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Comparison of Natural and Roasted Turkish Tombul Hazelnut (*Corylus avellana* L.) Volatiles and Flavor by DHA/GC/MS and Descriptive Sensory Analysis

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Natural (raw) and roasted hazelnuts were compared for their differences in volatile components and sensory responses. A total of 79 compounds were detected in both hazelnuts, of which 39 (27 positive, 5 tentative, and 7 unknown) were detected in natural hazelnut and 71 (40 positive, 14 tentative, and 17 unknown) were detected in roasted hazelnut. These included ketones, aldehydes, pyrazines, alcohols, aromatic hydrocarbons, furans, pyrroles, terpenes, and acids. Pyrazines, pyrroles, terpenes, and acids were detected in roasted hazelnut only. Concentrations of several compounds increased as a result of roasting and these may play significant roles in the flavor of roasted hazelnut. Pyrazines together with ketones, aldehydes, furans, and pyrroles may contribute to the characteristic roasted aroma of hazelnut. Descriptive sensory analysis (DSA) showed that some flavor attributes such as "aftertaste", "burnt", "coffee/chocolate-like", "roasty", and "sweet" were rated significantly higher in roasted hazelnut compared to its natural counterpart. Natural and roasted hazelnuts can be distinguished using these attributes.

KEYWORDS: Hazelnuts; natural; roasted; volatiles; flavor; descriptive sensory analysis; flavor attributes

INTRODUCTION

Turkey is the world's largest producer of hazelnut (approximately 650 000 MT in 2001, unshelled basis), contributing approximately 70% of the total global production (*1*). Besides its economic value (*2*) and potential health benefits (*3*−*5*), hazelnut provides a unique and distinctive flavor (*6*−*9*) and a pleasant crispness (*10*) as an ingredient in a variety of food products.

Sixteen varieties of hazelnuts are cultivated in Turkey. Among these only Tombul (Round) hazelnut, which is mainly grown throughout the Giresun province and neighboring cities, is classified as Giresun (or Premium) quality. The remaining varieties grown in all other areas of Turkey are known as Levant (or Secondary) quality. Giresun quality hazelnut has been famous for centuries because of its high oil content, distinctive taste and aroma, and easily removable brown skin during roasting (*1, 11*).

Hazelnut may be consumed natural (raw) or preferably roasted. The main purpose of roasting is to improve the desirable flavor, color, and crispy and crunchy texture (*7, 8, 10*). Volatile components of natural and roasted hazelnuts have been investigated by several researchers (*7, 9, 12*−*15*). Among several volatile aromatic compounds detected in roasted hazelnuts, 5-methyl-(*E*)-2-hepten-4-one (filbertone), has been reported as primary odorant (nutty-roasty and hazelnut-like) of roasted hazelnuts (*7, 15*). However, little is known about comparison of natural and roasted hazelnut volatiles (*9, 14*). Furthermore, the volatile components of natural and roasted Turkish hazelnuts have not been studied. Therefore, information about the volatile components of natural and roasted Turkish Tombul hazelnuts could lead to an increased consumption of hazelnuts, including their use as a snack food and ingredient in baked goods, confectionery products, cereals, ice cream, coffee, yogurt, various chocolate bars, sweet products, nougat, flavors, and fragrances, among others.

In flavor research, sensory evaluation is essential because of its high sensitivity and the ability to describe sensory properties. Descriptive sensory analysis (DSA) has been successfully used for comparing odor and taste attributes in foods and their products (*7, 45, 46*).

The objective of this study was to compare volatile components and descriptive sensory differences between natural and roasted Turkish Tombul hazelnuts.

MATERIALS AND METHODS

Preparation of Hazelnuts and Storage Conditions. Giresun quality natural (unshelled) and roasted (shelled) Tombul hazelnuts (*Corylus avellana* L.) were obtained (2 kg of each hazelnut) from Hazelnut

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Processing and Exporting Plant (Baskan Gida, Giresun, Turkey) at the beginning of the harvest season in August 2001.

The sun-dried (the usual commercial drying method) natural hazelnut samples were roasted (at 165 °C for 25 min with air velocity of 1 m/s) in the Hazelnut Processing and Exporting Plant (Baskan Gida) one week after harvesting and dispatched (packed into a sealed plastic bag) by DHL World Wide Express to the Food Research Center, University of Lincoln, U.K., within 1 day of roasting. Natural (unshelled) hazelnuts were also dispatched at the same time. Both hazelnuts were kept in a dark room at ambient temperature of around 15 °C until analyzed. All analyses were completed within one week of arrival. For sensory evaluation, both natural and roasted hazelnuts (10-g portion each) were served on different coded paper plates to panelists for DSA.

Materials. All chemicals used were obtained from Sigma-Aldrich-Fluka Company Ltd. (Fancy Road, Dorset, U.K.), unless otherwise specified.

Preparation of Internal Standard (IS) and Deodorized Water. The IS (2,4,6-trimethylpyridine) was dissolved in high-performance liquid chromatography (HPLC) grade methanol at a concentration of 1000 ppm. The final concentration of 5 ppm was prepared by dilution in deodorized water to fully hydrate the hazelnut sample for proper flavor release. HPLC-grade water and fitered water gave many artifacts on the chromatogram. Instead, deodorized water prepared daily was used. For this, HPLC-grade water was boiled in an open flask until its volume was decreased by one-third of the original. The flask was covered with aluminum foil after boiling and during cooling.

Dynamic Headspace Analysis/Gas Chromatography/Mass Spectrometry (DHA/GC/MS). Volatile compounds in hazelnuts were analyzed by DHA/GC/MS. Total ion chromatograms of volatiles were obtained using a Tekmar 3000 purge-and-trap concentrator (Tekmar Inc., Cincinnati, OH), a Star 3400 CX GC, and a Saturn GC/MS/MS 4D (Varian Associates Inc., Palo Alto, CA).

Immediately after cracking, 2.5 g of grated hazelnut (~3−4 mm × 1 mm) was placed in a 25-mL needle sparger tube (Tekmar Inc.), and a 1 mL aliquot of the 5 ppm aqueous 2,4,6-trimethylpyridine IS solution was added. The sparger tube was immediately attached to the sampling port of a Tekmar 3000 purge-and-trap concentrator and then pre-purged for 2.60 min to remove oxygen. Then, it was preheated at 50 °C for 1 min by a pocket heater (Tekmar Inc.) and purged with ultrahigh purity helium gas at a flow rate of 35 mL/min for 60 min at 50 °C to remove headspace volatiles, which were subsequently adsorbed on a Tenax trap no. 1 (Tekmar Inc.) maintained at room temperature of 22 ± 2 °C during purging. The trap was dry-purged for 6 min to remove water and then thermally desorbed at 200 °C for 4 min using helium gas at 1 mL/min. Desorbed compounds were automatically injected (in 0.75 min) into a WCOT fused-silica GC column (CP-Wax 52 CB, 60 m × 0.25 mm i.d. × 0.25 μm film thickness; Chrompack, Middelburg, The Netherlands). The flow rate of the helium carrier gas was 1 mL/min. After each run, the Tenax trap was baked at 220 °C for 10 min to remove any residual volatile compounds.

Each sample was injected in the splitless (model 1078) mode (200 °C injection temperature; 75 s valve delay). The GC oven temperature was programmed from 40 to 60 °C at 5 °C/min and then from 60 to 155 °C at 2.5 °C/min.

MS conditions were as follows: ion source temperature, 200 °C; ionization energy, 70 eV; mass scan range, 33−300 amu; electron multiplier voltage, 1650 V; scan rate, 1000 ms; and ion mode, electron ionization (EI). All analyses were performed in triplicate for each hazelnut sample and the results were averaged.

Compound Identification and Relative Amounts. Positive identifications were based on comparison of GC retention indices (RI), determined using *n*-alkanes (C_8−C_{15}) (*16*), and mass spectra of unknowns with those of authentic standard compounds analyzed under identical experimental conditions. Tentative identifications were based on matching mass spectra of unknowns with those in the NIST 92 mass spectral database (Varian Associates Inc.). Compounds were quantified according to Baek and Cadwallader (*17*).

DSA. Both natural and roasted hazelnuts were assessed using a flavor profile method (*18* with a slight modification). DSA was employed for evaluation of the natural and roasted hazelnuts, and using a 80-mm-long line with line anchors of 0 = *none* and 80 = *very*, by 10 well-trained panelists (6 males and 4 females, aged 25−50 years).

Table 1. Flavor Attributes Selected for DSA

attribute[a]	characteristics
aftertaste	remaining desirable and delicate flavor/taste after swallowing
bitter	taste associated with caffeine
burnt	smell of grilled meat, burnt smell
coffee/chocolate-like	flavor of coffee, chocolate
caramel-like	flavor of caramel or butter
fruity	delicate, desirable, fruity flavor associated with most fruits
green/grassy	odor of cut leaves of green plants
nutty	delicate, characteristic flavor of tree nut products
oily	oily taste or mouthfeel
painty	odor associated with linseed oil or oil-based paint
pungent	burning or stinging sensation
rancid	associated with old or oxidized fat
roasty	flavor of roasted meat
sour	taste associated with citric acid
sweet	taste associated with sugar or sweetener
woody	odor of hazelnut hard shell or hazelnut tree

[a] Flavor attributes were selected by observing odor and taste of 5 different coded natural and roasted hazelnut varieties.

Prior to DSA, panelists discussed the flavor properties of both hazelnut samples during three preliminary orientation sessions, each lasting 90 min, until they had agreed on their use of flavor attributes. During these orientation experiments, panelists evaluated 5 different coded natural and roasted hazelnut varieties; 16 flavor attributes (by observing odor and taste) were identified (standards were made available for panelists) when a consensus agreement was attained. DSA was performed for the 16 flavor attributes listed in **Table 1**. Hazelnut samples (10-g portion for each sample) were presented randomly to each panelist to evaluate (samples were evaluated twice). Each sample was coded with a three-digit random number.

Statistical Analysis. For statistical analysis of variances, the general linear models (GLM) procedure of statistical analysis systems (*19*) was used. One-way analysis of variance (ANOVA) and multiple-range least significant difference (LSD) tests for DSA were carried out by using a statistical program (SPSS ver. 5.0) for $p < 0.05$ significance level.

RESULTS AND DISCUSSION

Sensory Evaluation. Intensities for a number of flavor attributes ("bitter", "caramel-like", "fruity", "green/grassy", "nutty", "oily", "pungent", "sour", and "woody") were not significantly different ($p > 0.05$) between natural and roasted hazelnuts (**Figure 1**). However, in roasted hazelnut "burnt", "coffee/chocolate-like", and "roasty" notes were rated significantly ($p < 0.001$) higher than in natural hazelnut. Contributions of "bitter", "green/grassy", "pungent", and "sour" attributes to the overall flavor of natural and roasted hazelnuts were negligible. Because of the freshness of the materials, "rancid" and "painty" notes were not detected in either the natural or roasted hazelnuts. However, "bitter", "pungent", "sour", and "rancid" flavor attributes may develop during storage.

Volatile Compounds. DHA/GC/MS revealed a combined total of 79 volatile headspace compounds in both natural and roasted hazelnuts (**Table 2**). A total of 39 compounds were detected in natural hazelnut. Of these, 32 were identified (27 positive and 5 tentative) as ketones (10), aldehydes (8), alcohols (5), aromatic hydrocarbons (5), and furans (4); seven volatiles remained unidentified. On the other hand, 71 compounds were

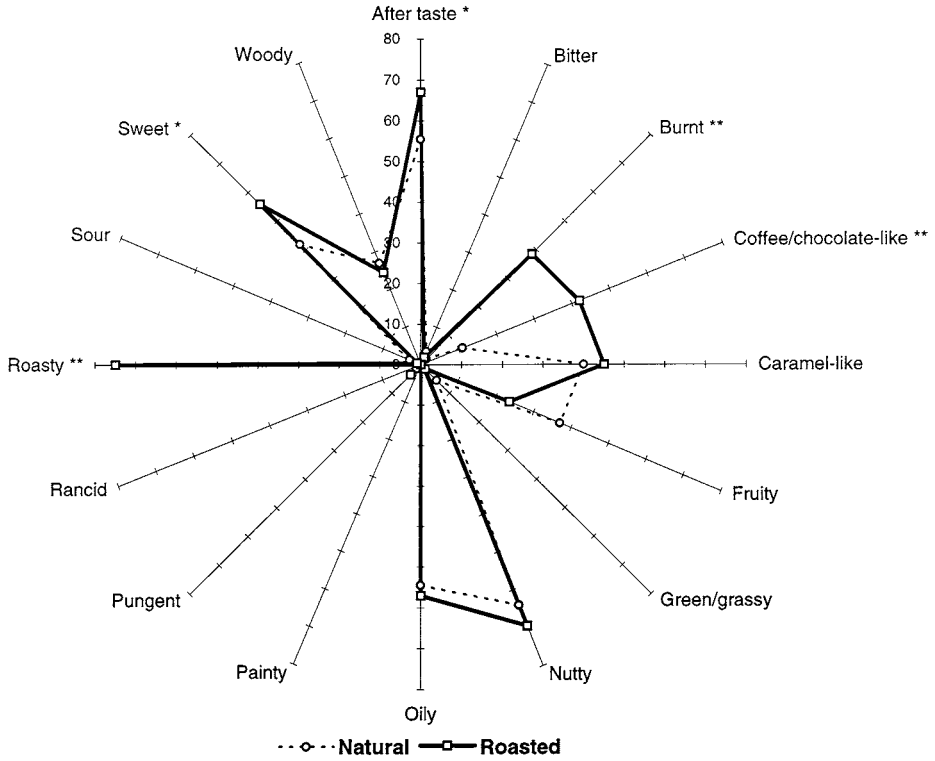

Figure 1. DSA of flavor attributes in natural and roasted Tombul hazelnuts. [Scaling: 0 = none, 80 = very. Statistical significance: **($p < 0.001$); *($p < 0.05$).]

detected in roasted hazelnut. Among these, 54 were identified (40 positive and 14 tentative) as ketones (11), pyrazines (10), aldehydes (9), alcohols (8), aromatic hydrocarbons (4), furans (4), terpenes (3), pyrroles (3), and acids (2). Seventeen volatiles were not identified (unknown). Pyrazines, terpenes, pyrroles, and acids were detected in roasted hazelnut only.

Wickland et al. (*9*) compared the volatile components of natural and roasted hazelnuts (supplied by American Almond Products Co., Inc., Brooklyn, NY) by a technique similar to what was used in the present study. They identified a combined total of 36 volatiles in both hazelnuts, with 23 (19 confirmed and 4 tentative) in natural hazelnut and 28 (21 confirmed and 7 tentative) in roasted hazelnut. Compounds identified were alcohols, aldehydes, aromatic hydrocarbons, terpenes, ketones, furans, pyrazines, pyrroles, and miscellaneous compounds. Furans, ketones, pyrazines, and pyrroles were isolated from only the roasted hazelnut. More volatile compounds were detected and identified in the present study than in that of Wickland et al. (*9*) for both the natural and roasted hazelnuts.

Natural and roasted hazelnuts exhibited complex volatile profiles. Results in **Table 2** show large differences between natural and roasted hazelnuts, and concentrations of several classes of compounds increased upon roasting. Total volatile concentrations in natural and roasted hazelnuts were 11 859 ± 1196 and 72 287 ± 7328 ng/g, respectively. Total unknown compounds contributed 9.9 and 5.4% to the total volatiles present in natural and roasted hazelnuts (data not shown), respectively. The combination of several groups of aroma-active compounds provide the distinctive and unique flavor of natural and roasted hazelnuts.

Ketones. Among 12 ketones detected, 10 were found in natural hazelnut and 11 were found in roasted hazelnut. Levels for most ketones increased upon roasting. Among these, 5-methyl-(*E*)-2-hepten-4-one (filbertone) (peak 37) has been reported to contribute an intense and characteristic odor (typical nutty-roasty and hazelnut-like aroma) to roasted hazelnut and roasted hazelnut oil (*7, 15, 20*−*23*). It contributed 1.75% (208 ± 29 ng/g) and 4.8% (3481 ± 127 ng/g) to the total volatiles present in natural and roasted hazelnuts, respectively. This compound has been reported to exert a significant odor impression even at very low concentrations (*15, 22*). Filbertone concentration has been shown to increase 472-fold after 9 min roasting of hazelnuts (*15*); however, Silberzahn (*14*) reported only an 80% increase after roasting. It was suggested that filbertone is mostly biosynthesized in the nuts, whereas a smaller portion is generated from a yet-unknown precursor (*15*). In the present study, filbertone increased by ∼16.7-fold as a result of industrial roasting of hazelnut. These significant variations among different studies show that the concentration of filbertone may vary depending upon variety, roasting time, temperature, and storage conditions. In addition to filbertone other ketones may play important roles in hazelnut aroma. For example, the compound (*E*)-3-penten-2-one (peak 16) was reported to be responsible for a fruity odor in roasted hazelnut (*7*) and 2,3-pentanedione (peak 11), a well-known sugar degradation product, contributes a sweet, buttery, and caramel-like odor (*24*). Vejaphan et al. (*25*) reported that C_4−C_8 aliphatic ketones were formed by lipid degradation during heating. Generally, because of their overall low aroma threshold values (*26*), ketones may play a significant contribution to overall flavor of both hazelnuts.

Aldehydes. Eight aldehydes were found in natural hazelnut and 9 were found in roasted hazelnut. Concentrations of several aldehydes increased significantly upon roasting. Among these, 2-methylpropanal (peak 1) and 2- and 3-methylbutanal (coeluted as peak 3 in roasted hazelnut) were predominant, comprising nearly 6.7 and 38%, respectively, of the total volatiles present in roasted hazelnut; whereas they comprised only 0.4 and 2.1%, respectively, in natural hazelnut. These three compounds have been previously reported to increase upon roasting of hazelnut (*13, 14*). Furthermore, 2- and 3-methylbutanal (peaks 2 and 3) were reported to be responsible for fruity, malty, nutty, and chocolate-like odors in roasted hazelnuts (*7*). They may originate

Table 2. Comparison of Volatile Compounds from Natural and Roasted Tombul Hazelnuts[a]

peak no.	compound[b]	RI[e]	concentration (ng/g) natural	roasted
1	2-methylpropanal	802	44 ± 9[j]	4875 ± 1172[j]
2	2-methylbutanal	897	64 ± 15	nd[ff]
3	3-methylbutanal	911	183 ± 12[j]	27445 ± 3611[j]
4	2,5-dimethylfuran	945	14 ± 5[i]	431 ± 82[j]
5	2-pentanone	968	1603 ± 148[j]	2774 ± 404[j]
6	3-methyl-2-pentanone	1013	108 ± 38[i]	597 ± 36[j]
7	α-pinene	1022	nd	598 ± 66
8	2-ethyl-5-methylfuran	1028	471 ± 98	nd
9	toluene	1038	55 ± 17[i]	723 ± 67[j]
10	2,3,5-trimethylfuran	1051	259 ± 102[i]	1595 ± 185[j]
11	2,3-pentanedione	1064	40 ± 15[i]	177 ± 41[i]
12	hexanal	1079	2780 ± 927[i]	2517 ± 445[j]
13	2-methyl-(*E*)-2-butenal	1094	nd	78 ± 28
14	2-pentanol	1109	1509 ± 221[i]	1841 ± 79[j]
16	(*E*)-3-penten-2-one[c]	1123	832 ± 163[j]	2277 ± 408[j]
18	*p*-xylene	1137	50 ± 12	nd
21	2-heptanone	1178	208 ± 25[j]	177 ± 47[i]
22	heptanal	1182	192 ± 38[j]	63 ± 24[j]
23	*o*-xylene	1188	89 ± 12	nd
24	3-methyl-1-butanol	1198	482 ± 141[i]	4983 ± 285[j]
25	1-cyclopentyl ethanone[c]	1203	tr[gi]	1562 ± 223[j]
26	(*E*)-2-hexanal	1210	59 ± 16[i]	370 ± 136[j]
28	2-pentylfuran	1230	20 ± 4[i]	120 ± 29[j]
29	1-pentanol	1240	344 ± 78[i]	684 ± 107[j]
30	3-carene	1246	nd	71 ± 8
31	5-methyl-2-heptanone[c]	1252	53 ± 11[i]	109 ± 12[j]
33	methylpyrazine	1262	nd	1181 ± 121
36	1,2,4-trimethylbenzene	1283	40 ± 10[j]	1523 ± 44[j]
37	5-methyl-(*E*)-2-hepten-4-one[cd]	1290	208 ± 29[j]	3481 ± 127[j]
38	1-octen-3-one	1293	40 ± 9	nd
39	5-methyl-5-hexen-2-one[c]	1300	nd	603 ± 253
41	2,5-dimethylpyrazine	1317	nd	1676 ± 175
42	2,6-dimethylpyrazine	1323	nd	196 ± 54
43	ethylpyrazine	1330	nd	254 ± 31
45	6-methyl-5-hepten-2-one	1334	41 ± 3[j]	332 ± 124[j]
46	1,2,3-trimethylbenzene	1340	38 ± 8[j]	526 ± 88[j]
47	1-hexanol	1344	432 ± 108[j]	123 ± 14[j]
49	IS[h]	1360		
50	2-ethyl-6-methylpyrazine	1380	nd	151 ± 19
51	2-ethyl-5-methylpyrazine	1386	nd	578 ± 32
52	nonanal	1392	203 ± 50[j]	232 ± 38[j]
53	2,5-dihydro-H-pyrrole[c]	1395	nd	125 ± 60
54	trimethylpyrazine	1397	nd	158 ± 69
55	2-ethyl-3-methylpyrazine	1399	nd	150 ± 53
56	(*E*,*E*)-2,4-hexadienal[c]	1411	27 ± 10	nd
58	3-ethyl-2,5-dimethylpyrazine	1438	nd	170 ± 19
59	1-octen-3-ol[c]	1442	nd	75 ± 19
60	1-heptanol	1447	196 ± 62[j]	31 ± 12[j]
61	2-ethyl-3,5-dimethylpyrazine	1454	nd	95 ± 31
62	acetic acid[c]	1460	nd	206 ± 23
63	2-furancarboxaldehyde[c]	1462	nd	591 ± 36
67	pyrrole	1513	nd	137 ± 29
68	benzaldehyde	1521	nd	834 ± 35
70	1-octanol	1549	nd	35 ± 11
71	1,6,7-trimethylnaphthalene[c]	1562	nd	112 ± 19
72	2-methyl-1H-pyrrole[c]	1570	nd	26 ± 3
75	3-methyl-2-cyclohexen-1-one[c]	1592	nd	74 ± 25
76	β-caryophyllene	1597	nd	62 ± 20
78	3-butenoic acid[c]	1627	nd	264 ± 101
79	4-methylbenzaldehyde[c]	1642	nd	46 ± 14
80	3-furanmethanol	1655	nd	253 ± 65
	total unknowns[k]		1177 ± 207[i]	3920 ± 560[j]
	total volatiles		11859 ± 1196[i]	72287 ± 7328[j]

[a] Data are expressed as mean ± SD ($n = 3$) on a fresh weight basis. [b] Mass spectra and GC retention indices (RI) were consistent with those of authentic standard compounds unless noted. [c] Tentatively identified (on the basis of mass spectral data only). [d] Mass spectra (MS/EI) and RI were obtained from Pfnuer et al., 1999 (*15*), and Schnermann and Schieberle, 1997 (*44*), respectively. [e] RI, retention indices. [f] nd, not detected. [g] tr, trace. [h] IS, internal standard (2,4,6-trimethylpyridine). [i,j] Means ± SD followed by the same letter, within a row, are not significantly different ($p > 0.05$). [k] Unknown compounds (data not shown; peak numbers 15, 17, 19, 20, 27, 32, 34, 35, 40, 44, 48, 57, 64–66, 69, 73, 74, and 77). [l] Coeluted as peak 3 in roasted hazelnut. Average percent RSD: 21.6%.

from Strecker degradation of isoleucine and leucine, respectively (*27*). In addition, 2-methylpropanal (peak 1) has been reported to contribute a malty odor in roasted hazelnut oil (*22*). The majority of aldehydes, which contribute green, fatty, sweet floral, and fruity aromas in foods, are generally considered lipid autoxidation products (*28*).

Pyrazines. Ten pyrazines were detected in roasted hazelnut only. Pyrazines have been previously reported in roasted hazelnuts and roasted hazelnut oil (*7, 12, 13*). In the present study, 2,5-dimethylpyrazine (peak 41) was most abundant pyrazine, followed by methylpyrazine (peak 33) and 2-ethyl-5-methylpyrazine (peak 51). Total pyrazine concentration was 4608 ± 269 ng/g (6.4% of total volatiles). Pyrazines contribute desirable nutty, roasty, and sweet odors to roasted hazelnuts and roasted hazelnut oil (*7, 22*). The compounds 2-ethyl-3,5-dimethylpyrazine (peak 61) and 2,3-diethyl-5-methylpyrazine, which elicit roasty odors, demonstrated the highest flavor-dilution (FD) factors (>1000) in roasted hazelnut oil (*22*). The latter compound was not detected or identified in roasted hazelnut in the present study.

Free amino acids and monosaccharides are essential flavor precursors for the development of the unique flavors generated during roasting and give rise to pyrazines via Maillard sugar-amine-type reactions. Moreover, pyrazines were reported to be formed by Maillard reaction through Strecker degradation from various nitrogen sources such as amino acids (*29*−*32*).

Alcohols. Five alcohols were identified in natural hazelnut and 8 were identified in roasted hazelnut. Among these, 3-methyl-1-butanol (peak 24) was the most abundant (4983 ± 285 ng/g) in roasted hazelnut. This compound was previously reported in roasted hazelnut (*12*) and may impart a dark chocolate, pungent, and sweet odor (*33, 34*). The majority of the other alcohols detected may be formed by the decomposition of hydroperoxides of fatty acids (*35*) or by reduction of aldehydes.

Aromatic Hydrocarbons. Six aromatic hydrocarbons were detected in both hazelnuts (5 in natural and 4 in roasted). Toluene (peak 9), 1,2,4-trimethylbenzene (peak 36), and 1,2,3-trimethylbenzene (peak 46) were found in significantly higher amounts in roasted than in the natural hazelnut. Aromatic hydrocarbons have been reported in natural and roasted hazelnuts by previous researchers (*9, 12*). Watanabe and Sato (*36*) reported the formation of various alkylbenzenes including 1,2,4-trimethylbenzene (peak 36) and 1,2,3-trimethylbenzene (peak 46) from beef fat during heating. These two compounds contributed a naphthalene-like note in roasted beef fat, the former having a slight green aroma (*37*).

Furans. Roasted hazelnut contained significantly higher levels of furans compared to its natural counterpart. The compounds 2-ethyl-5-methylfuran (peak 8) and 2,3,5-trimethylfuran (peak 10) could be considered to be practically odorless. Some furans have been reported to contribute burnt, sweet, bitter, cooked meat, and coconut-like flavor in some foods (*38*) and may play significant roles in the aroma of roasted hazelnut. The compound 2-methyl-3-furanthiol, which was not detected in this study, was previously reported to be a key aroma compound (roasty odor) in roasted hazelnut (*7*). Furans arise from amino acids and sugars through Maillard and Strecker degradation reactions (*39*).

Pyrroles. Three pyrroles (peaks 53, 67, and 72) were detected in roasted hazelnut only. Pyrroles, like the pyrazines and furans, are formed through the Maillard reaction during the roasting process (*39*). They possess mostly burnt aroma notes and are found among the volatiles of most heated foods (*40*).

Terpenes. Two monoterpenes (peaks 7 and 30) and one sesquiterpene (peak 76) were detected in roasted hazelnut only. The compound β-caryophyllene (peak 76) was reported to impart a perfumary, terpene-like, and woody odor in carrot (*41*). Because of the overall low odor intensities of terpenes (*42*), their contribution to the overall odor in roasted hazelnut is probably limited.

Acids. Acetic acid (peak 62) and 3-butenoic acid (peak 78) were found in roasted hazelnut only. Hexanoic acid, which was not detected in this study, was previously reported at a high FD factor (>1000) to be responsible for a sweaty odor in roasted hazelnut oil (*22*).

Precision of DHA. The precision of the DHA/GC/MS technique was assessed by calculating the standard deviation (SD) for triplicate measurements (**Table 2**). From these data the average percent relative standard deviation (%RSD) was calculated to be 21.6, ranging from 2.90 to 47.8%. %RSD for the most polar components were comparatively higher than those for the nonpolar components. Our findings agree with a previous report demonstrating that the precision of a purge-and-trap technique is very much dependent upon the polarity of the volatile compounds in the sample (*43*), as well as on the polarity and trapping efficiency of the chosen adsorbent. On the other hand, high %RSD values also may indicate large natural fluctuations in the concentrations of those compounds.

CONCLUSIONS

Differences in volatile composition and descriptive flavor attributes between natural and roasted hazelnuts were observed. The difference in volatiles recovered from the two treatments could be due to the compounds that form or increase during the roasting process (aldehydes, ketones, pyrazines, furans, and pyrroles) possibly due to nonenzymatic (Maillard) browning or Strecker degradation reactions. Therefore, volatile compounds that increase upon roasting may contribute to the characteristic flavor of roasted hazelnut. Knowledge about these compounds may assist manufacturers with food formulations, flavor and fragrance development, and other potential applications. DSA showed that natural and roasted hazelnuts can be distinguished by some flavor attributes ("aftertaste", "burnt", "coffee/chocolate-like", "roasty", and "sweet").

The experimental results indicated that the combined DHA/GC/MS technique is suitable for qualitative and quantitative analyses of hazelnut volatiles. The major advantages of the technique are its high sensitivity, simplicity, and rapid operation. Because this technique did not require exhaustive sample preparation strategies such as distillation and solvent extraction, changes in volatile components, losses, and artifact formation were minimized.

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