 ± 0.30	0.2 ± 0.06b
Butyl alcohol	1141	MS + LRI + Std	0.00 ± 0.00a	0.03 ± 0.01	0.08 ± 0.04b
2-Ethyl-1-hexanol	1485	MS + LRI + Std	0.00 ± 0.00a	0.19 ± 0.07	0.03 ± 0.02b
1-Octanol	1559	MS + LRI	0.14 ± 0.02a	nd	0.10 ± 0.13a
1-Dodecanol	1958	MS + LRI + Std	0.00 ± 0.00a	0.12 ± 0.07	0.22 ± 0.03b
1-Octadecanol	2584	MS + LRI + Std	0.44 ± 0.13a	2.06 ± 0.11	0.15 ± 0.08b
Total			1.80 ± 0.10a	5.48 ± 0.20	0.79 ± 0.20b
<i>Alkanes</i>					
Decane	983	MS + LRI + Std	nd	0.32 ± 0.04	nd
Undecane	1097	MS + LRI + Std	nd	0.52 ± 0.03	nd
Dodecane	1198	MS + LRI + Std	nd	2.03 ± 0.16	nd
Tridecane	1321	MS + LRI + Std	0.35 ± 0.24a	3.07 ± 0.08	0.00 ± 0.00b
Tetradecane	1398	MS + LRI + Std	nd	0.83 ± 0.05	nd
Pentadecane	1497	MS + LRI + Std	nd	2.70 ± 0.58	nd
Hexadecane	1597	MS + LRI + Std	nd	3.12 ± 0.24	nd
Heptadecane	1696	MS + LRI + Std	nd	1.90 ± 1.41	nd
Octadecane	1795	MS + LRI + Std	nd	1.69 ± 0.13	nd
Nonadecane	1896	MS + LRI + Std	nd	1.11 ± 0.46	nd
Eicosane	1996	MS + LRI + Std	nd	1.12 ± 0.01	nd
Heneicosane	2095	MS + LRI + Std	nd	0.73 ± 0.05	nd
Docosane	2194	MS + LRI + Std	nd	0.31 ± 0.01	nd
Tricosane	2294	MS + LRI + Std	nd	0.99 ± 0.04	nd
Tetracosane	2394	MS + LRI + Std	nd	0.48 ± 0.12	nd
Total			0.35 ± 0.24a	20.95 ± 1.15	0.00 ± 0.00b
<i>Aromatic compounds</i>					
Toluene	1018	MS + LRI	nd	0.14 ± 0.05	nd
Ethylbenzene	1118	MS + LRI	nd	0.30 ± 0.04	nd
<i>p</i> -Xylene	1126	MS + LRI + Std	nd	0.14 ± 0.01	nd
1,3-Dimethylbenzene	1132	MS + LRI + Std	nd	0.29 ± 0.02	nd
<i>o</i> -Xylene	1175	MS + LRI + Std	nd	0.10 ± 0.03	nd
Benzaldehyde	1510	MS + LRI + Std	0.00 ± 0.00a	0.07 ± 0.02	0.01 ± 0.00b
Acetophenone	1642	MS + LRI + Std	0.05 ± 0.01a	nd	0.00 ± 0.00b
Benzyl alcohol	1863	MS + LRI + Std	nd	2.32 ± 0.19	nd
Butylated hydroxytoluene	1899	MS + LRI	nd	0.15 ± 0.08	nd
Phenol	1990	MS + LRI + Std	0.00 ± 0.00a	0.03 ± 0.01	0.14 ± 0.03b
2,4-Di-tert-butylphenol	2296	MS + LRI	0.00 ± 0.00a	2.25 ± 0.29	1.25 ± 0.29b
Total			0.05 ± 0.01a	5.80 ± 0.60	1.39 ± 0.31b

Table 2 continued

Name	LRI ^A	Identification ^B	Raw garlic		Boiled garlic soup
			SPME ^C	SDE ^D	SPME ^C
<i>Sulfur compounds</i>					
Methyl disulfide	1058	MS + LRI	17.5 ± 6.02a	0.00 ± 0.01	0.00 ± 0.00b
Allyl sulfide	1137	MS + LRI + Std	4.69 ± 1.87a	0.04 ± 0.00	0.40 ± 0.03a
Methyl propyl disulfide	1221	MS + LRI	1.58 ± 0.53a	nd	0.38 ± 0.33a
3,4-dimethylthiophene	1244	MS + LRI	2.37 ± 0.58a	nd	0.00 ± 0.00b
Allyl methyl disulfide	1277	MS + LRI	342.92 ± 19.78a	0.22 ± 0.06	0.55 ± 0.03b
Methyl propenyl disulfide	1281	MS + LRI	97.14 ± 12.88a	nd	0.00 ± 0.00b
Dimethyltrisulfide	1365	MS + LRI	1.57 ± 0.27a	nd	0.00 ± 0.00b
Diallyl disulfide	1469	MS + LRI + Std	368.62 ± 25.09a	0.87 ± 0.22	7.11 ± 1.68b
Methyl allyl trisulfide	1579	MS + LRI	75.86 ± 18.90a	nd	0.00 ± 0.00b
Methyl (methylthiomethyl) persulfide	1648	MS + LRI	0.45 ± 0.01a	nd	0.00 ± 0.00b
Diallyl trisulfide	1776	MS + LRI + Std	56.25 ± 11.70a	1.17 ± 0.11	0.00 ± 0.00b
Total			968.95 ± 3.56a	2.30 ± 0.05	8.44 ± 1.36b
<i>Acids</i>					
Acetic acid	1470	MS + LRI	nd	0.06 ± 0.01	nd
Hexadecanoic acid	2942	MS + LRI	nd	1.31 ± 0.02	nd
Total			nd	1.37 ± 0.03	nd
<i>Esters</i>					
Butyl ethanoate	1061	MS + LRI	nd	0.07 ± 0.00	nd
Methyl hexadecanoate	2215	MS + LRI + Std	0.32 ± 0.11a	0.14 ± 0.06	0.00 ± 0.00b
Total			0.32 ± 0.11a	0.22 ± 0.06	0.00 ± 0.00b
<i>Furans</i>					
2-Pentylfuran	1227	MS + LRI + Std	nd	0.25 ± 0.05	nd
Furfural	1453	MS + LRI	nd	2.83 ± 0.67	nd
Total			nd	3.08 ± 0.62	nd
Total			971.59 ± 3.73a	42.36 ± 1.14	12.21 ± 1.12b

Analyzed by paired-samples *T* test, different letters within a row are significantly different at $p < 0.05$

nd not detected

^A Linear retention indices calculated in relation to the retention time of a series of alkanes (C8–C40) determined by using a DB-Wax column

^B MS + LRI + Std, mass spectrum and LRI agree with those of authentic compound; MS + LRI, mass spectrum identified using the NIST Mass Spectral Database and LRI agrees with the NIST Chemistry WebBook (Linstrom and Mallard 2001)

^C Peak area of the deconvoluted compound extracted by SPME with fiber of DVB/CAR/PDMS, 1×10^6

^D Total amount of volatile compounds extracted by SDE from soup was calculated by using 1,2-dichlorobenzene as internal reference, in μg

Due to the pungent odor of garlic, various cooking treatments have been used to enhance its olfactory and gustatory characteristics or nutritional and medicinal properties. As seen from Table 2, the profiles of the volatile components in garlic changed after boiling in water. After the boiling process, levels of most volatiles, especially sulfides clearly decreased, however the heating process also resulted in the detection of more components. The decrease in the concentration of sulfides at elevated temperatures has also been reported by Kim et al. (2011), who found that the content of most sulfur compounds such as diallyl disulfide decreased when garlic received autoclaving and roasting treatment, and roasting at 200 °C for 60 min caused the formation of a large amount of

pyrazines in garlic. In this study, the boiled garlic sample contained a total of 36 new compounds, consisting of four aldehydes, three alcohols, fourteen alkanes, ten aromatic compounds, two acids, one ester, and two furans. It has been reported that some components in garlic are unstable beyond 100 °C, and boiling may have caused degradation of non-volatiles such as thiosulfonates to volatiles. Therefore, heating may have decreased the amount of volatiles through evaporation or chemical degradation of volatiles, but may also resulted in the formation of new volatile compounds. This result is not unexpected since Chyau and Mau (1999) also reported that levels of most volatiles in garlic decreased as the heating time continued during microwave heating. Interestingly, previously

undetected nonanal and 2-octenal were found in microwave-heated garlic; the former was also found in the boiled garlic sample but not in the raw sample.

As mentioned above, due to the low sensitivity of the DVB-CAR-PDMS fiber used in the SPME method for non-polar or weakly-polar compounds, we could not establish whether the newly detected non-polar or weakly-polar compounds in the boiled garlic solution were formed as a result of boiling or whether they went undetected as a result of using the SPME extraction method with the DVB-CAR-PDMS fiber.

Effect of ginger and/or garlic on volatiles of grass carp soup

The four basic uses of spices in cooking are to enhance flavor, endow food with pungency, impart color, and mask unpleasant odors (Hirasa and Takemasa 1998). The “masking” function can be achieved three ways: chemical (compounds with unpleasant odors are changed to non-volatile compounds or to odorless substances by undergoing chemical changes), physical (unpleasant smelling compounds are adsorbed by porous activated carbon or zeolites), and sensation (a strong spice flavor covers an unpleasant smell or two compounds having different odors combined emit an odor that is no longer undesirable or even become odorless when mixed) (Hirasa and Takemasa 1998). Raw fish is generally characterized by a sweet, mild, green, plant-like, metallic, and weak fish odor (Morita et al. 2003). However, the grass carp soup we obtained after boiling in water without any added spices is characterized by a strong fish odor but a weak sweet, mild, green, plant-like odor, and cooked meat smell. Ginger and garlic are commonly used for neutralizing any unpleasant fish odor and for enhancing the flavor and aroma of fish soup cooked throughout Asia, and especially in China. Volatiles identified from fish soup prepared by boiling pan-fried grass carp with and without added ginger and/or garlic are shown in Table 3. Through a combination of SPME–GC–MS and SDE–GC–MS, a total of 46 volatile compounds (eleven aldehydes, two ketones, seven alcohols, five alkanes, fourteen aromatic compounds, two acids, two esters, one furan and two other compounds), were detected in grass carp soup without added spices. Among these compounds, aldehydes, ketones, and alcohols account for 61.9 % of the total identified volatiles from SDE extracts, and were mainly derived from enzymatic and non-enzymatic oxidation of polyunsaturated fatty acids in fish (Kawai and Sakaguchi 1996). Aldehydes, which were the second most abundant group of compounds from the mixture of volatiles, generally possess the lowest threshold values compared with other kinds of volatiles (Table 3), and may be the most significant group of volatiles in the grass carp

soup cooked without any spices. The presence of the aldehydes *trans,trans*-2,4-decadienal; 2,4-decadienal; *trans,trans*-2,4-heptadienal; hexanal; and heptanal, which are reported to be some of the most prominent compounds responsible for the presence of a fish odor (Suffet et al. 1999), might be the main factor contributing to the fish odor of the grass carp soup. Other compounds which have an important role in the flavor and aroma of the fish soup cooked without any spices are 2-pentylfuran, some aromatic compounds (ethylbenzene, styrene, acetophenone, vanillin, eugenol), and 2,5-dimethylpyrazine.

When spices were added, the volatile profile of the grass carp soup changed considerably. When ginger, garlic, or ginger plus garlic were added, there were 72, 51, and 71 compounds identified, respectively. Compared with the soup without ginger, the ginger and ginger plus garlic soups contained a large amount of terpenoids (including reduced and oxidized terpenes), which were shown to originate from ginger and to be stable under boiling conditions as demonstrated by their presence in fresh ginger and in the solution of boiled ginger (Table 1). Terpenes are described as typically having a floral, rose-like, coriander, camphoraceous, green, and herbaceous odor (Meilgaard 1975; Simpson 1979). The addition of ginger modified the flavor of the grass carp soup, giving it a floral smell which is attributed to the presence of terpenes. Similarly, 2-propen-1-ol and various sulfur compounds (allyl sulfide, diallyl disulfide, diallyl trisulfide) which are present in raw garlic and in the boiled garlic solution (Table 2), were also identified in the fish soup with added garlic and ginger plus garlic, it thus seems plausible to assume that these compounds originate directly from the garlic. Sulfur compounds play an important role in the flavor and odor of food due to their relatively low threshold values and their intense odor (Schutte and Teranishi 1974), e.g. the threshold value of allyl sulfide and diallyl disulfide in water is 32.5 and 30 µg/kg, respectively. The sulfur compounds detected in garlic conferred upon the fish soup a slight garlic and onion odor which masked the fish odor (Yoshida et al. 1984). The 2-Propen-1-ol detected in garlic-added soup has been reported to be formed in considerable quantities in heated garlic and alliin (Lee et al. 2006), and thus may also have been derived from thermal degradation of alliin in garlic when boiling.

With the exception of terpenes, 2-propen-1-ol, and sulfur compounds, generally, there was no obvious difference in the presence of other volatiles between the soups prepared by boiling pan-fried grass carp with and without spices. For example, in the soups without any added spices, with ginger, with garlic, and with garlic plus ginger, a total of 11, 13, 13, and 13 aldehydes were detected, respectively. The four samples had ten aldehydes in common: hexanal; *trans*-2-heptenal; nonanal; *trans*-2-octenal; *trans,trans*-2,4-

Table 3 Mean of volatile compounds isolated from fish soup prepared by boiling pan-fried grass carp with and without ginger and/or garlic using SPME (as peak area, 1×10^6) and SDE (as total amount, μg) ($n = 3$)

Name	LRI ^A	Identification ^B	Threshold value (mg/kg) ^C	Odor description ^D	Control		Ginger added	
					SDE ^E	SPME ^F	SDE ^E	SPME ^F
<i>Terpenes</i>								
α -Pinene	1008	MS + LRI	6.0 ^(a)	Pine, turpentine	nd	0.00 $\pm$ 0.00e	nd	2.01 $\pm$ 0.36f
Camphene	1048	MS + LRI + Std	1900.0 ^(a)	Camphor	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00e	1.85 $\pm$ 0.02b	4.68 $\pm$ 0.45f
β -Myrcene	1157	MS + LRI + Std	13.0 ^(a)	Balsamic, must, spice	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00e	0.00 $\pm$ 0.00a	0.11 $\pm$ 0.01f
Limonene	1189	MS + LRI + Std	10.0 ^(a)	Lemon, orange	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00e	0.86 $\pm$ 0.04b	1.65 $\pm$ 0.28f
β -Phellandrene	1198	MS + LRI	–	Mint, terpentine	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00e	6.19 $\pm$ 0.12b	7.16 $\pm$ 1.01f
1,8-Cineole	1203	MS + LRI + Std	12.0 ^(a)	Mint, sweet	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00e	0.80 $\pm$ 0.05b	0.76 $\pm$ 0.09f
Citronellal	1471	MS + LRI + Std	25.0 ^(a)	Fat	nd	0.00 $\pm$ 0.00e	nd	0.15 $\pm$ 0.04f
Linalool	1545	MS + LRI + Std	6.0 ^(a)	Flower, lavender	nd	0.00 $\pm$ 0.00e	nd	0.17 $\pm$ 0.04f
β -Citral	1676	MS + LRI	32.0 ^(a)	Lemon	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00e	4.44 $\pm$ 0.05b	4.95 $\pm$ 0.54f
α -Terpineol	1694	MS + LRI + Std	330.0 ^(a)	Oil, anise, mint	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00e	0.28 $\pm$ 0.05b	0.00 $\pm$ 0.00e
α -Zingiberene	1711	MS + LRI	–	Spice, fresh, sharp	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00e	3.76 $\pm$ 0.18b	0.00 $\pm$ 0.00e
(<i>E</i>)-Neral	1727	MS + LRI	32.0 ^(a)	Lemon, mint	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00e	7.22 $\pm$ 0.19b	7.21 $\pm$ 1.00f
α -Farnesene	1739	MS + LRI + Std	medium ^(b)	Wood, sweet	0.00 $\pm$ 0.00a	nd	0.47 $\pm$ 0.07b	nd
α -Curcumene	1762	MS + LRI	–	Herb	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00e	0.54 $\pm$ 0.05b	0.09 $\pm$ 0.03f
Citronellol	1763	MS + LRI + Std	40.0 ^(a)	Rose	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00e	0.19 $\pm$ 0.01b	0.00 $\pm$ 0.00e
Geraniol	1847	MS + LRI + Std	40.0 ^(a)	Rose, geranium	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00e	0.34 $\pm$ 0.08b	0.00 $\pm$ 0.00e
Total					0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00e	26.95 $\pm$ 0.16b	28.94 $\pm$ 1.86f
<i>Aldehydes</i>								
Pentanal	973	MS + LRI	12 ^(a)	Almond, malt, pungent	nd	0.17 $\pm$ 0.03e	nd	0.08 $\pm$ 0.01f
Hexanal	1073	MS + LRI + Std	4.50 ^(a)	Grass, tallow, fat, fishy	2.23 $\pm$ 0.51a	2.24 $\pm$ 0.61e	2.33 $\pm$ 0.05a	1.44 $\pm$ 0.20f
Heptanal	1180	MS + LRI + Std	3.0 ^(a)	Fat, citrus, rancid, fishy	0.00 $\pm$ 0.00a	nd	0.35 $\pm$ 0.01b	nd
Octanal	1283	MS + LRI + Std	0.7 ^(a)	Fat, soap, lemon, green	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00e	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00e
<i>trans</i> -2-Heptenal	1318	MS + LRI + Std	13.0 ^(a)	Soap, fat, almond	1.19 $\pm$ 0.38a	0.35 $\pm$ 0.06e	1.33 $\pm$ 0.12a	0.17 $\pm$ 0.01f
Nonanal	1387	MS + LRI + Std	1.0 ^(a)	Fat, citrus, green	0.90 $\pm$ 0.46a	0.00 $\pm$ 0.00e	2.08 $\pm$ 0.01b	0.84 $\pm$.15f
<i>trans</i> -2-Octenal	1423	MS + LRI + Std	3.0 ^(a)	Green leaf, walnut	0.43 $\pm$ 0.03a	0.25 $\pm$ 0.05e	0.78 $\pm$ 0.02b	0.00 $\pm$ 0.00f
<i>trans</i> , <i>trans</i> -2, 4-Heptadienal	1487	MS + LRI + Std	49.0 ^(a)	Nut, fat, fishy	1.70 $\pm$ 0.19a	nd	1.97 $\pm$ 0.11a	nd
Decanal	1491	MS + LRI + Std	0.1 ^(a)	Soap, orange, tallow	nd	0.00 $\pm$ 0.00e	nd	0.00 $\pm$ 0.00e
<i>trans</i> -2-Nonenal	1528	MS + LRI + Std	0.08 ^(a)	Cucumber, fat, green	0.00 $\pm$ 0.00a	0.00 $\pm$ 0.00e	0.37 $\pm$ 0.06b	0.00 $\pm$ 0.00e
<i>trans</i> -2-Decenal	1637	MS + LRI + Std	0.3 ^(a)	Orange	1.53 $\pm$ 0.24ab	0.25 $\pm$ 0.10e	2.10 $\pm$ 0.06a	0.00 $\pm$ 0.00f
<i>trans</i> -2-Undecenal	1746	MS + LRI	4200 ^(a)	Soap, fat, green	0.59 $\pm$ 0.31a	nd	1.31 $\pm$ 0.03b	nd
2,4-Decadienal	1759	MS + LRI	0.07 ^(c)	Seaweed, fishy	5.26 $\pm$ 2.69a	0.38 $\pm$ 0.03e	11.88 $\pm$ 0.15b	0.15 $\pm$ 0.03f
<i>trans</i> , <i>trans</i> -2, 4-Decadienal	1804	MS + LRI + Std	0.07 ^(c)	Fried, fat, fishy	29.40 $\pm$ 2.09a	1.99 $\pm$ 0.20 g	46.53 $\pm$ 1.65b	1.18 $\pm$ 0.11e
Hexadecanal	2129	MS + LRI	–	Cardboard	0.24 $\pm$ 0.11a	nd	1.14 $\pm$ 0.26b	nd
Total					43.46 $\pm$ 1.15a	5.62 $\pm$ 1.01e	72.17 $\pm$ 1.74b	3.87 $\pm$ 0.28f

Table 3 continued

Name	LRI ^A	Identification ^B	Threshold value (mg/kg) ^C	Odor description ^D	Control		Ginger added		
					SDE ^E	SPME ^F	SDE ^E	SPME ^F	
<i>Ketones</i>									
2,3-Pentanedione	1047	MS + LRI	20 ^(a)	Pungent, sweet, butter, creamy, caramel, nutty, cheese	0.10 ± 0.06a	nd	0.00 ± 0.00b	nd	
3-Penten-2-one	1121	MS + LRI	1.5 ^(a)	Fishy, pungent	nd	0.00 ± 0.00e	nd	0.24 ± 0.09f	
	1280	MS + LRI + Std	55.0 ^(a)	Sweet, buttery, creamy, dairy, milky, fatty	0.40 ± 0.03a	nd	0.75 ± 0.03b	nd	
6-Methyl-5-hepten-2-one	1332	MS + LRI + Std	50.0 ^(a)	Citrus, green, musty, lemongrass, apple	nd	0.00 ± 0.00e	nd	0.39 ± 0.04f	
Total					0.50 ± 0.09a	0.00 ± 0.00e	0.75 ± 0.03b	0.63 ± 0.05f	
<i>Alcohols</i>									
2-Propen-1-ol	1112	MS + LRI	–	Pungent, mustard	0.00 ± 0.00a	0.00 ± 0.00e	0.00 ± 0.00a	0.00 ± 0.00e	
	1251	MS + LRI + Std	4000.0 ^(a)	Fusel, oil, sweet, balsam	nd	0.53 ± 0.07e	nd	0.10 ± 0.02f	
1-Octen-3-ol	1448	MS + LRI + Std	1.0 ^(a)	Mushroom	nd	0.43 ± 0.04e	nd	0.00 ± 0.00f	
1-Heptanol	1455	MS + LRI	330 ^(a)	Herb	nd	0.05 ± 0.00e	nd	0.00 ± 0.00f	
2-Ethyl-1-hexanol	1489	MS + LRI + Std	1000.0 ^(a)	Rose, green	0.55 ± 0.32a	0.34 ± 0.04e	1.77 ± 0.18b	0.30 ± 0.04e	
	1558	MS + LRI	110.0 ^(a)	Chemical, metal, burnt	0.00 ± 0.00a	0.20 ± 0.05e	0.45 ± 0.06b	0.00 ± 0.00f	
1-Dodecanol	1966	MS + LRI + Std	100.0 ^(a)	Earthy, soapy, waxy, fatty, honey, coconut	2.43 ± 1.08ab	nd	3.50 ± 1.46a	nd	
1-Octadecanol	2586	MS + LRI + Std	–	Bland	79.53 ± 7.70a	0.16 ± 0.02e	79.12 ± 4.08a	0.65 ± 0.13f	
Total					82.51 ± 9.09a	1.72 ± 0.04e	84.83 ± 5.66a	1.05 ± 0.10f	
<i>Alkanes</i>									
Decane	984	MS + LRI + Std	–	Alkane	0.93 ± 0.34a	nd	2.14 ± 0.12b	nd	
Undecane	1186	MS + LRI + Std	–	Alkane	7.25 ± 2.03a	nd	3.67 ± 0.32b	nd	
Dodecane	1201	MS + LRI + Std	–	Alkane	0.00 ± 0.00a	nd	1.24 ± 0.20b	nd	
Tridecane	1303	MS + LRI + Std	–	Alkane	0.00 ± 0.00a	nd	5.27 ± 0.06b	nd	
Tetradecane	1403	MS + LRI + Std	–	Alkane	0.00 ± 0.00a	nd	1.07 ± 0.04b	nd	
Pentadecane	1504	MS + LRI + Std	–	Alkane	8.82 ± 1.15a	nd	8.36 ± 1.03ab	nd	
Hexadecane	1604	MS + LRI + Std	–	Alkane	0.57 ± 0.26a	nd	1.64 ± 0.01ab	nd	
Heptadecane	1696	MS + LRI + Std	–	Alkane	4.20 ± 1.23a	nd	4.14 ± 0.10a	nd	
Total					21.78 ± 2.71a	nd	27.54 ± 1.66b	nd	
<i>Aromatic compounds</i>									
Toluene	1018	MS + LRI	–	Paint	0.00 ± 0.00a	nd	0.84 ± 0.03b	nd	
Ethylbenzene	1118	MS + LRI	–	–	0.66 ± 0.16a	nd	1.19 ± 0.17a	nd	
p-Xylene	1125	MS + LRI + Std	–	–	0.79 ± 0.06a	nd	0.91 ± 0.11a	nd	
1,3-Dimethylbenzene	1131	MS + LRI + Std	–	Plastic	1.44 ± 0.21ab	nd	1.87 ± 0.15a	nd	
o-Xylene	1174	MS + LRI + Std	–	Geranium	0.90 ± 0.26a	nd	2.05 ± 0.04b	nd	
Propylbenzene	1199	MS + LRI	–	–	0.51 ± 0.18a	nd	2.00 ± 0.16c	nd	
1-Methyl-4-ethylbenzene	1213	MS + LRI	–	–	0.93 ± 0.02ac	nd	2.80 ± 1.19a	nd	

Table 3 continued

Name	LRI ^A	Identification ^B	Threshold value (mg/kg) ^C	Odor description ^D	Control		Ginger added	
					SDE ^E	SPME ^F	SDE ^E	SPME ^F
1-Ethyl-3-methylbenzene	1216	MS + LRI	–	–	1.79 ± 0.17a	nd	5.03 ± 0.52b	nd
1,3,5-Trimethylbenzene	1234	MS + LRI	–	–	0.71 ± 0.02a	nd	1.38 ± 0.10b	nd
Styrene	1247	MS + LRI	44 ^(a)	Balsamic, gasoline	0.07 ± 0.01a	nd	0.38 ± 0.18b	nd
11-Ethyl-2-methylbenzene	1251	MS + LRI	–	–	0.76 ± 0.15a	nd	1.23 ± 0.06a	nd
<i>p</i> -Cymene	1261	MS + LRI + Std	150.0 ^(a)	Solvent, gasoline, citrus	nd	0.00 ± 0.00e	nd	0.28 ± 0.06f
1,2,4-Trimethylbenzene	1270	MS + LRI	–	Plastic	0.00 ± 0.00a	nd	1.07 ± 0.70b	nd
α -Formylethylbenzene	1293	MS + LRI	5,760,000 ^(a)	Fresh, sharp, green, hyacinth, leaf lilac	0.00 ± 0.00a	nd	0.00 ± 0.00a	nd
1,2,3-Trimethylbenzene	1325	MS + LRI	–	–	0.00 ± 0.00a	nd	0.21 ± 0.11b	nd
Benzaldehyde	1512	MS + LRI + Std	350.0 ^(a)	Almond, burnt sugar	0.00 ± 0.00a	0.00 ± 0.00e	0.00 ± 0.00a	0.13 ± 0.02f
Acetophenone	1642	MS + LRI + Std	65.0 ^(a)	Must, flower, almond	1.27 ± 0.71a	nd	2.39 ± 0.15ab	nd
Butylated hydroxytoluene	1903	MS + LRI	1000 ^(a)	Mild phenolic, camphor	nd	1.53 ± 0.64e	nd	0.00 ± 0.00f
Decylbenzene	1936	MS + LRI	–	–	0.00 ± 0.00a	nd	0.54 ± 0.14b	nd
Vanillin	2560	MS + LRI + Std	58.0 ^(a)	Vanilla	0.00 ± 0.00a	nd	0.20 ± 0.07b	nd
3,4-Dimethylbenzaldehyde	1800	MS + LRI	–	–	0.10 ± 0.05a	nd	0.38 ± 0.09b	nd
Phenol	1998	MS + LRI + Std	5500.0 ^(a)	Phenol	4.76 ± 1.79a	3.48 ± 0.49e	13.33 ± 4.84b	5.79 ± 0.91f
Eugenol	2160	MS + LRI	6 ^(a)	Clove, honey	0.00 ± 0.00a	nd	2.31 ± 0.03b	nd
2,4-Di-tert-butylphenol	2305	MS + LRI	–	–	nd	0.00 ± 0.00e	nd	0.29 ± 0.02f
Total					14.68 ± 2.41a	5.01 ± 1.13ef	40.13 ± 5.40b	6.48 ± 0.99e
<i>Acids</i>								
Hexanoic acid	1863	MS + LRI	3000 ^(a)	Sour, fatty, sweat, cheese	nd	0.19 ± 0.02e	nd	0.16 ± 0.02e
Octanoic Acid	2080	MS + LRI + Std	3000.0 ^(a)	Sweat, cheese	nd	0.00 ± 0.00e	nd	0.00 ± 0.00e
Hexadecanoic acid	2928	MS + LRI	10,000 ^(a)	Slightly waxy, fatty	5.10 ± 0.07a	0.00 ± 0.00e	5.05 ± 0.49a	0.28 ± 0.06e
Total					5.10 ± 0.07a	0.19 ± 0.02e	5.05 ± 0.49a	0.44 ± 0.07e
<i>Esters</i>								
Ethyl citrate	2473	MS	–	Odorless to mild fruity wine	34.31 ± 12.77a	nd	58.95 ± 3.53b	nd
Phthalic acid, diisobutyl ester	2539	MS + LRI	–	–	0.00 ± 0.00a	nd	0.00 ± 0.00a	nd
Dibutyl phthalate	2695	MS + LRI	–	Faint odor	1.42 ± 0.36a	nd	0.00 ± 0.00b	nd
Total					35.73 ± 13.13a	nd	58.95 ± 3.53b	nd
<i>Sulfur compounds</i>								
Allyl sulfide	1138	MS + LRI + Std	32.5 ^(a)	Sulfurous, onion, garlic	0.00 ± 0.00a	0.00 ± 0.00e	0.00 ± 0.00a	0.00 ± 0.00e
Diallyl disulfide	1469	MS + LRI + Std	30.0 ^(a)	Onion, garlic, metallic	0.00 ± 0.00a	0.00 ± 0.00e	0.00 ± 0.00a	0.00 ± 0.00e
Diallyl trisulfide	1775	MS + LRI + Std	high ^(b)	Garlic, green, onion, metallic	0.00 ± 0.00a	nd	0.00 ± 0.00a	nd
Total					0.00 ± 0.00a	0.00 ± 0.00e	0.00 ± 0.00a	0.00 ± 0.00e
<i>Furan</i>								
2-Pentylfuran	1224	MS + LRI + Std	6.0 ^(a)	Green bean, butter	0.46 ± 0.16a	0.08 ± 0.01e	1.07 ± 0.23b	0.00 ± 0.00f

Table 3 continued

Name	LRI ^A	Identification ^B	Threshold value (mg/kg) ^C	Odor description ^D	Control		Ginger added	
					SDE ^E	SPME ^F	SDE ^E	SPME ^F
Furfural	1456	MS + LRI	3000 ^(a)	Bread, almond, sweet	0.00 ± 0.00a	0.00 ± 0.00e	0.00 ± 0.00a	0.00 ± 0.00e
5-Hydroxymethyl furfural	2499	MS + LRI + Std	high ^(b)	Fatty, buttery, musty, waxy, caramellic	nd	0.00 ± 0.00e	nd	0.17 ± 0.02f
Total					0.46 ± 0.16a	0.08 ± 0.01e	1.07 ± 0.23b	0.17 ± 0.02f
<i>Others</i>								
2,5-Dimethylpyrazine	1320	MS + LRI + Std	800.0 ^(a)	Cocoa, roasted nuts, roast beef, woody, grass, medical	nd	0.04 ± 0.01e	nd	0.00 ± 0.00f
Carbitol	1621	MS + LRI + Std	–	–	nd	0.32 ± 0.06e	nd	0.00 ± 0.00f
Total					nd	0.36 ± 0.05e	nd	0.00 ± 0.00f
Total					204.22 ± 28.50a	12.99 ± 2.13e	317.45 ± 7.24b	41.59 ± 0.59f
Name	Garlic added			SPME ^F	Ginger and garlic added			
	SDE ^E				SDE ^E			
<i>Terpenes</i>								
<i>α</i> -Pinene		nd		0.00 ± 0.00e	nd	nd	nd	1.77 ± 0.22f
Camphene		0.00 ± 0.00a		0.00 ± 0.00e		1.97 ± 0.25b		5.94 ± 0.38g
<i>β</i> -Myrcene		0.00 ± 0.00a		0.00 ± 0.00e		0.34 ± 0.03b		0.52 ± 0.05g
Limonene		0.00 ± 0.00a		0.00 ± 0.00e		0.37 ± 0.28b		1.69 ± 0.21f
<i>β</i> -Phellandrene		0.00 ± 0.00a		0.00 ± 0.00e		1.95 ± 0.38c		6.40 ± 0.31f
1,8-Cineole		0.00 ± 0.00a		0.00 ± 0.00e		0.25 ± 0.13c		0.86 ± 0.14f
Citronellal		nd		0.00 ± 0.00e		nd		0.35 ± 0.05g
Linalool		nd		0.00 ± 0.00e		nd		0.46 ± 0.07g
<i>β</i> -Citral		0.00 ± 0.00a		0.00 ± 0.00e		1.63 ± 0.08c		6.19 ± 0.46g
<i>α</i> -Terpineol		0.00 ± 0.00a		0.00 ± 0.00e		0.00 ± 0.00a		1.04 ± 0.31f
<i>α</i> -Zingiberene		0.00 ± 0.00a		0.00 ± 0.00e		3.07 ± 0.28c		1.11 ± 0.12f
(<i>E</i>)-Neral		0.00 ± 0.00a		0.00 ± 0.00e		2.82 ± 0.12c		9.2 ± 1.12g
<i>α</i> -Farnesene		0.00 ± 0.00a		nd		0.28 ± 0.09c		nd
<i>α</i> -Curcumene		0.00 ± 0.00a		0.00 ± 0.00e		0.50 ± 0.11b		0.15 ± 0.04g
Citronellol		0.00 ± 0.00a		0.00 ± 0.00e		0.00 ± 0.00a		0.29 ± 0.03f
Geraniol		0.00 ± 0.00a		0.00 ± 0.00e		0.28 ± 0.02b		0.53 ± 0.09f
Total		0.00 ± 0.00a		0.00 ± 0.00e		13.45 ± 1.17c		36.5 ± 1.76g
<i>Aldehydes</i>								
Pentanal		nd		0.00 ± 0.00 g		nd		0.00 ± 0.00g
Hexanal		1.03 ± 0.42b		2.44 ± 0.30 g		1.98 ± 0.46a		0.88 ± 0.27f
Heptanal		0.11 ± 0.03c		nd		0.00 ± 0.00a		nd
Octanal		0.10 ± 0.04b		0.00 ± 0.00e		0.15 ± 0.04b		0.13 ± 0.01f
<i>trans</i> -2-Heptenal		0.92 ± 0.32ab		0.00 ± 0.00 g		0.59 ± 0.03b		0.13 ± 0.02f
Nonanal		1.41 ± 0.06c		1.69 ± 0.50 g		0.98 ± 0.06ac		3.13 ± 0.35h
<i>trans</i> -2-Octenal		0.48 ± 0.03a		0.24 ± 0.04e		0.34 ± 0.06c		0.51 ± 0.09g
<i>trans</i> , <i>trans</i> -2, 4-Heptadienal		0.87 ± 0.22b		nd		0.65 ± 0.10b		nd

Table 3 continued

Name	Garlic added		Ginger and garlic added	
	SDE ^E	SPME ^F	SDE ^E	SPME ^F
Decanal	nd	0.00 ± 0.00e	nd	0.09 ± 0.00f
<i>trans</i> -2-Nonenal	0.34 ± 0.19b	0.00 ± 0.00e	0.00 ± 0.00a	0.43 ± 0.06f
<i>trans</i> -2-Decenal	1.45 ± 0.75ab	0.00 ± 0.00f	1.11 ± 0.07b	0.00 ± 0.00f
<i>trans</i> -2-Undecenal	0.47 ± 0.15a	nd	0.73 ± 0.05a	nd
2,4-Decadienal	4.25 ± 1.36a	0.29 ± 0.03 g	3.81 ± 0.12a	0.37 ± 0.04e
<i>trans</i> , <i>trans</i> -2, 4-Decadienal	17.71 ± 5.26c	1.51 ± 0.21ef	16.34 ± 1.23c	1.83 ± 0.20 fg
Hexadecanal	0.63 ± 0.28a	nd	0.58 ± 0.21a	nd
Total	29.77 ± 8.84c	6.16 ± 0.51e	27.24 ± 1.32c	7.49 ± 0.59g
<i>Ketones</i>				
2,3-Pentanedione	0.00 ± 0.00b	nd	0.00 ± 0.00b	nd
3-Penten-2-one	nd	0.00 ± 0.00e	nd	0.00 ± 0.00e
3-Hydroxy-2-butanone	0.00 ± 0.00c	nd	0.51 ± 0.03d	nd
6-Methyl-5-hepten-2-one	nd	0.00 ± 0.00e	nd	0.32 ± 0.09f
Total	0.00 ± 0.00c	0.00 ± 0.00e	0.51 ± 0.03a	0.32 ± 0.09g
<i>Alcohols</i>				
2-Propen-1-ol	7.01 ± 3.17b	0.94 ± 0.35f	6.38 ± 2.07b	0.31 ± 0.04e
1-Pentanol	nd	0.23 ± 0.03 g	nd	0.13 ± 0.03f
1-Octen-3-ol	nd	0.49 ± 0.08e	nd	0.39 ± 0.10e
1-Heptanol	nd	0.00 ± 0.00f	nd	0.00 ± 0.00f
2-Ethyl-1-hexanol	1.09 ± 0.33c	0.45 ± 0.03e	0.49 ± 0.02a	1.06 ± 0.19f
1-Octanol	0.00 ± 0.00a	0.10 ± 0.02 g	0.15 ± 0.05c	0.11 ± 0.01g
1-Dodecanol	1.10 ± 0.39b	nd	1.58 ± 0.13b	nd
1-Octadecanol	31.35 ± 5.99b	0.00 ± 0.00 g	52.54 ± 3.64c	0.31 ± 0.09h
Total	40.54 ± 9.85b	2.21 ± 0.39 g	61.14 ± 1.48c	2.32 ± 0.12g
<i>Alkanes</i>				
Decane	1.50 ± 0.47a	nd	1.32 ± 0.05a	nd
Undecane	1.71 ± 0.02b	nd	3.44 ± 0.67b	nd
Dodecane	0.00 ± 0.00a	nd	0.00 ± 0.00a	nd
Tridecane	0.00 ± 0.00a	nd	0.00 ± 0.00a	nd
Tetradecane	0.60 ± 0.03c	nd	0.55 ± 0.07c	nd
Pentadecane	6.26 ± 2.92ab	nd	5.28 ± 0.44b	nd
Hexadecane	2.28 ± 1.16b	nd	0.94 ± 0.09a	nd
Heptadecane	2.56 ± 0.62b	nd	3.85 ± 0.35ab	nd
Total	14.89 ± 5.04c	nd	15.38 ± 0.38c	nd
<i>Aromatic compounds</i>				
Toluene	0.00 ± 0.00a	nd	0.25 ± 0.05c	nd
Ethylbenzene	1.07 ± 0.51a	nd	0.81 ± 0.23a	nd
<i>p</i> -Xylene	0.74 ± 0.31a	nd	0.71 ± 0.14a	nd
1,3-Dimethylbenzene	1.08 ± 0.30b	nd	1.51 ± 0.24ab	nd
<i>o</i> -Xylene	0.68 ± 0.23a	nd	0.76 ± 0.43a	nd
Propylbenzene	0.59 ± 0.20ab	nd	0.90 ± 0.23b	nd

Table 3 continued

Name	Garlic added		Ginger and garlic added	
	SDE ^E	SPME ^F	SDE ^E	SPME ^F
1-Methyl-4-ethylbenzene	0.00 ± 0.00b	nd	1.38 ± 0.63c	nd
1-Ethyl-3-methylbenzene	2.45 ± 0.80a	nd	2.45 ± 0.63a	nd
1,3,5-Trimethylbenzene	0.93 ± 0.20ab	nd	1.14 ± 0.60ab	nd
Styrene	0.00 ± 0.00a	nd	0.17 ± 0.13a	nd
11-Ethyl-2-methylbenzene	0.00 ± 0.00b	nd	1.03 ± 0.54a	nd
<i>p</i> -Cymene	nd	0.00 ± 0.00e	nd	0.20 ± 0.02g
1,2,4-Trimethylbenzene	0.00 ± 0.00a	nd	0.00 ± 0.00a	nd
α -Formylethylbenzene	0.05 ± 0.01b	nd	0.00 ± 0.00a	nd
1,2,3-Trimethylbenzene	0.00 ± 0.00a	nd	0.19 ± 0.07b	nd
Benzaldehyde	0.17 ± 0.06b	0.10 ± 0.02f	0.08 ± 0.05c	0.26 ± 0.10g
Acetophenone	4.32 ± 2.24b	nd	3.31 ± 0.25ab	nd
Butylated hydroxytoluene	nd	0.00 ± 0.00f	nd	0.00 ± 0.00f
Decylbenzene	0.34 ± 0.05c	nd	0.00 ± 0.00a	nd
Vanillin	0.08 ± 0.01c	nd	0.09 ± 0.03c	nd
3,4-Dimethylbenzaldehyde	0.18 ± 0.03a	nd	0.15 ± 0.04a	nd
Phenol	8.64 ± 2.82ab	4.25 ± 0.90e	2.88 ± 0.21a	3.35 ± 0.77e
Eugenol	1.38 ± 0.30c	nd	3.47 ± 0.21d	nd
2,4-Di-tert-butylphenol	nd	0.10 ± 0.04 g	nd	0.00 ± 0.00e
Total	22.7 ± 7.90a	4.46 ± 0.89f	21.29 ± 3.45a	3.81 ± 0.85f
<i>Acids</i>				
Hexanoic acid	nd	0.00 ± 0.00f	nd	0.19 ± 0.03e
Octanoic Acid	nd	0.08 ± 0.01f	nd	0.00 ± 0.00e
Hexadecanoic acid	1.78 ± 0.31b	1.54 ± 0.40f	4.86 ± 1.77a	0.00 ± 0.00e
Total	1.78 ± 0.31b	1.62 ± 0.41f	4.86 ± 1.77a	0.19 ± 0.03e
<i>Esters</i>				
Ethyl citrate	41.81 ± 12.30ab	nd	44.67 ± 2.52ab	nd
Phthalic acid, diisobutyl ester	0.77 ± 0.22b	nd	0.00 ± 0.00a	nd
Dibutyl phthalate	1.58 ± 0.46a	nd	1.67 ± 0.14a	nd
Total	44.15 ± 12.97ab	nd	46.34 ± 2.66ab	nd
<i>Sulfur compounds</i>				
Allyl sulfide	0.16 ± 0.06b	1.46 ± 0.15f	0.24 ± 0.01c	0.24 ± 0.02g
Diallyl disulfide	4.59 ± 0.40b	20.77 ± 1.50f	1.90 ± 0.12c	24.92 ± 2.71g
Diallyl trisulfide	0.21 ± 0.03b	nd	0.27 ± 0.04c	nd
Total	4.96 ± 0.39b	22.23 ± 1.65f	2.41 ± 0.17c	25.16 ± 2.73f
<i>Furan</i>				
2-Pentylfuran	0.00 ± 0.00c	0.00 ± 0.00f	0.71 ± 0.36a	0.14 ± 0.02g
Furfural	4.96 ± 0.39b	0.00 ± 0.00e	2.41 ± 0.17c	0.07 ± 0.01f
5-Hydroxymethyl furfural	nd	0.00 ± 0.00e	nd	0.00 ± 0.00e
Total	0.00 ± 0.00c	0.00 ± 0.00 g	0.71 ± 0.36a	0.21 ± 0.03h
<i>Others</i>				
2,5-Dimethylpyrazine	nd	0.00 ± 0.00f	nd	0.00 ± 0.00f

Table 3 continued

Name	Garlic added		Ginger and garlic added	
	SDE ^E	SPME ^F	SDE ^E	SPME ^F
Carbitol	nd	0.00 ± 0.00f	nd	0.00 ± 0.00f
Total	nd	0.00 ± 0.00f	nd	0.00 ± 0.00f
Total	158.79 ± 44.51b	36.69 ± 2.17f	193.34 ± 11.83b	76.00 ± 4.71g

Analyzed by ANOVA, different letters within a row are significantly different at $p < 0.05$; a–d are for SDE; e–h are for SPME

–Not obtained

nd not detected

^A Linear retention indices calculated in relation to the retention time of a series of alkanes (C8–C40) determined by using a DB-Wax column

^B MS + LRI + Std, mass spectrum and LRI agree with those of authentic compound; MS + LRI, mass spectrum identified using the NIST Mass Spectral Database and LRI agrees with the NIST Chemistry WebBook (Linstrom and Mallard 2001). MS, mass spectrum agrees with spectrum in the NIST Mass Spectral Database

^C Threshold value in water: (a) Lowest threshold obtained from Leffingwell and Associates database (2012); (b) Obtained from Perflavory website (Luebke 2016); (c) obtained from literature of Chevanee and Farmer (1999)

^D Obtained from literature of Suffet et al. (1999) and electronic references (Acree and Arn 2015; Luebke 2016)

^E Total amount of volatile compounds extracted by SDE from soup was calculated by using 1,2-dichlorobenzene as the internal reference, in μg

^F Peak area of the deconvoluted compound extracted by SPME with fiber of DVB/CAR/PDMS, 1×10^6

heptadienal; *trans*-2-decenal; *trans*-2-undecenal; 2,4-decadienal; *trans,trans*-2,4-decadienal; and hexadecanal. However, the content of these compounds was not consistent throughout the four samples. Meanwhile, some volatiles such as pentanal, hexanal, nonanal, and dodecanol, were only detected in fish soup (including with and without spices) and boiled spiced solutions (Tables 1, 2), which suggested that these volatiles may be formed as a result of boiling spices and the pan-fried fish.

In addition, the levels of volatiles derived from ginger or garlic in the fish soups with added spices were generally higher than those in the boiled spiced solutions. One possible reason was that the volatiles were soluble in the soybean oil used for frying the grass carp and were protected by the soybean oil from evaporation or reacting with other substances during boiling, and this hypothesis was in agreement with the research results of Kim et al. (1995).

Overall, alcohol and the carbonyl compounds, alkane and furan in fish soups could be mainly formed during frying or boiling of fish and derived from the oxidation of lipids (Zakipour Rahimabadi et al. 2011; Zhang et al. 2013). With the addition of ginger and garlic, the content of volatiles responsible for the presence of a fish odor (such as *trans,trans*-2,4-decadienal; 2,4-decadienal; *trans,trans*-2,4-heptadienal; hexanal; and heptanal) was not significantly decreased, and in fact some volatiles increased in amount. Therefore, the masking function by ginger and garlic of the fish odor was not through physical absorption or chemical conversion of the compounds responsible for the undesirable odors, but through the release of strongly flavored compounds such as terpenes and sulfur compounds which covered the unpleasant fish smell or mixed with the fish-odor compounds thereby creating an odorless mixture, a process called “sensational deodorizing” according to the classification of Hirasa and Takemasa (1998).

Conclusion

The most abundant volatile compounds in ginger were found to be terpenes, while raw garlic consisted mostly of sulfides (diallyl disulfide, allyl methyl disulfide, and methyl propenyl disulfide). Boiling spices in water decreased the amount of the principal volatile constituents and result in the formation of new volatiles, whereas boiling spices together with grass carp previously fried in soybean oil increased content of the residual volatile compounds. Terpenes detected in the fish soup with added ginger were derived from fresh ginger and, in contrast to the boiled ginger solution where their content was negligible which were retained in the fish soup despite the boiling. Similarly, 2-propen-1-ol and sulfides detected in the fish soup with added garlic were derived from crushed garlic and also

remained in the solution even after boiling. In conclusion, the addition of spices into a fish soup resulted in the dissolution of the main flavor volatiles from ginger and garlic into the solution, and that in contrast to the boiled ginger and garlic solution, the volatiles were retained to a greater extent in the solution even after boiling without prior frying of fish. In addition, few additional volatiles were formed during the boiling process. The masking function of ginger and garlic on fish odor was the result of “sensational deodorizing”.

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Compliance with ethical standards

Conflict of interest None.

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