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1 **Chemical, mechanical and sensory monitoring of hot air- and infrared-**
2 **roasted hazelnuts (*Corylus avellana* L.) during nine months of storage**

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12
13 **Keywords:** hazelnut, roasting, storage, oxidative stability, antioxidants, mechanical properties,
14 acoustic properties.

26 **Abstract**

27 Roasted hazelnuts can be consumed as whole nuts, or as an ingredient in the confectionary and
28 bakery industries and are highly appreciated for their typical taste, aroma and crunchy texture. In
29 this work, two hazelnut types (TGT, Ordu) from two harvests were roasted using two different
30 systems (hot air, infrared) at different time/temperature combinations, and the evolution of
31 oxidative stability, the total phenolic content (TPC), the antioxidant capacity, the mechanical and
32 acoustic properties and the sensory perception were determined during storage. The results showed
33 that the oxidative stability was increased by roasting hazelnuts at 120 °C for 40 min with hot air
34 system. Similar overall trends were not found for the TPC, the antioxidant capacity and the
35 mechanical-acoustic properties. However, for the maintenance of high antioxidant activity, a
36 storage time of 6 months at 4 °C is recommended. The two roasting systems gave hazelnuts with
37 significant sensory differences only at high roasting temperature.

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52 **1. Introduction**

53 Hazelnuts are typically consumed as whole nuts (raw or roasted) or as ingredient for confectionary
54 and bakery industries as they are highly appreciated for their typical taste, aroma and crunchy
55 texture. An industrial roasting process is applied to remove the hazelnut skin, to reduce the moisture
56 and to develop the unique sensory features (Özdemir, Açıktur, Yıldız, Biringen, Gürcan & Löker,
57 2001; Demir & Cronin, 2005). Additionally, roasting is often used to extend the nut's shelf life due
58 to the inactivation of the oxidative enzyme system (lipoxygenic enzymes) and the formation of
59 reaction products, which exhibit antioxidant activity (Krings & Berger, 2001; Perren & Escher,
60 2007).

61 Although favourable for many aspects, roasting can also lead to a number of physical and chemical
62 changes, such as microstructural and lipid modifications, which might increase the sensitivity of the
63 product to oxidation and, hence, reduce its shelf life (Alamprese, Ratti & Rossi, 2009). Due to these
64 modifications, the assessment of hazelnut characteristics after roasting has been the subject of
65 different studies (Demir & Cronin, 2005; Brown, Rothwell & Davidson, 2001; Uysal, Sumnu &
66 Sahin 2009) aimed at both determining the most suitable machines and parameters for roasting as
67 well as at obtaining high quality indexes in terms of colour, texture, moisture, oxidative stability (in
68 terms of peroxide value and free fatty acids) and sensory characteristics.

69 Industrially, the most commonly reported roasting time-temperature combinations are in the range
70 of 100 to 180 °C for 5-60 min (Demir & Cronin, 2005). Moreover, roasting can be achieved by
71 using different methods, such as commercial electrical ovens, hot air dryers or even by exploiting
72 other techniques, such as infrared heating and the dielectric processes of radiofrequency and
73 microwave (Ciarmiello et al., 2013). Infrared heating has been reported to have many advantages
74 over conventional heating, such as reduced heating time, uniform heating, reduced quality losses,
75 compactness of equipment and significant energy savings (Rastogi, 2012). Infrared roasters have
76 been developed to roast cracked cereal grain, whereas infrared combined with microwave
77 techniques have been used to roast hazelnuts, producing results in terms of colour, texture, moisture

78 content and fatty acid composition similar to the results obtained by a commercial electrical oven
79 (Brown, Rothwell & Davidson, 2001; Uysal, Sumnu & Sahin 2009).

80 The effect of roasting has been studied extensively on metabolites, such as volatile compounds,
81 amino acids, vitamin B, the lipidic fraction (unsaturated fatty acids and tocopherols) and phenolic
82 compounds (Özdemir et al., 2001; Alasalvar, Shahidi & Cadwallader, 2003; Kirbaşlar & Erkmen,
83 2003; Amaral, Casal, Seabra & Oliveria, 2006; Schmitzer, Slatnar, Veberic, Stampar & Solar, 2011;
84 Pelvan, Alasalvar & Uzman, 2012; Schlörmann et al., 2015). Roasting has been shown to not
85 substantially affect the content of mono- and polyunsaturated fatty acids, tocotrienols, and phenolic
86 compounds, whereas roasting caused a decrease in the content of tocopherols. All of these
87 compounds have been indicated as health-related compounds, and although controversial, data with
88 respect to their fate during roasting is of great interest.

89 The preservation of the overall characteristics of the roasted hazelnuts during storage should be a
90 major concern for the industry and market. In fact, from an industrial point of view, it could be
91 desirable to have ready-to-use roasted hazelnuts that are well preserved for as long as possible.
92 Unfortunately, very little information is currently available in the literature about the shelf life of
93 roasted hazelnuts.

94 Therefore, the aim of this work was to contribute to knowledge about the chemical (fatty acids,
95 peroxide value, oleic to linoleic ratio, iodine value, total phenolic content and antioxidant capacity),
96 mechanical (rupture force, rupture slope and rupture energy), acoustic (maximum acoustic emission
97 peak, acoustic peak number and average peak emission) and sensory changes in two different
98 hazelnut cultivars that were both hot air (HA) roasted, as a “traditional method,” and infrared (IR)
99 roasted, as an “innovative method,” using two combinations of time and temperature common used
100 by processors, for two consecutive years. In each year, parameters were monitored at three points
101 over 9 months of storage..

102

103 **2. Materials and methods**

104 **2.1 Chemicals**

105 Supelco 37 component FAME mix 10 mg/mL, nonadecanoic acid methyl ester (C19:0), 2,2-
106 diphenyl-1-picrylhydrazyl (DPPH), potassium persulfate, sodium carbonate, Trolox (6-hydroxy-
107 2,5,7,8-tetramethylchroman-2-carboxylic acid), 2,2'-Azino-bis-(3-ethylbenzothiazolin-6-sulfonic
108 acid) diammonium salt (ABTS), Folin-Ciocalteu reagent, ethanol, methanol, *n*-hexane and acetone
109 were purchased from Sigma-Aldrich (Milan, Italy); potassium hydroxide, formic acid and gallic
110 acid were purchased from Fluka Chemicals (Milan, Italy). Acetone, methanol, *n*-hexane were of
111 analytical or higher grade. Aqueous solutions were prepared using ultra-pure water produced with a
112 Milli-Q System (Millipore, Milan, Italy).

113

114 **2.2 Hazelnuts**

115 One Italian cultivar, Tonda Gentile Trilobata (TGT), and one Turkish blend consisting of three
116 major cultivars, Tombul, Palaz and Kalinkara from the Ordu region (here called Ordu), were used in
117 this study. Raw hazelnuts from the 2010 and 2011 harvests (calibre within 12-13 mm) were
118 supplied by La Gentile S.r.L. (Cortemilia, CN, Italy). The initial moisture content of the raw
119 hazelnuts was 3.26 % and 3.86 % for TGT and Ordu, respectively, harvested in 2010, and 3.13 %
120 and 3.76 % for TGT and Ordu, respectively, harvested in 2011. The moisture content was
121 determined using a Eurotherm EUR thermo-balance (Gibertini, Milano, Italy) at 105 °C. Hazelnuts
122 were roasted using the HA and IR roasting methods at the Brovind – GBV company
123 Srl (Cortemilia, CN, Italy). HA roasting was performed with three forced air circulation sections
124 (drying, roasting and cooling to obtain a product using an optimal thermal process) using electronic
125 control of planned and recorded process parameters, whereas IR roasting was carried out with a
126 patented system using a vibrating helical track and a ventilation system to obtain a uniform roasting
127 level. Hazelnuts were roasted at 120 °C for 40 min (light roast) and 170 °C for 20 min (dark roast)
128 with both systems separately. Three sample replicates for each roasting condition were processed.
129 After roasting, hazelnut samples were let cooling before being placed in non-permeable

130 polypropylene/aluminium/polyethylene bags under vacuum and stored at 4 °C for 9 months. The
131 sampling times were 0, 6 and 9 months. At time 0, raw hazelnut samples obtained by hand peeling
132 after soaking in warm water were also analysed to determine the effect of roasting on the kernel
133 without skin.

134

135 **2.3 Extraction of hazelnut oil**

136 The hazelnut oil was extracted using a cold-pressing method using CDR's nut oils extraction system
137 (CDR s.r.l., Florence, Italy). Approximately 50 g of the hazelnut kernels were compressed, and the
138 recovered oil was clarified by centrifugation at 4800 rpm for 5 min. The oil was stored at -18 °C in
139 an amber vial until analyses. Each sample was prepared in triplicate.

140

141 **2.4 Fatty acid composition**

142 Fatty acid methyl esters (FAMES) were determined by gas-chromatography according to the
143 method described by Ficarra, Lo Fiego, Minelli and Antonelli (2010), with slight modification.
144 Briefly, 50 mg of oil was mixed thoroughly with 1 ml of hexane and 300 µl of 2 M KOH in
145 methanol (w/v) in a dark tube. The tube was shaken vigorously for 1 min, and then, C19:0 (200
146 mg/L) was added as an internal standard. The extract was then transferred into a dark glass vial and
147 immediately analysed by GC. Profiling of the FAMES was determined using a GC-2010 Shimadzu
148 gas chromatograph (Shimadzu, Milan, Italy) equipped with a flame ionization detector, split-
149 splitless injector, an AOC-20i autosampler and a capillary column SP-2560 (100 m × 0.25 mm id ×
150 0.20 µm, Supelco, Milan, Italy). The following temperature program was used: the initial oven
151 temperature was 165 °C increasing to 200 °C at 3 °C/min, and then, the temperature was held at 200
152 °C for 45 min. The injector temperature and the detector were 250 °C. Each fatty acid methyl ester
153 was identified and quantified by comparing retention times with Supelco 37 components FAME
154 mix 10 mg/mL. The fatty acid concentration was expressed as mg fatty acid/g of oil calculated
155 according to the AOAC 963.22 method (AOAC, 2000). All analyses were performed in triplicate.

156 The obtained fatty acid composition was used to calculate the sum of the saturated (Σ SFA),
157 monounsaturated and polyunsaturated (Σ MUFA, Σ PUFA) fatty acids as well as the ratio (Σ MUFA
158 + Σ PUFA)/(Σ SFA).

159

160 **2.5 Oxidation parameters**

161 To evaluate the oxidative stability, the peroxide value (PV), which is expressed as meqO₂/kg oil, the
162 ratio of oleic to linoleic (O/L), and the iodine value (IV) were determined.

163 The PV was performed using the *FoodLab* method (CDR s.r.l., Florence, Italy) on the hazelnut oil
164 (Kamvissis, Barbounis, Megoulas & Koupparis, 2008). The IV was determined according to the
165 percentages of fatty acids using the following formula: (palmitoleic acid*1.901)+(oleic
166 acid*0.899)+(linoleic acid*1.814)+(linolenic acid*2.737) (Hashempour, Ghazvini, Bakhshi &
167 Sanam, 2010). All analyses were performed in triplicate.

168

169 **2.6 Extraction of antioxidant compounds**

170 Hazelnuts were frozen using liquid nitrogen and ground finely using an A 11 basic analytical mill
171 (IKA[®]-Werke GmbH & Co. KG, Staufen, Germany). Ground kernels (approximately 2 g) were then
172 extracted according to El Monfalouti et al. (2012) with some modifications. Briefly, samples were
173 mixed with a fresh mixture of acetone/water/formic acid (70:29.5:0.5, v/v/v), and the combined
174 extracts obtained after the two-step extraction procedure were defatted by washing with hexane (10
175 mL × 3 times, 3 min each). Then, acetone was evaporated under nitrogen by using a digital pulse
176 mixer with an evaporator (Glas-Col, Terre Haute, Indiana, USA), and the aqueous extracts obtained
177 were filtered (0.45 μm) and used for further analyses. All extractions were performed in triplicate.

178

179 **2.6.1 Determination of total phenolic content (TPC)**

180 The amount of total phenolics was determined spectrophotometrically by means of the modified
181 Folin–Ciocalteu method (Singleton & Rossi, 1965; Singleton, Orthofer & Lamuela-Raventos,
182 1999). Briefly, 2.5 mL of 10-fold diluted Folin–Ciocalteu reagent, 2 mL of 7.5% aqueous sodium
183 carbonate solution, and 0.5 mL of phenolic extract were mixed well. After 15 min of heating at 45
184 °C (Pinelo, Rubilar, Sineiro & Núñez, 2004), the absorbance was measured at 765 nm with a UV-
185 Visible spectrophotometer (UV-1700 PharmaSpec, Shimadzu, Milan, Italy). A mixture of solvent
186 and reagents was used as a blank. The phenolic content was expressed as mg of gallic acid
187 equivalents (GAE) per g of sample by means of a calibration curve. All analyses were performed in
188 triplicate.

189

190 **2.6.2 Determination of antioxidant activity**

191 **2.6.2.1 Trolox equivalent antioxidant capacity (TEAC)**

192 The Trolox equivalent antioxidant capacity (TEAC) of the hazelnut extract was estimated according
193 to the original analytical procedure described by Re, Pellegrini, Proteggente, Pannala, Yang and
194 Rice-Evans (1999), with slight modifications. The ABTS radical cation (ABTS^{•+}) was produced by
195 reacting 7 mmol of the ABTS stock solution with 2.45 mmol of potassium persulphate (final
196 concentration). The mixture was allowed to stand in the dark at room temperature for 12–16 h
197 before use. The radical was stable in this form for no more than two days when protected from light
198 and stored at room temperature. Just prior to analysis, the ABTS^{•+} stock solution was diluted with
199 ethanol to an absorbance of 0.70 (± 0.02) at 734 nm and allowed to equilibrate at 30 °C. Sample
200 solutions (or standard) (30 µL) were mixed with the ABTS^{•+} solution (3 mL). Absorbance readings
201 were taken at 30 °C exactly 6 min after the initial mixing. An appropriate solvent blank was
202 obtained by mixing ultrapure water (30 µL) with the ABTS^{•+} solution (3 mL). The ABTS^{•+}
203 scavenging effect (% Inhibition) was calculated using the following equation:

204

$$\% \text{ Inhibition} = [(A_{734\text{blank}} - A_{734\text{sample}})/A_{734\text{blank}}] \times 100$$

205 where $A_{734\text{blank}}$ and $A_{734\text{sample}}$ are the absorbances of the ABTS^{++} solution at 734 nm before and after
206 the sample addition. The results were expressed as micromoles of Trolox equivalents (TE) per gram
207 of sample by means of a dose–response curve for Trolox (0–350 μmol). All analyses were
208 performed in triplicate.

209

210 **2.6.2.2 DPPH radical scavenging capacity**

211 The radical scavenging activity (RSA) of the hazelnut phenolic extract was measured using the
212 discoloration of a purple-coloured methanol solution of the 2,2-diphenyl-1-picrylhydrazyl (DPPH)
213 radical (von Gadow, Joubert & Hansmann, 1997). Briefly, 75 μL of the sample extract was added to
214 3 mL of a $6.1 \times 10^{-5} \text{ mol l}^{-1}$ DPPH \cdot methanol solution and was incubated for 1 h at room temperature
215 in the dark. The absorbance was measured at 515 nm against a methanol solution of DPPH \cdot as a
216 blank. The inhibition percentage (IP) of the DPPH \cdot by the hazelnut extract was calculated according
217 to the following formula:

$$218 \quad \text{IP} = [(A_{0\text{min}} - A_{60\text{min}})/A_{0\text{min}}] \times 100$$

219 where $A_{0\text{min}}$ is the absorbance of the blank at $t = 0$ min and $A_{60\text{min}}$ is the absorbance of the samples
220 at 60 min. The results were expressed as micromoles of Trolox equivalent (TE) per gram of sample.
221 All analyses were performed in triplicate.

222

223 **2.7 Instrumental mechanical and acoustic properties**

224 For the evaluation of the mechanical and acoustic properties, a TA.XTplus universal testing
225 machine (Stable Micro Systems, Godalming, UK) was used with the following operating
226 conditions: 50-kg load cell, P/75 flat probe, HDP/90 platform from the same manufacturer,
227 acquisition at 200 points per second, and a compression test speed of 1 mm/s until 50 % of sample
228 deformation (Ghirardello et al., 2013). The hazelnuts were compressed along the compression axis,

229 which corresponded to the longitudinal axis through the hilum containing the major dimension
230 (Güner, Dursun & Dursun, 2003), and 20 hazelnuts were analysed for each sample. From the
231 resulting force-distance curve, three mechanical parameters were calculated in accordance with
232 Saklar, Ungan, and Katnas (1999): rupture force (F_1 , N), rupture slope (E_1 , N/mm), and rupture
233 energy (W_1 , mJ), which corresponded to the first fracture point force, the slope with respect to the
234 initial point, and the total area beneath the curve, respectively.

235 The instrumental acoustic properties evaluated during the compression test were acquired using an
236 acoustic envelope detector (AED) (SMS, Stable Micro Systems, Surrey, UK) equipped with a 12.7-
237 mm diameter Brüel & Kjær 4188-A-021 microphone (Nærum, DK). The microphone was
238 positioned at an angle of 30° and 40 mm from the sample (due to the shape of the probe) and was
239 connected to the TA.XTplus equipment. No instrumental gain or filters were applied. The acoustic
240 emissions were acquired for the entire compression measuring the following parameters: maximum
241 acoustic emission peak [dB], acoustic peak number and average peak emission [dB] (Torchio,
242 Giacosa, Río Segade, Mattivi, Gerbi & Rolle, 2012) using a peak threshold value of 10 dB.

243

244 **2.8 Sensory analysis**

245 A sensory evaluation was performed using a duo-trio test (ISO 10399, 2004) with $\alpha = 0.05$, $p_d =$
246 30% and $\beta = 0.2$ on a group of 70 panellists (42 female, 28 male, 25-35 years old). Hazelnut
247 samples coded with different three-digit numbers were furnished in white plastic cups containing 6-
248 7 kernels. Water was provided for palate cleaning. The testing was carried out in a sensory
249 laboratory that was designed in accordance with ISO 8589 (1988). The tests were performed after
250 roasting and during storage at 6 and 9 months comparing for each hazelnut and roasting system, the
251 two roasting conditions.

252

253 **2.9 Statistical analysis**

254 An analyses of variance was performed using SPSS software (version 18.0 for Windows, SPSS
255 Inc., Chicago, Illinois). Significant differences ($P < 0.05$) among the means were determined using
256 the Duncan's test at a fixed level of $\alpha = 0.05$.

257

258 **3. Results and discussion**

259 **3.1 Fatty acids**

260 The FAMES analysis of the TGT and Ordu hazelnuts identified a total of fourteen fatty acids,
261 among which oleic acid (C18:1 ω 9) was predominant, followed by linoleic acid (C18:2 ω 6), palmitic
262 acid (C16:0), stearic acid (C18:0), palmitoleic acid (C16:1) and α -linolenic acid (C18:3 ω 3)
263 [Supplementary Tables 7-8]. Table 1 shows the sum of the fatty acids detected in the raw and
264 roasted TGT and Ordu hazelnuts during the first year of study. In general, the sum (Σ) of MUFAs
265 was predominant in both varieties, but TGT had a lower amount of Σ PUFAs and had a greater
266 amount of Σ SFAs than the Ordu.

267 With the aim of studying the oxidation stability of the roasted hazelnuts, the fatty acids mentioned
268 above were considered when calculating the oxidative parameters presented in Tables 1 and 2. The
269 oleic to linoleic acid (O/L) ratio was considered to be an important criterion to evaluate the kernel
270 quality, as a greater value indicates better oxidative stability (Alasalvar, Pelvan & Topal, 2010;
271 Vujević, Petrović, Vahčić, Milinović & Čmelik, 2014). During the first year of study (Table 1),
272 significant differences were observed in the O/L ratio for the TGT and Ordu roasted at the two
273 different conditions: 170°C for 20 min and 120°C for 40 min. In particular, IR roasting appeared to
274 have a more positive effect than HA, resulting in greater oxidative stability in the TGT hazelnuts.
275 The same behaviour was observed in the Ordu, but only for the initial point at 170 °C-20 min.
276 Instead, when the 120°C-40 min treatment was applied, similar O/L ratio values were observed
277 (except at month 6). The rapid decrease of the values observed during storage highlighted the
278 decreased stability for both the TGT and Ordu roasted at 170°C for 20 min by IR. Overall, during

279 storage a more pronounced decrease in the values were observed in both hazelnuts roasted at 170
280 °C-20 min.

281 The iodine value is a measure of the degree of unsaturation of a lipid. A greater iodine value
282 indicates that the oil is more reactive, less stable, and more susceptible to oxidation and
283 rancidification. Between the two varieties, a general increase in IV can be observed during storage,
284 which appeared to be more pronounced in the IR compared with the HA system.

285 The peroxide value is a common lipid oxidation index. The greatest PV values were detected when
286 the 170°C for 20 min roasting conditions were used for both the TGT and Ordu. Between varieties
287 and during all storage times, the lowest results were detected in the TGT hazelnuts.

288 These results were in agreement with others (Amaral, Casal, Alves, Seabra & Oliveira, 2006;
289 Schlörmann et al., 2015), confirming that lower roasting temperatures increase the stability of the
290 hazelnuts without any particular changes in the lipid profile composition. The greatest PV value
291 was found for the Ordu roasted at 170 °C for 20 min by HA at the initial point; then, the PV values
292 decreased. This result is likely due to the fluctuation of PV during processing or storage (Özdemir
293 et al., 2001). In general, hazelnuts roasted using the HA system at 120 °C for 40 min were more
294 stable in terms of O/L, IV as well as PV after 6 months of storage where the three indexes seem to
295 be not strongly affected. As showed by data, under the influence of unfavourable conditions as high
296 temperatures (170 °C – 20 min) combined with extreme exposure to light as IR, increases of PV
297 and IV values and a corresponding decreases of O/L values were observed. In particular, PV and IV
298 indexes highlight as the primary oxidation as well as the number of degree of unsaturation of the
299 lipids change proportionally due to the presence of much higher contents of oleic acid. The latter is
300 affected at high temperatures hence lowering its relative levels and, as a consequence, increasing
301 saturated and polyunsaturated fatty acids percentages (Amaral et al., 2006b). Therefore, the
302 degradation rate of oleic acid led to an increase of O/L value as reported in Table 1, with similar
303 trends for both hazelnut varieties roasted using IR system. Regarding HA roasting system, the data
304 obtained showed that the values of the three indexes remained unvaried, less than for PV value,

305 which significantly decreased when TGT as well as Ordu were roasted at 170 °C for 20 min. This
306 PV value decreasing highlights the low incidence of the treatment on the primary oxidation of lipids
307 in terms of hydroperoxide production.

308 In the second year of study (Table 2), slight changes in the FA composition were observed. At the
309 beginning, the TGT was characterized by an increase in MUFAs balanced by a decrease in SFAs,
310 and the PUFAs were almost unchanged. In the Ordu, the MUFA content was stable, whereas the
311 SFA and PUFA content increased and decreased, respectively.

312 These differences in the FA composition were likely due to the difference in the harvest season and
313 growing conditions, as previously reported by other authors (Vujević et al., 2014; Alasalvar,
314 Amaral, Satir & Shahidi, 2009; Beyhan, Elmastas, Genc & Aksit, 2011). Despite the slight
315 variations, better oxidative stability in both varieties was confirmed by roasting at 120°C for 40 min
316 for both the HA and IR conditions. In particular, the O/L ratio for both varieties significantly
317 increased, reaching the greatest values in the TGT roasted using HA at 120°C for 40 min. No
318 differences were observed for the IV values in both the TGT and Ordu, whereas PV significantly
319 increased more in the TGT roasted using IR at 170°C for 20 min compared with the Ordu subjected
320 to the same conditions. As observed in first year, data obtained for the three indexes confirmed the
321 prevalent influence of the IR system compared to HA on the oxidative stability of the hazelnuts.

322

323 **3.2 TPC and antioxidant capacity**

324 There are very few works in the literature reporting data on the TPC and antioxidant capacity of
325 roasted hazelnuts, whereas there are no works at all, to our knowledge, that reported this type of
326 data over over an extended storage period. A comparison with data already present in the literature
327 is not always possible due to the different experimental conditions used. Therefore, here, a
328 comparison with related literature trends rather than with numerical values was attempted.

329 The results of the TPC, TEAC and RSA of the TGT and Ordu, which were harvested 2010, are
330 shown in Table 3. The TPC content of the roasted TGT ranged from 0.48 to 0.69 mg GAE g⁻¹,

331 depending on the roasting conditions and systems applied. Moreover, the TPC slightly increased
332 during roasting. These results were similar to those obtained by Schmitzer al. (2011) who studied
333 the effect of roasting on various parameters, such as the TPC and antioxidant capacity among
334 others. The similarity of our results to the previous study is likely due to the use of a raw hazelnut
335 without a pellicle. Indeed, when a raw hazelnut with a pellicle is used as reference, there is a
336 dramatic decrease in the TPC content after roasting, due to the loss of the skin (Pelvan, Alasalvar &
337 Uzman, 2012). Both roasting conditions and storage time had a significant effect on the TPC content
338 of the TGT. The effects of the roasting conditions could be seen at the 9th month of storage for the
339 TGT roasted using IR, with a greater TPC content for the 120 °C – 40 min treatment, and at months
340 0 and 9 for the TGT roasted using HA, with a greater TPC content for the 170 °C – 20 min
341 treatment. A significant increase in TPC was observed during storage in the TGT roasted with IR at
342 120 °C for 40 min and in the TGT roasted with HA at 170 °C for 20 min. Instead, the TPC content
343 of the hazelnuts roasted at 170 °C for 20 min using IR and at 120 °C for 40 min using HA did not
344 vary during storage. The comparison between the two roasting systems showed that the TPC
345 contents of the TGT roasted using HA were greater than the TPC contents of the TGT roasted using
346 IR at each time of storage for the 170 °C – 20 min treatment, probably because IR caused a higher
347 heating in the hazelnut than HA and, then, a higher degradation of phenolic compounds.

348 With respect to antioxidant capacity, the TEAC values of the roasted TGT ranged from 2.09 to 3.09
349 $\mu\text{mol TE g}^{-1}$, whereas the RSA ranged from 0.76 to 1.42 $\mu\text{mol TE g}^{-1}$. As for the TPC, roasting gave
350 rise to a slight increase in the TEAC and RSA values compared with the raw TGT. These results
351 were still in agreement with the results from Schmitzer et al. (2011), who also determined the
352 antioxidant capacity of TGT by means of the DPPH radical scavenging method. The effects of
353 roasting conditions, storage time and roasting system on the TEAC were almost the same as the
354 effects described above for the TPC. Indeed, the unique difference was that storage time had no
355 effect on the TEAC values of the TGT roasted using HA at 170 °C for 20 min. The RSA pattern
356 was quite similar to that of the TEAC and TPC with the main differences being that storage time

357 had an additional and significant effect on RSA of TGT roasted by IR at 170 °C – 20 min, and the
358 roasting system had a significant effect on RSA value of TGT roasted at 120 °C for 40 min at the 9th
359 month. The observed relationship between TPC and TEAC/RSA values was not surprising, because
360 all these assays are similar and act by the same mechanism. It is well known that Folin-Ciocalteu,
361 ABTS and DPPH assays, based on similar electron-transfer redox reactions, are able to assess not
362 only the phenolic compounds but also the antiradical or antioxidant capacity of non-phenolic
363 compounds, such as the Maillard reaction products, including melanoidins formed during roasting
364 (Pérez-Martínez et al., 2010). Similar to TGT, in most cases, the TPC, TEAC and RSA values of the
365 roasted Ordu were similar or greater than the corresponding values for the raw sample. Again,
366 similar to TGT, a significant effect of roasting system could be seen on the Ordu roasted at 170 °C
367 for 20 min, but in this case, not all of the greatest values were associated with the HA roasting
368 system. Unlike the TGT, in most cases, the roasting conditions significantly affected the Ordu
369 parameters and the storage time had a more marked effect. However, it was not possible to find a
370 regular pattern because the greatest values were randomly distributed between the two roasting
371 conditions. Even the trend due to the storage time was not regular: the highest values were
372 distributed between months 6 and 9. Ordu TPC, TEAC and RSA were in the ranges 0.57 – 1.09 mg
373 GAE g⁻¹, 1.64 – 5.71 µmol TE g⁻¹ and 0.55 – 3.01 µmol TE g⁻¹, respectively. The TPC values were
374 similar to those found by Pelvan et al. (2012) in a study of different Turkish varieties of roasted
375 hazelnuts.

376 The results of the TPC, TEAC and RSA for the TGT and Ordu that were harvested in 2011 are
377 shown in Table 4.

378 An overall view of the data from the harvest in 2011 shows behaviour and trends that are different
379 from the hazelnuts harvested in 2010. Indeed, as opposed to the hazelnuts harvested in 2010, the
380 TPC content and antioxidant capacity of the roasted TGT were affected by storage time and, in
381 most cases, by the roasting conditions and the roasting system. Basically, roasting using IR at 170
382 °C for 20 min resulted in greater TPC compared with HA at 120 °C for 40 min. Furthermore, in

383 most cases the greatest TPC, TEAC and RSA values were achieved at month 6 and were followed
384 by a decrease. The TPC content and TEAC and RSA values were in the range 0.28 – 0.91 mg GAE
385 g⁻¹, 0.71 – 5.03 μmol TE g⁻¹ and 0.76 – 3.73 μmol TE g⁻¹, respectively. As in 2010, roasting
386 resulted in an increase in these parameter values compared with raw hazelnuts

387 With respect to Ordu, it was confirmed that in 2011 there was an effect of storage time on all of the
388 studied parameters. Moreover, there was a more regular trend than in 2010, with the greatest values
389 always found at month 6. Instead, the effect of roasting system and roasting conditions were less
390 significant in 2010. However, when significantly different, most of the greatest parameters values
391 were obtained when using the IR roasting system and roasting conditions at 120 °C for 40 min. The
392 TPC, TEAC and RSA values were in the range 0.45 – 2.18 mg GAE g⁻¹, 1.13 – 11.20 μmol TE g⁻¹
393 and 0.77 – 6.81 μmol TE g⁻¹, respectively.

394 In both years, the parameter values measured for Ordu were basically greater than the parameters
395 measured for TGT. The increase in the parameters values (TPC, TEAC and RSA), which occurred
396 after roasting, was not surprising; indeed, other authors have observed the same behaviour in other
397 nuts and have linked the increase in extractable phenolic compounds after roasting to the formation
398 of Maillard products (Ioannou & Ghoul, 2012). Thermal processing may cause complex physical
399 and chemical reactions on phenolics, including leaching of water soluble phenolics, freeing
400 phenolics from bond forms, degradation of polyphenols, breakdown and transformation of
401 phenolics, such as formation of complex products from phenolics and proteins, and formation of
402 Maillard reaction products having antioxidative activity (Xu & Chang, 2008).

403

404 **3.3 Instrumental mechanical and acoustic properties**

405 The results of the assessment of the first year's mechanical and acoustic properties are shown in
406 Table 5. To our knowledge, the assessment of the joint mechanical-acoustic properties on roasted
407 hazelnut kernels during storage is presented here for the first time. Several parameters were selected
408 to evaluate the ease of breaking a hazelnut during compression and to evaluate a possible

409 crunchiness indicator for the roasted product. A decrease in the rupture force (F1) was found with
410 the roasting process, and in particular, the use of the IR or the HA roasting systems reduced F1.
411 With respect to the raw hazelnut measurements, the HA treatment was more effective in the
412 reduction of the force necessary to break the nut.

413 In relation to the applied time-temperature roasting conditions, a rupture force reduction was found
414 using the IR system when increasing the treatment time to 40 min despite the lower temperature.
415 This was not found in the HA treatment where the longer treatments resulted in greater F1 values;
416 however, these differences were not significantly different from the 170 °C-20 min treatment. In
417 particular, the predominance of roasting temperature effect over the roasting time was also found by
418 Demir and Cronin (2005) when using conventional fan ovens.

419 The reduction in F1 when using the HA system also caused a reduction in the maximum acoustic
420 peak intensity, which decreased to a lower value than those found for the IR trials with significant
421 differences at the initial point. This could be related to the crunchiness sensory perception; however,
422 selective studies on the correlation between sensory and mechanical-acoustic properties on
423 hazelnuts were not carried out in the present work. Limited only to the relationship with mechanical
424 properties, Saklar, Ungan and Katnas (1999) found a negative correlation between the sensory
425 crunchiness and crispness and the force parameters specifically the rupture force. In addition, the
426 same authors, by using the response surface methodology, showed that more intense roasting
427 conditions caused a reduction in the force parameters and an increase in sensory crispness and
428 crunchiness parameters. Based on the data included in the present work, this cannot be confirmed,
429 neither for IR or HA roasting systems, but some hypotheses about the crunchiness based on the loss
430 of rupture force could indicate the HA roasting system potentially results in crunchier products.

431 When observing the results of the second year (Table 6), all of the aforementioned differences were
432 reduced either by treatment or roasting system. A steep decrease of the F1 parameter values
433 between raw and roasted samples was already found, but no or few significant differences were
434 found in the force measurements between the roasting systems or conditions. The lower rupture

435 force found in the raw second harvest samples with respect to those at the first harvest, in both
436 cultivars, might have had a role in this behaviour. In particular, the IR roasting system samples also
437 resulted in an important F1 reduction from raw to roasted. Greater F1 values were found in the
438 170 °C – 20 min roasting condition.

439 Moreover, these differences may have characterized the acoustic measurements values found before
440 and after roasting. The number of acoustic peaks detected was quite high in the raw hazelnuts from
441 the second harvest as well the average peak emission.

442 The overall results from the two-year data set did not show common trends for the mechanical and
443 acoustic properties between the two harvest years. The different raw samples seemed to change the
444 evaluated properties trends; indeed, the different composition of the raw hazelnuts between the two
445 harvests may have caused a different response to the roasting process and thus different products.

446 In general, the HA roasting system appears to be less sensitive to starting product variations.
447 Unfortunately, to our knowledge, the literature data covering two consecutive harvests in raw and
448 roasted hazelnuts composition is scarce and limited to physical properties (Koksal, Gunes & Belge,
449 2012). Single compositional effects or characteristics might have had an influence on the
450 mechanical properties, such as a different water activity effect as previously found on hazelnuts and
451 other nut samples (Borges & Peleg, 1997).

452 The storage of raw hazelnuts (TGT cultivar) was found to have significant effects on the
453 mechanical properties of the hazelnuts: after 8-12 months, an increase in the rupture force was
454 observed, whereas a decrease in the rupture energy was observe, except for hazelnuts stored in-
455 shell, at ambient temperature (Ghirardello et al., 2013). In the present study, roasted hazelnuts from
456 the first harvest after 9 months of storage showed some trends. A significant decrease in the rupture
457 force and energy was found in the Ordu samples, but only when using IR roasting at the high
458 temperature. In the second harvest, an increase of the F1 and W1 parameters was found in almost
459 all of the samples, but the differences were, for the most part, not significant likely due to the
460 common high variability in these measurements as found by others (Ghirardello et al., 2013).

461 **3.4 Sensory analysis**

462 For all of the sampling times, years and hazelnut cultivars, the obtained results from the duo-trio
463 test highlighted a significant difference ($\alpha < 0.05$) between the IR and HA roasting method when
464 roasted at 170 °C for 20 min. Instead, no significant differences between roasting methods were
465 found when the low temperature (120 °C for 40 min) was used. The two roasting processes,
466 independent of the hazelnut cultivars, resulted in products with significant sensory differences only
467 when the roasting temperature was high, and this difference persisted during storage.

468

469 **Conclusions**

470 In conclusion, this study showed that roasting with hot air system at low temperature gave rise to
471 products with a better oxidative stability over six months of storage at 4 °C. Hot air system also
472 seemed to be better for obtaining hazelnuts with lower rupture force which probably correlates with
473 crunchier products. Significant sensory differences between hazelnuts roasted with HA and IR
474 systems were found only when roasting was performed at high temperatures. (170 °C - 20 min)
475 Even if it was not possible to draw similar overall conclusion for the TPC and antioxidant capacity,
476 the storage time of six months at 4 °C could be suggested for the maintenance of a high antioxidant
477 capacity of the hazelnuts.

478

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484

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590 **Tables**

591 **Table 1.** Sums of fatty acids (mg/g) and oxidative stability of raw and roasted hazelnuts as a
592 function of the roasting system (IR = infrared rays, HA = hot air), roasting conditions and storage
593 time; 2010 harvest.

594 **Table 2.** Sums of fatty acids (mg/g) and oxidative stability of raw and roasted hazelnuts as a
595 function of the roasting system (IR = infrared rays, HA = hot air), roasting conditions and storage
596 time; 2011 harvest.

597 **Table 3.** Total phenolic content (TPC) and antioxidant capacity (TEAC and RSA) of raw and
598 roasted hazelnuts as a function of the roasting system (IR = infrared rays, HA = hot air), roasting
599 conditions and storage time; 2010 harvest.

600 **Table 4.** Total phenolic content (TPC) and antioxidant capacity (TEAC and RSA) of raw and
601 roasted hazelnuts as a function of the roasting system (IR = infrared rays, HA = hot air), roasting
602 conditions and storage time; 2011 harvest.

603 **Table 5.** Mechanical properties of raw and roasted hazelnuts as a function of the roasting system
604 (IR = infrared rays, HA = hot air), roasting conditions and storage time; 2010 harvest.

605 **Table 6.** Mechanical properties of raw and roasted hazelnuts as a function of the roasting system
606 (IR = infrared rays, HA = hot air), roasting conditions and storage time; 2011 harvest.

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616 **Supplementary tables**

617 **Table 7.** Main fatty acids (mg/g) in raw and roasted hazelnuts as a function of the roasting system
618 (IR = infrared rays, HA = hot air), roasting conditions and storage time; 2010 harvest.

619 **Table 8.** Main fatty acids (mg/g) of raw and roasted hazelnuts as a function of the roasting system
620 (IR = infrared rays, HA = hot air), roasting conditions and storage time; 2011 harvest.

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Table 1. Sums of fatty acids and oxidative stability of raw and roasted hazelnuts from TGT and ORDU cultivars as function of roasting system (IR = infrared rays, HA = hot air), roasting conditions and storage time, harvest 2010.

Parameter	Roasting system	Storage (months)	TGT				ORDU				
			Raw	170°C - 20 min	120°C - 40 min	Sign. ^a	Raw	170°C - 20 min	120°C - 40 min	Sign. ^a	
ΣSFAs (mg/g)	IR	0	9.75 ± 0.00	9.73 ± 0.03c	9.04 ± 0.02a	***	7.16 ± 0.03	7.37 ± 0.02a	8.15 ± 0.01b	***	
		6		9.41 ± 0.06b	9.19 ± 0.02b	**		7.40 ± 0.01b	7.62 ± 0.01a	***	
		9		9.32 ± 0.00a	9.23 ± 0.01b	***		7.61 ± 0.00c	7.62 ± 0.04a	ns	
	HA	0	9.75 ± 0.00	9.23 ± 0.13b	9.18 ± 0.00a	ns	7.16 ± 0.03	7.82 ± 0.02	7.57 ± 0.34c	ns	
		6		9.09 ± 0.01ab	9.24 ± 0.00b	***		7.44 ± 0.02	7.77 ± 0.01a	***	
		9		8.94 ± 0.02a	9.29 ± 0.03c	***		7.62 ± 0.00	7.64 ± 0.06b	ns	
	<i>Sign.^b</i>			** , ** , ***	*** , * , *			*** , ** , ns	* , *** , ns		
	ΣMUFAs (mg/g)	IR	0	83.70 ± 0.00	84.68 ± 0.02c	85.21 ± 0.01c	***	85.71 ± 0.02	85.47 ± 0.03c	84.59 ± 0.01a	***
			6		84.46 ± 0.08b	84.32 ± 0.03a	*		84.91 ± 0.01b	85.13 ± 0.01b	***
9				84.03 ± 0.04a	84.68 ± 0.04b	***		84.67 ± 0.01a	84.45 ± 0.12c	*	
HA		0	83.70 ± 0.00	84.24 ± 0.05a	84.21 ± 0.01b	ns	85.71 ± 0.02	84.68 ± 0.03	84.33 ± 0.89a	ns	
		6		84.47 ± 0.01b	84.61 ± 0.01c	***		85.40 ± 0.02	84.90 ± 0.01c	***	
		9		84.48 ± 0.02b	83.66 ± 0.07a	***		85.11 ± 0.00	84.66 ± 0.10b	**	
<i>Sign.^b</i>			*** , ns , ***	*** , *** , ***			*** , *** , ***	ns , *** , ns			
ΣPUFAs (mg/g)		IR	0	6.53 ± 0.00	5.59 ± 0.01a	5.76 ± 0.01a	***	7.13 ± 0.01	7.16 ± 0.02a	7.25 ± 0.01a	**
			6		6.13 ± 0.14b	6.48 ± 0.00c	*		7.70 ± 0.01b	7.25 ± 0.01a	***
	9			6.65 ± 0.04c	6.09 ± 0.03b	***		7.72 ± 0.01c	7.93 ± 0.08b	*	
	HA	0	6.53 ± 0.00	6.53 ± 0.17	6.61 ± 0.01b	ns	7.13 ± 0.01	7.50 ± 0.01	8.11 ± 1.24c	ns	
		6		6.44 ± 0.01	6.15 ± 0.01a	***		7.15 ± 0.00	7.33 ± 0.01a	***	
		9		6.55 ± 0.03	7.01 ± 0.04c	***		7.27 ± 0.00	7.70 ± 0.16b	*	
	<i>Sign.^b</i>			** , * , *	*** , *** , ***			*** , *** , ***	ns , *** , ns		
	Σ(MUFAs+PUFAs)/SFAs	IR	0	9.26 ± 0.00	9.28 ± 0.03a	10.06 ± 0.02b	***	12.97 ± 0.05	12.57 ± 0.02c	11.26 ± 0.01a	***
			6		9.62 ± 0.07b	9.88 ± 0.03a	**		12.52 ± 0.01b	12.12 ± 0.01b	***
9				9.73 ± 0.00c	9.84 ± 0.01a	***		12.14 ± 0.01a	12.13 ± 0.04b	ns	
HA		0	9.26 ± 0.00	9.84 ± 0.16a	9.89 ± 0.01c	ns	12.97 ± 0.05	11.79 ± 0.03	12.24 ± 0.58	ns	
		6		10.00 ± 0.01ab	9.82 ± 0.00b	***		12.43 ± 0.03	11.87 ± 0.01	***	
		9		10.18 ± 0.02b	9.76 ± 0.04a	***		12.12 ± 0.00	12.09 ± 0.10	ns	
<i>Sign.^b</i>			** , ** , ***	*** , * , *			*** , ** , **	* , *** , ns			
O/L		IR	0	12.91 ± 0.01	15.23 ± 0.01c	14.97 ± 0.01c	***	12.13 ± 0.01	12.07 ± 0.03c	11.76 ± 0.01b	***
			6		13.93 ± 0.34b	13.13 ± 0.01a	*		11.13 ± 0.01b	11.86 ± 0.01b	***
	9			12.77 ± 0.08a	14.06 ± 0.07b	***		11.07 ± 0.01a	10.77 ± 0.11a	**	
	HA	0	12.91 ± 0.01	13.03 ± 0.34	12.88 ± 0.01b	ns	12.13 ± 0.01	11.40 ± 0.01	10.68 ± 1.94a	ns	
		6		13.25 ± 0.01	13.89 ± 0.01c	***		12.08 ± 0.01	11.71 ± 0.01c	***	

		9			13.03 ± 0.06	12.03 ± 0.07a	***		11.83 ± 0.01	11.11 ± 0.24b	**
					***, *, *	***, ***, ***			***, ***, ***	ns, ***, ns	
IV	IR	0	86.94 ± 0.00	86.16 ± 0.04a	86.85 ± 0.02a	***	89.84 ± 0.70	89.68 ± 0.02a	89.12 ± 0.01a	***	
		6		87.04 ± 0.20b	87.57 ± 0.03c	*		90.23 ± 0.01b	89.63 ± 0.00c	***	
		9		87.71 ± 0.04c	87.25 ± 0.03b	***		90.10 ± 0.01c	90.28 ± 0.15b	***	
	HA	0	86.94 ± 0.00	87.40 ± 0.28a	87.53 ± 0.01b	ns	89.84 ± 0.70	89.60 ± 0.02	90.38 ± 1.43b	ns	
		6		87.61 ± 0.01a b	87.22 ± 0.01a	***		89.68 ± 0.02	89.56 ± 0.01a	***	
		9		87.89 ± 0.03b	88.01 ± 0.01c	**		89.68 ± 0.01	90.05 ± 0.19b	*	
					, **, **	*, ***, ***		**, ***, ***	ns, ***, ns		
PV (meqO ₂ /kg)	IR	0	0.01 ± 0.00	1.31 ± 0.01c	0.64 ± 0.00b	***	0.70 ± 0.01	4.69 ± 0.01c	4.07 ± 0.02c	***	
		6		0.37 ± 0.04a	0.42 ± 0.00a	ns		0.21 ± 0.01a	0.20 ± 0.01a	***	
		9		2.95 ± 0.01b	2.15 ± 0.08c	***		1.32 ± 0.00b	0.16 ± 0.00b	***	
	HA	0	0.01 ± 0.00	2.54 ± 0.01c	nq	***	0.70 ± 0.01	9.98 ± 0.08	0.06 ± 0.01b	***	
		6		0.51 ± 0.08a	nq	***		1.42 ± 0.15	0.01 ± 0.01a	***	
		9		1.64 ± 0.09b	nq	***		1.74 ± 0.12	0.28 ± 0.03c	***	
					***, ns, ***	***, ***, ***		***, ***, **	***, ns, **		

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Values are expressed as mean ± standard deviation ($n = 9$). Different letters in columns, for each different roasting system, mean significantly different values among storage points. Where letters in columns were not reported, no statistical differences were observed.

Sign^a: *, **, *** and “ns” mean significance at $p < 0.05$, 0.01, 0.001 and “not significant”, respectively, between roasting time-temperature conditions.

Sign^b: *, **, *** and “ns” mean significance at $p < 0.05$, 0.01, 0.001 and “not significant”, respectively, between roasting systems for each point separately.

nq: not quantifiable

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Table 2. Sums of fatty acids and oxidative stability of raw and roasted hazelnuts from TGT and ORDU cultivars as function of roasting system (IR = infrared rays, HA = hot air), roasting conditions and storage time, harvest 2011.

Parameter	Roasting system	Storage (months)	TGT					ORDU				
			Raw		170°C - 20 min		120°C - 40 min	Sign. ^a	Raw		170°C - 20 min	
ΣSFAs (mg/g)	IR	0	8.31 ± 0.00	7.68 ± 0.63	8.41 ± 0.00b	ns	8.50 ± 0.71	7.76 ± 0.01a	8.13 ± 0.21	ns		
		6		8.41 ± 0.02	8.25 ± 0.00a	**		7.85 ± 0.05ab	7.99 ± 0.01	ns		
		9		8.36 ± 0.00	8.43 ± 0.01b	*		7.96 ± 0.04c	7.76 ± 0.01	*		
	HA	0	8.31 ± 0.00	8.14 ± 0.00a	8.34 ± 0.01b	**	8.50 ± 0.71	7.83 ± 0.01a	8.50 ± 0.70	ns		
		6		8.62 ± 0.00c	8.26 ± 0.02a	**		7.87 ± 0.01a	7.87 ± 0.01	ns		
		9		8.31 ± 0.00b	8.66 ± 0.01c	***		8.03 ± 0.01b	8.20 ± 0.00	**		
	Sign. ^b			ns, **, ***		**, ns, **		*, ns, ns		ns, **, **		
	ΣMUFAs (mg/g)	IR	0	85.31 ± 0.00	86.68 ± 1.10	85.43 ± 0.01	ns	85.28 ± 0.01	84.90 ± 0.01	85.38 ± 0.38	ns	
			6		85.15 ± 0.05	85.08 ± 0.01	ns		85.25 ± 0.06	85.33 ± 0.05	ns	
9				85.13 ± 0.44	85.33 ± 0.30	ns		85.43 ± 0.48	85.55 ± 0.36	ns		
HA		0	85.31 ± 0.00	85.25 ± 0.01b	85.02 ± 0.01	**	85.28 ± 0.01	87.51 ± 0.01c	85.28 ± 0.01a	***		
		6		84.34 ± 0.01a	85.34 ± 0.01	***		84.72 ± 0.01a	85.25 ± 0.04a	**		
		9		84.91 ± 0.34ab	85.00 ± 0.33	ns		85.73 ± 0.33b	86.36 ± 0.31b	ns		
Sign. ^b			ns, **, ns		***, **, ns		***, **, ns		ns, ns, ns			
ΣPUFAs (mg/g)		IR	0	6.38 ± 0.01	5.65 ± 0.47	6.17 ± 0.01	ns	6.73 ± 0.01	7.34 ± 0.00	6.49 ± 0.17	*	
			6		6.45 ± 0.03	6.68 ± 0.01	**		6.91 ± 0.01	6.68 ± 0.03	**	
	9			6.51 ± 0.44	6.25 ± 0.29	ns		6.61 ± 0.44	6.70 ± 0.37	ns		
	HA	0	6.38 ± 0.01	6.61 ± 0.01	6.65 ± 0.00	ns	6.73 ± 0.01	6.65 ± 0.01a	6.73 ± 0.01b	*		
		6		7.05 ± 0.01	6.41 ± 0.01	***		7.42 ± 0.01b	6.88 ± 0.06b	**		
		9		6.79 ± 0.33	6.35 ± 0.31	ns		6.24 ± 0.31a	5.44 ± 0.31a	ns		
	Sign. ^b			ns, **, ns		***, **, ns		***, **, ns		ns, *, ns		
	Σ(MUFAs+PUFAs)/SFAs	IR	0	11.03 ± 0.00	12.07 ± 1.07	10.89 ± 0.00a	ns	10.87 ± 0.90	11.89 ± 0.01c	11.31 ± 0.31a	ns	
			6		10.90 ± 0.04	11.12 ± 0.01b	*		11.75 ± 0.08ab	11.51 ± 0.02ab	ns	
9				10.96 ± 0.00	10.87 ± 0.02a	*		11.57 ± 0.06a	11.90 ± 0.02b	*		
HA		0	11.03 ± 0.00	11.29 ± 0.00c	11.00 ± 0.01b	**	10.87 ± 0.90	12.02 ± 0.03c	10.87 ± 0.91	ns		
		6		10.60 ± 0.00a	11.11 ± 0.03c	**		11.71 ± 0.01b	11.71 ± 0.02	ns		
		9		11.04 ± 0.00b	10.56 ± 0.01a	***		11.46 ± 0.02a	11.20 ± 0.01	**		
Sign. ^b			ns, **, ***		**, ns, **		*, ns, ns		ns, *, **			
O/L		IR	0	13.54 ± 0.01	15.60 ± 1.50	14.03 ± 0.01	ns	12.78 ± 0.03	11.66 ± 0.00	13.30 ± 0.42	*	
			6		13.37 ± 0.06	12.86 ± 0.02	**		12.46 ± 0.01	12.90 ± 0.07	*	
	9			13.27 ± 0.98	13.86 ± 0.70	ns		13.10 ± 0.91	12.93 ± 0.77	ns		

	HA	0	13.54 ± 0.01	13.05 ± 0.02	12.93 ± 0.00	*	12.78 ± 0.03	13.01 ± 0.02b	12.78 ± 0.03a	*
		6		12.09 ± 0.01	13.48 ± 0.02	***		11.52 ± 0.03a	12.48 ± 0.11a	**
		9		12.68 ± 0.70	13.58 ± 0.76	ns		13.93 ± 0.76b	16.12 ± 1.03b	ns
	<i>Sign.^b</i>			ns, **, ns	***, **, ns			***, **, ns	ns, *, ns	
IV	IR	0	88.27 ± 0.00	88.15 ± 0.13	87.98 ± 0.01a	ns	88.78 ± 0.04	89.56 ± 0.00b	88.45 ± 0.03	***
		6		88.23 ± 0.01	88.57 ± 0.01b	**		89.08 ± 0.04ab	88.74 ± 0.02	**
		9		88.30 ± 0.45	88.03 ± 0.28a	ns		88.66 ± 0.35a	88.97 ± 0.40	ns
	HA	0	88.27 ± 0.00	88.64 ± 0.01	88.49 ± 0.01	**	88.78 ± 0.04	88.86 ± 0.01b	88.78 ± 0.04b	ns
		6		88.60 ± 0.00	88.35 ± 0.02	**		89.55 ± 0.02c	89.04 ± 0.08b	*
		9		88.61 ± 0.35	87.93 ± 0.33	ns		88.29 ± 0.30a	87.41 ± 0.31a	ns
	<i>Sign.^b</i>			*, ***, ns	***, **, ns			***, **, ns	*, *, ns	
PV (meqO ₂ /kg)	IR	0	0.03 ± 0.02	1.27 ± 0.04a	0.75 ± 0.01c	**	0.97 ± 0.08	4.73 ± 0.00b	0.06 ± 0.02a	***
		6		1.55 ± 0.01a	0.21 ± 0.02a	***		4.66 ± 0.17b	0.20 ± 0.00a	**
		9		9.92 ± 0.25b	0.37 ± 0.05b	***		3.08 ± 0.03a	1.66 ± 0.17b	**
	HA	0	0.03 ± 0.02	1.33 ± 0.04a	1.33 ± 0.04c	ns	0.97 ± 0.08	0.43 ± 0.06a	0.06 ± 0.00b	*
		6		1.93 ± 0.18b	0.15 ± 0.00b	**		1.63 ± 0.11c	0.08 ± 0.02b	**
		9		1.69 ± 0.22ab	0.01 ± 0.00a	**		1.37 ± 0.04b	0.01 ± 0.00a	***
	<i>Sign.^b</i>			ns, ns, **	** , ns, *			***, **, ***	ns, *, **	

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Values are expressed as mean ± standard deviation ($n = 9$). Different letters in columns, for each different roasting system, mean significantly different values among storage points. Where letters in columns were not reported, no statistical differences were observed.

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Sign^a: *, **, *** and “ns” mean significance at $p < 0.05$, 0.01, 0.001 and “not significant”, respectively, between roasting time-temperature conditions.

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Sign^b: *, **, *** and “ns” mean significance at $p < 0.05$, 0.01, 0.001 and “not significant”, respectively, between roasting systems for each point separately.

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Table 3. Total Phenolic Content (TPC) and antioxidant capacity (TEAC and RSA) of raw and roasted hazelnuts from TGT and ORDU cultivars as function of roasting system (IR = infrared rays, HA = hot air), roasting conditions and storage time, harvest 2010.

Parameter	Roasting system	Storage (months)	TGT						ORDU								
			Raw		170°C - 20 min		120°C - 40 min		Sign. ^a	Raw		170°C - 20 min		120°C - 40 min		Sign. ^a	
TPC (mg GAE/g)	IR	0	0.42	± 0.01	0.48	± 0.02	0.49	± 0.02a	ns	0,51	± 0,01	0.57	± 0.01a	0.61	± 0.00a	**	
		6			0.50	± 0.01	0.53	± 0.00ab	ns			0.63	± 0.04a	0.90	± 0.04c	**	
		9			0.51	± 0.00	0.54	± 0.01b	**			0.94	± 0.06b	0.71	± 0.02b	**	
	HA	0	0.42	± 0.01	0.61	± 0.02a	0.47	± 0.01	***	0,51	± 0,01	0.91	± 0.01ab	0.64	± 0.02	***	
		6			0.64	± 0.01ab	0.69	± 0.23	ns			1.09	± 0.16b	0.82	± 0.27	ns	
		9			0.67	± 0.01b	0.56	± 0.03	**			0.72	± 0.01a	0.99	± 0.10	*	
	<i>Sign.^b</i>				***, ***, ***		ns, ns, ns					***, **, **		ns, ns, **			
	TEAC (µmol TE/g)	IR	0	1.99	± 0.07	2.20	± 0.07	2.09	± 0.09a	ns	1,76	± 0,05	1.64	± 0.01a	1.99	± 0.13a	**
			6			2.10	± 0.10	2.10	± 0.05a	ns			2.32	± 0.24b	4.13	± 0.29c	**
9					2.04	± 0.01	2.25	± 0.08b	*			4.58	± 0.37c	2.50	± 0.15b	**	
HA		0	1.99	± 0.07	3.01	± 0.11	2.13	± 0.06	***	1,76	± 0,05	4.16	± 0.10ab	2.19	± 0.08	***	
		6			2.83	± 0.06	3.09	± 1.36	ns			5.71	± 1.54b	3.78	± 1.76	ns	
		9			2.82	± 0.11	2.40	± 0.10	**			2.50	± 0.06a	4.40	± 0.68	**	
<i>Sign.^b</i>				***, ***, ***		ns, ns, ns					***, *, ***		ns, ns, **				
RSA (µmol TE/g)		IR	0	0.64	± 0.05	0.79	± 0.08a	0.76	± 0.05a	ns	0,60	± 0,02	0.55	± 0.01a	0.63	± 0.02a	**
			6			1.02	± 0.07b	0.84	± 0.03a	*			1.17	± 0.17b	2.26	± 0.27c	**
	9				0.88	± 0.04ab	0.97	± 0.02b	*			2.63	± 0.27c	1.09	± 0.06b	**	
	HA	0	0.64	± 0.05	1.22	± 0.06	0.78	± 0.03	***	0,60	± 0,02	1.99	± 0.04ab	0.70	± 0.05a	***	
		6			1.24	± 0.03	1.42	± 0.79	ns			3.01	± 0.84b	1.99	± 1.14ab	ns	
		9			1.21	± 0.02	1.12	± 0.04	**			1.03	± 0.01a	2.41	± 0.51b	*	
	<i>Sign.^b</i>				** , ** , ***		ns, ns, **					***, *, ***		ns, ns, *			

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Values are expressed as mean ± standard deviation ($n = 9$). Different letters in columns, for each different roasting system, mean significantly different values among storage points. Where letters in columns were not reported, no statistical differences were observed.

Sign^a: *, **, *** and “ns” mean significance at $p < 0.05$, 0.01, 0.001 and “not significant”, respectively, between roasting time-temperature conditions.

Sign^b: *, **, *** and “ns” mean significance at $p < 0.05$, 0.01, 0.001 and “not significant”, respectively, between roasting systems for each point separately.

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Table 4. Total Phenolic Content (TPC) and antioxidant capacity (TEAC and RSA) of raw and roasted hazelnuts from TGT and ORDU cultivars as function of roasting system (IR = infrared rays, HA = hot air), roasting conditions and storage time, harvest 2011.

Parameter	Roasting system	Storage (months)	TGT					ORDU				
			Raw		170°C - 20 min		120°C - 40 min	Sign. ^a	Raw		170°C - 20 min	
TPC (mg GAE/g)	IR	0	0.27 ± 0.01	0.62 ± 0.02a	0.51 ± 0.02a	**	0.39 ± 0.05	0.60 ± 0.05a	0.52 ± 0.02a	ns		
		6		0.83 ± 0.03b	0.91 ± 0.10b	ns		1.58 ± 0.15b	1.96 ± 0.22b	ns		
		9		0.89 ± 0.03b	0.47 ± 0.02a	***		0.57 ± 0.01a	0.55 ± 0.04a	ns		
	HA	0	0.27 ± 0.01	0.35 ± 0.02a	0.28 ± 0.04a	ns	0.39 ± 0.05	0.51 ± 0.01a	0.48 ± 0.02a	ns		
		6		0.77 ± 0.05c	0.59 ± 0.07c	*		1.31 ± 0.05b	2.18 ± 0.00b	***		
		9		0.57 ± 0.02b	0.47 ± 0.00b	**		0.56 ± 0.01a	0.45 ± 0.03a	**		
	<i>Sign.^b</i>			***, ns, ***		***, *, ns		ns, *, ns		ns, ns, *		
	TEAC (µmol TE/g)	IR	0	0.59 ± 0.09	2.12 ± 0.05a	1.67 ± 0.03a	***	1.08 ± 0.25	1.75 ± 0.03a	1.69 ± 0.17a	ns	
			6		3.16 ± 0.14b	5.03 ± 0.82b	*		8.49 ± 0.85b	10.63 ± 0.51b	*	
9				3.55 ± 0.17c	1.52 ± 0.00a	***		1.90 ± 0.03a	1.76 ± 0.14a	ns		
HA		0	0.59 ± 0.09	0.96 ± 0.07a	0.71 ± 0.13a	*	1.08 ± 0.25	1.44 ± 0.06a	1.13 ± 0.10a	*		
		6		3.73 ± 0.45c	2.60 ± 0.48c	*		7.22 ± 0.18b	11.20 ± 0.00b	***		
		9		2.02 ± 0.10b	1.47 ± 0.04b	**		1.93 ± 0.08a	1.52 ± 0.18a	*		
<i>Sign.^b</i>			***, ns, ***		***, *, ns		***, ns, ns		**, ns, ns			
RSA (µmol TE/g)		IR	0	0.68 ± 0.08	1.50 ± 0.05a	1.20 ± 0.03a	**	0.67 ± 0.08	1.22 ± 0.10a	1.04 ± 0.19a	ns	
			6		2.12 ± 0.09b	3.56 ± 0.44b	**		5.29 ± 0.30b	6.02 ± 0.26b	*	
	9			2.02 ± 0.12b	0.79 ± 0.03a	***		1.02 ± 0.02a	0.91 ± 0.02a	**		
	HA	0	0.68 ± 0.08	0.89 ± 0.03a	0.76 ± 0.08a	*	0.67 ± 0.08	0.85 ± 0.04a	0.77 ± 0.03a	ns		
		6		2.55 ± 0.23b	1.65 ± 0.54b	ns		4.57 ± 0.12b	6.81 ± 0.07b	***		
		9		1.11 ± 0.01a	0.84 ± 0.03a	***		1.04 ± 0.03a	0.77 ± 0.10a	**		
	<i>Sign.^b</i>			***, *, ***		***, **, ns		**, *, ns		ns, **, ns		

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Values are expressed as mean ± standard deviation ($n = 9$). Different letters in columns, for each different roasting system, mean significantly different values among storage points. Where letters in columns were not reported, no statistical differences were observed.

Sign^a: *, **, *** and "ns" mean significance at $p < 0.05$, 0.01, 0.001 and "not significant", respectively, between roasting time-temperature conditions.

Sign^b: *, **, *** and "ns" mean significance at $p < 0.05$, 0.01, 0.001 and "not significant", respectively, between roasting systems for each point separately.

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Table 5. Mechanical properties of raw and roasted hazelnuts from TGT and ORDU cultivars as function of roasting system (IR = infrared rays, HA = hot air), roasting conditions and storage time, harvest 2010.

Parameter	Roasting system	Storage (months)	TGT				ORDU				
			Raw	170°C - 20 min	120°C - 40 min	Sign. ^a	Raw	170°C - 20 min	120°C - 40 min	Sign. ^a	
F1 (N)	IR	0	93.2 ± 16.7	83.4 ± 18.7	57.7 ± 19.5	***	96.4 ± 20.4	78.7 ± 19.2b	63.3 ± 25.7	*	
		6		80.3 ± 16.7	59.9 ± 17.9	***		73.7 ± 12.9b	45.7 ± 18.7	***	
		9		80.5 ± 26.0	61.3 ± 18.2	**		62.0 ± 19.8a	51.8 ± 29.9	ns	
	HA	0	93.2 ± 16.7	40.1 ± 14.8	47.9 ± 16.5	ns	96.4 ± 20.4	35.0 ± 17.1	41.7 ± 15.6	ns	
		6		38.8 ± 12.4	44.7 ± 17.4	ns		37.7 ± 13.8	40.4 ± 16.3	ns	
		9		44.0 ± 17.4	57.7 ± 21.4	*		43.9 ± 21.0	48.9 ± 17.7	ns	
	<i>Sign.^b</i>			***, ***, ***	ns, **, ns		***, ***, **	** , ns, ns			
	W1 (mJ)	IR	0	113.9 ± 53.0	82.4 ± 42.7	37.7 ± 24.1	***	117.6 ± 45.9	78.2 ± 39.2b	42.4 ± 23.8	**
			6		83.3 ± 34.4	38.8 ± 21.0	***		67.4 ± 26.2ab	24.4 ± 13.1	***
9				72.6 ± 45.7	45.9 ± 31.8	*		48.4 ± 26.1a	33.0 ± 34.4	ns	
HA		0	113.9 ± 53.0	23.1 ± 18.6	29.1 ± 22.1	ns	117.6 ± 45.9	17.2 ± 14.7	19.9 ± 13.5	ns	
		6		20.9 ± 13.5	27.8 ± 18.6	ns		20.7 ± 16.4	21.5 ± 15.1	ns	
		9		29.8 ± 22.8	43.7 ± 31.1	ns		27.5 ± 24.4	32.5 ± 22.6	ns	
<i>Sign.^b</i>			***, ***, ***	ns, ns, ns		***, ***, *	***, ns, ns				
E1 (N/mm)		IR	0	40.9 ± 7.0	44.0 ± 7.2ab	44.1 ± 10.3	ns	39.6 ± 8.1	41.6 ± 11.6	45.5 ± 15.6	ns
			6		39.3 ± 8.0a	46.7 ± 7.4	**		39.1 ± 5.6	44.2 ± 19.8	ns
	9			49.0 ± 11.8b	42.7 ± 7.5	*		40.8 ± 7.4	44.3 ± 12.5	ns	
	HA	0	40.9 ± 7.0	35.3 ± 8.9	40.9 ± 12.4	ns	39.6 ± 8.1	36.2 ± 15.9	43.2 ± 11.2	ns	
		6		37.2 ± 7.8	39.6 ± 8.2	ns		36.3 ± 8.3	40.2 ± 7.6	ns	
		9		34.6 ± 5.3	41.5 ± 8.4	**		36.9 ± 8.8	38.8 ± 7.3	ns	
	<i>Sign.^b</i>			** , ns, ***	ns, **, ns		ns, ns, ns	ns, ns, ns			
	Maximum acoustic peak (dB)	IR	0	99.9 ± 6.4	101.3 ± 5.7	97.5 ± 8.2	ns	95.7 ± 7.7	101.9 ± 6.1	100.0 ± 6.5	ns
			6		101.3 ± 8.5	100.2 ± 4.7	ns		102.0 ± 5.2	100.0 ± 4.3	ns
9				103.8 ± 4.6	100.7 ± 5.7	*		104.5 ± 4.4	100.1 ± 6.1	*	
HA		0	99.9 ± 6.4	93.3 ± 5.5a	93.8 ± 7.1a	ns	95.7 ± 7.7	92.7 ± 5.4a	95.4 ± 4.8a	ns	
		6		99.1 ± 5.0b	99.5 ± 5.4b	ns		100.3 ± 4.3b	97.0 ± 6.9a	ns	
		9		99.7 ± 6.1b	101.0 ± 5.3b	ns		97.9 ± 7.1b	101.8 ± 5.4b	ns	
<i>Sign.^b</i>			***, ns, **	ns, ns, ns		***, ns, **	*, ns, ns				
Number of acoustic peaks		IR	0	26.0 ± 10.5	32.0 ± 20.2a	52.5 ± 18.9a	**	48.3 ± 17.3	80.6 ± 42.2a	85.2 ± 37.2a	ns
			6		102.5 ± 34.0b	139.9 ± 70.0b	*		104.0 ± 32.7a	165.9 ± 49.1b	***
	9			164.5 ± 51.4c	184.7 ± 61.2c	ns		156.6 ± 68.4b	202.2 ± 50.0c	*	
	HA	0	26.0 ± 10.5	61.8 ± 22.7a	58.8 ± 22.0a	ns	48.3 ± 17.3	117.8 ± 35.6a	85.6 ± 45.7a	*	
		6		91.4 ± 22.1b	63.5 ± 31.8a	**		96.2 ± 27.4a	198.8 ± 37.3b	***	

			9		215.6 ± 58.8c	269.6 ± 56.2b	**		162.3 ± 57.7b	225.3 ± 52.6b	***
		<i>Sign.^b</i>			***, ns, **	ns, ***, ***			** , ns, ns	ns, *, ns	
Average acoustic peaks (dB)	IR		0	59.9 ± 6.6	59.9 ± 6.2a	55.3 ± 4.9a	*	59.4 ± 5.0	61.6 ± 4.7ab	60.5 ± 4.3a	ns
			6		60.3 ± 5.4a	62.1 ± 6.4b	ns		60.8 ± 5.5a	62.1 ± 3.8a	ns
			9		65.7 ± 4.0b	63.2 ± 3.0b	*		64.4 ± 3.9b	66.6 ± 3.7b	ns
	HA		0	59.9 ± 6.6	56.2 ± 5.1a	53.8 ± 3.9a	ns	59.4 ± 5.0	61.5 ± 3.1a	65.5 ± 3.1b	***
			6		61.1 ± 6.0b	56.2 ± 5.0a	**		60.0 ± 5.3a	63.1 ± 3.1a	*
			9		68.0 ± 3.7c	67.7 ± 2.3b	ns		68.8 ± 2.9b	66.6 ± 2.8b	*
		<i>Sign.^b</i>			*, ns, *	ns, **, ***		ns, ns, ***	***, ns, ns		

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Values are expressed as mean ± standard deviation ($n = 9$). Different letters in columns, for each different roasting system, mean significantly different values among storage points. Where letters in columns were not reported, no statistical differences were observed.

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Sign^a: *, **, *** and “ns” mean significance at $p < 0.05$, 0.01, 0.001 and “not significant”, respectively, between roasting time-temperature conditions.

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Sign^b: *, **, *** and “ns” mean significance at $p < 0.05$, 0.01, 0.001 and “not significant”, respectively, between roasting systems for each point separately.

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Table 6. Mechanical properties of raw and roasted hazelnuts from TGT and ORDU cultivars as function of roasting system (IR = infrared rays, HA = hot air), roasting conditions and storage time, harvest 2011.

Parameter	Roasting system	Storage (months)	TGT				ORDU				
			Raw	170°C - 20 min	120°C - 40 min	Sign. ^a	Raw	170°C - 20 min	120°C - 40 min	Sign. ^a	
F1 (N)	IR	0	83.3 ± 21.8	48.8 ± 19.1	40.7 ± 16.2	ns	84.3 ± 22.0	42.7 ± 14.5	30.3 ± 12.4	**	
		6		57.5 ± 21.9	40.7 ± 19.3	*		41.6 ± 13.9	27.7 ± 8.7	***	
		9		57.0 ± 26.8	44.7 ± 22.6	ns		51.0 ± 13.6	37.6 ± 18.5	*	
	HA	0	83.3 ± 21.8	40.8 ± 10.5a	41.5 ± 19.2	ns	84.3 ± 22.0	40.8 ± 16.1	37.7 ± 10.7	ns	
		6		49.6 ± 17.4ab	38.6 ± 13.5	*		41.6 ± 11.6	37.4 ± 11.5	ns	
		9		54.9 ± 14.8b	38.5 ± 15.8	**		47.5 ± 11.2	44.2 ± 19.1	ns	
	<i>Sign.^b</i>			ns, ns, ns	ns, ns, ns			ns, ns, ns	ns, **, ns		
	W1 (mJ)	IR	0	67.4 ± 32.2	31.7 ± 24.2	28.8 ± 17.7	ns	94.9 ± 42.7	26.2 ± 18.3	16.4 ± 14.2ab	ns
			6		39.3 ± 30.3	27.1 ± 20.4	ns		25.9 ± 21.0	12.3 ± 5.8a	**
9				36.7 ± 26.5	37.7 ± 29.6	ns		34.1 ± 17.2	26.9 ± 24.3b	ns	
HA		0	67.4 ± 32.2	21.7 ± 11.2a	25.1 ± 23.9	ns	94.9 ± 42.7	23.6 ± 20.0	19.5 ± 10.3	ns	
		6		29.6 ± 20.4ab	22.6 ± 18.7	ns		24.3 ± 11.0	21.5 ± 12.7	ns	
		9		39.0 ± 23.3b	23.6 ± 18.2	*		26.7 ± 11.1	31.6 ± 28.0	ns	
<i>Sign.^b</i>			ns, ns, ns	ns, ns, ns			ns, ns, ns	ns, **, ns			
E1 (N/mm)		IR	0	50.1 ± 6.6	40.2 ± 9.7	29.8 ± 9.5	**	37.8 ± 3.6	38.3 ± 8.9	29.5 ± 6.9	**
			6		45.7 ± 12.3	31.5 ± 9.5	***		34.9 ± 8.3	31.4 ± 12.2	ns
	9			47.9 ± 18.5	26.6 ± 8.1	***		38.0 ± 6.8	27.4 ± 7.3	***	
	HA	0	50.1 ± 6.6	37.4 ± 6.5	35.5 ± 6.6	ns	37.8 ± 3.6	37.0 ± 8.1a	36.4 ± 7.4	ns	
		6		41.3 ± 7.2	35.9 ± 7.0	*		34.8 ± 4.9a	34.0 ± 8.7	ns	
		9		39.4 ± 5.9	31.9 ± 6.6	***		41.6 ± 8.2b	32.4 ± 6.3	***	
	<i>Sign.^b</i>			ns, ns, ns	*, ns, *			ns, ns, ns	**, ns, *		
	Maximum acoustic peak (dB)	IR	0	100.6 ± 7.2	97.9 ± 5.6b	96.2 ± 7.8	ns	95.8 ± 6.3	89.9 ± 5.4a	84.9 ± 7.9a	*
			6		89.6 ± 9.2a	91.5 ± 4.7	ns		91.5 ± 6.8a	89.5 ± 5.8b	ns
9				96.5 ± 5.4b	93.4 ± 7.0	ns		99.7 ± 3.9b	91.5 ± 7.8b	***	
HA		0	100.6 ± 7.2	99.2 ± 5.6b	94.9 ± 6.2b	*	95.8 ± 6.3	95.7 ± 5.5a	96.9 ± 5.9b	ns	
		6		89.4 ± 8.1a	86.6 ± 7.9a	ns		93.3 ± 5.2a	89.9 ± 4.3a	*	
		9		99.0 ± 7.0b	95.3 ± 6.4b	ns		99.1 ± 3.9b	96.3 ± 5.8b	ns	
<i>Sign.^b</i>			ns, ns, ns	ns, *, ns			**, ns, ns	***, ns, *			
Number of acoustic peaks		IR	0	122.3 ± 32.0	285.6 ± 46.5b	232.4 ± 28.8b	***	214.3 ± 37.4	190.2 ± 41.6a	203.2 ± 54.8a	ns
			6		195.7 ± 66.6a	255.7 ± 46.9c	**		250.2 ± 74.5b	282.1 ± 52.2b	ns
	9			181.0 ± 24.4a	171.4 ± 23.5a	ns		198.6 ± 24.3a	178.6 ± 41.6a	ns	
	HA	0	122.3 ± 32.0	231.6 ± 33.3	200.0 ± 28.9b	**	214.3 ± 37.4	270.5 ± 71.9b	260.3 ± 50.8	ns	

		6		215.0 ± 63.3	265.8 ± 35.5c	**		217.6 ± 71.2a	252.3 ± 63.3	ns
		9		204.2 ± 33.7	173.4 ± 29.2a	**		197.1 ± 32.5a	223.3 ± 28.0	**
		<i>Sign.^b</i>		***, ns, *	** , ns, ns			***, ns, ns	** , ns, ***	
Average acoustic peaks emission (dB)	IR	0	64.5 ± 2.9	63.9 ± 1.3	64.5 ± 3.0b	ns	67.9 ± 2.8	64.9 ± 3.4	61.8 ± 3.8a	**
		6		63.8 ± 1.9	64.3 ± 3.1b	ns		64.5 ± 2.5	65.0 ± 3.5b	ns
		9		64.0 ± 1.6	62.3 ± 1.6a	**		66.0 ± 2.0	61.4 ± 2.0a	***
	HA	0	64.5 ± 2.9	63.4 ± 2.4	62.4 ± 3.4	ns	67.9 ± 2.8	65.1 ± 3.5ab	66.4 ± 2.0c	ns
		6		64.1 ± 2.9	62.4 ± 2.7	ns		64.1 ± 3.0a	63.3 ± 2.6a	ns
		9		63.3 ± 2.2	63.1 ± 2.4	ns		66.5 ± 2.9b	64.9 ± 2.4b	ns
		<i>Sign.^b</i>		ns, ns, ns	* , * , ns		ns, ns, ns	***, ns, ***		

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Values are expressed as mean ± standard deviation ($n = 9$). Different letters in columns, for each different roasting system, mean significantly different values among storage points. Where letters in columns were not reported, no statistical differences were observed.

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Sign^a: *, **, *** and “ns” mean significance at $p < 0.05$, 0.01, 0.001 and “not significant”, respectively, between roasting time-temperature conditions.

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Sign^b: *, **, *** and “ns” mean significance at $p < 0.05$, 0.01, 0.001 and “not significant”, respectively, between roasting systems for each point separately.

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Table 7. Main fatty acids (mg/g) in raw and roasted hazelnuts from TGT and ORDU cultivars as function of roasting system (IR = infrared rays, HA = hot air), roasting conditions and storage time, harvest 2010.

Parameter	Roasting system	Storage (months)	TGT					ORDU				
			Raw	170°C - 20 min	120°C - 40 min	Sign. ^a	Raw	170°C - 20 min	120°C - 40 min	Sign. ^a		
C16:0	IR	0	7.04 ± 0.00	6.84 ± 0.02b	6.35 ± 0.00a	***	4.62 ± 0.00	4.93 ± 0.01a	5.29 ± 0.01b	***		
		6		6.62 ± 0.00a	6.45 ± 0.00b	*		5.11 ± 0.00c	5.14 ± 0.00a	**		
		9		6.59 ± 0.00a	6.42 ± 0.03b	**		5.08 ± 0.00b	5.13 ± 0.03a	*		
	HA	0	7.04 ± 0.00	6.51 ± 0.26	6.33 ± 0.01a	ns	4.62 ± 0.00	5.21 ± 0.00b	5.00 ± 0.38	ns		
		6		6.34 ± 0.00	6.45 ± 0.00b	***		5.05 ± 0.00a	5.20 ± 0.00	***		
		9		6.31 ± 0.03	6.31 ± 0.02a	***		5.24 ± 0.00c	5.18 ± 0.07	ns		
	<i>Sign.^b</i>			ns, **, ***	*, ns, *		***, ***, ***			ns, ***, ns		
	C16:1	IR	0	0.34 ± 0.00	0.30 ± 0.01b	0.27 ± 0.01	**	0.13 ± 0.00	0.13 ± 0.01	0.14 ± 0.01	ns	
			6		0.28 ± 0.00a	0.28 ± 0.00	ns		0.15 ± 0.01	0.14 ± 0.00	ns	
9				0.30 ± 0.00b	0.28 ± 0.00	***		0.14 ± 0.00	0.14 ± 0.00	ns		
HA		0	0.34 ± 0.00	0.29 ± 0.03	0.26 ± 0.00a	ns	0.13 ± 0.00	0.14 ± 0.00	0.14 ± 0.02	ns		
		6		0.27 ± 0.00	0.28 ± 0.00b	***		0.14 ± 0.01	0.14 ± 0.00	ns		
		9		0.26 ± 0.01	0.26 ± 0.01a	***		0.15 ± 0.01	0.14 ± 0.01	ns		
<i>Sign.^b</i>			ns, **, ***	*, ns, **		ns, ns, **			ns, ns, ns			
C18:0		IR	0	2.48 ± 0.00	2.63 ± 0.01c	2.46 ± 0.02a	***	2.34 ± 0.02	2.22 ± 0.01b	2.62 ± 0.01b	***	
			6		2.58 ± 0.00b	2.53 ± 0.00b	***		2.09 ± 0.01a	2.28 ± 0.00a	***	
	9			2.51 ± 0.01a	2.57 ± 0.00c	**		2.33 ± 0.01c	2.28 ± 0.01a	**		
	HA	0	2.48 ± 0.00	2.50 ± 0.13	2.63 ± 0.01c	ns	2.34 ± 0.02	2.39 ± 0.02b	2.35 ± 0.04b	ns		
		6		2.53 ± 0.00	2.58 ± 0.01b	**		2.20 ± 0.01a	2.38 ± 0.00b	***		
		9		2.41 ± 0.00	2.41 ± 0.01a	***		2.18 ± 0.01a	2.25 ± 0.02a	***		
	<i>Sign.^b</i>			ns, ***, ***	***, **, ***		***, ***, ***			***, ***, *		
	C18:19t	IR	0	0.02 ± 0.00	0.02 ± 0.01	0.02 ± 0.00	ns	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	ns	
			6		0.02 ± 0.00	0.02 ± 0.00	ns		0.02 ± 0.00	0.02 ± 0.00	ns	
9				0.02 ± 0.01	0.01 ± 0.01	ns		0.02 ± 0.00	0.02 ± 0.00	ns		
HA		0	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	ns	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	ns		
		6		0.02 ± 0.00	0.02 ± 0.00	ns		0.02 ± 0.00	0.02 ± 0.00	ns		
		9		0.02 ± 0.00	0.02 ± 0.00	ns		0.02 ± 0.00	0.03 ± 0.01	ns		
<i>Sign.^b</i>			ns, ns, ns	ns, ns, ns		ns, ns, ns			ns, ns, ns			
C18:1ω9		IR	0	83.16 ± 0.00	84.16 ± 0.02c	84.70 ± 0.01c	***	85.35 ± 0.02	85.11 ± 0.02c	84.24 ± 0.00a	***	
			6		83.96 ± 0.07b	83.84 ± 0.03a	ns		84.54 ± 0.00b	84.77 ± 0.01b	***	
	9			83.52 ± 0.03a	84.19 ± 0.03b	***		84.31 ± 0.01a	84.09 ± 0.12a	*		
	HA	0	83.16 ± 0.00	83.72 ± 0.04a	83.74 ± 0.00a	ns	85.35 ± 0.02	84.31 ± 0.02a	83.97 ± 0.88	ns		
		6		83.99 ± 0.01b	84.11 ± 0.00c	***		85.05 ± 0.01c	84.55 ± 0.01	***		

		9			84.00 ± 0.01b	84.00 ± 0.01b			84.74 ± 0.00b	84.29 ± 0.11	**
	<i>Sign.^b</i>				***, ns, ***	***, ***, ***			***, ***, ***	ns, ***, ns	
C18:2ω6	IR	0	6.44 ± 0.00	5.53 ± 0.00a	5.66 ± 0.01a	***	7.03 ± 0.01	7.05 ± 0.02a	7.16 ± 0.00a	**	
		6		6.03 ± 0.14b	6.39 ± 0.00c	*		7.59 ± 0.01b	7.15 ± 0.00a	***	
		9		6.54 ± 0.04c	5.99 ± 0.03b	***		7.62 ± 0.00b	7.81 ± 0.06b	**	
	HA	0	6.44 ± 0.00	6.43 ± 0.16	6.50 ± 0.00c	ns	7.03 ± 0.01	7.39 ± 0.01c	8.01 ± 1.24	ns	
		6		6.34 ± 0.01	6.06 ± 0.01a	***		7.04 ± 0.00a	7.22 ± 0.00	***	
		9		6.45 ± 0.03	6.45 ± 0.03b	ns		7.16 ± 0.00b	7.59 ± 0.15	**	
	<i>Sign.^b</i>			** , * , *	***, ***, ***			***, ***, ***	ns, ***, ns		
C18:3ω3	IR	0	0.06 ± 0.00	0.06 ± 0.01a	0.06 ± 0.00	ns	0.08 ± 0.00	0.09 ± 0.00b	0.09 ± 0.00b	ns	
		6		0.06 ± 0.00ab	0.06 ± 0.00	ns		0.08 ± 0.00ab	0.08 ± 0.00a	ns	
		9		0.07 ± 0.00b	0.06 ± 0.00	**		0.08 ± 0.01a	0.09 ± 0.00b	*	
	HA	0	0.06 ± 0.00	0.07 ± 0.01	0.07 ± 0.00b	ns	0.08 ± 0.00	0.09 ± 0.00b	0.08 ± 0.00	ns	
		6		0.07 ± 0.00	0.06 ± 0.00a	**		0.08 ± 0.00a	0.08 ± 0.00	ns	
		9		0.07 ± 0.01	0.07 ± 0.01ab	ns		0.08 ± 0.01ab	0.09 ± 0.01	ns	
	<i>Sign.^b</i>			ns, **, ns	** , ns, ns			ns, ns, ns	* , ns, ns		

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Values are expressed as mean ± standard deviation ($n = 9$). Different letters in columns, for each different roasting system, mean significantly different values among storage points. Where letters in columns were not reported, no statistical differences were observed.

Sign^a: *, **, *** and “ns” mean significance at $p < 0.05$, 0.01, 0.001 and “not significant”, respectively, between roasting time-temperature conditions.

Sign^b: *, **, *** and “ns” mean significance at $p < 0.05$, 0.01, 0.001 and “not significant”, respectively, between roasting systems for each point separately.

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Table 8. Main fatty acids (mg/g) of raw and roasted hazelnuts from TGT and ORDU cultivars as function of roasting system (IR = infrared rays, HA = hot air), roasting conditions and storage time, harvest 2011.

Parameter	Roasting system	Storage (months)	TGT				ORDU				
			Raw	170°C - 20 min	120°C - 40 min	Sign. ^a	Raw	170°C - 20 min	120°C - 40 min	Sign. ^a	
			<i>Sign.^b</i>								
C16:0	IR	0	5.48 ± 3.37	5.50 ± 0.40	6.30 ± 0.41	ns	5.57 ± 0.00	5.00 ± 0.01	6.12 ± 0.37	ns	
		6		5.63 ± 0.40	5.13 ± 0.81	ns		5.11 ± 0.35	5.25 ± 0.14	ns	
		9		5.52 ± 0.01	6.39 ± 0.44	ns		5.50 ± 0.05	5.37 ± 0.48	ns	
	HA	0	5.48 ± 3.37	5.86 ± 0.58	5.49 ± 0.06	ns	5.57 ± 0.00	5.64 ± 0.08	5.92 ± 0.34	ns	
		6		5.54 ± 0.18	5.55 ± 0.24	ns		4.86 ± 0.09	4.80 ± 0.82	ns	
		9		5.76 ± 0.44	5.65 ± 0.40	ns		5.37 ± 0.42	5.67 ± 0.53	ns	
				<i>Sign.^b</i>							
				ns, ns, ns		ns, ns, ns		**, ns, ns		ns, ns, ns	
	C16:1	IR	0	0.23 ± 0.01	0.22 ± 0.01	0.26 ± 0.02	ns	0.17 ± 0.00	0.15 ± 0.00	0.18 ± 0.01	*
6				0.22 ± 0.01	0.20 ± 0.03	ns		0.15 ± 0.01	0.16 ± 0.01	ns	
9				0.22 ± 0.02	0.27 ± 0.04	ns		0.16 ± 0.01	0.18 ± 0.03	ns	
HA		0	0.23 ± 0.01	0.26 ± 0.04	0.22 ± 0.00	ns	0.17 ± 0.00	0.18 ± 0.01	0.18 ± 0.01	ns	
		6		0.24 ± 0.01	0.23 ± 0.01	ns		0.15 ± 0.00	0.15 ± 0.02	ns	
		9		0.24 ± 0.04	0.24 ± 0.03	ns		0.16 ± 0.02	0.16 ± 0.03	ns	
			<i>Sign.^b</i>								
			ns, ns, ns		ns, ns, ns		*, ns, ns		ns, ns, ns		
C18:0		IR	0	2.20 ± 0.14	2.23 ± 0.15	2.38 ± 0.16	ns	2.29 ± 0.06	1.89 ± 0.00	2.51 ± 0.15b	*
	6			2.33 ± 0.16	2.06 ± 0.31	ns		2.00 ± 0.13	1.97 ± 0.06a	ns	
	9			2.36 ± 0.16	2.51 ± 0.06	ns		2.24 ± 0.12	2.14 ± 0.05ab	ns	
	HA	0	2.20 ± 0.14	2.23 ± 0.23	2.23 ± 0.01	ns	2.29 ± 0.06	2.07 ± 0.03	2.34 ± 0.13	ns	
		6		2.15 ± 0.08	2.15 ± 0.11	ns		1.80 ± 0.02	1.89 ± 0.33	ns	
		9		2.27 ± 0.04	2.17 ± 0.03	ns		2.20 ± 0.04	2.49 ± 0.06	*	
				<i>Sign.^b</i>							
				ns, ns, ns		ns, ns, *		*, ns, ns		ns, ns, *	
	C18:19t	IR	0	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	ns	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	ns
6				0.02 ± 0.00	0.02 ± 0.00	ns		0.02 ± 0.00	0.02 ± 0.00	ns	
9				0.03 ± 0.01	0.02 ± 0.00	ns		0.03 ± 0.01	0.02 ± 0.00	ns	
HA		0	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00a	ns	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	ns	
		6		0.02 ± 0.00	0.02 ± 0.00a	ns		0.02 ± 0.00	0.02 ± 0.00	ns	
		9		0.02 ± 0.00	0.02 ± 0.00b	ns		0.02 ± 0.00	0.03 ± 0.01	ns	
			<i>Sign.^b</i>								
			ns, ns, ns		ns, ns, ns		ns, ns, ns		ns, ns, ns		
C18:1ω9		IR	0	80.31 ± 4.91	89.15 ± 2.23	89.81 ± 5.79	ns	87.88 ± 2.22	76.90 ± 0.16a	92.52 ± 2.84	*
	6			82.23 ± 5.53	75.57 ± 11.8	ns		78.90 ± 5.85b	78.70 ± 2.34	ns	
	9			81.77 ± 2.25	91.84 ± 4.62	ns		84.86 ± 2.76b	84.52 ± 5.54	ns	
	HA	0	80.31 ± 4.91	86.44 ± 8.61	80.34 ± 1.01	ns	87.88 ± 2.22	86.01 ± 1.40	91.75 ± 5.13	ns	

		6	76.52 ± 2.48	80.95 ± 3.44	ns		73.20 ± 1.27	74.03 ± 12.75	ns
		9	83.70 ± 4.50	78.22 ± 3.67	ns		82.68 ± 4.53	87.98 ± 5.98	ns
	<i>Sign.^b</i>		ns, ns, ns	ns, ns, ns			*, ns, ns	ns, ns, ns	
C18:2ω6	IR	0	5.74 ± 0.40	6.40 ± 0.42	ns	6.88 ± 0.16	6.60 ± 0.01	6.96 ± 0.43	ns
		6	6.15 ± 0.44	5.87 ± 0.93	ns		6.34 ± 0.46	6.10 ± 0.16	ns
		9	6.18 ± 0.29	6.65 ± 0.67	ns		6.49 ± 0.23	6.56 ± 0.82	ns
	HA	0	6.63 ± 0.64	6.22 ± 0.08	ns	6.88 ± 0.16	6.62 ± 0.09	6.87 ± 0.39	ns
		6	6.33 ± 0.20	6.01 ± 0.25	ns		6.36 ± 0.12	5.93 ± 0.97	ns
		9	6.62 ± 0.72	5.78 ± 0.59	ns		5.96 ± 0.65	5.48 ± 0.72	ns
	<i>Sign.^b</i>		ns, ns, ns	ns, ns, ns		ns, ns, ns	ns, ns, ns		
C18:3ω3	IR	0	0.08 ± 0.01	0.09 ± 0.01	ns	0.06 ± 0.00	0.06 ± 0.00	0.07 ± 0.00	**
		6	0.08 ± 0.00	0.07 ± 0.01	ns		0.06 ± 0.00	0.06 ± 0.00	ns
		9	0.07 ± 0.01	0.09 ± 0.01	ns		0.06 ± 0.01	0.07 ± 0.01	ns
	HA	0	0.09 ± 0.01	0.08 ± 0.01	ns	0.06 ± 0.00	0.07 ± 0.01	0.07 ± 0.00	ns
		6	0.07 ± 0.00	0.08 ± 0.01	ns		0.06 ± 0.00	0.06 ± 0.01	ns
		9	0.08 ± 0.01	0.07 ± 0.01	ns		0.06 ± 0.01	0.06 ± 0.00	ns
	<i>Sign.^b</i>		ns, *, ns	ns, ns, ns		ns, ns, ns	ns, ns, ns		

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Values are expressed as mean ± standard deviation ($n = 9$). Different letters in columns, for each different roasting system, mean significantly different values among storage points. Where letters in columns were not reported, no statistical differences were observed.

Sign^a: *, **, *** and “ns” mean significance at $p < 0.05$, 0.01, 0.001 and “not significant”, respectively, between roasting time-temperature conditions.

Sign^b: *, **, *** and “ns” mean significance at $p < 0.05$, 0.01, 0.001 and “not significant”, respectively, between roasting systems for each point separately.