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Microwave Irradiation for Dry-Roasting of Hazelnuts and Evaluation of Microwave Treatment on Hazelnuts Peeling and Fatty Acid Oxidation

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Abstract

European hazelnut is an important nut crop in Italy, where about 121,750 tons of in-shell nuts are produced every year. Roasting is the most important practice for hazelnut preservation and commonly is carried out in commercial electrical ovens at 120-160°C for 10-20 min. This needful practice is time and energy expensive, so the development of new processing methods is required to reduce processing costs and to obtain top quality roasted nuts. The aim of this study was to develop a simple microwave treatment for hazelnuts peeling and roasting.

With this aim, some physical (colour, temperature, moisture) and chemical (taste, lipoxygenase activity, fatty acids, vitamins, sensory attributes) features of inshell nuts and kernels of three Italian hazelnut varieties (Tonda di Giffoni, Tonda Romana and Nocchione) after conventional oven or microwave roasting were evaluated.

Results showed that microwave roasting of kernels for 450 s gave a higher peeling score than the conventional oven treatment. This paralleled with better colour and taste scores for microwaved roasted kernels. Furthermore, a 360-450 s microwave roasting was able to inactivate almost completely lipoxygenases, avoiding adverse effects on fatty acids hydroperoxides and PUFA content. A shorter microwave treatment (360 s) was enough to obtain good peeling and sensory scores of inshell hazelnuts.

Taken together our results indicated that microwave technology can be successfully applied to both kernels and inshell hazelnuts to obtain suitable peeling and high quality roasted nuts.

Keywords: *Corylus avellana* L., hazelnut roasting, microwave, LOX activity, fatty acid

1. Introduction

European hazelnut (*Corylus avellana* L.) is the fifth important nut crop in the world and Italy has an average of 121,750 tons in-shell annual production (ISTAT, 2008). About 90% of the world crop is shelled and sold as kernels, whereas the remaining 10% is sold inshell for table consumption (Valentini et al., 2006).

Hazelnuts are a rich source of essentials minerals, sterols, tannins, free phenolic acids, sugars, organic acids and phenolic compounds (i. e. gallic acid), all greatly contributing to its peculiar sensory properties (Cristofori et al., 2008; Alasalvar et al., 2009; Alasalvar et al., 2010; Jakopic et al., 2011; Schmitzer et al., 2011). Due to their high polyphenols content, hazelnuts are recognised as a good source of natural antioxidants (Solar & Stampar, 2011).

Furthermore, hazelnuts contain unsaturated fatty acids, α-tocopherol and carotenoids which are reported to lower the risk of chronic diseases (Özdemir et al., 2001; Amaral et al., 2006; Köksal et al., 2006; Kornsteiner et al., 2006).

During storage, hazelnuts suffer significant changes in their chemical, physical, structural and sensorial properties with a consequent loss in their nutritional and quality value. Roasting is the most important practice for preservation improvement (Basaran & Akhan, 2010).

Conventional roasting of hazelnut is currently carried out by commercial electrical ovens at 120-160°C for 10-20 min depending on the shell thickness. This thermal process reduces moisture content from 4-6% to 1-3%; therefore contributing to reduce possible microbial contaminations and the activity of enzymes involved in lipid peroxidation (Demir et al., 2003). Roasting involves a number of physico-chemical changes including dehydration and chemical reactions. Maillard reactions in particular give rise to brown pigments and pyrazine compounds associated with the development of typical roasted flavour and of a light golden colour, while dehydration develops a crispy and crunchy texture (Saklar et al., 2001; Sagrero-Nieveso, 2006; Wang et al., 2011).

Flavor development by roasting is also a basic processing step of the multibillion dollar nut industry. The principal flavor component of the hazelnut is filbertone, which is formed during roasting (Özilgen & Özdemir, 2001).

Burdack-Freitag and Schieberle (2010) showed that roasting induced changes in the key volatile compounds of cv Tonda Romana and identified 46 aroma compounds in roasted hazelnuts.

The effects of roasting on enzymes involved in fatty acid oxidation, i.e. lipase and lipoxygenase, have not yet been fully elucidated. As reported for peanuts, oven roasting reduced oxidative activity of lipase and lipoxygenase (Adelsberg & Sanders, 1997; Schirack et al., 2006). In another work (Sanders et al., 1999), the same process was reported to slightly increase these enzymatic activities with little impact on shelf life.

Tensions generated by roasting at the interface between kernel and skin ease subsequent skin removal (peeling) by mechanical brushing. Commonly, a first heating step of 45 min at 85-90°C is used for peeling and, after peeling, a second step of 40-60 min at 120-160°C is carried out for roasting (Ory et al., 1992; Adelsberg & Sanders, 1997; Sanders et al., 2002; Alamprese et al., 2009). The percentage of pellicle removal increases proportionally with temperature increase.

Several other peeling methods have been proposed, even though they often require relatively long processing times, thereby increasing processing costs. Therefore, there is a need to develop new processing methods to obtain top quality roasted nuts.

As alternative, infrared heating was successfully used for dry-roasting and pasteurization of almonds (Yang et al., 2010). Infrared (IR) radiation is an energy in the form of electromagnetic wave with a more rapid heat transfer than convectional conduction mechanisms. IR heating has been found to be more effective compared to conventional heating, but requires an initial high capital cost (Krishnamurthy et al., 2008).

Dielectric processes of radiofrequency (RF) and microwave (MW) are among the fastest growing applications in food processing (Akgul et al., 2008). Microwave radiation is between common radio and infrared frequencies, being usually at 2.45 gigahertz (GHz)-or, in large industrial/commercial ovens, at 915 megahertz (MHz). Water, fat, and other substances in the food absorb energy from the microwaves in a process called dielectric heating. The frequency range of MW (300 MHz-3 GHz) corresponds to quantum energies that can be absorbed by the polar materials and as a result the food gets warmer.

There has been a great deal of research on the application of MW to food for a variety of purposes e.g., drying, cooking, fruits and vegetables blanching, pasteurization and disinfection (Brody, 1992; Ramesh et al., 2002; Akgul et al., 2008). Microwave was successfully used for drying of lettuce cubes, vegetable soup, carrot and apple chips (Cui et al., 2008; Wang et al., 2009; Feng et al., 2012).

Microwave treatment can be an attractive alternative to traditional processing methods because the treatment is faster than conventional ones, and heating takes place only in the food material and not in the surrounding medium, reducing energy costs (Giese, 1992).

During conventional roasting processes, moisture is initially removed from the surface of the nut and water moves from the interior of the product to the dried surface through a diffusion process. This phenomenon is time and energy consuming. In a microwave drying system, the product heating is associated with a volumetric heat generation, which leads to higher internal temperature resulting in an increase in internal vapour pressure which helps to push liquid flow towards the surface, producing higher drying rates (Akkarachaneeyakorn & Birlouez-Aragon, 2010). In a conventional roaster, the temperature increase to 120-160°C in nuts needs about one hour whereas microwave heating requires few minutes.

Indeed, as reported by Schirack et al. (2006) in their experiment on peanuts peeling, shorter heating times also lead to greater nutrient retention and better quality characteristics such as texture and flavour. Indeed, no changes in walnut, hazelnut and almond kernel lipids were detected after microwave roasting at full power for 180 s (Momchilova & Nikolova-Damyanova, 2007).

Microwave treatment of inshell hazelnuts has been found effective for reducing contamination of the aflatoxin producing micro-organism *Aspergillus parasiticus* without any noticeable change in nutritional and sensory properties of nuts (Basaran & Akhan, 2010).

The aim of this study was to assess the impact of microwave heating on peeling and some hazelnut quality characteristics and therefore, the development of a simple technique for hazelnut roasting. With this aim, a Microwave oven with 2.45 GHz radiation was applied directly to hazelnuts roasting to test a range of exposure times on both kernels and inshell nuts of three Italian varieties.

2. Materials and Methods

2.1 Plant Materials

Three cultivars of hazelnut (*C. avellana* L.) from the Fruit Tree Research Unit's collection (Pignataro Maggiore-Caserta, Italy) were chosen for their different peeling features: cv Tonda di Giffoni (cv T. Giffoni), high; cv Nocchione, average; cv Tonda Romana (cv T. Romana), low (Manzo & Tamponi, 1982; Farinelli et al., 2001; Bioversity International, 2008). Nut and kernel characteristics, including nut and kernel weight, shell thickness, kernel yield (%), kernel fibre were also evaluated for each cultivar (Table 1) (Bioversity International, 2008).

Table 1. Nut and kernel characters of the three cultivars. Carpological traits were evaluated from three years data

Cultivar	Nut Shape	Shape Ratio	Shell Seal	Shell Colour	Shell Tickness	Nut Weight (g)	Kernel Weight (g)	Kernel Yield (%)	Kernel Fibre Texture
Nocchione	sub-elliptic	spheroidal	smooth	light brown striated	high	2,7	1,1	40,7	strongly corky
Tonda Romana	sub-spherical	spheroidal	smooth	light brown striated	thin	2,7	1,3	48	lightly corky
Tonda di Giffoni	sub-spherical	spheroidal	smooth	brown striated	relatively thin	3	1,5	50	lightly corky

2.2 Hazelnuts Processing

Microwave treatments with exposures times of 240, 300, 360, 450 and 600 s, selected after preliminary trials, were performed and were compared with a conventional oven treatment of 20 min at 120°C. Exposures time was measured by a stopwatch.

The different treatments were applied to kernel and inshell nut samples from the three selected cultivars. Each treatment consisted of five replicates of 20 nuts. Samples, about 100 g, were placed in the rotating device of the microwave input area.

Nut samples from the three selected cultivars, harvested two months before, had been dried at 43°C to prevent quality deterioration and rancidity, frozen with carbon dioxide to destroy insect pests and stored according to good handling practices in clean, closed vials at room temperature.

All experimental treatments were performed in triplicate. Before processing, nut moisture was determined on samples of inshell nuts and kernels by oven drying for 10 hours at 130°C, using the modified procedure described by Walton and Wallace (2010) and expressing the moisture lost as a percentage from the original weight. Average temperatures of nuts before treatments, evaluated using thermal imaging, were on average 24°C.

Microwave applications were performed at the Emitech S.R.L (Molfetta-Bari, Italy) factory, using an ALTER microwave device with a microwave frequency of 2.45 GHz, producing 6 kW of microwave power, provided with a special fanning system to achieve homogeneous heat distribution.

The microwave system consisted of a metal structure and an inner metal surface that reflects microwaves into the cell. The surface was made of stainless steel (compatible with food products) with an asymmetric geometry

specifically designed to optimize the electromagnetic reflection. Access was through a high efficiency screening door. Glare surface inside the cell was further enhanced by the continuous rotation of a wave stirrer which reflected the microwave thus helping the generation of a statistically uniform electromagnetic field and consequently a uniform heating.

The microwave source consisted of an ALTER microwave generator with a maximum power of 6 kW connected to the cavity via an asymmetric type of WR340 waveguide. In order to improve the uniformity of dielectric heating, a device has been installed in the static device to enable the continuous mixing of the food matrix, simulating a dynamic treatment, obtaining more uniform temperature profiles.

Conventional roasting was performed in a Binder ED 23-720 oven (Binder GmbH-Tuttlingen, Germany).

A single layer of nuts was placed on a wire net, at half height of the oven chamber. Oven temperature was continuously registered by means of a thermo probe 80 T-150 UA (Fluke Corporation) placed at 10 cm above hazelnuts.

At the end of treatments kernels and inshell nuts were cooled at room temperature for 2 min, and hand-peeled. Hazelnuts were stored under vacuum at 4°C and analyzed within three days from treatment. Hazelnuts used for colour analyses, were kept at room temperature and analyzed within 24 h after roasting.

Before and after roasting experiments, external temperatures, heat distribution and maximum temperature of the hazelnut were steadily measured using an infrared camera whose emissivity was fixed at a value of 0.95 (Fluke IR Thermal Imager TI20).

2.3 Peeling and Sensory Evaluation

The roasted nuts were peeled by manual brushing the day after treatment and assessed for peeling, taste and colour by an industry expert. Peeling was expressed in percentage; colour assessment was classified in three classes (RSH, 1966, 1986, 1995); taste assessment was in five classes: raw, lightly roasted, roasted, darkly roasted and burnt. Taste and colour (creamy, tanned, browned) classes were combined in a sensory index by geometric averaging after transformation in percent scores (Wang et al., 2009). An overall grade index was synthesized combining the peeling and sensory scores, also by geometric averaging.

2.4 Protein Extraction and Lipoxygenase Activity

Soluble protein samples were extracted from hazelnut kernels as previously reported (Santino et al., 2003). Lipoxygenase (LOX) activity was assayed spectrophotometrically, monitoring the increase in A_{234} of the conjugated-diene structures as previously reported by Santino et al. (2003). Linoleic acid was used as substrate in a reaction mixture (1.0 mL) consisting of 100 mM sodium phosphate buffer pH 6.0 containing 0.3 mM substrate and different amounts of protein samples. The enzymatic activity (expressed as nmol of hydroperoxide formed min^{-1} mg^{-1} of proteins) was calculated by measuring absorbance changes at 234 nm using a molar extinction coefficient of 25000 M^{-1} cm^{-1}. Proteins were quantified by the Bradford dye-binding method (1976) using bovine serum albumin (BSA, Sigma) as a standard.

2.5 HPLC Analysis of Hydroperoxy Fatty Acids

Free fatty acids (FFA) and polyunsaturated fatty acids (PUFA) hydroperoxides were extracted with chloroform/methanol (2:1, v/v) from grounded hazelnut kernels as previously reported by Mita et al. (2007). FFA were dried and resuspended in methanol before monitoring the absorbance at 234 nm. An aliquot of the extracts was submitted to RP-HPLC with a C18 Ultrasphere column (Beckman, 0.46 x 25 cm) and a solvent system of methanol: water: acetic acid (85:15:0.1). Detection of hydroperoxy fatty acids (HFA) was carried out recording the absorbance at 234 nm (indicating the conjugated diene system).

2.6 Tocopherol Extraction and Quantification

Hazelnut kernels (0.1 g) were frozen in liquid nitrogen and ground in a mortar. Samples were incubated in a screw-capped tube with 10 mL 12% potassium hydroxide, 20% (v/v) ethanol, 0.1% (w/v) sodium chloride and 3% (w/v) pyrogallol. After alkaline digestion at 70°C for 30 min and subsequent cooling, 15 mL 1% (w/v) sodium chloride solution was added. The sample was then extracted twice with 15 mL n-hexane:ethyl acetate (9:1). The organic phase was collected, evaporated and the dry residue was dissolved in 1 mL 98% (v/v) methanol. A sample volume of 20 µL was separated by reverse phase (RP)-HPLC. Chromatographic separation was performed using a Beckman HPLC Analytical System. An aliquot of the extracts was submitted to RP-HPLC with a C18 Ultrasphere column (Beckman, 0.46 x 25 cm) in methanol (98%, v/v). Detection of tocopherols was carried out recording the absorbance at 289 nm. The tocopherol content was calculated by means of standard calibration curves.

2.7 Determination of Fatty Acids

Fatty acids methyl esters were prepared according to standard methods (Ichihara & Fukubayashi, 2010) and analysed on a GC-MS system (Shimadzu 17A) fitted with a DB-5 capillary column (30 m x 0.25 mm ID and 0.25 µm thickness). Oxygen-free nitrogen was used as carrier gas at a flow rate of 1.0 $mL \cdot min^{-1}$. Other conditions were as follows: initial oven temperature, 80ºC, ramp rate $10ºC \cdot min^{-1}$ up to 150ºC, than $5ºC \cdot min^{-1}$ up to 250ºC. Compounds were identified by using online NIST-library spectra and published MS data. The FA composition was reported as a relative percentage of the total peak area. Nonadecanoic acid was used as an internal standard.

2.8 Statistical Analysis

Statistical summaries of treatment effects on the peeling, sensory and overall response indexes were calculated applying a general linear model to the set of all factor combinations and a mixed model with random effects for varieties to the treatment x shell condition combinations, with average batch values as observation units, using the logits of the indexes after scaling to proportions, in order to satisfy model requirements and preserve score boundaries. Expected values and their predictive intervals for treatment combinations, back-transformed to the percent scale, were obtained by simulated distributions of model coefficients. Computations and graphical presentations of their results were performed with the *R* environment (Holleczek & Brenner, 2009; R Development Core Team, 2010; Holleczek & Brenner, 2012) and functions of the *arm* (Gelman et al., 2010), *lme4* (Bates & Maechler, 2010), *rms* (Harrell, 2012) and *ggplot2* (Wickham, 2008) packages.

3. Results and Discussion

3.1 Effect of Microwave Treatments on Hazelnut Roasting and Taste

The effects of microwave and oven roasting on taste, colour and peeling were compared for all combinations of treatments and hazelnut samples (Figure 1). Relative frequencies of different taste and colour scores after oven (1200 s) and microwave (240, 300, 360, 450, 600 s) treatments were compared for both inshell hazelnuts and kernels of the selected three cultivars (Figure 1).

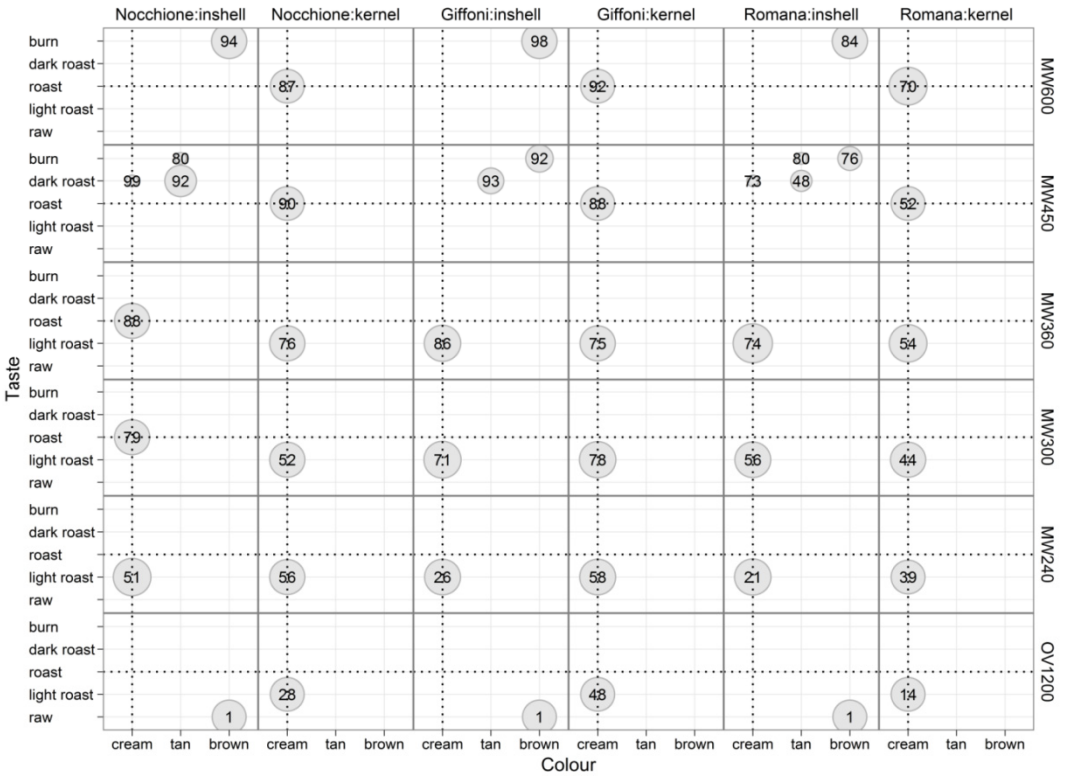

Figure 1. Relative frequency of taste and color classes (size of circles) and percentage of skin removal (numbers in circles) of inshell nut and kernels from three hazelnut varieties after conventional oven roasting for 1200 s (OV1200) and microwave oven roasting for 240 to 600 s (MW). The best outcome is marked by the crossing of the dashed lines

The best taste score was recorded with 450 s microwave treatment for kernels of Nocchione and T. Giffoni cultivars and with 600 s treatment for cv T. Romana (Figure 1). Conventional oven roasting gave creamy, lightly roasted nuts in roughly similar proportions for all cultivars.

In the case of unshelled hazelnuts, a smaller roasting time (360 s for cv Nocchione and cv T. Giffoni; and 450 s for cv T. Romana) was enough to obtain the best taste score. Longer exposures (450-600 s) resulted in darkly roasted or burned inshell nuts from all cultivars.

Inshell nuts showed, after conventional oven treatment, a peeling score of 0% and a higher score for kernels, with the highest average score observed for cv T. Giffoni (48%).

The peeling score increased with exposure time both for kernels and inshell nuts of all cultivars, though inshell nuts tended to peel better than kernels with longer microwave exposures. Varieties differences in peeling ability still persisted, since cv Nocchione and cv T. Giffoni showed a peeling score higher than cv T. Romana.

The comparison between the peeling and sensory scores between the conventional oven and the 240 s microwave treatment is summarized in boxplots (Figure 2). Boxplot gives a good sense of data distribution (median, minimum and maximum) relative to different processing methods and gives a good idea about the distance of the data to the extremes if they lie near the median (Upton Gand Cook, 1996).

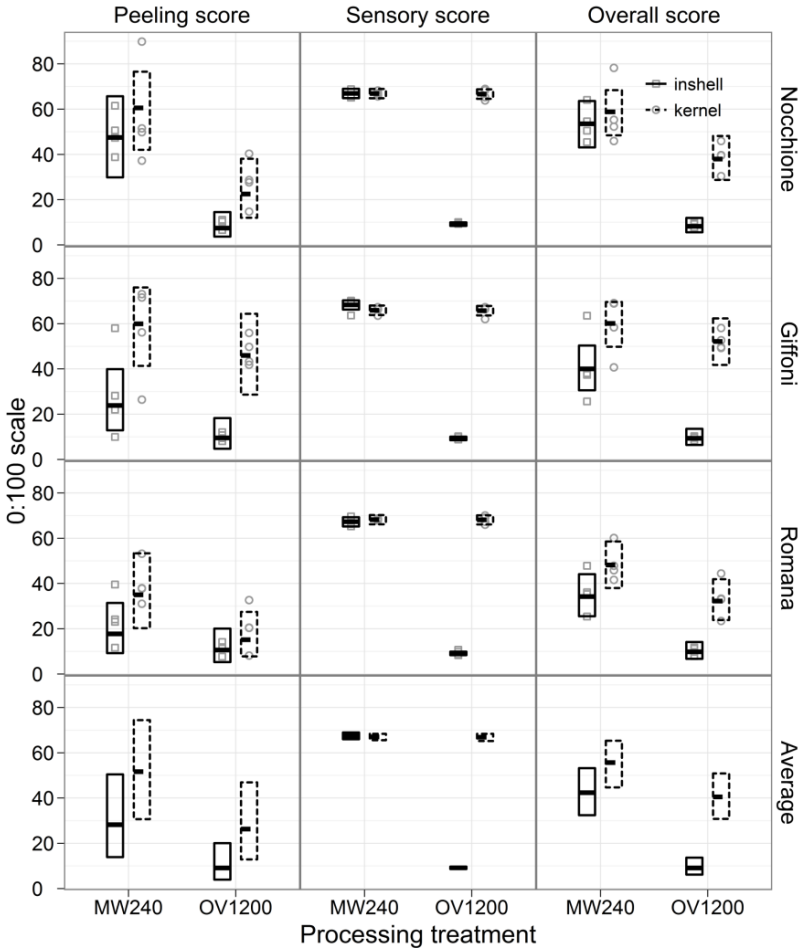

Figure 2. Effect of roasting by microwave treatment for 240 s (MW240) vs conventional oven for 1600 s (OV1600) of inshell nuts and kernels on peeling score (peeling), sensory (combination of color and taste) score and their combination (overall) score for three hazelnut varieties (cv Nocchione, cv T. Giffoni, cv T. Romana) and averaged over varieties. Boxplots displaying the extremes, the upper and lower values, and the median of the maximum difference within a category. Observed values (symbols) and means with 95% confidence intervals (crossbars). Black lines represent confidence intervals for inshell nuts; black dashed lines represent confidence intervals for kernels trends

Peeling was generally higher for kernels and microwave treatment, with the highest score (60%) observed for kernels of cv Nocchione and T. Giffoni. Remarkably, cv Nocchione showed a significant higher peeling score either for kernels and inshell nuts after microwave treatment in comparison with traditional oven (Figure 2; peeling score). The sensory scores were similar without significant differences after both treatments either for kernels as for inshell nuts (Figure 2; sensory scores). The overall score, obtained combining peeling and sensory scores, was significant higher for microwaved inshell nuts than oven roasted samples (Figure 2; overall score). The overall score for microwaved and oven roasted kernels were comparable, even though a higher score was recorded from microwaved samples.

Taken together these results indicated that the microwave treatment of 240 s outperformed the conventional oven treatment on both the peeling and sensory indexes, showing a significantly higher overall score for inshell nuts (Figure 2).

The response of peeling and sensory scores to different microwave exposure times is reported in Figure 3.

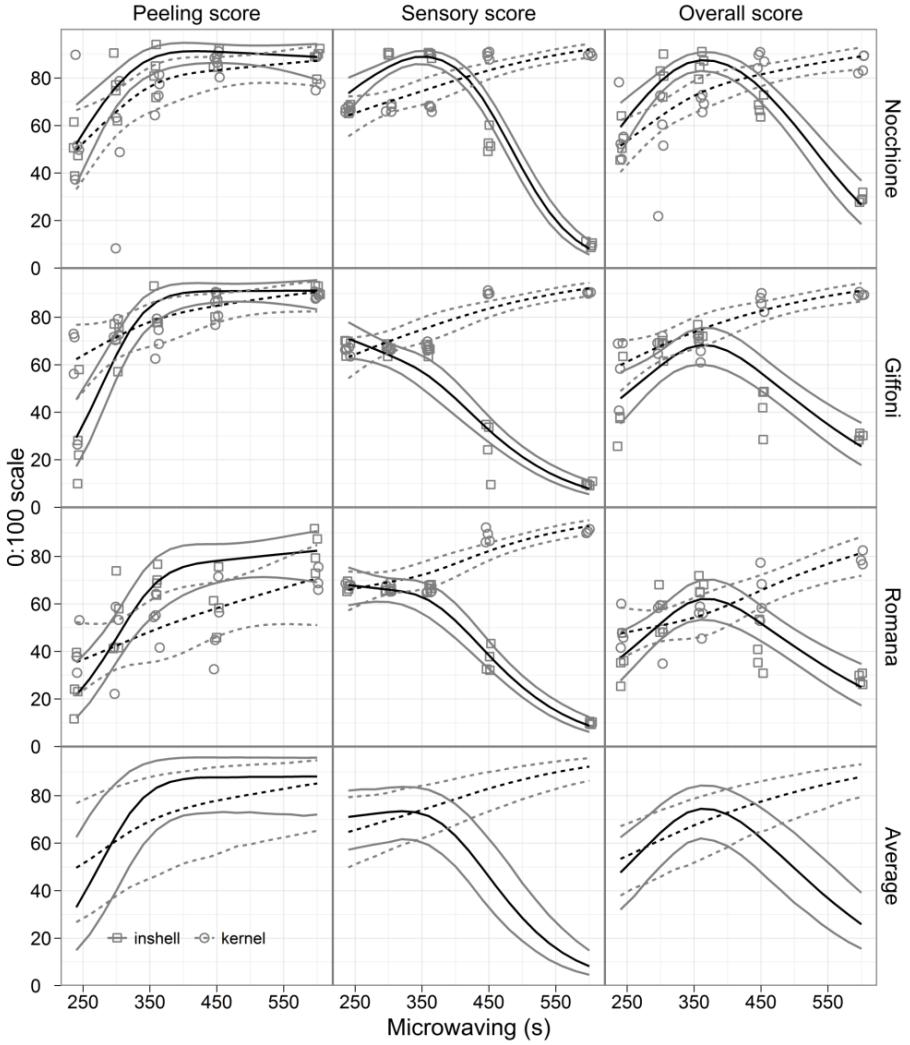

Figure 3. Effect of microwave roasting (from 240 to 600 s) on inshell nuts and kernels on peeling score, sensory score (combination of color and taste) and their combined (overall) scores for three hazelnut varieties (cv Nocchione, cv T. Giffoni, cv T. Romana) and averaged over varieties. Observed values (symbols) and smoothed trends with 95% confidence bands. Gray lines are minimum and maximum trends for inshell nuts; gray dashed lines are minimum and maximum trends for kernels. Black lines represent medium trends for inshell nuts; black dashed lines represent medium trends for kernels

A smooth fit was preferred over other fitting choices with the aim of showing essential trends. The peeling scores increased slightly with the increase of the microwave exposure from 240 to 360 s in inshell nuts of all three cultivars. In particular, the recorded peeling percentage reached 90% at 360 s from 20% at 240 s in the cv Nocchione, from 30% to 90% in the cv T. Giffoni and from 20% to 70% in the cv T. Romana (Figure 3, peeling score). At longer exposure times, the peeling score reached a plateau and did not show any further increase. A similar trend was observed with kernels whose peeling scores showed only a marginal increase at MW exposure times longer than 360 s. At the 240-360 s MW treatment range, the sensory scores were similar either in inshell nuts and kernels (Figure 3, sensory scores). At longer exposures, the recorded trend of sensory scores was opposite, since it increased in kernels and sharply decreased in inshell nuts. The overall score allowed to identify the best MW processing time for inshell nuts and kernels, i.e. 360 s and 450/600 s, respectively (Figure 3, overall score).

According to Mitcham et al. (2004), the diverging behaviour in the sensory scores recorded for kernels and inshell nuts after microwave treatments longer than 360 s, may be due to different water contents and consequently different temperatures were reached during treatment. Humidity content, determined before treatment application, was 2.2 times higher for inshell nuts (6.4% and 2.9% for inshell and kernels, respectively). The recorded humidity level of kernels was adequate for storage and comparable to levels found in peanuts subjected to peeling trials (Sanders et al., 2002). Improved peeling of peanuts after microwave treatment (Adelsberg & Sanders, 1997) was positively related to a higher water content. The temperatures of hazelnuts batches calculated on the average of temperatures of single nut, were higher for inshell nuts (about 3°C, 8°C, 14°C for cv T. Romana, T. Giffoni and Nocchione, respectively; Figure 4).

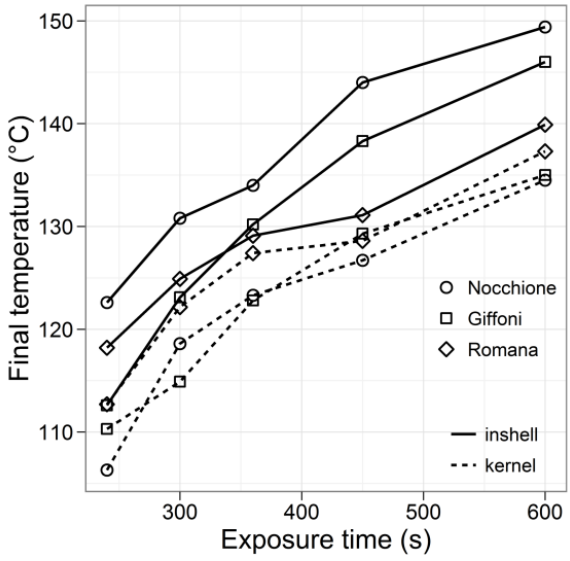

Figure 4. Temperature recorded in inshell hazelnuts and kernels of three varieties after roasting by microwave and traditional oven. Dots, rectangles and rhomboids represent cv Nocchione, cv T. Giffoni and cv. T. Romana respectively. Black lines represent inshell nuts; black dashed lines represent kernels

Shell thickness and the presence of fibres around the kernel, two well known cultivar related genetic traits, might affect the maximum temperature of the inshell nuts. Indeed, a thick shell might preserve a higher temperature inside the shell for longer times compared to a thin shell, with a consequent negative effect on the taste and the colour of the kernels. However, temperatures higher than 135°C, as those reached by inshell kernels with microwave exposures longer than 360 s, resulted in an excessive roasting with a negative impact on sensory scores.

Moreover, according to other authors (Giese, 1992; Akkarachaneeyakorn & Birlouez-Aragon, 2010) microwave treatment reduces process energy costs. Energy consumption for microwave drying (about 0.6 kW for the longest tested treatment) was about a half of that of the conventional oven (1.34 kW).

3.2 Effect of Microwave on Hazelnut Quality

Lipoxygenase (LOX) activity was assayed in kernels and inshell hazelnuts after microwave exposition ranging from 240 to 600 s using untreated dry hazelnuts and oven roasted kernels as controls. Data recorded were summarized in boxplots (Figure 5A).

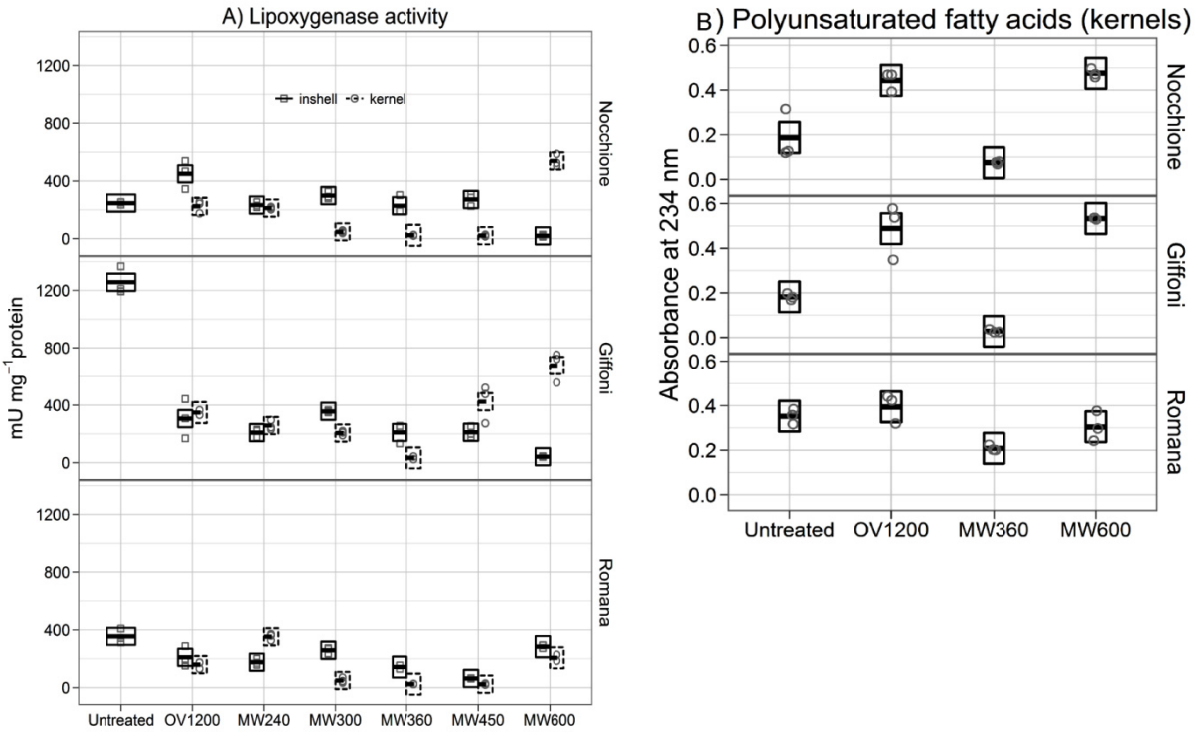

Figure 5. Effect of roasting treatment by microwave oven for 240 s up to 600 s of inshell and kernels of three hazelnut varieties (cv Nocchione, cv T. Giffoni, cv T. Romana) on lipoxygenase activity (A), polyunsaturated fatty acids (PUFA) hydroperoxides (Abs_{234} nm; B). Observed values (symbols) and means with 95% confidence intervals (bars)

Hazelnuts belonging to cv T. Romana and Nocchione showed a similar LOX activity in all the conditions here considered. A higher LOX activity was recorded in untreated samples from cv T. Giffoni (Figure 5 A). These results may indicate some variability in LOX activity among different hazelnut cv. Roasting with conventional or microwave oven was able to reduce LOX activity in most the samples analysed. In general, LOX activity in hazelnut samples after microwave treatment was lower than that recoded from samples roasted with conventional oven. The best results in term of LOX inhibition were obtained with kernels after microwave roasting of 360 s. In these conditions, LOX activity was almost undetectable. However, increasing the roasting time to 600 s, resulted in a rapid increase of LOX activity. This was more evident in kernels samples from cv T. Giffoni and T. Romana.

To confirm these results, the absorbance of free fatty acids (FFA) at 234 nm, indicative of polyunsaturated fatty acids (PUFA) hydroperoxide content, was monitored. A net increase in the hydroperoxide content was observed in hazelnuts roasted with a traditional oven or microwaved for 600 s. On the other hand, microwave roasting for 360 s resulted in a significant decrease in hydroperoxides (Figure 5 B). These results confirmed that microwave roasting for 360 s was able to inactivate LOX activity and consequently the production of PUFA hydroperoxides.

The colour of oil extracted from roasted hazelnut showed an absorbance peak at 485 nm (Abs_{485}) and was used as a parameter of the quality of the roasting process. The Abs_{485} recorded from oils of hazelnuts microwaved for 240 s and 360 s was lower than that recorded from traditionally roasted hazelnut. However, it increased significantly in oils obtained from hazelnuts microwaved for 600 s (Figure 6 A), turning from light yellow to

yellow/brown. The browning of substances in many heat-treated food can result from Maillard-type non enzymatic reactions, from caramel or phospholipids degradation and it commonly increases with roasting time.

We also evaluated the effects of roasting on tocopherol content. α-tocopherol is the main form, representing about 98-99% of the total α-tocopherols in hazelnut kernels. In agreement with results already published by Amaral et al. (2006b), our results indicated that, the roasting process either with a traditional oven or microwave resulted in a decrease in the α-tocopherol content (about 20-30%) compared to untreated hazelnuts of cv Nocchione and T. Romana. No significant reduction was found in α-tocopherol in roasted hazelnuts of cv T. Giffoni (Figure 6 B).

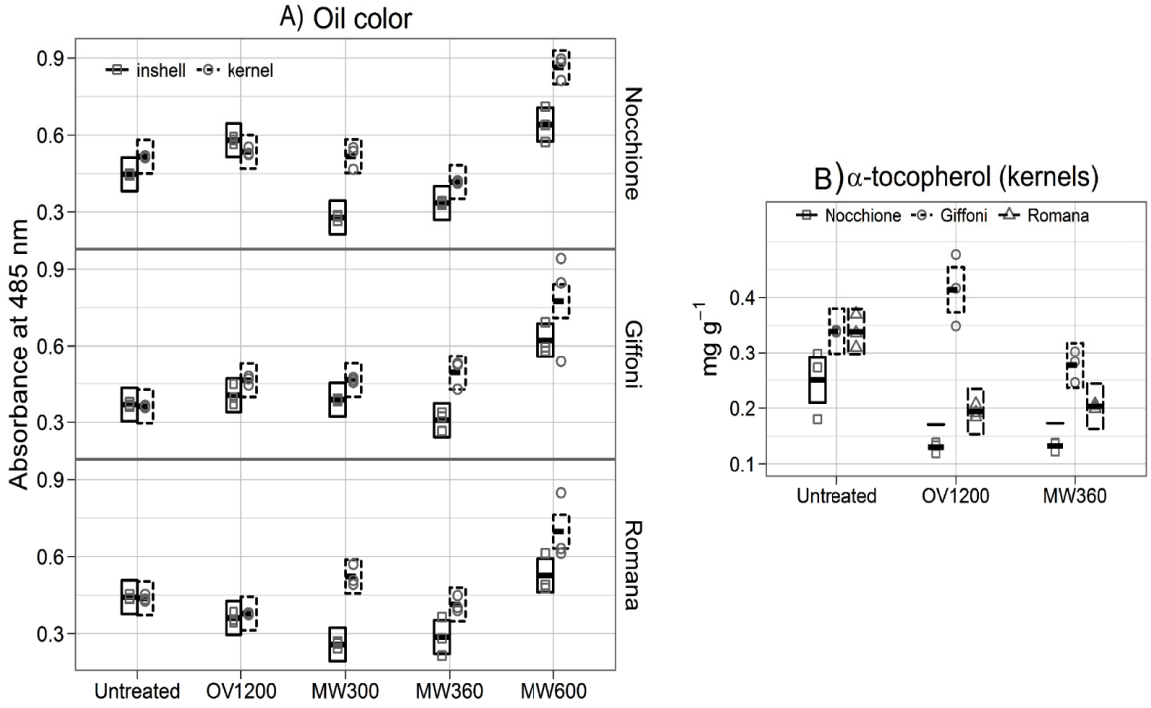

Figure 6. Effect of roasting treatment by microwave oven for 240 s up to 600 s of inshell and kernels of three hazelnut varieties (cv Nocchione, cv T. Giffoni, cv T. Romana) on oil color (Abs_{485} nm; A); alpha-tocopherol content (B). Boxplots displaying the extremes, the upper and lower values, and the median of the maximum difference within a category. Observed values (symbols) and means with 95% confidence intervals (bars)

PUFA content is another parameter of stability of oils during roasting, since higher PUFA content parallels with a higher oxidation rate of the oils. The main fatty acids composition of hazelnut oil from cv T. Giffoni kernels after roasting is shown in Figure 7.

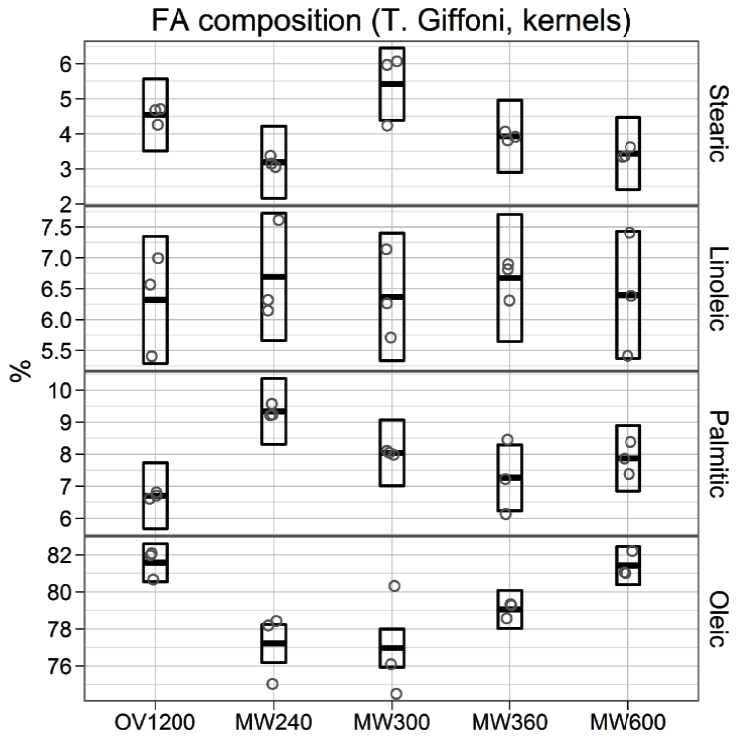

Figure 7. Effect of roasting treatment by microwave oven for 240 s up to 600 s of cv T. Giffoni kernels on main fatty acids content. Boxplots displaying the extremes, the upper and lower values, and the median of the maximum difference within a category. Observed values (symbols) and means with 95% confidence intervals (bars)

Similar values of linoleic and linolenic acids were found in all the tested oils. A lower oleic acid content was recorded in the oils from microwaved kernels (240-300 s). This paralleled with a higher content in palmitic acid at the same conditions (Figure 7).

4. Conclusion

Results show that microwave roasting for 360 and 450 s (for inshell nuts and kernels, respectively) allowed high peeling, good colour and taste of hazelnuts. Moreover, the low energy input required, the short process times and the easy process control indicate that the process here reported could be considered suitable for hazelnut processing. Indeed, adverse effects on texture, aroma and nutritional properties were minimised, due to the short times of heat exposure.

Furthermore, in contrast to conventional oven treatment, which needs to be applied to kernels with consequent unsatisfactory peeling scores, microwave roasting can be successfully applied to both kernels and inshell hazelnuts, giving in both cases, with appropriate exposure times, very good peeling and the desired roasted colour.

Taken together these results confirmed the potential of microwave technology for nuts processing in a context of sustainable agro-food industry.

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