JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Turkish Tombul Hazelnut (*Corylus avellana* L.). 1. Compositional Characteristics

CESARETTIN ALASALVAR,*,† FEREIDOON SHAHIDI,‡
CHANDRIKA M. LIYANAPATHIRANA,‡ AND TOSHIAKI OHSHIMA§

Faculty of Health and Life Sciences, Food Research Center, University of Lincoln, Brayford Pool, Lincoln, LN6 7TS, United Kingdom, Department of Biochemistry, Memorial University of Newfoundland, St. John's, Newfoundland A1B 3X9, Canada, and Department of Food Science and Technology, Tokyo University of Fisheries, Konan 4, Minato-ku, Tokyo 108-8477, Japan

The quality of Tombul (Round) hazelnut, grown in the Giresun province of Turkey, was determined by measuring proximate composition, minerals, vitamins, dietary fiber, amino acids, and taste active components (free amino acids, sugars, and organic acids). Fat was the predominant component in Tombul hazelnut (~61%). The major minerals were potassium, phosphorus, calcium, magnesium, and selenium. Hazelnut was also found to serve as an excellent source of vitamin E (24 mg/100 g) and a good source of water soluble (B complex) vitamins and dietary fiber. The major amino acids were glutamic acid, arginine, and aspartic acid. The three nonessential amino acids and the essential amino acids contributed 44.9 and 30.9% to the total amino acids present, respectively, while lysine and tryptophan were the limiting amino acids in Tombul hazelnut. Twenty-one free amino acids, six sugars, and six organic acids were positively identified; among these, arginine, sucrose, and malic acid predominated, respectively. These taste active components may play a significant role in the taste and flavor characteristics of hazelnut. Thus, the present results suggest that Tombul hazelnut serves as a good source of vital nutrients and taste active components.

KEYWORDS: Tombul hazelnut; proximate composition; minerals; vitamins; dietary fiber; amino acids; taste active components

INTRODUCTION

Turkey is the world's largest hazelnut producer (about 650 000 MT/year in 2001, unshelled basis), contributing approximately 70% to the total global production, followed by Italy (about 130 000 MT/year), the U.S. (about 45 000 MT/year), and Spain (about 25 000 MT/year). In addition, Turkey is responsible for more than 80% of world hazelnut trade totaling approximately 1 billion U.S. dollars annually (*1*). Hazelnut is, therefore, of vital importance to the economy of Turkey. Besides its economic value, hazelnut provides a unique and distinctive flavor as an ingredient in a variety of food products and plays a major role in human nutrition and health.

Turkish hazelnut is classified as Giresun or Levant in terms of its quality. Tombul (Round) hazelnut variety (contributing 25−30% of the total of Turkey's production), which is mainly grown throughout the Giresun province and neighboring cities, is classified as Giresun (or Premium) quality. Hazelnut varieties grown in all other areas of Turkey are known as Levant (or Secondary) quality. Giresun quality hazelnut has been famous for centuries due to its high oil content, distinctive taste and aroma, and easily and quickly removable brown skin during roasting (*1*). Therefore, there is a high demand for Giresun quality Tombul hazelnut both nationally and internationally.

Hazelnut has found its way into nontraditional foods due to the recognition of its nutritional and nutraceutical properties. Among nut species, hazelnut plays a major role in human nutrition and health because of its special composition of fat (mainly oleic acid), protein, carbohydrate, dietary fiber, vitamins (vitamin E), minerals, phytosterols (mainly β-sitosterol), and antioxidant phenolics (*2*−*10*).

Hazelnut is the best source of vitamin E among tree nuts (*11*) and serves as a good source of natural antioxidants (*10*). Vitamin E or α-tocopherol is a lipid soluble phenolic antioxidant. The antioxidant activity of phenolics is based on their ability to donate a hydrogen atom to free radicals. Because these compounds are able to scavenge free radicals, they are believed to have potential in the prevention of cancer, atherosclerosis, and diabetes (*12*). Hazelnut has also been reported to serve as a good source of essential minerals, amino acids, and the B complex vitamins (*7*, *9*, *11*, *13*, *14*). The good nutritional value of hazelnut is also based on its dietary fiber content, which makes it suitable for the preparation of fiber-based foods and dietary supplements. Dietary fiber has important therapeutic implications for certain conditions (diabetes, hyperlipidemia, and obesity) and may exhibit a protective effect against hypertension,

* To whom correspondence should be addressed. Tel: +44(0)1522 886024. Fax: +44(0)1522 886026. E-mail: calasalvar@lincoln.ac.uk.
† University of Lincoln.
‡ Memorial University of Newfoundland.
§ Tokyo University of Fisheries.

10.1021/jf0212385 CCC: $25.00
Published on Web 05/14/2003

CHD, cholesterol, colorectal and prostate cancers, and intestinal disorders (*15*−*19*).

Besides nutritional value, the presence of taste active components such as free amino acids, sugars, and organic acids can improve the sensory characteristics of products. Thus, better taste and flavor of hazelnut may increase the consumption of this nutritionally important nut.

More detailed research on the nutritional composition and health-promoting components of hazelnut will enhance our knowledge and appreciation for the use of hazelnut and its products in a variety of food and specialty products. The objective of this research was to investigate the nutritional composition, taste active, and health-promoting components of Turkish Tombul hazelnut. The health aspects of these components, where possible, are discussed.

MATERIALS AND METHODS

Samples. The sun-dried (commercial way of drying) premium class natural Tombul (Round) hazelnut variety (*Corylus avellana* L.) was procured from the Giresun province of Turkey at the beginning of the harvest season (August 2001) and kept unshelled in a dark room at 5 °C until analyses were carried out (all analyses were completed within 3 months). The hazelnuts were shelled before analysis. All chemicals were obtained from Sigma-Aldrich-Fluka Company Ltd. (Dorset, U.K.), unless otherwise specified.

Proximate Analysis. Percentages of moisture by vacuum oven (method 934.06), total fat by Soxhlet extraction (method 920.39C), protein by Kjeldahl nitrogen (method 920.152), and ash by direct analysis (method 940.26) were determined according to the AOAC methods (*20*). The percentage of crude protein was estimated by multiplying the total nitrogen content by a factor of 5.30 (*20*). Total carbohydrates were calculated by subtracting the total percentage of other components from 100.

Mineral Analysis. Grated hazelnut (5 g) was ashed according to the AOAC (*20*) method 985.35 to obtain ash free from carbon. The ash obtained was dissolved in 5 mL of 1 M HNO_3 and then heated over a steam bath (at 50−60 °C) for 5 min to help with dissolution. Subsequently, materials were transferred to a 100 mL volumetric flask and made up to a final volume of 100 mL with the extraction solvent. Minerals were determined using an Unicam 969 AA spectrometer equipped with a GF90 furnace and a FS90 furnace autosampler (Unicam Limited, Cambridge, U.K.). Minerals were quantified on the basis of peak areas and comparison with a calibration curve obtained with corresponding standards.

Vitamin Analysis. AOAC (*20*) methods were used for the following vitamin analyses: niacin by microbiological method (944.13), thiamin (B_1) by fluorometric method (942.23), riboflavin (B_2) by fluorometric method (970.65), pyridoxine (vitamin B_6) by microbiological method (961.15), and pantothenic acid by microbiological method (945.74). The total folate was determined according to the microbiological method of DeSouza and Eitenmiller (*21*). Biotin and vitamin B_{12} were measured by a microbiological method (*22*).

Carotene and tocol isomers were determined according to the method described by Bushway (*23*) and Katsanidis and Addis (*24*) with some modifications, respectively. Vitamin E activity (α-tocopherol equivalents) was calculated according to the RDA (*25*) and Papas (*26*).

Ascorbic Acid Analysis. Ascorbic acid was measured according to the HPLC method of Sanchez-Mata et al. (*27*). A 5 g sample of grated hazelnut was extracted with 30 mL of 6% metaphosphoric acid for 15 min using a magnetic stirrer. Then, the extract was 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 Toyo No. 5C filter paper (Toyo Roshi Co. Ltd., Tokyo, Japan). The filtrate was made up to a final volume of 100 mL with the extraction solvent. Finally, the filtrate was refiltered through a GELMAN Acrodisc LC13 PVDV 0.45 μm pore size syringe filter (PALL Life Sciences, Ann Arbor, MI) and then immediately injected (20 μL) into an Econosphere C18 column, 300 mm × 0.25 mm i.d., 5 μm particles (Alltech Associates, Deerfiled, IL). Delaying injection caused degradation of ascorbic acid. The chromatograph consisted of a model LC-9A liquid chromatography pump (Shimadzu, Kyoto, Japan) and HP 1050 diode array detector (Hewlett-Packard, Boise, ID). The prefiltered and degassed mobile phase used was 1.8 mM H_2SO_4 (pH 2.6) at 1 mL/min. The wavelength of the diode array detector for ascorbic acid was set at 245 nm. Ascorbic acid was quantified on the basis of peak area and comparison with a calibration curve obtained with a standard (ascorbic acid was dissolved in 3% metaphosphoric acid in concentrations between 0.25 and 1 mg/100 g).

Dietary Fiber Analysis. Total, soluble, and insoluble fiber were determined by the AOAC enzymatic−gravimetric method (991.43) (*20*). The oven-dried grated hazelnut (at 105 °C for 24 h) was defatted three times each with petroleum ether (10 mL/g). The samples were then dried overnight at 40 °C. Finally, the flow diagram outlined by the AOAC procedure was followed. Crude protein was calculated as total nitrogen × 5.30.

Total Amino Acid Analysis. The amino acid composition of each sample was determined according to the procedure described by Blackburn (*28*). Samples were lyophilized and then hydrolyzed for 24 h at 110 °C with 6 M HCI. Hydrochloric acid in the hydrolyzate was removed under vacuum, and the dried sample was reconstituted with a lithium citrate buffer (0.2 M, pH 2.2) for analysis. The amino acids in the hydrolyzate were separated, identified, and quantified using a Beckman 121 MB amino acid analyzer (Beckman Instruments Inc., Palo Alto, CA). Sulfur-containing amino acids were determined by oxidizing the samples with performic acid before their hydrolysis in a 6 M HCI solution (*28*). Cysteine and methionine were measured as cysteic acid and methionine sulfone, respectively. To determine tryptophan, samples were hydrolyzed in 3 M mercaptoethanesulfonic acid at 110 °C for 22 h under nitrogen and then neutralized with lithium hydroxide and adjusted to pH 2.2 (*29*).

Free Amino Acid Analysis. A 10 g grated hazelnut was extracted with 20 mL of a 6% perchloric acid solution by homogenization using a Polytron homogenizer (Brinkmann Instruments, Rexdale, ON) at 10 000 rpm for 2 min in an ice bath. The homogenized samples were then incubated in an ice bath for 30 min. This was followed by centrifugation (IEC Centra MP4 Centrifuge, International Equipment Co., Needham Heights, MA) at 2000*g* for 15 min. The residue was reextracted with another 20 mL of 6% perchloric acid. The supernatants were combined and filtered through a Whatman No. 4 filter paper. The pH of the filtrate was adjusted to 7.0 using a 33% KOH solution. Precipitates of potassium perchlorate were removed by centrifugation at 2000*g* for 10 min. The supernatant was then acidified to pH 2.2 using a 10 M HCI solution, and the volume of the extract was brought to 50 mL with distilled water. Three milliliters of lithium citrate buffer (pH 2.2, 0.3 M) was added to 1 mL of the extract, and the resultant solution was analyzed using a Beckman 121 MB amino acid analyzer (Beckman Instruments, Inc.) for individual amino acids.

Sugar Analysis. Sugar levels were measured according to the HPLC method of Schwarzenbach (*30*) with a slight modification. 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 (stirring frequently to aid dissolving sugars). After it was 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) and then injected (20 μL) into a SUPELCOSIL LC-NH_2 column, 250 mm × 4.6 mm i.d., 5 μm particles (Supelco, Dorset, UK). The equipment consisted of a LaChrom L-7100 pump, LaChrom L-7490 RI detector, LaChrom L-7200 autosampler, and LaChrom L-7300 column oven (Merck KgaA, Darmstadt, Germany). The 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 Nisperos-Carriedo et al. (*31*) with a slight modification. A 10 g sample of grated hazelnut was homogenized in 80 mL of 0.1%

Table 1. Proximate Composition and Caloric Value of Tombul Hazelnut[a]

composition	(g/100 g)
protein	15.35 ± 0.42
fat	61.21 ± 0.99
carbohydrates[b]	17.30 ± 0.48
moisture	3.90 ± 0.20
ash	2.24 ± 0.03
energy[c]	631 kcal in 100 g/2640 kJ in 100 g

[a] Data are expressed as mean ± SD ($n = 6$). [b] Carbohydrates were calculated by subtracting the total percent values of other measurements from 100. [c] Energy was calculated according to the MAFF (*42*).

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 of the extract solution through a disposable C_{18} Sep-Pack cartilage (Waters Corporations, 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 LaChrom L-7100 pump, LaChrom L-7455 diode array detector, LaChrom L-7200 autosampler, and LaChrom L-7300 column oven (Merck KgaA). The 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 diode array detector was set at 210 nm. Identified organic acids were quantified on the basis of peak heights and comparison with a calibration curve obtained with the corresponding standards.

Statistical Analysis. Data were analyzed by SAS software (*32*). The mean and SD were determined. All determinations were performed in triplicate, unless otherwise specified.

RESULTS AND DISCUSSION

Proximate Analysis. Table 1 shows the proximate composition and caloric value of Tombul hazelnut. Fat was the predominant component (61.21 g/100 g), followed by carbohydrate (17.30 g/100 g) and protein (15.35 g/100 g). These values were comparable with those published previously in the literature for the Tombul variety of hazelnut (*9*, *10*, *33*). Parcerisa et al. (*34*) compared 10 different varieties of hazelnut cultivated in Spain and found that the average total fat content for all shelled hazelnuts was 60.2%. Harvest time, farming and drying methods, season, geographical origin, environmental factors, storage and handling conditions, in addition to the variety of hazelnut, affected the final composition of hazelnut (*6*, *9*, *10*, *35*−*37*).

Tombul hazelnut was found to be an excellent source of energy (631 kcal/100 g), due to its high fat content. The energy requirement for adult men ranges from 2300 to 2900 kcal/day and is 1900−2200 kcal/day for adult women (*25*). Hence, 100 g of hazelnut supplies approximately one-fourth of the total energy requirement per day for adults.

Minerals. Eighteen minerals (15 essential together with aluminum, cadmium, and silver) were found for the first time in hazelnut. Potassium was most abundant (761 mg/100 g), followed by phosphorus (356 mg/100 g), calcium (193 mg/100 g), and magnesium (176 mg/ 100 g) (**Table 2**). Tombul hazelnut was also found to serve as a good source of iron (4.97 mg/100 g), manganese (3.29 mg/100 g), copper (1.60 mg/100 g), and selenium (0.06 mg/100 g). Among tree nuts, only Brazil nuts contained a higher selenium content than that of Tombul hazelnut. Most mineral contents of the Tombul hazelnut were relatively higher than those reported for Tombul and other hazelnut varieties (*7*, *9*, *11*, *13*, *14*, *33*). Several studies indicated that the mineral composition of hazelnut is affected by variety, geographical origin, harvest year, climate, composition of soil, irrigation, use of fertilizer, and method of cultivation (*7*, *13*, *38*−*40*). Açkurt et al. (*7*) studied the effect of variety and geographical origin on mineral composition of eight commercial Turkish hazelnut varieties and concluded that mineral composition was strongly influenced by the variety.

Table 2. Mineral Content of Tombul Hazelnut[a]

minerals	(mg/100 g)	minerals	(mg/100 g)
aluminum	5.02 ± 0.04	manganese	3.29 ± 0.06
cadmium	0.01 ± 0.00	nickel	1.25 ± 0.03
calcium	193.4 ± 0.60	phosphorus	355.7 ± 4.16
chromium	0.01 ± 0.00	potassium	761.0 ± 2.65
cobalt	0.22 ± 0.01	selenium	0.06 ± 0.00
copper	1.60 ± 0.02	silver	0.01 ± 0.00
iron	4.97 ± 0.07	sodium	3.13 ± 0.45
lead	0.03 ± 0.01	vanadium	0.08 ± 0.00
magnesium	176.5 ± 0.50	zinc	1.94 ± 0.10

[a] Data are expressed as mean ± SD ($n = 3$) on a fresh weight basis.

With regard to human nutritional aspects, Tombul hazelnut has a significant mineral content. Eating 100−400 g of Tombul hazelnut per day supplies 100% of the RDA for adults (*25*) for the following minerals (∼100−125 g for selenium; ∼100−150 g for manganese and copper; ∼200−250 g for iron, magnesium, and phosphorus; ∼260 g for potassium; and ∼400 g for calcium). A high potassium/sodium ratio makes hazelnut interesting for diets with a defined electrolytic balance (*41*).

Although each mineral has its own health benefits, minerals are generally important as constituents of bones, teeth, soft tissues, hemoglobin, muscle, blood, and nerve cells. Minerals are also vital to overall mental and physical well-being (*42*−*44*). As mentioned above, Tombul hazelnut was found to be an excellent source of selenium, which plays a major antioxidant role. Selenium protects cell membranes by preventing free radical generation, thereby decreasing the risk of cancer and disease of the heart and blood vessels. Medical surveys have shown that increased selenium intake decreases the risk of breast, colon, lung, and prostate cancer and may preserve tissue elasticity (*45*−*47*).

Vitamins. Tombul hazelnut was found to serve as a good source of vitamin B_1 (0.42 mg/100 g), B_6 (0.63 mg/100 g), biotin (0.08 mg/100 g), and total folate (0.12 mg/100 g) and an excellent source of vitamin E (24 mg/100 g) (**Table 3**). Small amounts of vitamins B_2 (0.10 mg/100 g), niacin (1.94 mg/100 g), pantothenic acid (1.12 mg/100 g), and vitamin C (5.54 mg/100 g) were also present. These results are, in general, comparable with those published previously (*7*, *11*, *14*). Among 11 tree nuts (hazelnut, almond, Brazil nut, cashew, macademia, pecan, pinenut, pistachio, walnut, chestnut, and coconut), hazelnut contains the highest amount of vitamin E, total folate, and biotin (*11*). No vitamin B_{12} or carotene was found in Tombul hazelnut, which is in agreement with the report of Holland et al. (*11*). In addition, hazelnut was reported by the USDA (*14*) to contain 2 μg of vitamin A (retinol equivalents). No attempt was made in this study to measure vitamin A due to its negligible amount in hazelnut. Açkurt et al. (*7*) found significant differences between the vitamin content (niacin, B_1, B_2, B_6, and α-tocopherol) of different Turkish hazelnut varieties.

One hundred grams of Tombul hazelnut provides up to 59% folate of the daily 200 μg of total folate recommended for adults.

Table 3. Vitamin Content of Tombul Hazelnut[a] and Percentage of RDA

vitamins	(mg/100 g)	% of RDA[c]
E[b]	24.0 ± 0.54	240.0
thiamin (B_1)	0.42 ± 0.03	27.9
riboflavin (B_2)	0.10 ± 0.01	6.1
pyridoxine (B_6)	0.63 ± 0.04	31.3
cobalamin (B_{12})	nd[d]	0.0
niacin	1.94 ± 0.15	10.2
pantothenic acid	1.12 ± 0.07	11.2
biotin	0.08 ± 0.01	27.0
total folate	0.12 ± 0.01	59.0
ascorbic acid (C)	5.54 ± 0.23	9.2
carotene	nd	0.0

[a] Data are expressed as mean ± SD ($n = 3$) on a fresh weight basis. [b] Vitamin E (α-tocopherol equivalents). [c] RDA for adults (*25*). [d] nd, not detected.

Table 4. Dietary Fiber Content of Tombul Hazelnut[a]

dietary fiber	(g/100 g)
insoluble	10.67 ± 0.15
soluble	2.21 ± 0.10
total	12.88 ± 0.24

[a] Data are expressed as mean ± SD ($n = 3$) on a fresh weight basis.

Eating only ~40 g of hazelnut per day supplies 100% of the RDA for vitamin E (*25*) for adults. Vitamin E is a popular and the most powerful antioxidant in the body and serves as the primary defense against lipid peroxidation (*48*). The health benefits of vitamin E are strongly supported by numerous reports (*26*, *49*−*54*). Its primary task is certainly as an antioxidant, protecting the body's cells from free radical damage.

Dietary Fiber. Table 4 presents the content of dietary fiber (insoluble, soluble, and total) in Tombul hazelnut. The total dietary fiber content of hazelnut was 12.88 g/100 g, of which 2.21 g/100 g was soluble fiber. Tombul hazelnut contained a higher amount of total dietary fiber than that reported in the literature for different varieties of hazelnut, ranging from 6.5 to 9.7 g/100 g (fresh weight basis) (*11*, *14*, *55*). In addition, Savage and McNeil (*6*) compared the dietary fiber content of six cultivars of hazelnut grown in New Zealand. Their results ranged from 9.8 to 13.2 g/100 g (dry weight basis), being lowest in Tonda di Giffoni and highest in Campanica.

Although no RDA has been set, most health/nutrition professionals agree on the benefit of increased consumption of dietary fiber up to 25−35 g/day (*56*, *57*). Eating ~200 g of Tombul hazelnut per day is adequate for this requirement. Although fiber-rich foods (wheat bran, whole grains, oats, vegetables, fruits, seeds, etc.) often contain a combination of both soluble and insoluble fibers, some foods are particularly rich in soluble fiber (oats, fruits, vegetables, pulses, legumes, etc.). Tombul hazelnut was found to be a good source of both insoluble and soluble fiber.

Dietary fiber (indigestible carbohydrate) is not a nutrient, but it still plays a very important role in maintaining good health (*15*−*17*). Soluble fiber dissolves in the gut to form a viscous gel that slows down the release of some nutrients, particularly glucose, into the bloodstream; it is therefore good for diabetics in controlling their blood sugar levels. Blood cholesterol is a major risk factor for CHD, and increasing dietary fiber has been recommended as a means to lower cholesterol levels. It has been suggested that soluble fiber reduces total and LDL cholesterol. One gram of soluble fiber from oat products has been reported to decrease total cholesterol by 0.045 mmol/L and LDL cholesterol by 0.057 mmol/L (*18*). In addition, many studies have found that high-fiber diets, especially those high in soluble fiber, can reduce the risk of prostate cancer (*19*).

Insoluble fiber, which is present in high levels (10.67 g/100 g) in hazelnut, has a spongelike effect in the gut, soaking up water and swelling in size. This effect produces a feeling of fullness and adds bulk to the gut contents, increasing the mass frame waste matter and speeding it through the large intestine, thus reducing the risk of constipation and possibly even cancers of the digestive system (*58*−*60*).

Table 5. Amino Acid Composition of Tombul Hazelnut[a]

composition	(mg/g protein)	(g/100 g hazelnut)
alanine	45.5 ± 0.9	0.70 ± 0.02
arginine	140.4 ± 6.9	2.16 ± 0.06
aspartic acid	99.0 ± 3.3	1.52 ± 0.04
cysteine	30.2 ± 0.7	0.46 ± 0.01
glutamic acid	204.2 ± 8.7	3.13 ± 0.08
glycine	46.4 ± 3.3	0.71 ± 0.02
histidine[b]	29.1 ± 0.4	0.45 ± 0.01
hydroxyproline	3.6 ± 0.1	0.06 ± 0.00
isoleucine[b]	37.6 ± 2.1	0.58 ± 0.02
leucine[b]	69.8 ± 2.2	1.07 ± 0.03
lysine[b]	27.0 ± 1.1	0.41 ± 0.01
methionine[b]	15.3 ± 0.4	0.23 ± 0.01
phenylalanine[b]	43.0 ± 0.9	0.66 ± 0.02
proline	36.5 ± 1.5	0.56 ± 0.02
serine	42.5 ± 2.7	0.65 ± 0.02
threonine[b]	34.6 ± 1.1	0.53 ± 0.01
tryptophan[b]	2.5 ± 0.3	0.04 ± 0.00
tyrosine	34.7 ± 1.1	0.53 ± 0.01
valine[b]	46.0 ± 1.4	0.71 ± 0.02
total essential amino acids	304.9 ± 2.8	4.68 ± 0.13
total amino acids	987.9 ± 9.3	15.16 ± 0.41

[a] Data are expressed as mean ± SD ($n = 3$) on a fresh weight basis. [b] Essential amino acids.

Amino Acids. Tombul hazelnut was a good source of both essential and nonessential amino acids (**Table 5**). Glutamic acid was the most abundant (3.13 g/100 g) amino acid, followed by arginine (2.16 g/100 g) and aspartic acid (1.52 g/100 g). The three nonessential and essential amino acids contributed 44.9 and 30.9% to the total amino acids present, respectively, in good agreement with values reported in the literature (*14*, *33*). As in previous studies, asparagine and glutamine were not found in hazelnut (*14*, *33*). Pala et al. (*33*) did not detect any tryptophan in eight Turkish hazelnut varieties including Tombul. Except for lysine and tryptophan, which existed below the levels (mg/g protein) of reference protein (*61*), other essential amino acids were present above the reference values (**Table 5**). Additionally, the content of amino acids in hazelnuts varies according to genotype, variety, growing seasons, environmental factors, and maturity (*33*, *62*).

In general, animal proteins (meat, fish, poultry, milk, cheese, and eggs), which contain ample amounts of all essential amino acids, are considered good sources of complete proteins. On the other hand, plant proteins (including nuts) are often called incomplete proteins, because they generally do not have enough of one or more of the essential amino acids. Although Tombul hazelnut protein contained all of the essential amino acids, lysine and tryptophan were considered as potential limiting amino acids, as noted earlier.

Free Amino Acids. Table 6 shows the free amino acids present in Tombul hazelnut. Hazelnut contained large amounts of arginine (204.9 mg/100 g) and glutamic acid (128.7 mg/100 g) along with lesser amounts of aspartic acid (71.3 mg/100 g), alanine (68.1 mg/100 g), and asparagine (53.6 mg/100 g). These five amino acids constituted 73.6% of the total free amino acids in Tombul hazelnut. Although individual free amino acids have

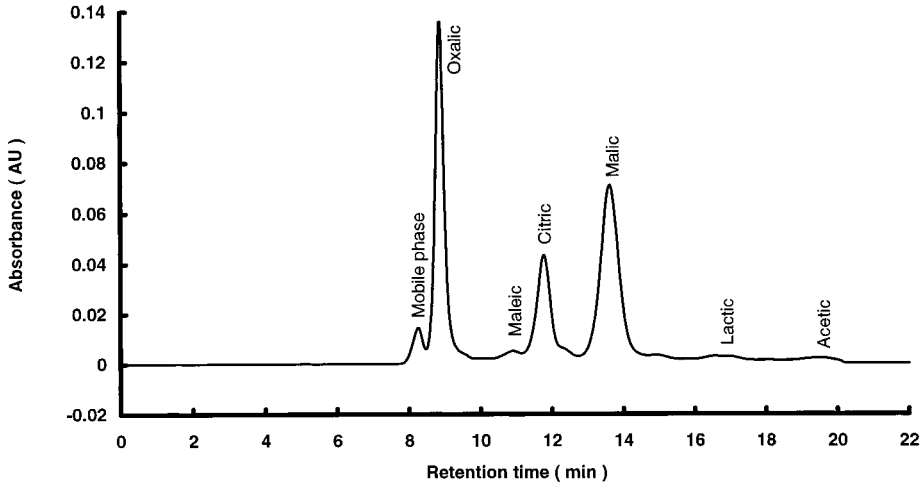

Figure 1. HPLC organic acids profile of Tombul hazelnut.

Table 6. Free Amino Acid Composition of Tombul Hazelnut[a]

composition	(mg/100 g)
alanine	68.13 ± 0.99
arginine	204.92 ± 2.94
aspartic acid	71.32 ± 1.31
asparagine	53.65 ± 0.72
cysteine	14.14 ± 1.52
glutamic acid	128.68 ± 1.34
glutamine	7.99 ± 0.11
glycine	16.10 ± 0.27
histidine	8.16 ± 0.13
hydroxyproline	0.31 ± 0.01
isoleucine	11.07 ± 1.17
leucine	11.16 ± 0.54
lysine	14.86 ± 0.46
methionine	0.72 ± 0.01
phenylalanine	10.18 ± 0.25
proline	14.52 ± 0.85
serine	14.23 ± 0.03
threonine	19.73 ± 0.15
tryptophan	13.50 ± 1.27
tyrosine	12.52 ± 0.37
valine	19.36 ± 0.30
total	715.25 ± 3.40

[a] Data are expressed as mean ± SD ($n = 3$) on a fresh weight basis.

Table 7. Sugar and Organic Acid Compositions of Tombul Hazelnut[a]

sugars	(g/100 g)	organic acids	(g/100 g)
fructose	0.14 ± 0.05	oxalic	0.080 ± 0.002
glucose	0.11 ± 0.03	maleic	0.001 ± 0.000
sucrose	2.67 ± 0.43	citric	0.412 ± 0.005
myo-inositol	0.04 ± 0.01	malic[b]	1.050 ± 0.036
raffinose	0.14 ± 0.10	lactic	0.032 ± 0.001
stachyose	0.48 ± 0.08	acetic	0.049 ± 0.001
total	3.58 ± 0.56	total	1.624 ± 0.032

[a] Data are expressed as mean ± SD ($n = 3$) on a fresh weight basis. [b] Malic acid may contain 5.54 mg/100 g ascorbic acid.

been reported to impart distinct taste and flavor to foods (*63*−*66*), the free amino acids found in the highest amounts in Tombul hazelnut are responsible for bitter, sour, and sweet tastes in foods (*66*, *67*). However, free amino acids play an important role in the formation of color and aroma during roasting (*68*, *69*).

Sugars. Six sugars were positively identified in Tombul hazelnut; these included monosaccharides (fructose, glucose, and *myo*-inositol) as well as sucrose and its galactosides, namely, raffinose and stachyose. The total sugar content of hazelnut averaged 3.58 g/100 g, and sucrose contributed 74.6% to the total amount, followed by stachyose at 13.4% (**Table 7**). Other sugars (fructose, glucose, *myo*-inositol, and raffinose) were present in low amounts, totaling 12%. The same six sugars were also found by Botta et al. (*69*) in 12 different varieties of Oregon and Italian hazelnuts although at different levels totaling an average of 4 g/100 g (dry weight basis) ranging from 2.8 to 5.6 g/100 g with sucrose being predominant. The USDA (*14*) has identified only three sugars (sucrose, glucose, and fructose) in hazelnut with sucrose being the predominant sugar (4.20 g/100 g), followed by the same amount of glucose and fructose (0.07 g/100 g). The number of sugars identified and levels found in this study concur with data published by Botta et al. (*69*, *70*). Low levels of monosaccharides in hazelnut serve as an indicator of good storage conditions of products (*71*, *72*).

Sugars are responsible for the sweetness of foods. Individual sugars possess different relative sweetness scores; fructose has been reported to be the sweetest sugar (1.1−1.8) followed by sucrose (1.0) and glucose (0.5−0.8) (*73*).

Organic Acids. Figure 1 illustrates the typical chromatographic separation of organic acids extracted from Tombul hazelnut. Six organic acids were positively identified, among which malic acid predominated (1.050 g/100 g), followed by lesser amounts of citric acid (0.412 g/100 g) and oxalic acid (0.080 g/100 g). Malic, citric, and oxalic acids contributed 95% to the total organic acids present (**Table 7**). Small quantities of acetic and lactic acids and trace amounts of maleic acid were also found in Tombul hazelnut. In addition, Tombul hazelnut contained 5.54 mg/100 g ascorbic acid (**Table 3**), which coeluted (or superimposed) with malic acid (malic acid, 13.63 min, and ascorbic acid, 13.95 min). In other words, malic acid may contain 5.54 mg/100 g ascorbic acid. Therefore, a different HPLC technique and column were used to quantify ascorbic acid.

The contents of organic acids of Tombul hazelnut were somewhat higher than those reported for different varieties of Oregon and Italian hazelnuts (*69*). Malic, galacturonic, levulinic, succinic, citric, oxalic, acetic, and butyric acids were present in 12 varieties of hazelnuts; malic acid was the most abundant (ranging from 42 to 209 mg/100 g, dried weight basis). Galacturonic, succinic, levulinic, and butyric acids were not detected in Tombul hazelnut in this work. The observed differences may be due to either variety or soil type.

Organic acids have generally been reported to be responsible for sour, tart, acidic, and characteristic fruity tastes of many foods (*74*−*77*). Malic acid, which was the predominant organic

acid in hazelnut, has a characteristic fruity, mellow, smooth, tart, and sour taste in fresh fruits and vegetables.

The presence and composition of taste active components (free amino acids, sugars, and organic acid) of hazelnut may be affected by various factors such as variety, growing condition, maturity, season, geographic origin, fertilization, soil type, storage conditions, amount of sunlight received, and time of harvest, among others (*69*−*72*).

CONCLUSIONS

The data presented in this study show that Tombul hazelnut can play a major role in human nutrition and health because of its high and special nutritional components. Thus, these nutritional attributes show that hazelnut can serve as an important healthy food in the human diet. The content and composition of free amino acids, sugars, and organic acids may play a significant role in the taste and flavor of Tombul hazelnut.

ABBREVIATIONS USED

AA, atomic absorption; AOAC, association of analytical chemists; CHD, coronary heart disease; HPLC, high-performance liquid chromatography; LDL, low-density lipoprotein; MAFF, Ministry of Agriculture, Fisheries and Food; MT, metric tons; RDA, recommended dietary allowances; SAS, statistical analytical systems; SD, standard deviation; USDA; United States Department of Agriculture.

LITERATURE CITED

(1) Turkish Hazelnut Exporter's Union. *The Turkish Hazelnut*; Hazelnut Promotion Group: Giresun, Turkey, 2002.

(2) Alphan, E.; Pala, M.; Açkurt, F.; Yilmaz, T. Nutritional composition of hazelnuts and its effects on glucose and lipid metabolism. *Acta Hortic.* **1997**, *445*, 305−310.

(3) Parcerisa, J.; Richardson, D. G.; Rafecas, M.; Codony, R.; Boatella, J. Fatty acid distribution in polar and nonpolar lipid classes of hazelnut oil (*Corylus avellana* L.). *J. Agric. Food Chem.* **1997**, *45*, 3887−3890.

(4) Richardson, D. G. The health benefits of eating hazelnuts: implications for blood lipid profiles, coronary heart disease, and cancer risks. *Acta Hortic.* **1997**, *445*, 295−300.

(5) Savage, G. P.; McNeil, D. L.; Dutta, P. C. Lipid composition and oxidative stability of oils in hazelnuts (*Corylus avellana* L.) grown in New Zealand. *J. Am. Oil Chem. Soc.* **1997**, *74*, 755−759.

(6) Savage, G. P.; McNeil, D. L. Chemical composition of hazelnuts (*Corylus avellana* L.) grown in New Zealand. *Int. J. Food Sci. Technol.* **1998**, *49*, 199−203.

(7) Açkurt, F.; Özdemir, M.; Biringen, G.; Löker, M. Effects of geographical origin and variety on vitamin and mineral composition of hazelnut (*Corylus avellana* L.) varieties cultivated in Turkey. *Food Chem*. **1999**, *65*, 309−313.

(8) Durak, I.; Köksal, I.; Kaçmaz, M.; Büyükkoçak, S.; Çimen, B. M. Y.; Öztürk, H. S. Hazelnut supplementation enhances plasma antioxidant potential and lowers plasma cholesterol levels. *Clin. Chim. Acta* **1999**, *284*, 113−115.

(9) Özdemir, M.; Devres, O. Turkish hazelnuts: properties and effect of microbiological and chemical changes on quality. *Food Rev. Int.* **1999**, *15*, 309−333.

(10) Yurttas, H. C.; Schafer, H. W.; Warthesen, J. J. Antioxidant activity of nontocopherol hazelnut (*Corylus spp.)* phenolics. *J. Food Sci.* **2000**, *65*, 276−280.

(11) Holland, B.; Welch, A. A.; Unwin, I. D.; Buss, D. H.; Paul, A. A.; Southgate, D. A. T. *McCance and Widdowson's The Composition of Foods*, 5th ed.; The Royal Society of Chemistry and Ministry of Agriculture, Fisheries and Food: Cambridge, U.K., 1995.

(12) Thompson, L. U. Antioxidant and hormone-mediated health benefits of whole grains. *Crit. Rev. Food Sci. Nutr.* **1994**, *34*, 473−497.

(13) Bonvehi, J. S.; Coll, F. V. A chemical study of the mineral fraction of Tarragona hazelnuts (*Corylus avellana* L.). *Acta Aliment.* **1997**, *26*, 243−253.

(14) *USDA (United States Department of Agriculture) Nutrition Data Base for Standard Reference, Release 15 (NDB No: 12120)*; National Technical Information Service, USDA: Springfield, VA, 2002.

(15) Anderson, J. W.; Bridges, S. R. Dietary fiber of selected foods. *Am. J. Clin. Nutr.* **1988**, *47*, 440−447.

(16) Kritchevsky, D. Dietary fiber. *Annu. Rev. Nutr.* **1988**, *8*, 301−328.

(17) Johnson, I. T.; Southgate, D. A. T. *Dietary Fibre and Related Substances*; Chapman and Hall: London, U.K., 1994.

(18) Brown, L.; Rosner, B.; Willett, W. W.; Sacks, F. M. Cholesterol-lowering effects of dietary fiber: a meta-analysis. *Am. J. Clin. Nutr*. **1999**, *69*, 30−42.

(19) Tariq, N.; Jenkins, D. J. A.; Vidgen, E.; Fleshner, N.; Kendall, C. W. C.; Story, J. A.; Singer, W.; D'Coosta, M.; Struthers, N. Effect of soluble and insoluble fiber diets on serum prostate specific antigen in men. *J. Urol.* **2000**, *163*, 114−118.

(20) AOAC. *Official Methods of Analysis*, 16th ed.; Association of Analytical Chemists: Arlington, VA, 1995.

(21) DeSouza, S.; Eitenmiller, R. R. Effects of different enzyme treatments on extraction of total folate from various foods prior to microbiological and radioassay. *J. Micronutr. Anal.* **1990**, *7*, 37−57.

(22) Favell, D. J. Vitamin analysis − microbiological methods. *J. Micronutr. Anal.* **1990**, *7*, 237−246.

(23) Bushway, R. J. Determination of α- and β-carotene in some fruits and vegetables by high-performance liquid chromatography. *J. Agric. Food Chem.* **1986**, *34*, 409−412.

(24) Katsanidis, E.; Addis, P. B. Novel HPLC analysis of tocopherols, tocotrienols and cholesterol in tissue. *Free Radical Biol. Med*. **1999**, *27*, 1137−1140.

(25) Recommended Dietary Allowances. *Recommended Dietary Allowances/Subcommittee on the Tenth Edition of the RDAs, Food and Nutrition Board, Commission on Life Sciences, National Research Council*, 10th ed.; National Academy Press: Washington, DC, 1989.

(26) Papas, A. M. Vitamin E: tocopherols and tocotrienols. In *Antioxidant Status, Diet, Nutrition and Health*; Papas, A. M., Ed.; CRC Press: Boca Raton, FL, 1999; pp 189−210.

(27) Sanchez-Mata, M. C.; Camara-Hurado, M.; Diez-Marques, C.; Torija-Isasa, M. E. Composition of high-performance liquid chromatography and spectrofluorimetry for vitamin C analysis of green beans (*Phaseolus vulgaris* L.). *Eur. Food Res. Technol.* **2000**, *210*, 220−225.

(28) Blackburn, S. *Amino Acid Determination: Methods and Techniques*; Marcel Dekker: New York, 1968.

(29) Penke, B.; Ferenczi, B.; Kovacs, K. A new acid hydrolysis method for determining tryptophan in peptides and proteins. *Anal. Biochem.* **1974**, *60*, 45−50.

(30) Schwarzenbach, R. A chemically bonded stationary phase for carbohydrate analysis in liquid chromatography. *J. Chromatogr.* **1976**, *117*, 206−210.

(31) Nisperos-Carriedo, M. O.; Buslig, B. S.; Shaw, P. E. Simultaneous detection of dehydroascorbic, ascorbic and some organic acids in fruits and vegetables by HPLC. *J. Agric. Food Chem.* **1992**, *40*, 1127−1130.

(32) SAS. *Statistical Analytical Systems User's Guide*; SAS Institute Inc: Cary, NC, 1990; Vol. 2.

(33) Pala, M.; Açkurt, F.; Löker, M.; Yildiz, M.; Ömeroglu, S. Composition and nutritional evaluation of different hazelnut varieties. *Turk. J. Agric. For.* **1996**, *20*, 43−48 (in Turkish).

(34) Parcerisa, J.; Boatella, J.; Codony, R.; Rafecas, M.; Castellote, A. I.; García, J.; López, A.; Romero, A. Comparison of fatty acid and triacylglycerol compositions of different hazelnut varieties (*Corylus avellana* L.) cultivated in Catalonia (Spain). *J. Agric. Food Chem.* **1995**, *43*, 13−16.

(35) Bonvehi, J. S.; Coll, F. V. Oil content, stability and fatty acid composition of the main varieties of Catalonian hazelnuts (*Corylus avellana* L.). *Food Chem.* **1993**, *48*, 237−241.
(36) Parcerisa, J.; Boatella, J.; Codony, R.; Farràn, A.; Garcia, J.; López, A.; Rafecas, M.; Romero, A. Influence of variety and geographical origin on the lipid fraction of hazelnuts (*Corylus avellana* L.) from Spain: (I). Fatty acid composition. *Food Chem.* **1993**, *48*, 411−414.
(37) Ebrahem, K. S.; Richardson, D. G.; Tetley, R. M.; Mehlenbacher, S. A. Oil content, fatty acid composition, and vitamin E concentration of 17 hazelnut varieties, compared to other types of nuts and oil seeds. *Acta Hortic.* **1994**, *351*, 685−692.
(38) Shrestha, G. K.; Thompson, M. M. Mineral contents in normal and brown stained fruits of *Corylus avellana* L. *J. Inst. Agric. Anim. Sci*. **1987**, *8*, 111−120.
(39) Parcerisa, J.; Rafecas, M.; Castellote, A. I.; Codony, R.; Farràn, A.; Garcia, J.; Gonzalez, C.; López, A.; Romero, A.; Boatella, J. Influence of variety and geographical origin on the lipid fraction of hazelnuts (*Corylus avellana* L.) from Spain: (III). Oil stability, tocopherol content and some mineral contents (Mn, Fe, Cu). *Food Chem.* **1995**, *53*, 71−74.
(40) Özdemir, M.; Açkurt, F.; Kaplan, M.; Yildiz, M.; Löker, M.; Gürcan, T.; Biringen, G.; Okay, A.; Seyhan, F. G. Evaluation of new Turkish hybrid hazelnut (*Corylus avellana* L.) varieties: fatty acid composition, α-tocopherol content, mineral composition and stability. *Food Chem.* **2001**, *73*, 411−415.
(41) Stamler, J. Assessing diets to improve world health, nutritional research on disease causation in population. *Am. J. Clin. Nutr*. **1994**, *59*, S146−S156.
(42) MAFF. *Manual of Nutrition*, 10th ed.; Reference Book 342; HMSO: London, U.K., 1995.
(43) O'Dell, B. L.; Sunde, R. A. Introduction. In *Handbook of Nutritionally Essential Minerals*; O'Dell, B. L., Sunde, R. A., Eds.; Marcel Dekker: New York, 1997; pp 1−12.
(44) Sardesai, V. M. *Introduction to Clinical Nutrition*; Marcel Dekker: New York, 1998.
(45) Jansson, B. Selenium and cancer. *Cancer Bull.* **1984**, *36*, 164−166.
(46) Combs, G. F., Jr.; Combs, S. B. *The Role of Selenium in Nutrition*; Academic Press: Orlando, FL, 1986.
(47) Oldfield, J. E. Some implications of selenium for human health. *Nutr. Today* **1991**, *26*, 6−11.
(48) Burton, G. W.; Joyce, A.; Ingold, K. U. First proof that vitamin E is major lipid-soluble, chain-breaking antioxidant in human blood plasma. *Lancet* **1982**, *8292 ii*, 327.
(49) Belcher, J. D.; Balla, J.; Balla, G.; Jacobs, D. R., Jr.; Gross, M.; Jacob, H. S.; Vercellotti, G. M. Vitamin E, LDL, and endothelium: brief oral vitamin supplementation prevents oxidized LDL-mediated vascular injury in vitro. *Arterioscler. Thromb.* **1993**, *13*, 1779−1789.
(50) Gerrish, K. E.; Gensler, H. L. Prevention of photocarcinogenesis by dietary vitamin E. *Nutr. Cancer* **1993**, *19*, 125−133.
(51) Prasad, K.; Kalra, J. Oxygen free radicals and hypercholesterolemic atherosclerosis: effect of vitamin E. *Am. Heart J.* **1993**, *125*, 958−973.
(52) Rimm, E. B.; Stampfer, M. J.; Ascherio, A.; Giovannucci, E.; Colditz, G. A.; Willett, W. C. Vitamin E consumption and the risk of coronary heart disease in men. *N. Engl. J. Med.* **1993**, *328*, 1450−1456.
(53) Stephens, N. G.; Parsons, A.; Schofield, P. M.; Kelly, F.; Cheeseman, K.; Mitchinson, M. J. Randomised controlled trial of vitamin E in patients with coronary disease: Cambridge Heart Antioxidant Study (CHAOS). *Lancet* **1996**, *347*, 781−786.
(54) Wang, X.; Quinn, P. J. Vitamin E and its function in membranes. *Prog. Lipid Res.* **1999**, *38*, 309−336.
(55) Lintas, C.; Cappelloni, M. Dietary fiber content of Italian fruit and nuts. *J. Food Compos. Anal.* **1992**, *5*, 146−151.
(56) NACNE. Proposals for nutritional guidelines for health education in Britain. *Lancet* **1983**, *12*, 835−837.
(57) Dreher, M. L. *Handbook of Dietary Fiber*; Marcel Dekker: New York, 1987.
(58) Kritchevsky, D. Dietary fiber and atherosclerosis. In *Dietary Fiber: Basic and Clinical Aspects*; Vahouny, G. V., Kritchevsky, D., Eds.; Plenum Press: New York, 1986; pp 265−274.
(59) Kritchevsky, D.; Banfield, C. *Dietary Fiber in Health and Disease*; Eagan Press: St. Paul, MN, 1995.
(60) Nicklas, T. A.; Farris, R. P.; Myers, L.; Berenson, G. S. Dietary fiber intake of children and young adults: the bogalusa heart study. *J. Am. Diet. Assoc.* **1995**, *95*, 209−214.
(61) FAO/WHO/UNU. *Energy and Protein Requirement, Report of a Joint FAO/WHO/UNU Expert Consultation*; World Health Organization Technical Report Series 724; WHO: Geneva, Switzerland, 1985.
(62) Villarroel, M.; Biolley, E.; Schneeberger, R.; Ballester, D.; Ramirez, S. Amino acid composition of Chilean hazelnuts. *Food Chem*. **1987**, *25*, 155−158.
(63) Kuninaka, A. Taste and flavor enhancers. In *Flavor Research: Recent Advances*; Teranishi, R., Flath, R. A., Eds.; Marcel Dekker: New York, 1981; pp 305−353.
(64) Kato, H.; Rhue, M. R.; Nishimura, T. Role of free amino acids and peptides in food taste. In *Flavor Chemistry: Trends and Developments*; Teranishi, R., Buttery, R. G., Shahidi, F., Eds.; ACS Symposium Series 388; American Chemical Society: Washington, DC, 1989; pp 158−174.
(65) Fuke, S.; Konosu, S. Taste-active components in some foods: A review of Japanese research. *Physiol. Behav.* **1991**, *49*, 863−868.
(66) Fuke, S. Taste-active components of seafoods with special reference to umami substances. In *Seafoods: Chemistry, Processing, Technology and Quality*; Shahidi, F., Botta, J. R., Eds.; Blackie Academic and Professional: Glasgow, U.K., 1994; pp 115−139.
(67) Macleod, G. The flavour of beef. In *Flavor of Meat, Meat Products and Seafoods*, 2nd ed.; Shahidi, F., Ed.; Blackie Academic & Professional: London, U.K., 1998; pp 27−60.
(68) Basha, S. M.; Young, C. T. Changes in the polypeptide composition of peanut (*Arachis hypogaea* L.) seed during oil roasting. *J. Agric. Food Chem.* **1985**, *33*, 350−354.
(69) 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.
(70) 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.
(71) Keme, T.; Messerli, M.; Shejbal, J.; Vitali, F. The storage of hazelnuts at room temperature under nitrogen (I). *Rev. Choc. Confect. Bakery* **1983**, *8*, 24−28.
(72) Keme, T.; Messerli, M.; Shejbal, J.; Vitali, F. The storage of hazelnuts at room temperature under nitrogen (II). *Rev. Choc. Confect. Bakery* **1983**, *8*, 15−20.
(73) Alexander, R. J. *Sweeteners: Nutritive*; Eagan Press: St. Paul, MN, 1998.
(74) Johnston, F. B.; Hammill, M. M. The nonvolatile organic acids of some fresh fruits and vegetables. *Can. Inst. Food Technol. J.* **1968**, *1*, 3−5.
(75) Ulrich, R. Organic acids. In *The Biochemistry of Fruits and Their Products*; Hulme, A. C., Ed.; Academic Press: New York, 1970; Vol. 1, pp 89−118.
(76) Jadhav, S. J.; Andrew, W. T. Effects of cultivars and fertilizers on nonvolatile organic acids in potato tubers. *Can. Inst. Food Sci. Technol.* J. **1977**, *10*, 13.
(77) Siebert, K. J. Modeling the flavor thresholds of organic acids in beer as a function of their molecular properties. *Food Qual. Pref.* **1999**, *10*, 129−137.

Received for review December 23, 2002. Revised manuscript received March 6, 2003. Accepted March 14, 2003. We thank the Turkish Hazelnut Promotion Group for their financial support.

JF0212385