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ARTICLE

Effects of Roasting on Taste-Active Compounds of Turkish Hazelnut Varieties (*Corylus avellana* L.)

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The effect of roasting on taste-active components of 18 native hazelnut varieties, grown in the Giresun province of Turkey, was assessed. Samples were examined for their sugars, organic acids, condensed tannins, and free phenolic acids. Six sugars (fructose, glucose, sucrose, *myo*-inositol, raffinose, and stachyose), seven organic acids (oxalic, maleic, citric, malic, lactic, succinic, and acetic), and one phenolic acid (gallic acid) were positively identified in natural and roasted hazelnut varieties; among these, sucrose, malic acid, and gallic acid predominated, respectively. Total sugars among hazelnut varieties ranged from 1.99 to 4.94 g/100 g, organic acids from 0.96 to 2.72 g/100 g, condensed tannins from 3.99 to 40.56 mg of catechin equivalents/g, and gallic acid from 0.159 to 0.871 mg/100 g. Differences existed in the sugar and organic acid contents between natural and roasted hazelnut varieties, but they did not follow any particular trend. Significant losses ($p < 0.05$) in condensed tannins (~97.3%) and gallic acid (~66.7%) were noted when the hazelnuts were roasted. The present work suggests that roasting resulted in significant loss in condensed tannins and gallic acid due to the removal of the brown skin. The effect of roasting on sugars and organic acids was not noteworthy.

KEYWORDS: Natural hazelnuts; roasted hazelnuts; taste-active components; sugars; organic acids; condensed tannins; phenolic acids

INTRODUCTION

Hazelnut (*Corylus avellana* L.) belongs to the *Betulaceae* family and is a popular tree nut worldwide; it is mainly distributed along the coasts of the Black Sea region of Turkey, southern Europe (Italy, Spain, Portugal, and France), and in some areas of the United States (Oregon and Washington). Hazelnut is also grown in New Zealand, China, Azerbaijan, Chile, Iran, and Georgia. Turkey is the world's largest producer of hazelnuts (500,000 MT in 2009, in shell basis), contributing around 70.3% to the total global production, followed by Italy (11.9%), the United States (4.5%), Azerbaijan (4.2%), Georgia (3.8%), and Spain (2.5%). Other countries contribute only 2.8% to the total global production (*1*).

Eighteen varieties (Acı, Cavcava, Çakıldak, Foşa, Ham, İncekara, Kalınkara, Kan, Karafındık, Kargalak, Kuş, Mincane, Palaz, Sivri, Tombul, Uzunmusa, Yassı Badem, and Yuvarlak Badem) of hazelnuts are cultivated in Turkey (*2*). Among these varieties, only Tombul (round) hazelnut, mainly grown in the Giresun province, is classified as prime quality (also known as Giresun quality) due to its high oil content, distinctive taste and aroma, and easily and quickly removable brown skin during roasting. The remaining varieties grown in all parts of Turkey are known as second-grade quality (also known as Levant quality) (*2*).

Besides hazelnut's potential health benefits and nutritional values (*3*−*7*), hazelnut as a food ingredient provides a unique and distinctive flavor (*8*, *9*) and an pleasant crispness (*10*). The presence of taste-active components (e.g., free amino acids, free phenolic acids, sugars, organic acids, and condensed tannins) and aroma-active components (such as ketones, aldehydes, pyrazines, alcohols, aromatic hydrocarbons, furans, pyrroles, terpenes, and acids) in natural and roasted hazelnuts improves the sensory characteristics of the product (*3*, *8*, *11*). Thus, better flavor (taste and aroma) of hazelnut may increase the consumption of this nutritionally important nut.

Hazelnut may be consumed as natural (raw) or preferably roasted. The main purpose of roasting is to improve the desirable flavor, color, crispy, and crunchy texture of products (*8*, *10*, *12*). As mentioned earlier, only the Tombul hazelnut variety in Turkey is classified as prime-grade quality, the remaining varieties are known as second-grade quality. Although one of the criteria for this selection is distinctive taste and aroma, detailed information is limited for other hazelnut varieties besides Tombul hazelnut, which is superior to others in terms of taste and aroma. The taste and aroma of 18 natural and roasted Turkish hazelnut varieties have not yet been studied. Therefore, information about the taste and aroma of natural and roasted Turkish hazelnut varieties could lead to better characterization of hazelnuts. In parallel experiments, the aroma-active components of natural and roasted

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Turkish hazelnuts were evaluated. The objectives of this study were to assess the effect of roasting on taste-active components of 18 native Turkish hazelnut varieties grown in the Giresun province of Turkey and to see whether taste-active components could differentiate the prime- and second-grade quality hazelnuts.

MATERIALS AND METHODS

Samples. Eighteen sun-dried (3 days at ~20−25 °C) native Turkish hazelnut varieties (namely, Acı, Cavcava, Çakıldak, Foşa, Ham, İncekara, Kalınkara, Kan, Karafındık, Kargalak, Kuş, Mincane, Palaz, Sivri, Tombul, Uzunmusa, Yassı Badem, and Yuvarlak Badem) were procured from the Hazelnut Research Institute in Giresun at the beginning of the harvest season of 2008. All hazelnut varieties (1 kg from each variety) except Ham were obtained from the same location/field in order to make a true comparison. The Ham variety was obtained from the Giresun province. The natural hazelnut samples were kept in their shell in a temperature-controlled cabinet (at 5 °C with a relative humidity of 65−70%) at the Food Institute (TÜBİTAK Marmara Research Centre, Gebze, Turkey) until they were analyzed. All samples were analyzed within 2 months of arrival. The hazelnuts were shelled before analysis.

Reagents and Standards. All chemical reagents were obtained from Sigma-Aldrich-Fluka Co. Ltd. (Prolab, Istanbul, Turkey), unless otherwise stated.

Roasting of Hazelnuts. The hazelnuts were cracked and then kept at room temperature for 3 h. They were roasted at 140 °C for 30 min with an air velocity of 1 m/s (model CS02-KF Hazelnut Roasting Oven, Ceselsan Machinery Ltd., Giresun, Turkey). Each variety was roasted in three replicates in order to do statistical analyses between natural and roasted hazelnuts. The same temperature and time were applied for all hazelnut varieties regardless of kernel size.

Sugar Analysis. Sugar levels were measured according to the high-performance liquid chromatography (HPLC) method of Alasalvar et al. (*11*). A 25 g sample of grated hazelnut was homogenized in 100 mL of acetonitrile/water (1:1, v/v) for 3 min. The homogenate was then kept in a water bath at 55−60 °C for 15 min (with frequent stirring to aid in dissolving the sugars). Having centrifuged at 1500*g* for 15 min at room temperature, the supernatant was then filtered through a Whatman no. 541 filter paper. The filtrate was made up to a final volume of 100 mL with the extraction solvent to give the extract. Finally, the extract was refiltered through a Gelman Acrodisc LC13 PVDV 0.45 μm pore size syringe filter (Pall Life Sciences, Ann Arbor, MI) and then injected (20 μL) into a Supelcosil LC-NH_2 column, 250 mm × 4.6 mm i.d., 5 μm particles (Supelco, Dorset, U.K.). The equipment consisted of a Shimadzu LC-20AD pump, an RF-10AXL refractive index (RI) detector, a SIL-20A HT autosampler, a CTO-2OAC column oven, a DGU-20A_5 degasser, and a CMB-20A communications bus module (Shimadzu Corp., Kyoto, Japan). Column temperature was set at 30 °C. The mobile phase (filtered through a 0.45 μm Millipore filter and degassed prior to use) was a mixture of acetonitrile and HPLC grade water in the ratio of 75:25 (v/v) at 1 mL/min. Identified sugars were quantified on the basis of peak areas and comparison with a calibration curve obtained with the corresponding standards.

Organic Acid Analysis. Organic acids were extracted according to the method of Alasalvar et al. (*11*). A 10 g sample of grated hazelnut was homogenized in 80 mL of 0.1% phosphoric acid (H_3PO_4) for 3 min in an ice bath. The extract was subsequently centrifuged at 1500*g* for 15 min at 4 °C. The water-soluble layer was carefully collected with a pipet and then filtered through a Whatman no. 1 filter paper. The filtrate was brought to 100 mL with the extraction solvent to give the extract. After that, the filtrate was cleaned by passing 5 mL through a disposable C_{18} Sep-Pak cartridge (Waters Corp., Milford, MA), previously conditioned by flushing with 2 mL of acetonitrile followed by 5 mL of HPLC grade water. Finally, the purified extract was refiltered through a Gelman Acrodisc LC13 PVDV 0.45 μm pore size syringe filter (Pall Life Sciences) and then injected (20 μL) into a Supelcogel C-610H column, 300 mm × 7.8 mm i.d. (Supelco). The equipment consisted of a Shimadzu LC-20AD pump, an SPD-M20A diode array detector (DAD), a SIL-20A HT autosampler, a CTO-2OAC column oven, a DGU-20A_5 degasser, and a CMB-20A communications bus module (Shimadzu Corp.). Column temperature was set at 30 °C. The mobile phase (filtered through a 0.45 μm Millipore filter and degassed prior to use) was a 0.1% phosphoric acid at a flow rate of 0.5 mL/min. The DAD was set at 210 nm. Identified organic acids were quantified on the basis of peak areas and comparison with a calibration curve obtained with the corresponding standards.

Determination of Condensed Tannins. The condensed tannins were assayed colorimetrically according to a modified vanillin/HCl method (*13*). For this method were added to 1 mL of methanolic solution of condensed tannins, 5 mL of freshly prepared 0.5% vanillin solution in methanol containing 4% concentrated HCl (sample) or 5 mL of 4% concentrated HCl in methanol (blank) and mixed well. The absorbance of the sample or blank was measured using a UV spectrometer (Jasco, Tokyo, Japan) at 500 nm after 20 min of standing at room temperature. Results were expressed as milligrams of catechin equivalents (CE) per gram of sample.

Determination of Free Phenolic Acids. Free phenolic acids were assessed according to the HPLC method of Shahidi et al. (*14*). An aqueous suspension of the extract (100 mg in 10 mL) was adjusted to pH 2 (using 6 M HCl), and free phenolic acids were extracted five times, each into 10 mL of diethyl ether, using a separatory funnel. The combined extracts were then evaporated to dryness under vacuum at room temperature. The dry residue of free phenolics was dissolved separately in 2 mL of methanol and finally filtered through a Gelman Acrodisc LC13 PVDV 0.45 μm pore size syringe filter (Pall Life Sciences) for HPLC analysis.

Free phenolic acids were analyzed using a Shimadzu HPLC system (LC-20AD pump, SPD-M20A DAD detector, SIL-20A HT autosampler, CTO-2OAC column oven, DGU-20A_5 degasser, and CMB-20A communications bus module, Shimadzu Corp.). Twenty microliters of the sample extracts was automatically injected into a prepacked LiChrospher 100 RP-18 column (250 mm × 4 mm inner diameter, 5 μm particles, Merck, Darmstadt, Germany) at room temperature. Isocratic elution (filtered through a 0.45 μm Millipore filter prior to use) was employed with a mobile phase consisting of HPLC grade water/acetonitrile/acetic acid (88:10:2, v/v/v) at a flow rate of 1 mL/min. The wavelengths of the DAD were set at 280 and 320 nm for monitoring phenolic acids. Tentatively identified phenolic acids were quantified on the basis of their peak areas and comparison with a calibration curve obtained with the corresponding standards (gallic acid, caffeic acid, *p*-coumaric acid, *o*-coumaric acid, *m*-coumaric acid, ferulic acid, sinapic acid, vanillic acid, protocatechuic acid, syringic acid, gentisic acid, and salicylic acid). Results were expressed as milligrams of free phenolics per 100 g of sample.

Statistical Analysis. Results were expressed as mean ± standard deviation (SD) ($n = 3$) for each analysis. The statistical significance (*t* test: two-sample equal variance, using two-tailed distribution) was determined using Microsoft Excel statistical software (Microsoft Office Excel 2003, Microsoft Corp., Redmond, WA). Differences at $p < 0.05$ were considered to be significant.

RESULTS AND DISCUSSION

Sugars. Six sugars were positively identified in natural and roasted hazelnut varieties; these included monosaccharides (fructose, glucose, and *myo*-inositol) as well as sucrose and its galactosides, namely, raffinose and stachyose. The total sugar content of natural hazelnuts ranged from 1.99 to 4.94 g/100 g, being lowest in Kan and highest in Uzunmusa. In roasted hazelnuts, total sugar content ranged from 1.82 g/100 g in Kan to 5.52 g/100 g in Kuş (**Table 1**). Among identified sugars in natural and roasted hazelnuts, sucrose represented about 80−90% of the total amount, followed by stachyose at 5−13%. Other sugars (fructose, glucose, *myo*-inositol, and raffinose) were present in low amounts. Although there were slight increases in sugar content of some roasted hazelnuts, this could be due to moisture difference between the natural and roasted hazelnuts. We expressed the results on a fresh weight basis in all analyses because we wanted to see the edible amount of taste-active components in natural and roasted hazelnuts.

The same six sugars were also found by Botta et al. (*15*) in 12 different varieties of natural Oregon and Italian hazelnuts, although at different levels with a mean value of 4 g/100 g (dry weight basis) ranging from 2.8 to 5.6 g/100 g, with sucrose being predominant. These sugars, with the exception of *myo*-inositol,

Table 1. Sugar Content (Grams per 100 g) of Natural and Roasted Turkish Hazelnut Varieties[a]

sugar	Acı (N)	Acı (R)	Cavcava (N)	Cavcava (R)	Çakıldak (N)	Çakıldak (R)	Foşa (N)	Foşa (R)
fructose	0.02 ± 0.00 a	0.02 ± 0.00 a	0.01 ± 0.00 a	0.02 ± 0.00 b	0.02 ± 0.00 a	0.03 ± 0.00 b	0.02 ± 0.00 a	0.02 ± 0.00 a
glucose	0.01 ± 0.00 a	0.01 ± 0.00 b	0.03 ± 0.00 a	0.01 ± 0.00 b	0.03 ± 0.00 a	0.02 ± 0.00 b	0.02 ± 0.00 a	0.01 ± 0.00 b
sucrose	1.80 ± 0.07 a	2.05 ± 0.04 b	2.67 ± 0.00 a	4.39 ± 0.02 b	3.25 ± 0.02 a	4.10 ± 0.16 b	3.54 ± 0.08 a	3.17 ± 0.06 b
myo-inositol	0.06 ± 0.00 a	0.04 ± 0.00 b	0.08 ± 0.00 a	0.07 ± 0.00 a	0.09 ± 0.01 a	0.07 ± 0.01 a	0.09 ± 0.00 a	0.06 ± 0.00 b
raffinose	0.08 ± 0.01 a	0.07 ± 0.01 a	0.09 ± 0.00 a	0.11 ± 0.00 b	0.10 ± 0.00 a	0.12 ± 0.00 b	0.10 ± 0.00 a	0.12 ± 0.00 b
stacyhose	0.27 ± 0.00 a	0.32 ± 0.01 b	0.37 ± 0.01 a	0.43 ± 0.00 b	0.37 ± 0.01 a	0.35 ± 0.00 b	0.26 ± 0.01 a	0.27 ± 0.00 a
total	2.24	2.51	3.25	5.03	3.86	4.69	4.03	3.65
sugar	Ham (N)	Ham (R)	İncekara (N)	İncekara (R)	Kalınkara (N)	Kalınkara (R)	Kan (N)	Kan (R)
fructose	0.02 ± 0.00 a	0.02 ± 0.00 a	0.02 ± 0.00 a	0.02 ± 0.00 b	0.02 ± 0.00 a	0.02 ± 0.00 a	0.02 ± 0.00 a	0.02 ± 0.00 a
glucose	0.02 ± 0.00 a	0.01 ± 0.00 a	0.02 ± 0.00 a	0.01 ± 0.00 b	0.04 ± 0.00 a	0.01 ± 0.00 b	0.03 ± 0.00 a	0.01 ± 0.00 b
sucrose	3.82 ± 0.04 a	3.15 ± 0.02 b	3.38 ± 0.02 a	3.44 ± 0.00 a	2.97 ± 0.08 a	4.11 ± 0.00 b	1.59 ± 0.03 a	1.47 ± 0.01 b
myo-inositol	0.07 ± 0.00 a	0.06 ± 0.00 b	0.05 ± 0.00 a	0.08 ± 0.00 b	0.05 ± 0.00 a	0.04 ± 0.00 a	0.06 ± 0.01 a	0.03 ± 0.00 b
raffinose	0.11 ± 0.00 a	0.06 ± 0.00 b	0.08 ± 0.00 a	0.13 ± 0.00 b	0.10 ± 0.00 a	0.12 ± 0.00 b	0.05 ± 0.01 a	0.07 ± 0.01 a
stacyhose	0.26 ± 0.01 a	0.20 ± 0.00 b	0.27 ± 0.00 a	0.45 ± 0.00 b	0.31 ± 0.01 a	0.35 ± 0.00 b	0.24 ± 0.02 a	0.22 ± 0.00 a
total	4.30	3.50	3.82	4.13	3.49	4.65	1.99	1.82
sugar	Karafındık (N)	Karafındık (R)	Kargalak (N)	Kargalak (R)	Kuş (N)	Kuş (R)	Mincane (N)	Mincane (R)
fructose	0.03 ± 0.00 a	0.02 ± 0.00 b	0.02 ± 0.00 a	0.02 ± 0.00 a	0.03 ± 0.01 a	0.03 ± 0.00 a	0.02 ± 0.00 a	0.02 ± 0.00 a
glucose	0.04 ± 0.01 a	0.01 ± 0.00 b	0.02 ± 0.00 a	0.01 ± 0.00 a	0.04 ± 0.01 a	0.02 ± 0.00 b	0.01 ± 0.00 a	0.01 ± 0.00 b
sucrose	3.03 ± 0.02 a	2.89 ± 0.02 b	3.12 ± 0.02 a	3.58 ± 0.06 b	3.49 ± 0.00 a	4.78 ± 0.01 b	1.97 ± 0.03 a	2.76 ± 0.02 b
myo-inositol	0.07 ± 0.01 a	0.03 ± 0.00 b	0.08 ± 0.00 a	0.07 ± 0.00 a	0.07 ± 0.01 a	0.07 ± 0.00 a	0.05 ± 0.00 a	0.05 ± 0.00 a
raffinose	0.08 ± 0.00 a	0.11 ± 0.00 b	0.10 ± 0.00 a	0.12 ± 0.01 a	0.09 ± 0.01 a	0.14 ± 0.01 b	0.05 ± 0.00 a	0.11 ± 0.00 b
stacyhose	0.26 ± 0.01 a	0.31 ± 0.00 b	0.35 ± 0.00 a	0.34 ± 0.01 a	0.36 ± 0.03 a	0.48 ± 0.01 b	0.23 ± 0.00 a	0.30 ± 0.01 b
total	3.51	3.37	3.69	4.14	4.08	5.52	2.33	3.25
sugar	Palaz (N)	Palaz (R)	Sivri (N)	Sivri (R)	Tombul (N)	Tombul (R)	Uzunmusa (N)	Uzunmusa (R)
fructose	0.02 ± 0.00 a	0.02 ± 0.00 a	0.02 ± 0.00 a	0.02 ± 0.00 a	0.02 ± 0.00 a	0.02 ± 0.00 b	0.02 ± 0.00 a	0.02 ± 0.00 b
glucose	0.02 ± 0.00 a	0.01 ± 0.00 a	0.03 ± 0.00 a	0.01 ± 0.00 b	0.03 ± 0.00 a	0.01 ± 0.00 b	0.03 ± 0.00 a	0.01 ± 0.00 b
sucrose	2.25 ± 0.02 a	2.34 ± 0.08 a	2.56 ± 0.06 a	3.98 ± 0.14 b	2.26 ± 0.02 a	2.49 ± 0.02 b	4.25 ± 0.38 a	2.97 ± 0.04 b
myo-inositol	0.06 ± 0.00 a	0.04 ± 0.00 b	0.09 ± 0.00 a	0.07 ± 0.00 b	0.03 ± 0.00 a	0.04 ± 0.00 b	0.08 ± 0.01 a	0.06 ± 0.00 a
raffinose	0.06 ± 0.00 a	0.09 ± 0.01 b	0.06 ± 0.00 a	0.12 ± 0.00 b	0.09 ± 0.00 a	0.09 ± 0.00 b	0.12 ± 0.02 a	0.09 ± 0.00 a
stacyhose	0.19 ± 0.02 a	0.23 ± 0.01 a	0.15 ± 0.00 a	0.29 ± 0.00 b	0.29 ± 0.00 a	0.37 ± 0.00 b	0.44 ± 0.03 a	0.34 ± 0.00 a
total	2.60	2.73	2.91	4.49	2.72	3.02	4.94	3.49

sugar	Yassı Badem (N)	Yassı Badem (R)	Yuvarlak Badem (N)	Yuvarlak Badem (R)
fructose	0.02 ± 0.00 a	0.02 ± 0.00 a	0.02 ± 0.00 a	0.02 ± 0.00 a
glucose	0.02 ± 0.00 a	0.01 ± 0.00 b	0.02 ± 0.00 a	0.01 ± 0.00 b
sucrose	2.67 ± 0.20 a	2.88 ± 0.38 a	3.03 ± 0.19 a	3.42 ± 0.07 a
myo-inositol	0.08 ± 0.00 a	0.04 ± 0.01 b	0.11 ± 0.00 a	0.09 ± 0.01 a
raffinose	0.12 ± 0.01 a	0.14 ± 0.00 b	0.08 ± 0.00 a	0.13 ± 0.00 b
stacyhose	0.39 ± 0.05 a	0.41 ± 0.01 a	0.34 ± 0.01 a	0.36 ± 0.00 a
total	3.30	3.50	3.60	4.03

[a] Data are expressed as mean ± SD ($n = 3$) on a fresh weight basis. Means ± SD followed by the same letter, within a row [between the same variety of natural (N) and roasted (R) hazelnuts], are not significantly different ($p > 0.05$).

were also reported by Ruggeri et al. (*16*) in the Italian variety of Tonda Gentile Romana, with a total content of 4.1 g/100 g (fresh weight basis), as well as by Cristofori et al. (*17*) in 24 Italian and foreign hazelnut cultivars ranging from 3.98 to 5.95 (mg/100 g, dry weight basis), being lowest in Tonda Rossa and highest in Tonda Gentile Romana. In both studies, sucrose was the predominant sugar. Recently, the USDA (*6*) reported only three sugars (sucrose, glucose, and fructose) in natural hazelnut, with sucrose being the predominant one (4.20 g/100 g, fresh weight basis), followed by equal amounts of glucose and fructose (0.07 g/100 g). The number of sugars identified and the levels found in this study concur with data published by Botta et al. (*15*, *18*).

Although total sugar contents present were low in natural and roasted hazelnut varieties, sugars contribute to hazelnut flavor, thus playing an important role in nut quality. Free amino acids and monosaccharides are essential flavor precursors for the development of the unique flavors generated during roasting and give rise to pyrazines (aroma-active compounds) via Maillard reducing sugar−amino type reactions. Pyrazines contribute desirable nutty, roasty, and sweet odors to roasted hazelnuts (*8*, *12*, *19*).

Organic Acids. Six organic acids (oxalic, citric, malic, lactic, succinic, and acetic) together with trace amounts of maleic acid (only in natural Kalınkara and Kargalak varieties) were positively identified in natural and roasted hazelnuts. Organic acid content and profiles differed among natural and roasted hazelnuts as well as within the varieties (**Table 2**). The total organic acid content of natural hazelnuts varied between 0.96 g/100 g for Palaz and 2.72 g/100 g for Kuş. The corresponding values for roasted hazelnuts varied between 0.63 g/100 g for Palaz and 2.97 g/100 g for Kuş. Among identified organic acids, malic acid was predominant in most of the hazelnut varieties, ranging from 0.38 to 2.05 g/100 g and representing about 26−73% to the total organic acids present. The second most abundant organic acid was citric acid, which ranged from 0.06 to 0.98 g/100 g and represented about 5−47% to the total organic acids present. In some natural

Table 2. Organic Acid Content (Grams per 100 g) of Natural and Roasted Turkish Hazelnut Varieties[a]

organic acid	Acı (N)	Acı (R)	Cavcava (N)	Cavcava (R)	Çakıldak (N)	Çakıldak (R)	Foşa (N)	Foşa (R)
oxalic	0.06 ± 0.00 a	0.05 ± 0.00 b	0.06 ± 0.00 a	0.07 ± 0.00 b	0.03 ± 0.00 a	0.02 ± 0.00 b	0.05 ± 0.00 a	0.05 ± 0.00 a
maleic	nd	nd	nd	nd	nd	nd	nd	nd
citric	0.47 ± 0.00 a	0.17 ± 0.00 b	0.48 ± 0.01 a	0.15 ± 0.00 b	0.43 ± 0.01 a	0.14 ± 0.00 b	0.50 ± 0.01 a	0.13 ± 0.00 b
malic	0.66 ± 0.01 a	1.03 ± 0.02 b	0.68 ± 0.01 a	1.32 ± 0.01 b	0.38 ± 0.01 a	0.72 ± 0.00 b	0.46 ± 0.01 a	0.56 ± 0.01 b
lactic	0.03 ± 0.00 a	0.17 ± 0.01 b	0.02 ± 0.00 a	0.20 ± 0.00 b	0.04 ± 0.00 a	0.16 ± 0.00 b	0.03 ± 0.00 a	0.17 ± 0.00 b
succinic	0.05 ± 0.00 a	0.11 ± 0.00 b	0.09 ± 0.00 a	0.16 ± 0.00 b	0.04 ± 0.00 a	0.12 ± 0.00 b	0.05 ± 0.00 a	0.05 ± 0.00 a
acetic	0.13 ± 0.00 a	0.09 ± 0.00 b	0.09 ± 0.00 a	0.10 ± 0.01 a	0.05 ± 0.00 a	0.03 ± 0.00 b	0.16 ± 0.00 a	0.07 ± 0.00 b
total	1.40	1.62	1.42	2.00	0.97	1.19	1.25	1.03
organic acid	Ham (N)	Ham (R)	İncekara (N)	İncekara (R)	Kalınkara (N)	Kalınkara (R)	Kan (N)	Kan (R)
oxalic	0.08 ± 0.00 a	0.08 ± 0.00 a	0.04 ± 0.00 a	0.04 ± 0.00 b	0.05 ± 0.00 a	0.05 ± 0.00 b	0.03 ± 0.00 a	0.03 ± 0.00 b
maleic	nd	nd	nd	nd	tr	nd	nd	nd
citric	0.56 ± 0.01 a	0.19 ± 0.00 b	0.68 ± 0.00 a	0,14 ± 0.00 b	0.57 ± 0.00 a	0.16 ± 0.00 b	0.36 ± 0.00 a	0.15 ± 0.00 b
malic	0.46 ± 0.01 a	0.55 ± 0.00 b	1.30 ± 0.00 a	1.23 ± 0.00 b	1.53 ± 0.01 a	1.26 ± 0.01 b	0.56 ± 0.00 a	0.61 ± 0.03 a
lactic	0.03 ± 0.00 a	0.27 ± 0.14 a	0.06 ± 0.00 a	0.28 ± 0.00 b	0.06 ± 0.00 a	0.13 ± 0.00 b	0.04 ± 0.00 a	0.10 ± 0.00 b
succinic	0.05 ± 0.00 a	0.05 ± 0.01 a	0.06 ± 0.00 a	0.14 ± 0.01 b	0.07 ± 0.00 a	0.06 ± 0.00 a	0.07 ± 0.00 a	0.05 ± 0.00 b
acetic	0.14 ± 0.00 a	0.18 ± 0.15 a	0.13 ± 0.00 a	0.14 ± 0.01 b	0.13 ± 0.00 a	0.07 ± 0.00 b	0.05 ± 0.00 a	0.02 ± 0.00 b
total	1.32	1.32	2.27	1.97	2.41	1.73	1.11	0.96
organic acid	Karafındık (N)	Karafındık (R)	Kargalak (N)	Kargalak (R)	Kuş (N)	Kuş (R)	Mincane (N)	Mincane (R)
oxalic	0.06 ± 0.00 a	0.06 ± 0.00 a	0.02 ± 0.00 a	0.06 ± 0.00 b	0.04 ± 0.00 a	0.06 ± 0.00 b	0.05 ± 0.00 a	0.04 ± 0.00 b
maleic	nd	nd	tr	nd	nd	nd	nd	nd
citric	0.34 ± 0.00 a	0.14 ± 0.01 b	0.63 ± 0.00 a	0.16 ± 0.00 b	0.88 ± 0.01 a	0.16 ± 0.00 b	0.53 ± 0.00 a	0.24 ± 0.00 b
malic	0.84 ± 0.01 a	0.97 ± 0.03 b	0.68 ± 0.00 a	0.68 ± 0.00 a	1.51 ± 0.11 a	2.05 ± 0.01 b	0.48 ± 0.00 a	0.47 ± 0.01 a
lactic	0.01 ± 0.00 a	0.15 ± 0.00 b	0.09 ± 0.00 a	0.22 ± 0.00 b	0.06 ± 0.00 a	0.33 ± 0.00 b	0.04 ± 0.00 a	0.17 ± 0.00 b
succinic	0.04 ± 0.00 a	0.05 ± 0.00 a	0.03 ± 0.00 a	0.02 ± 0.00 b	0.10 ± 0.00 a	0.26 ± 0.00 b	0.08 ± 0.00 a	0.08 ± 0.00 b
acetic	0.04 ± 0.00 a	0.04 ± 0.00 a	0.08 ± 0.00 a	0.10 ± 0.00 b	0.13 ± 0.00 a	0.11 ± 0.00 b	0.09 ± 0.00 a	0.04 ± 0.00 b
total	1.33	1.41	1.53	1.24	2.72	2.97	1.27	1.04
organic acid	Palaz (N)	Palaz (R)	Sivri (N)	Sivri (R)	Tombul (N)	Tombul (R)	Uzunmusa (N)	Uzunmusa (R)
oxalic	0.04 ± 0.00 a	0.05 ± 0.00 a	0.04 ± 0.00 a	0.05 ± 0.00 b	0.05 ± 0.00 a	0.05 ± 0.00 a	0.05 ± 0.00 a	0.05 ± 0.00 a
maleic	nd	nd	nd	nd	nd	nd	nd	nd
citric	0.29 ± 0.01 a	0.06 ± 0.00 b	0.56 ± 0.01 a	0.17 ± 0.00 b	0.44 ± 0.00 a	0.14 ± 0.00 b	0.48 ± 0.00 a	0.12 ± 0.00 b
malic	0.43 ± 0.01 a	0.38 ± 0.01 a	0.74 ± 0.01 a	0.71 ± 0.03 a	0.44 ± 0.00 a	0.44 ± 0.00 a	0.74 ± 0.01 a	1.17 ± 0.00 b
lactic	0.05 ± 0.00 a	0.10 ± 0.00 b	0.05 ± 0.00 a	0.12 ± 0.00 b	0.05 ± 0.00 a	0.14 ± 0.00 b	0.12 ± 0.00 a	0.21 ± 0.00 b
succinic	0.03 ± 0.00 a	0.01 ± 0.00 b	0.11 ± 0.00 a	0.09 ± 0.00 b	0.06 ± 0.00 a	0.02 ± 0.00 b	0.09 ± 0.00 a	0.14 ± 0.00 b
acetic	0.12 ± 0.00 a	0.03 ± 0.00 b	0.04 ± 0.00 a	0.01 ± 0.00 b	0.07 ± 0.00 a	0.04 ± 0.00 b	0.05 ± 0.00 a	0.08 ± 0.00 b
total	0.96	0.63	1.54	1.15	1.11	0.83	1.53	1.77

organic acid	Yassı Badem (N)	Yassı Badem (R)	Yuvarlak Badem (N)	Yuvarlak Badem (R)
oxalic	0.06 ± 0.00 a	0.07 ± 0.00 b	0.02 ± 0.00 a	0.04 ± 0.00 b
maleic	nd	nd	nd	nd
citric	0.79 ± 0.01 a	0.12 ± 0.00 b	0.98 ± 0.01 a	0.18 ± 0.00 b
malic	0.47 ± 0.01 a	0.60 ± 0.01 b	0.79 ± 0.01 a	0.87 ± 0.00 b
lactic	0.10 ± 0.01 a	0.40 ± 0.00 b	0.21 ± 0.00 a	0.31 ± 0.00 b
succinic	0.02 ± 0.00 a	0.02 ± 0.00 a	0.06 ± 0.00 a	0.03 ± 0.00 b
acetic	0.26 ± 0.00 a	0.18 ± 0.00 b	0.21 ± 0.00 a	0.04 ± 0.00 b
total	1.70	1.39	2.27	1.47

[a] Data are expressed as mean ± SD ($n = 3$) on a fresh weight basis. Means ± SD followed by the same letter, within a row [between the same variety of natural (N) and roasted (R) hazelnuts], are not significantly different ($p > 0.05$). nd, not detected; tr, trace amount (0.001 g/100g). Malic acid may contain coeluted (or superimposed) compound.

hazelnut varieties (Çakıldak, Foşa, Ham, Mincane, Yassı Badem, and Yuvarlak Badem), citric acid was present in higher amounts than malic acid. Other organic acids were detected in small quantities. In general, variations were observed among natural hazelnuts as well as between natural and roasted hazelnuts. Ribeiro et al. (*29*) checked the influence of the processing (roasting, boiling, and frying) on organic acids of two Portuguese chestnut varieties and found that processing led to significant reduction of seven organic acids including oxalic, citric, and malic acids. In the present study, malic acid was somehow higher ($p < 0.05$) in roasted hazelnuts than natural counterparts. The possible explanation could be due to coeluted or superimposed compounds occurring at the same retention time with malic acid as a result of roasting.

The contents of organic acids of natural and roasted hazelnuts were somewhat higher than those reported for different varieties of Oregon and Italian hazelnuts (*15*). Malic, galacturonic, levulinic, succinic, citric, oxalic, acetic, and butyric acids were present in 12 varieties of hazelnuts, malic acid being the most abundant (ranging from 42 to 209 mg/100 g, dry weight basis). Galacturonic, levulinic, and butyric acids were not detected in Tombul hazelnut in this work. Recently, Cristofori et al. (*17*) identified three organic acids (namely, malic, citric, and succinic) in 24 Italian and foreign hazelnut cultivars and found that the total content ranged from 0.367 g/100 g in Tombul to 0.944 g/100 g (dry weight basis) in Gunslebert. Malic acid was the predominant organic acid, ranging from 0.268 to 0.720 g/100 g (dry weight

Table 3. Condensed Tannin Content (Milligrams of Catechin Equivalents per Gram) of Natural and Roasted Turkish Hazelnut Varieties[a]

hazelnut variety	condensed tannins in natural hazelnuts	condensed tannins in roasted hazelnuts	lost in roasted hazelnuts (%)
Acı	13.76 ± 0.07 a	0.34 ± 0.03 b	97.3
Cavcava	14.47 ± 0.46 a	0.10 ± 0.07 b	99.3
Çakıldak	10.76 ± 0.10 a	0.35 ± 0.04 b	96.7
Foşa	3.99 ± 0.05 a	0.21 ± 0.01 b	94.7
Ham	6.83 ± 0.10 a	0.00 ± 0.00 b	100
İncekara	26.89 ± 0.44 a	0.70 ± 0.02 b	97.4
Kalınkara	7.75 ± 0.22 a	0.00 ± 0.06 b	100
Kan	10.01 ± 0.42 a	0.10 ± 0.03 b	99.0
Karafındık	20.13 ± 0.55 a	0.63 ± 0.04 b	96.9
Kargalak	17.87 ± 0.22 a	1.06 ± 0.00 b	94.1
Kuş	40.56 ± 0.37 a	3.06 ± 0.60 b	92.5
Mincane	16.63 ± 0.05 a	0.20 ± 0.01 b	98.8
Palaz	13.41 ± 0.08 a	0.40 ± 0.05 b	97.0
Sivri	11.68 ± 0.10 a	0.22 ± 0.03 b	98.1
Tombul	10.38 ± 0.12 a	0.04 ± 0.00 b	99.6
Uzunmusa	17.42 ± 0.17 a	0.16 ± 0.06 b	99.1
Yassı Badem	4.27 ± 0.21 a	0.08 ± 0.01 b	98.1
Yuvarlak Badem	27.40 ± 0.26 a	1.83 ± 0.02 b	93.3

[a] Data are expressed as mean ± SD ($n = 3$) on a fresh weight basis. Means ± SD followed by the same letter, within a row of natural and roasted hazelnuts, are not significantly different ($p > 0.05$).

Table 4. Free Phenolic Acid Content (Milligrams per 100 g) of Natural and Roasted Turkish Hazelnut Varieties[a]

hazelnut variety	gallic acid in natural hazelnuts	gallic acid in roasted hazelnuts	lost in roasted hazelnuts (%)
Acı	0.217 ± 0.01 a	0.119 ± 0.00 b	45.0
Cavcava	0.738 ± 0.03 a	0.249 ± 0.01 b	57.7
Çakıldak	0.454 ± 0.02 a	0.312 ± 0.01 b	45.1
Foşa	0.484 ± 0.02 a	0.112 ± 0.00 b	76.8
Ham	0.709 ± 0.03 a	0.106 ± 0.00 b	85.0
İncekara	0.489 ± 0.02 a	0.092 ± 0.00 b	81.1
Kalınkara	0.270 ± 0.01 a	0.061 ± 0.00 b	77.5
Kan	0.520 ± 0.02 a	0.077 ± 0.00 b	85.3
Karafındık	0.871 ± 0.03 a	0.066 ± 0.00 b	92.4
Kargalak	0.364 ± 0.01 a	0.066 ± 0.00 b	82.0
Kuş	0.345 ± 0.01 a	0.102 ± 0.00 b	70.6
Mincane	0.358 ± 0.01 a	0.124 ± 0.00 b	65.4
Palaz	0.298 ± 0.01 a	0.129 ± 0.01 b	56.6
Sivri	0.407 ± 0.02 a	0.156 ± 0.01 b	61.7
Tombul	0.159 ± 0.01 a	0.119 ± 0.00 b	25.5
Uzunmusa	0.171 ± 0.01 a	0.099 ± 0.00 b	41.9
Yassı Badem	0.553 ± 0.02 a	0.241 ± 0.01 b	54.8
Yuvarlak Badem	0.304 ± 0.01 a	0.232 ± 0.01 b	23.6

[a] Data are expressed as mean ± SD ($n = 3$) on a fresh weight basis. Means ± SD followed by the same letter, within a row of natural and roasted hazelnuts, are not significantly different ($p > 0.05$).

basis) and representing about 80% to the total organic acid present. The present results are, in general, comparable with those of Cristofori et al. (*17*). The observed differences may be due to either variety or soil type.

Condensed Tannins (Proanthocyanidins). Tannins are partly responsible for the bitter and astringent taste as well as the brown color in many plant foods. They have a puckering effect in the mouth because of precipitating proteins (*3*, *20*). In addition to their taste-active properties, tannins have been reported to possess antioxidant and antiradical properties (*5*, *21*, *22*).

The content of condensed tannins, expressed as milligrams of CE per gram of sample, varied quite markedly among natural hazelnut varieties, from a low of 3.99 for Foşa to 40.56 for Kuş. A significant loss (~97.3%) was observed ($p < 0.05$) when hazelnuts were roasted (**Table 3**). In other words, < 3% of condensed tannins were retained in the roasted hazelnuts when the skins were removed. This reveals that most of the condensed tannins are located in the skins of hazelnuts. Several studies have found that phenolic compounds including condensed tannins are mainly located in the skin of the nut (*22*−*25*). Hazelnut has been reported to contain the highest amount of condensed tannins among seven tree nuts (hazelnut, almond, cashew, chestnut, pecan, pistachio, and walnut) (*26*, *27*).

Free Phenolic Acids. Phenolic acids in plant-derived foods occur in free and bound (esterified, glycosidic, and insoluble-bound) forms. Among them, free phenolic acids are known to contribute to the taste of foods.

Only gallic acid was detected in the free form in both natural and roasted hazelnut samples. The content of gallic acid varied considerably among natural hazelnut varieties, being lowest in Tombul (0.159 mg/100 g) and highest in Karafındık (0.871 mg/100 g). Significant differences ($p < 0.05$) existed between natural and roasted hazelnut varieties. Around 66.7% of gallic acid was lost upon roasting (**Table 4**). Several factors may affect the gallic acid content upon roasting such as content of gallic acid in the skin, its thermal decomposition, and eventually its liberation from esters, glucosides, and bounded forms. We did not control these processes, but we believe that the broad range of the gallic acid lost in roasted hazelnut varieties could be caused by different contents of this acid in the skin. The hazelnut samples with high levels of loss were probably characterized by the high content of gallic acid in the skins. In contrast, for hazelnut samples with low level of loss, the majority of gallic acid was probably located in the kernels and only heat treatment caused their decreases. Alasalvar et al. (*28*) did not detect any free phenolics in Tombul hazelnut, but gallic acid, *p*-coumaric acid, and sinapic acid were found in the esterified form. Therefore, free phenolics present in hazelnut may not contribute significantly to the taste of natural and roasted hazelnuts.

The present work suggests that roasting has a significant effect on the loss of condensed tannins and gallic acid due to the removal of the brown skin. In contrast, differences existed in the sugar and organic acid contents between natural and roasted hazelnuts. Prime- and second-grade natural and roasted hazelnut varieties should not be distinguished on the basis of their taste-active components. The combination of taste-active components together with aroma-active components renders synergistic effects that provide the characteristic flavor of each hazelnut.

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LITERATURE CITED

(1) INC. *Global Statistics*; International Nut and Dried Fruit Foundation: Reus, Spain, 2010.

(2) Alasalvar, C.; Pelvan, E.; Topal, B. Effects of roasting on oil and fatty acid composition of Turkish hazelnut varieties (*Corylus avellana* L.). *Int. J. Food Sci. Nutr.* **2010** (in press).

(3) Alasalvar, C.; Shahidi, F.; Amaral, J. S.; Oliveira, B. P. P. Compositional characteristics and health effects of hazelnut (*Corylus avellana* L.): an overview. In *Tree Nuts: Composition, Phytochemicals, and Health Effects*; Alasalvar, C., Shahidi, F., Eds.; CRC Press, Taylor & Francis Group: Boca Raton, FL, 2009; pp 185−214.

(4) Mercanlıgil, S. M.; Arslan, P.; Alasalvar, C.; Okut, E.; Akgül, E.; Pınar, A.; Geyik, P. Ö.; Tokgözoğlu, L.; Shahidi, F. Effects of hazelnut-enriched diet on plasma cholesterol and lipoprotein profiles in hypercholesterolemic adult men. *Eur. J. Clin. Nutr.* **2007**, *61*, 212–220.

(5) Alasalvar, C.; Shahidi, F. Natural antioxidants in tree nuts. *Eur. J. Lipid Sci. Technol.* **2009**, *111*, 1056–1062.

(6) USDA. National Nutrition Database for Standard Reference, Release 22; http://www.nal.usda.gov/fnic/foodcomp/search/ (accessed March 2010).
(7) Yücesan, F. B.; Örem, A.; Kural, B. V.; Örem, C.; Turan, İ. Hazelnut consumption decrease the susceptibility of LDL to oxidation, plasma oxidized LDL level and increases the ratio of large/small LDL in normolipidemic healthy subjects. *Anatolian J. Cardiol.* **2010**, *10*, 28–35.
(8) Alasalvar, C.; Shahidi, F.; Cadwallader, K. R. Comparison of natural and roasted Turkish Tombul hazelnut (*Corylus avellana* L.) volatiles and flavor by DHA/GC/MS and descriptive sensory analysis. *J. Agric. Food Chem.* **2003**, *51*, 5067–5072.
(9) Alasalvar, C.; Odabası, A. Z.; Demir, N.; Balaban, M. Ö.; Shahidi, F.; Cadwallader, K. R. Volaties and flavor of five Turkish hazelnut varieties as evaluated by descriptive sensory analysis, electronic nose, and dynamic headspace analysis/gas chromatography−mass spectrometry. *J. Food Sci.* **2004**, *69*, SNQ99–SNQ106.
(10) Saklar, S.; Katnas, S.; Ungan, S. Determination of optimum hazelnut roasting conditions. *Int. J. Food Sci. Technol.* **2001**, *36*, 271–281.
(11) Alasalvar, C.; Shahidi, F.; Liyanapathirana, C. M.; Ohshima, T. Turkish Tombul hazelnut (*Corylus avellana* L.). 1. Compositional characteristics. *J. Agric. Food Chem.* **2003**, *51*, 3790–3796.
(12) Langourieux, S.; Perren, R.; Escher, F. Influence of processing parameters on the aroma of dry-roasted hazelnuts. In *Frontiers of Flavour Science*; Schieberle, P., Engel, K. H., Eds.; Deutsche Forschungsanstalt für Lebensmittelchemie: Garching, Germany, 2000; pp 527−535.
(13) Price, M. L.; Scoyoc, S. V.; Butler, L. G. A critical evaluation of the vanillin reaction as an assay for tannin in sorghum grain. *J. Agric. Food Chem.* **1978**, *26*, 1214–1218.
(14) Shahidi, F.; Alasalvar, C.; Liyana-Pathirana, C. M. Antioxidant phytochemicals in hazelnut kernel (*Corylus avellana* L.) and hazelnut byproducts. *J. Agric. Food Chem.* **2007**, *55*, 1212–1220.
(15) Botta, R.; Gianotti, C.; Richardson, D.; Suwanagul, A.; Sanz, C. L. Hazelnut variety organic acids, sugars, and total lipid fatty acids. *Acta Hortic.* **1994**, *351*, 693–699.
(16) Ruggeri, S.; Cappelloni, L.; Gambelli, S.; Carnovale, E. Chemical composition and nutritive value of nuts grown in Italy. *Ital. J. Food Sci.* **1998**, *3*, 243–252.
(17) Cristofori, V.; Ferramondo, S.; Bertazza, G.; Bignami, C. Nut and kernel traits and chemical composition of hazelnut (*Corylus avellana* L.) cultivars. *J. Sci. Food Agric.* **2008**, *88*, 1091–1098.
(18) Botta, R.; Gianotti, C.; Me, G. Kernel quality in hazelnut cultivars and selections analyzed for sugars, lipids and fatty acid composition. *Acta Hortic.* **1997**, *445*, 319–326.
(19) Koehler, P. E.; Odell, G. V. Factors affecting the formation of pyrazine compounds in sugar−amine reactions. *J. Agric. Food Chem.* **1970**, *18*, 895–898.
(20) Shahidi, F.; Naczk, M. *Phenolics in Food and Nutraceuticals*; CRC Press: Boca Raton, FL, 2004.
(21) Amarowicz, R. Tannins: the new natural antioxidants? *Eur. J. Lipid Sci. Technol.* **2007**, *109*, 549–551.
(22) Monagas, M.; Garrido, I.; Lebrón-Aguilar, R.; Gómez-Cordovés, M. C.; Rybarczyk, A.; Amarowicz, R.; Bartolomé, B. Comparative flavol-3-ol profile and antioxidant capacity of roasted peanut, hazelnut, and almond skins. *J. Agric. Food Chem.* **2009**, *57*, 10590–10599.
(23) Sang, S.; Lapsley, K.; Jeong, W.-S.; Lachance, P. A.; Ho, C.-T.; Rosen, R. T. Antioxidantive phenolic compounds isolated from almond skins (*Prunus amygdalus* Batsch). *J. Agric. Food Chem.* **2002**, *50*, 2459–2463.
(24) Alasalvar, C.; Karamać, M.; Kosińska, A.; Rybarczyk, A.; Shahidi, F.; Amarowicz, R. Antioxidant activity of hazelnut skin phenolics. *J. Agric. Food Chem.* **2009**, *57*, 4645–4650.
(25) Monagas, M.; Garrido, I.; Lebrón-Aguilar, R.; Bartolome, B.; Gómez-Cordovés, C. Almond (*Prunus dulcis* (Mill.) D.A. Webb) skins as a potential source of bioactive polyphenolics. *J. Agric. Food Chem.* **2007**, *55*, 8498–8507.
(26) Gu, L.; Kelm, M. A.; Hammerstone, J. F.; Beecher, G.; Holden, J.; Haytowitz, D.; Gebhardt, S.; Prior, R. L. Concentrations of proanthocyanidins in common foods and estimations of normal consumption. *J. Nutr.* **2004**, *134*, 613–617.
(27) USDA. Database for the Proanthocyanidin Content of Selected Foods, August 2004; http://www.nal.usda.gov/fnic/foodcomp (accessed March 2010).
(28) Alasalvar, C.; Karamać, M.; Amarowicz, R.; Shahidi, F. Antioxidant and antiradical activities in extracts of hazelnut kernel (*Corylus avellana* L.) and hazelnut green leafy cover. *J. Agric. Food Chem.* **2006**, *54*, 4826–4832.
(29) Ribeiro, B.; Rangel, J.; Valentão, P.; Andrade, P. B.; Pereira, J. A.; Bölke, H.; Seabra, R. M. Organic acids in two Portuguese chestnut (*Castanea sativa* Miller) varieties. *Food Chem.* **2007**, *100*, 504–508.

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