INFLUENCE OF MICROWAVE TREATMENT ON QUALITY PARAMETERS OF SNACKS FOOD. IMPACT ISSUEES.

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Abstract
The following publication presents results of the research on a new, innovative, mild technology of food processing with microwaves technology in order to develop novel food in the form of "on the go" healthy snacks. Different aspects of microwave treatment technologies within the context of physical model of electromagnetic field interaction with a food product, marketing and energy aspects were considered. Furthermore, comparison of sensory quality of conventionally and microwave treated nuts was shown, which is a key feature of nuts, seeds and dried fruits for most consumers. A comparative LCA analysis of convectional and microwave roasting was performed as well.

Keywords
roasting, microwave, convection, nuts, sensory quality, LCA, economy

Introduction

Global market context

The food industry is constantly looking for new products and solutions, following customer expectations. One of the trends that has been observed for several years on the Polish and global market is introduction to the market products that are defined as "novel foods" [1]. The answer to this trend is the development of new production technologies that result in unique product features without the need to increase selling price of the products. Novel food is defined as innovative food, produced with the use of modern technologies and production processes.

The global healthy snacks "on the go" market is worth 389,228 million USD in 2020, and the nuts and seeds market segment will reach 9,841 million USD in 2020. The total market of snacks is projected to grow by 4.8% (CAGR 2020-2025) annually and by 3.0% (CAGR 2020-2025) for nuts and seeds [2]. According to the report "Worldwide Healthy Snack Food Market: Analysis and Industry Forecast 2022", the global snack market will reach 620 billion USD by 2021 with a cumulative annual growth rate of 5.8% [3].

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The size and the expected growth of the market, anticipated by all market analysts mean that reducing the cost of the roasting process only in relation to energy inputs will bring global energy and environmental benefits, and consequently will be a source of the promising competitive advantage for the producers of healthy snacks.

The quality of food products is very important for consumers, as it affects their health and also determines the taste. Many methods of assessing the quality of such products have been developed [4]. These are organoleptic and instrumental methods. From the point of view of the majority of consumers, the most important quality feature of food products is taste. They are mainly assessed by organoleptic methods: sensory analysis or organoleptic evaluation.

Snack food appeared in consumer behaviour as an alternative to full-fledged meals. “Snacks” are defined as dried fruit, nuts, seeds, grains, chips, crackers, popcorn, salty sticks, bars, etc. This is due to the growing market share of people who pays a special attention to ecological, pro-health products and the convenience offer. For active people, the quality of the consumed products is of the greatest importance, and at the same time, they want snacks to be comfortable to use "on the go". The ingredients found in the products are important from the health point of view. Dried fruits contain a large amount of fibber, supporting the digestive system and protecting against atherosclerosis, obesity and cancer. At the same time, they have a low or moderate glycaemic index (GI), which is the effect of food on blood sugar levels. Nuts and seeds are a rich source of potassium, magnesium, and folic acid - they improve memory and concentration. They also contain unsaturated fatty acids that lower the level of bad cholesterol in the blood. Although nuts contain various substances that have cardio protective effects, their omega-3 fatty acid profile is at least partially responsible for the response to hyperlipidaemia.

The increasing concentration of consumers on the nutritional value of the product, such as high content of vitamins and proteins and low calories, works to the advantage and expanding of the market. Healthy snacks “on the go” are widely eaten in mature economies [5].

Increasing consumer pressure in Europe and North America first of all, on quality of health products “on the go” due to increasing consumer purchasing power, could strengthen the market in the coming years. The growing demand for snacks, combined with the rising purchasing power of customers, can stimulate market development.

Analysing the expectations of individual customers (consumers), regardless of the purchase motivation and the intended use of the product, the key feature of the dried nuts and seeds for the majority of consumers is taste. This is reflected in the KPMG report, which shows that for over 90% of the surveyed consumers the most important things are the taste and quality of the sweets and snacks they buy [6].

The growing awareness of consumers means that they consciously choose the available products, which are actually less processed, more natural and therefore - healthier. Active people attach particular importance to the quality of the consumed products, and at the same time, they want them to be comfortable to use "on the go".

Disposable snacks and drinks are increasingly consumed around the world due to the long working hours of the special group of consumers, so called “Millennials”. Millennials that is the baby boom generation of the 1980s and 1990s. Today's 20- and 30-year-olds represent over half of the reproductive age population in the world, approximately 1.7 billion people. Globally, the Millennials, regardless of their country of origin, have similar attributes. They are the group of consumers brought up in the online environment. The Millennial generation pays special attention to ecological and pro-health products and the convenience offer. Millennials are an increasingly important purchasing group for food producers, because today they largely make purchasing decisions (they expect new products, new forms of marketing etc.). Because of that, any food producer who thinks about the future is definitely including this segment of consumers in their activities and is trying to meet the new needs of increasing demand on healthy snacks eaten “on the go” which becoming more and more popular. The answer for this challenge is to increasing volume of sales, and make greater profits, however without necessarily increasing the selling price. It is advantageous when it fits in the "green economy" trend, since it can be used for marketing purposes [7].

Research hypothesis

In research on the development of a new food processing technology, dedicated to healthy snack products "on the go", and in particular – with regards nuts and seeds, it was hypothesized that the use of microwave roasting technology will improve the taste of the snacks and at the same time will result in energy savings.

The research hypothesis in relation to the taste values assumed that mixtures of nuts and seeds roasted under low-pressure microwave technology will be characterised with more favourable proportions of fatty acids and other nutritional values supporting the proper functioning of the body, than in conventional technologies.

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The research hypothesis in relation to the cost of energy of the roasting process assumed that the production costs of healthy snacks would be reduced through the use of microwave technology. Due to the fact, that microwaves operate across the entire cross-section and heat up products volumetrically, the duration of the roasting processes will be shortened, and the energy efficiency of the thermal treatment of nuts and seeds will be improved. The energy costs of the roasting processes of nuts and seeds account for from 1.5% of the final consumer price for e.g. in regards to cashew nuts and up to 6.7% for sunflower seeds [8].
Simultaneously the hypothesis with regard to the energy efficiency of the thermal process assumed that the use of microwave roasting technology would reduce the emission of harmful by-products, especially GHG emission.
There is no doubt that when food safety conditions are met, food sensory quality and price determine food selection and consumption. As soon as a complete supply of food is achieved - quantitatively and in terms of its diversity - the question of the motivation of consumer choice becomes an important marketing and nutritional problem. Hence, other research question concerns the effect of type of roasting on the sensory properties of nuts. Food selection is influenced by many interrelated factors. They relate to the food itself, the appearance, smell, texture and flavour; to the consumer - his individual preferences and aversion as well as psychological factors such as personality, beliefs (views), experiences and moods; finally, to external factors - economic, cultural and sociological. They all influence food choice and consumption. Sensory properties are by definition a phenomenon that arises because of the sensory perceptions of certain physical and chemical properties of food. The implication of the above is that they cannot be considered without connection to the human sensory apparatus. Sensory attractiveness of food products and meals prepared on their basis is the basic criterion for the acceptance of the product selection by the consumer. The set of features that create sensory attractiveness, apart from availability and health, contribute to the generally understood quality of a food product. These characteristics include taste, texture, odour, and appearance.
Combining the results of consumer research with the results of laboratory profiling of sensory quality allows for a rational modification of the existing ones and the development of new products of high quality in the opinion of consumers.

Physical model of electromagnetic field interaction with a food product during microwave treatment

The results of microwave processing depend on the interconnection of several factors, in particular, the generation of microwave energy, its transfer through the media, penetration into the product and conversion into heat. Current frequency and power output are two determining factors that are the most significant for microwave generator. Electromagnetic oscillation frequency is constant and, as a rule, frequency of 2450 MHz is mainly used for processing of food products.
During the work of microwave generator, strength of electromagnetic field in the media depend on its power output. Value of microwave energy that reaches the surface of food product depends to the product's volume, its geometrical dimensions and dielectric permeability.
Thermophysical and dielectric properties to a great degree depends on moisture capacity of a product. An increase in the number of water molecules causes an increase in dielectric losses and, as a consequence, more active heating. Dehydration of a product in the process of heating is followed by nonuniformity of moisture by volume. Whereby wetter sections obtain more quantity of energy but in consequence of moisture movement, its concentration equalizes. Gradual decrease in moisture content results in decrease of dielectric loss and, consequently, decrease of heat energy that is released in the product.
Thus, a set of thermophysical and dielectric properties determines resistance for transferring electromagnetic field, depth of penetration of electromagnetic field. Penetrating the product electromagnetic field strength is attenuated that results in decrease in heating rate of a product. As a rule, to maintain effective heating at the current frequency, products of thickness not more than 30-50 mm should be processed in most cases.
Thus, to ensure efficient work of microwave oven and obtain high quality products it is necessary to determine rational values of electromagnetic field strength depending on the output power of magnetron and physical properties of food product, that determine the depth of penetration of electromagnetic field in to the material.
The power absorbed by a product during microwave heating, on the one hand, depends on electric parameters of the field (current frequency and strength of electromagnetic field) and, on the other hand, on dielectric parameters of a product (dielectric loss factor and relative dielectric constant) and it is determined by the known formula

$$Q_d = 2\pi f \varepsilon_0 \varepsilon'' E^2, \tag{1}$$

where Q_d is the power density of microwave absorbed per unit volume of the material, W/m^3; ε_0 is the permittivity of free space ($8.85 \cdot 10^{-12}$ F/m); f is microwave frequency, Hz, ε'' is the relative dielectric loss factor; E is the electromagnetic field strength in the medium (product), V/m.
Among the above-mentioned factors, electromagnetic field strength that can be regulated during microwave treatment has priority significance.
Our task is to determine electromagnetic field strength that is formed by microwave generator on the surface and inner layers of a product.

Let's to determine electromagnetic field on the surface of a food product, the following well-known electrodynamics equation is used [9]. The energy flux density of an electromagnetic wave transmitted by in an arbitrary medium is determined by the formula

$$\Pi = v_f \varepsilon \varepsilon_0 E^2 , \tag{2}$$

where Π is the energy flux density of electromagnetic wave in an arbitrary medium, W/m^2; $v_f = c / \sqrt{\varepsilon\mu}$ is the light velocity in the medium, m/sec; c is the light velocity in the vacuum; μ_0 is the magnetic constant (μ_0=4π·10^7 H/m); μ is the magnetic permeability of the medium.
In the working volume of microwave oven electromagnetic wave transfers practically at light velocity in vacuum because dielectric and magnetic permeability for air equals one (ε=μ=1). That is why energy flux density that is transferred from the microwave generator to the product equals

$$\Pi = c\varepsilon_0 E_0^{\ 2} , \tag{3}$$

where E_0 is magnitude of electric field in the microwave oven, V/m.
On the other hand, energy flux density of an electromagnetic wave on the surface of a product can determined as ratio of microwave generator power to surface area of a product, that is

$$\Pi = \frac{P}{S} , \tag{4}$$

where P is the power of microwave generator, W; S is the surface area of a product, m^2.
Equating the right-hand sides of expressions (4) and (3), we can obtain formula for calculating the magnitude of the electromagnetic field on the surface of the product

$$E_0 = \sqrt{\frac{P}{\varepsilon_0 c S}} . \tag{5}$$

Further let's define the magnitude of electric field that occurs in the product itself, which it differs from the electric field on the border of product because electromagnetic wave transfer rate on depends from dielectric properties of product. Under conditions of optimal loading of microwave oven all energy of electromagnetic waves is absorbed by the product, i.e. energy flux density Π does not change on the surface of a product. Then it is possible to write down next equality

$$v_f \varepsilon \varepsilon_0 E^2 = c\varepsilon_0 E_0^{\ 2} . \tag{6}$$

From here with regard of expression for light velocity in the medium we obtain

$$E^2 = \frac{E_0^{\ 2}}{\sqrt{\varepsilon}} . \tag{7}$$

With regard of the expression (5) we obtain

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$$E = \sqrt{\frac{P}{\varepsilon_0 c S \sqrt{\varepsilon}}}\,. \tag{8}$$

Thus, formula (8) takes into account interrelation between microwave generator power and magnitude of electromagnetic field on the surface of a food product.
For calculation of magnitude of electromagnetic field according to the thickness of a product, we use formula

$$E_\Delta = E \cdot \exp\left(-\frac{\Delta}{\delta}\right), \tag{9}$$

where E_Δ is the magnitude of electromagnetic field on the distance Δ from surface of product, m.

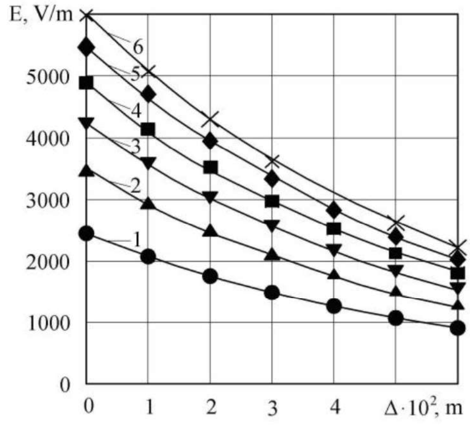
$$\delta = \frac{c\sqrt{\varepsilon}}{\pi f \varepsilon''} \tag{10}$$

δ is the penetration depth of electromagnetic field into the dielectric material, m.

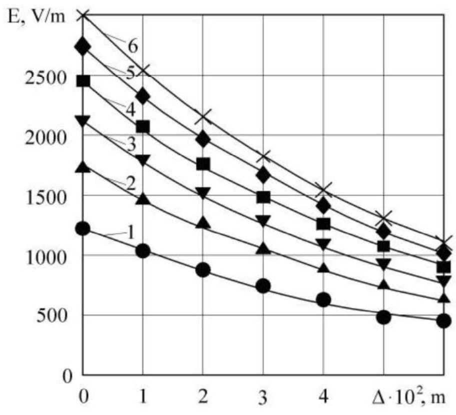
Substituting in formula (9) expressions for E (8) and δ (10), we obtain a formula for calculating the strength of the electromagnetic field depending on the thickness of the product, its surface area and microwave power.

$$E_\Delta = \sqrt{\frac{P}{\varepsilon_0 \sqrt{\varepsilon} c S}} \cdot \exp\left(-\frac{\pi f \varepsilon'' \Delta}{c\sqrt{\varepsilon}}\right), \tag{11}$$

We used formula (11) to calculate the dependences of the magnitude electromagnetic field on the power of the microwave generator and the surface area of the product, depending on the layer thickness of two products: 1 - a mixture of finely chopped root vegetables of spicy vegetables (Figure 1); 2 - a mixture of finely chopped herbs of spicy vegetables (Fig. 2) [10].



a)



b)

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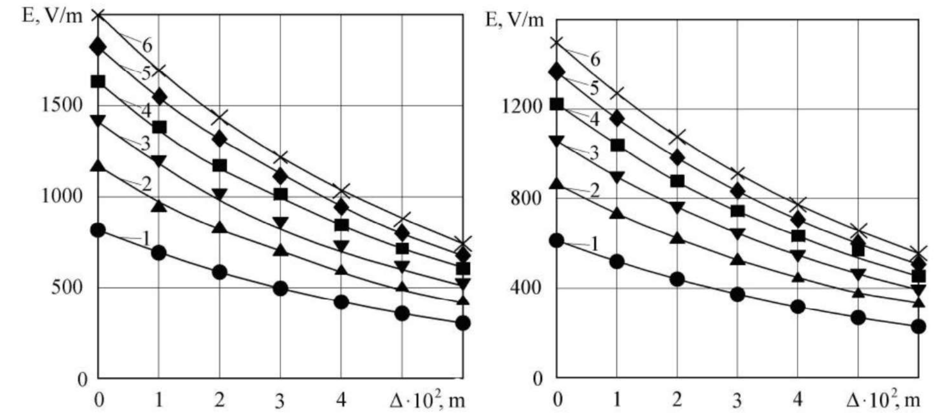
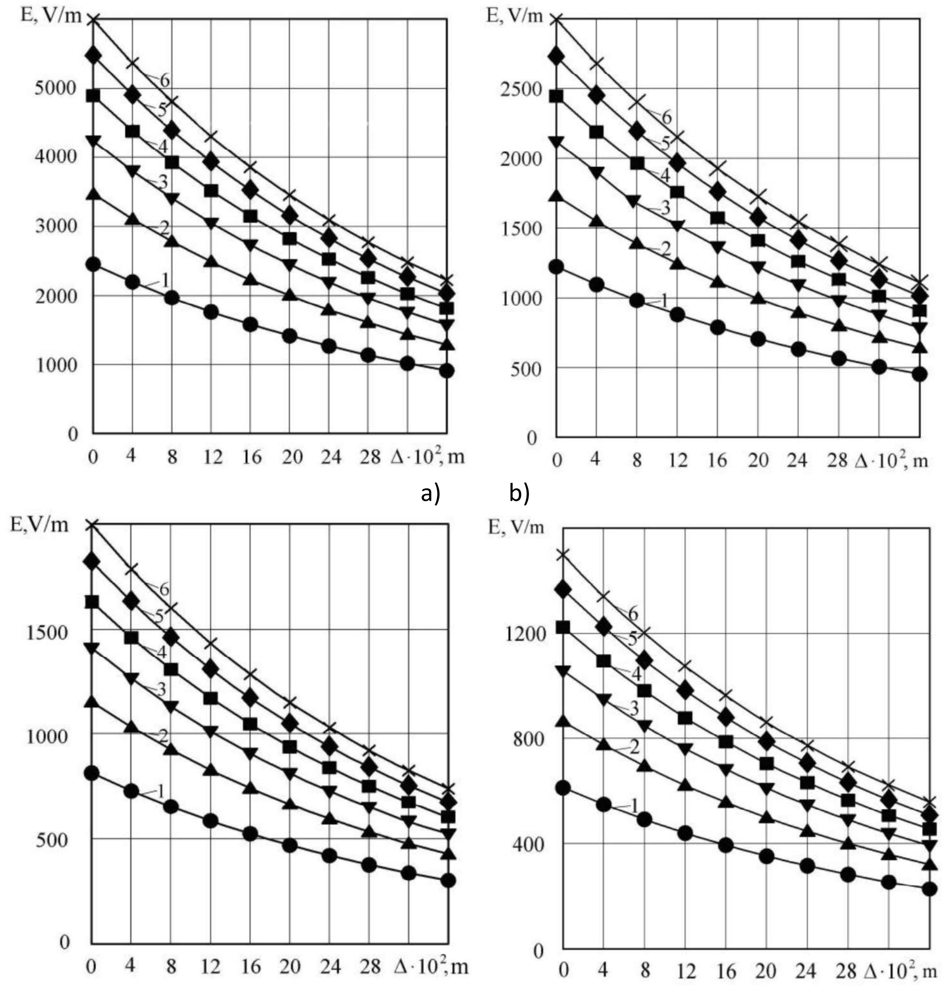


c) d)

Fig. 1. Magnitude of strength of electromagnetic field depending on the thickness of the layer (Δ) and microwave power (*P*) for mixture of finely-chopped roots of spicy vegetables: 1 – 500 W; 2 – 1000 W; 3 – 1500 W; 4 – 2000 W; 5 – 2500 W; 6 – 3000 W, for surface area of a product: a – 50 cm2; b – 200 cm2; c – 450 cm2; d – 800 cm2.



c) d)

Fig 2. Magnitude of strength of electromagnetic field depending on the thickness of the layer (Δ) and microwave power (*P*) for mixture of finely-chopped greenery of spicy vegetables: 1 – 500 W; 2 – 1000 W; 3 – 1500 W; 4 – 2000 W; 5 – 2500 W; 6 – 3000 W, for surface area of a product: a – 200 cm2; b – 800 cm2; c – 1800 cm2; d – 3200 cm2

According to the data of (Figure 1, Figure 2) it can be seen that with the increase of microwave generator power within the above mentioned range from 500 W to 3000 W electromagnetic field strength increases approximately by 2 times in all cases. Magnitude of electromagnetic field strength into the product is inversely to the surface area of a product.
Hence, by this example of calculations it was shown that electromagnetic field strength can be regulated through the change of microwave power and surface area of the product.
Since the intensity of internal heat sources arising during microwave heating depends on the square of the strength of the electromagnetic field (1) penetrating into the product, the proposed formula (11) allows to choose the rational characteristics of the microwave heating process, that is, regulate the radiation power, surface areas and the thickness of the product.

Comparison of sensory quality of conventionally treated nuts and microwaved nuts
Sensory quality evaluation

The interest in sensory evaluation grew rapidly in the second half of the 20th century, which is related to the development of industry, the appearance of processed foods and consumer products. The first initiation of formal quality control or sensory programs by use of trained panels dates to 1950 [11], [12]. Sensory evaluation
The interest in sensory evaluation grew rapidly in the second half of the 20th century, which is related to the development of industry, the appearance of processed foods and consumer products. The first initiation of formal quality control or sensory programs by use of trained panels dates to 1950 [11], [12]. Sensory evaluation involves a suite of techniques to accurately measure human responses to food and minimizes the potentially biased effects of brand identity and other information affecting consumer perception.
As such, it tries to isolate the sensory properties of the food itself and provides important and useful information about the product to developers, food scientists, and managers about the sensory qualities of their products.
One of the most complex, dynamically developing and frequently used methods of sensory analysis is Quantitative Descriptive Analysis (QDA) [13], [14]. This method, also known as the profiling method, is used for the qualitative and quantitative determination of the comprehensive characteristics of food products. Its basic assumption is that the palatability, smell or texture are not individual product quality features, but a complex of many individual features that can be distinguished, identified and defined. A special preliminary procedure allows selecting the characteristic units of the analysed products and establishing their definitions. The profile analysis may be complete, i.e. it may concern discriminants perceived through all senses (sight, smell, taste and sensory and tactile senses) or partial, including only smell and taste features or texture features. Each feature is quantified on a linear (or numerical) scale with appropriate boundary definitions. The results of the assessment are converted into numerical values and then subjected to statistical processing, using the analysis of variance (ANOVA) to determine which of the characteristics significantly differentiate the tested samples and whether the repeated assessments (separate sessions) are not a significant factor of variation.

Thermal processing of nuts
One of the most important processing methods of dried nuts is roasting. It significantly increases the sensory qualities of nuts, especially the palatability, by enhancing the taste, colour and increasing crunchiness [15], [16]. Roasted nuts can be eaten without any additives as popular snacks “on the go”, they constitute material in confectionery, bakery and others. The most often roasted are peanuts, hazelnuts, almonds and pistachio nuts [17]. Roasting the nuts involves heat treatment (e.g. with hot air or infrared) at a temperature of 104-300 °C, for time depending on the type of nuts and desired properties [15], [16]. Hot air roasting is one of the simplest and low-cost methods. However, it usually requires a long period of roasting time which results in undesirable changes in the final product, mainly due to the Maillard reaction [16], [18]. In conventional roasting methods, the outer surface of the nut is scorched while the centre of the nut is not perfectly baked. This may cause uneven roasting, surface scorching, unpleasant odours and a bitter-burnt taste. To overcome uneven roasting and its disadvantages, new methods such as infrared heating can improve roasting properties. New mild food processing technologies that use low temperatures and limited amounts of processing aids can facilitate preservation of nutrients, maintain good nutritional quality and bioavailability, extend product shelf life, optimize individual ingredients and maximize functional properties (technological functions, sensory attributes, nutritional value) [15], [19], [20]. One of that technology is microwave roasting. This process assures lower processing time by a significantly reduced temperature. Interaction of an electromagnetic field with chemical components of food

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causes a heating of food products. These interactions immediately generate heat due to molecular friction andexcitation [21]. In the present study we are comparing two methods (microwave and convection) of roasting nuts (peanuts, hazelnuts, walnuts), we considered on the sensory evaluation and environmental impact of roasting.

Materials and methods

Raw shelled nuts (peanuts, hazelnuts, walnuts) were split into batches. The first batch of nuts was exposed to microwave radiation for 4, 6 and 8 minutes, using microwave power of 500, 600 and 800 W (Table 1). Each sample (200 g) was placed in a turn vessel, roasted, and then cooled. The microwave radiation treatment was carried out using a microwave oven under constant air pressure. The average temperature of a sample immediately after roasting was 75 °C. The second batch was dry roasted at a temperature of 180 °C for 5, 15, 20 and 25 minutes (WINKLER kiln) (Table 1). After cooling to ambient temperature, seeds were sealed in a protective atmosphere (N2 according to EC Directive 1272/2008 [22]) and stored at 20 °C prior to processing.

Sensory properties of nuts were tested by means of Quantitative Descriptive Analysis (QDA) by a trained panel. The panel (15 assessors chosen by means of a suitability test and trained for the evaluation of seeds) drew up a sensory profile of products with the following characteristics: odour (total odour intensity – total strength of all odours in the sample; characteristic odour – typical for nuts; foreign odour – atypical for nuts), colour and size (typical for nuts), hardness (sample resistance on biting and crispness – susceptibility to cracking under the pressure of teeth), taste (sour – basic flavour; foreign – atypical for nuts). The intensity evaluation of the sensory perception by the trained panel was carried out by use of unstructured scales (0 – not perceptible and 100 – strongly perceptible). Moreover, the degree of consumer preference was determined. The trained panel worked in a laboratory under defined conditions. The results were captured with the MySurveyLab software.

The environmental impact of roasting methods was determined using the LCA analysis. The study was conducted in the OpenLCA software, using the ELCD 3.2 database. To assess the impact of the processes on the environment, the ReCiPe Endpoint (E, A) method was used, which allowed to obtain harmonized results and compare nuts in terms of their impact on various elements of the environment. As the input data, we took into account only theses parameters by which roasting methods differ from each other, i.e. energy consumption and exhaust emissions. The analysis was performed only for these nuts that have been assessed of having the most favourable sensory parameters.

Table 1. Roasting conditions for nuts

Roasting	**Convection**				**Microwave**									
temperature [°C]	180	180	180	180	**power [W]**	500	500	500	600	600	600	800	800	800
time (min)	5	15	20	25	**time (min)**	4	6	8	4	6	8	4	6	8
peanuts symbol	AK5	AK15	AK20	AK25	**peanuts symbol**	AM54	AM56	AM58	AM64	AM66	AM68	AM84	AM86	AM88
hazelnuts symbol	LK5	LK15	LK20	LK25	**hazelnuts symbol**	LM54	LM56	LM58	LM64	LM66	LM68	LM84	LM86	LM88
walnuts symbol	WK5	WK15	WK20	WK25	**walnuts symbol**	WM54	WM56	WM58	WM64	WM66	WM68	WM 84	WM86	WM 88

Result and discussion

Peanuts

Statistical analysis of the results showed significant differences in overall odour intensity and nutty flavour in conventionally roasted samples. After roasting for 20 minutes, higher scores for these parameters were recorded. Moreover, the nutty taste of these samples (AK20) was rated higher than those of the samples roasted for 5, 15 and 25 minutes (Figure 3, A). The degree of consumer acceptance and overall product desirability for peanuts roasted for 5 minutes was significantly lower.

In the case of microwave-roasted samples, significant differences were observed in the overall intensity of the nutty odour and total odour as well as the nutty and sweet taste. The highest values of these parameters were

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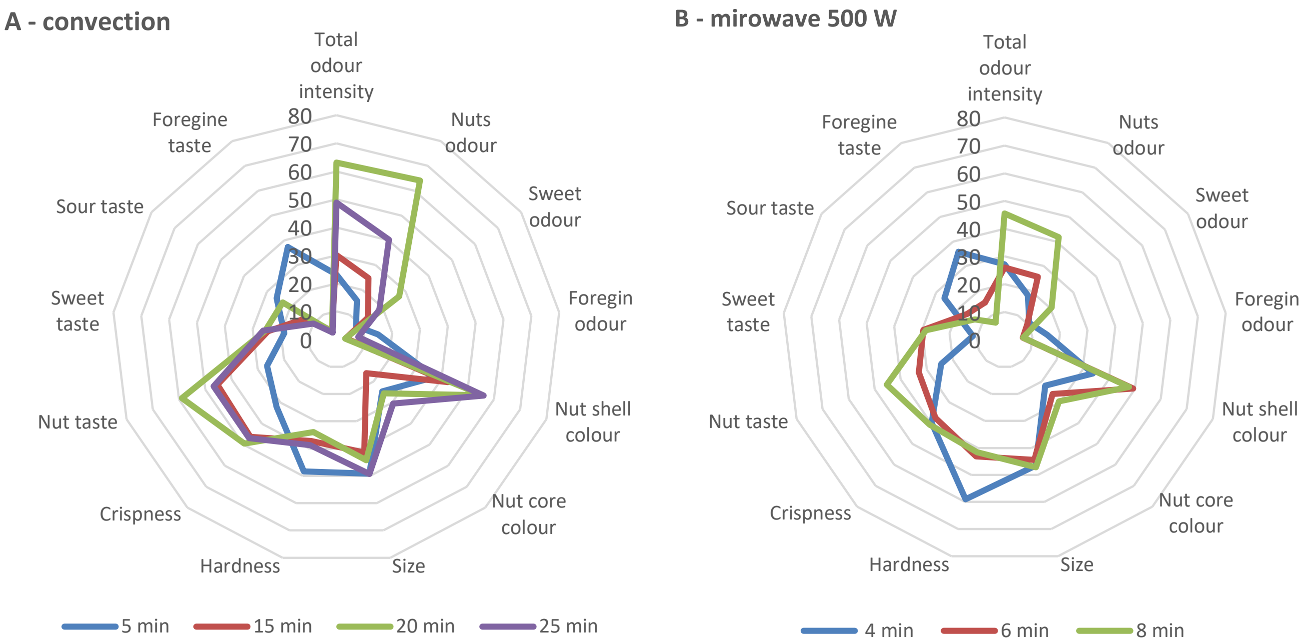
determined in samples processed for 6 minutes, 800 W (Figure 3, D, E). These samples (AM86) were rated the best by the panel of experts. According to the evaluators, extending the roasting time reduces the hardness of microwave roasted peanuts. Similar, Jindal et al. study shows that the sensory crispness score based on the overall acceptability of roasted peanuts appeared to increase at first with an increase in power level and roasting time, and then showing a decrease due to excessive roasting [23]. On the other hand, the degree of consumer acceptance and the general desirability of the product for samples roasted at 800 W were rated significantly better than peanuts roasted at 500 W and 600 W. The worst grades were those roasted for 4 minutes, 500 W. Similar results were obtained in the publication Raigar et al., in this study, the microwave roasting of peanuts was attempted, optimized and compared with conventional drum roasting. Overall acceptability of microwave roasted peanuts increased with power levels. The observed trend can be explained by the increase in the formation of flavour qualities and Maillard serial roasting tests, which include the overall sensory quality of peanuts. The optimal overall acceptability was obtained with roasting time 201 s and power 898 W [24]. On the other hand, peanuts which were heated as part of the blanching process using a 5 kW, 915 MHz microwave unit in comparison to roast samples at 177 °C were significantly higher in total off note, which is a term encompassing all negative aspects of the sample that are different from a reference. The microwave-blanched peanuts also displayed higher intensities of dark/ashy, bitter, and cardboard/stale notes, which also may contribute in part to the total offnote score. The microwave and lowest temperature oven roast had the highest level of dark roast attribute, which may be explained by the unevenness of the microwave roasting and long roasting time in the oven, respectively [25].



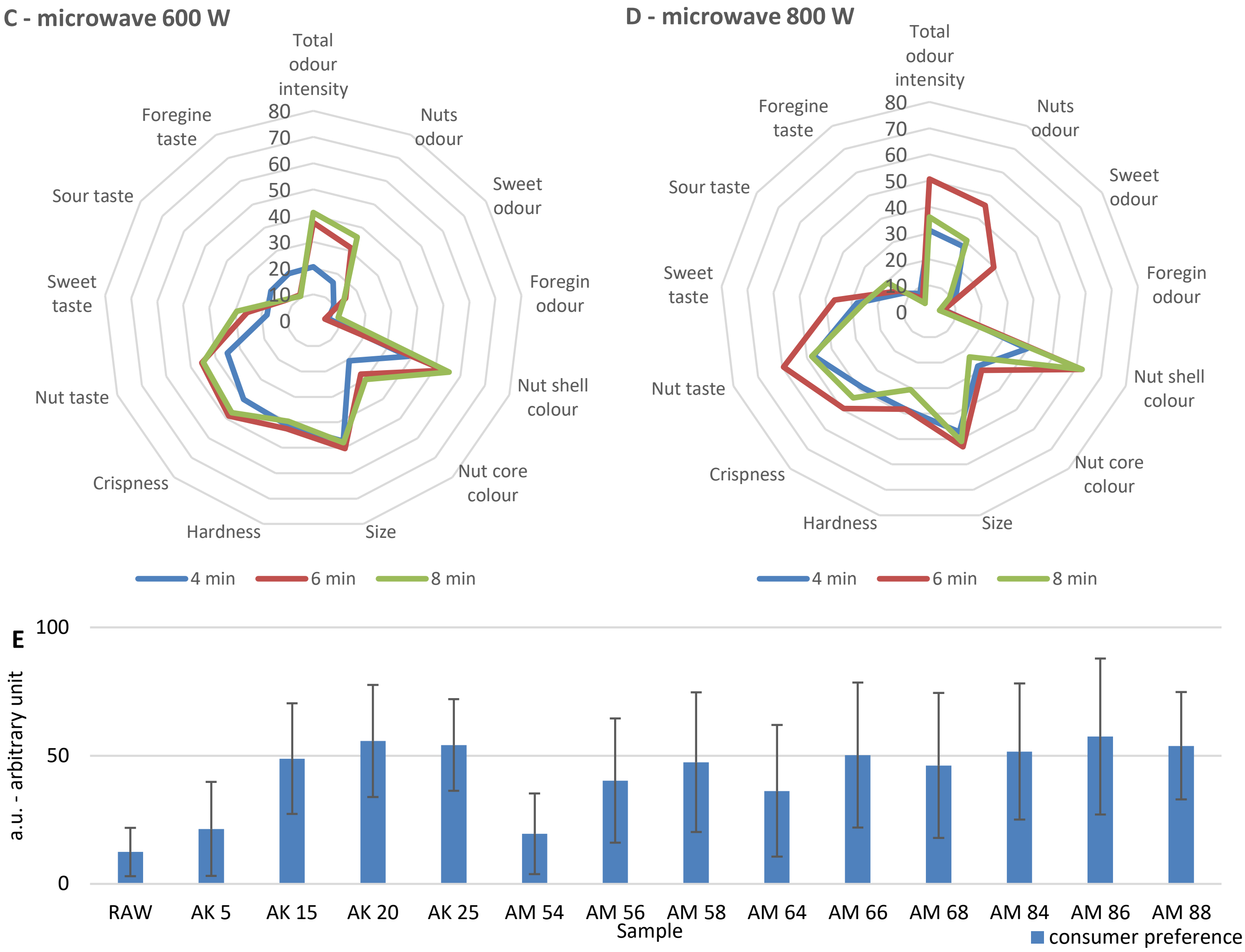


Fig. 3 Sensory profile of peanuts roasting by use of convection (A), microwave - power 500 W (B), microwave - power 600 W (C), microwave - power 800 W (D) and consumer preference of peanuts (E); (a.u. – arbitrary unit)

Hazelnuts

Based on the results obtained for the conventionally roasted samples, it was found that the roasting time of 20 minutes (LK20) was the most favourable according to the evaluators. These samples had higher ratings for the degree of consumer acceptance (Figure 4, E), and were also characterized by lower hardness (Figure 4, A). Hazelnuts roasted conventionally for 5 minutes had a higher hardness rate. In addition, the evaluators found them more bitter than those conventionally roasted for a longer time. Roasting the hazelnuts for 25 minutes caused the shell and core of the samples to turn darker. Extending the conventional roasting time increased brittleness of the tested nuts.

The statistical analyses performed showed a homogeneity of all groups of microwave-roasted samples, except for the discriminants characterizing the colour. The samples processed at the power of 800 W were characterized by a darker colour of the shell and core (Figure 4, D). On the other hand, Donno et al. study shows that roasting temperature is the most important factor affecting the nut quality indicators and the descriptor that varied the most among samples is hazelnut odour [26]. The team Belvisio at al. made similar observations about temperature of roasting. Significant sensory differences occur only when the roasting temperature was high, and this difference persisted during storage [27].

In comments, the evaluators described microwave-roasted hazelnuts as "typical for good-quality chocolates with nuts". Ciarmiello et al. studies compared microwave-roasted hazelnuts treated with exposures times of 240, 300, 360, 450 and 600 s (microwave frequency of 2.45 GHz) with conventional oven treatment of 20 min at 120 °C indicated that the best taste score was recorded with 450 s and 600 s microwave treatment [28].

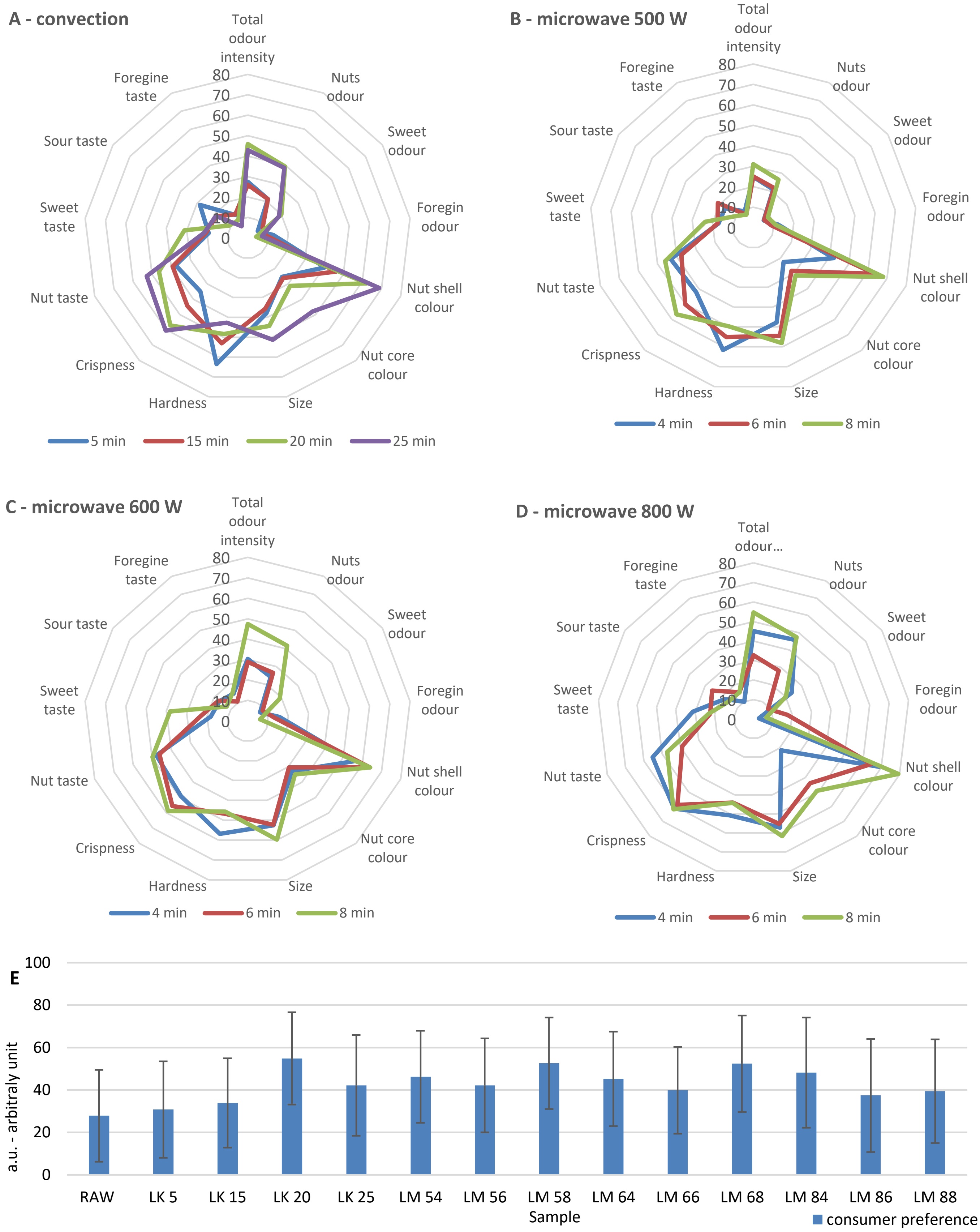


Fig. 4. Sensory profile of hazelnuts roasting by use of convection (A), microwave - power 500 W (B), microwave - power 600 W (C), microwave - power 800 W (D) and consumer preference of hazelnuts (E); (a.u. – arbitrary unit)

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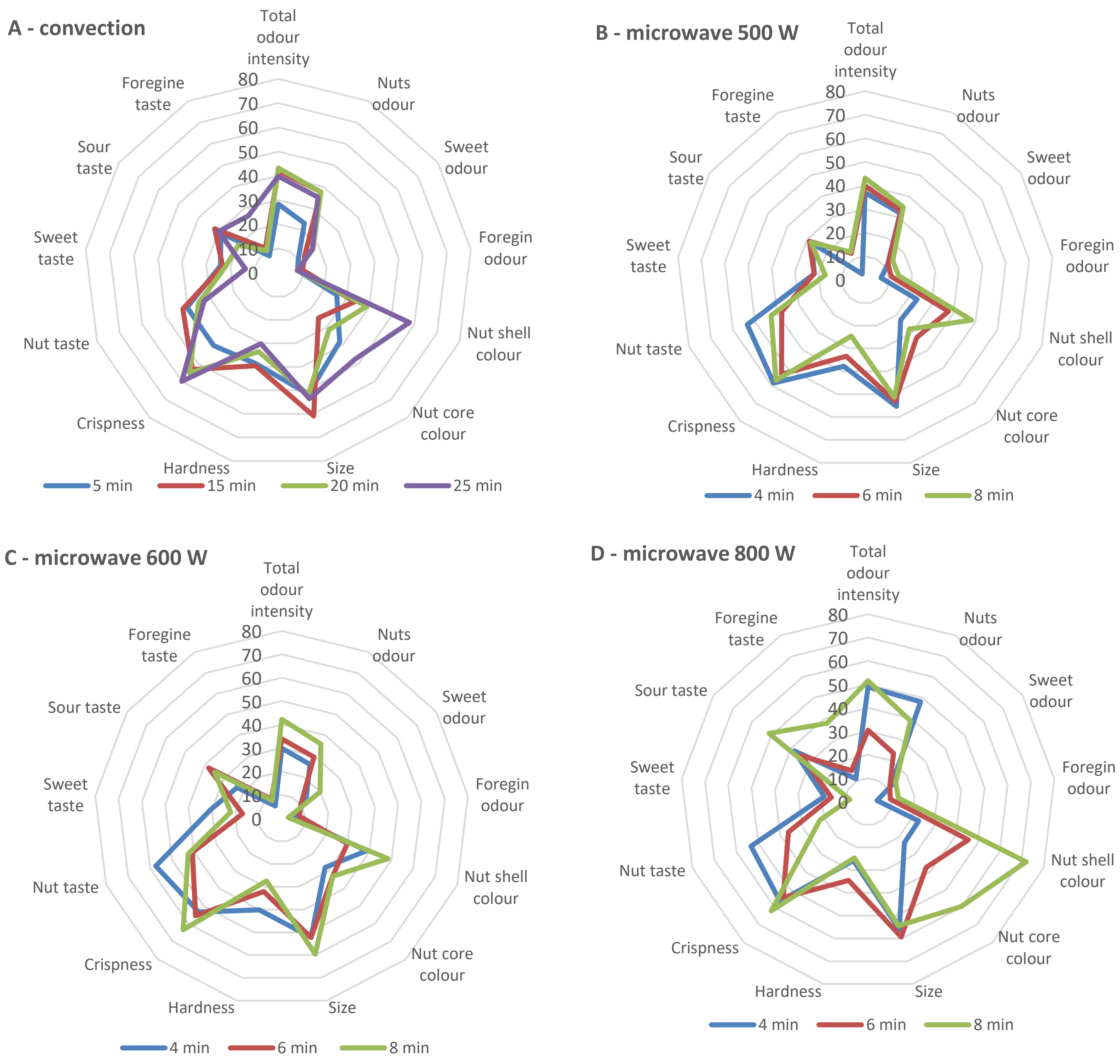
<u>Walnuts</u>

In assessing the degree of consumer acceptance, samples of walnut conventionally roasted for 15 minutes (WK15) were rated as better. Conventional roasting of the samples for 25 minutes caused the shell and core to turn darker (Figure 5, A). Along with the extension of the roasting time from 5 to 25 minutes, an increase in the perception of foreign taste was observed. These observations are confirmed by the studies of Kita et al., it was observed that with increasing temperature and roasting time, nuts became more and more bitter, and their taste can be described as strange and unpleasant [17].

The analysis of the results of expert evaluation of microwave-roasted walnuts showed that the most favourable sensory properties were those of the samples roasted for 4 minutes, 600 W (Figure 5, E). According to the expert panel, these samples (WM64) were sweeter and had a more perceptible nut flavour (Figure 5, C). Moreover, in assessing the degree of consumer acceptance and general desirability of the product, samples of microwave-roasted walnut (600 W, 4 minutes) were characterized by higher scores. Worse assessments of the sensory evaluation factors were observed in case of walnuts samples roasted with microwaves at the power of 800 W for 8 minutes (Figure 5, D). For all tested kind of nuts, there were none statistically significant differences between judges regarding sensory attributes observed.



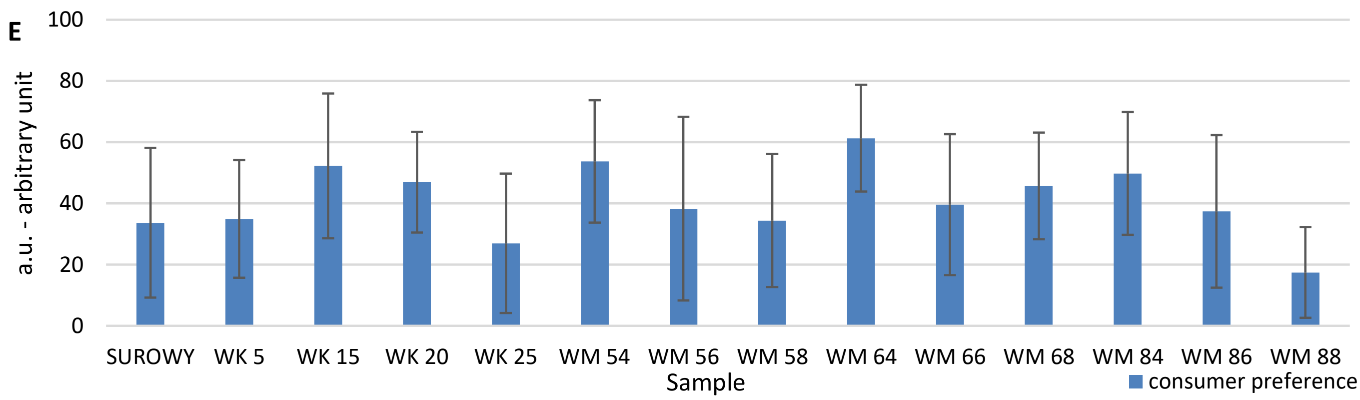


Fig. 5 Sensory profile of walnuts roasting by use of convection (A), microwave - power 500 W (B), microwave - power 600 W (C), microwave - power 800 W (D) and consumer preference of walnuts (E); (a.u. – arbitrary unit)

Environmental impact of roasting methods

The demand for energy in the microwave roasting process is higher than in the conventional roasting for all of the tested nuts (Table 2). The smallest difference was observed for walnuts (~ 14 times) and the largest for hazelnuts (~ 21 times). The disadvantage of convectional roasting is the emission of greenhouse gases resulting from the combustion of butane, which is used to power traditional kilns. In the case of microwave devices, which are powered entirely by electricity, there are no direct exhaust gases emissions. Due to the fact that neither process generates waste nor requires the use of water, convectional and microwave roasting are equivalent in this respect.

Table 2. Energy consumption and CO2 emissions related to roasting seeds and nuts with various methods

Symbol	Nuts	Roasting method	Electricity consumption [kWh/kg nuts]	Buthane consumption [kWh/kg nuts]	Exhaust emissions [kg CO_2/ kg nuts]
WM64	walnuts	microwave	6.2096	0	0
LM68	hazelnuts	microwave	12.4316	0	0
AM86	peanuts	microwave	9.3075	0	0
WK15	walnuts	convection	0	0.4339	0.0957
LK20	hazelnuts	convection	0	0.5786	0.1276
AK20	peanuts	convection	0	0.5786	0.1276

To analyse other environmental impacts, not only energy consumption and direct emissions, we performed the LCA analysis for three variants: convectional roasting in a butane-powered kiln, microwave roasting powered by electricity from the Polish power grid, and microwave roasting powered by energy from renewable energy sources (RES). For each of the materials, microwave roasting powered by the power grid is the least favourable. The total environmental impact is from ~ 11 (walnut) to ~ 16 times (hazelnut) higher than convectional roasting (Figure 6). However, when switching from a national power grid to RES, the microwave roasting has significantly smaller impact on the environment - it is one order of magnitude smaller than for convectional roasting and two orders of magnitude smaller than for microwave roasting using energy from the power grid (Figure 6).

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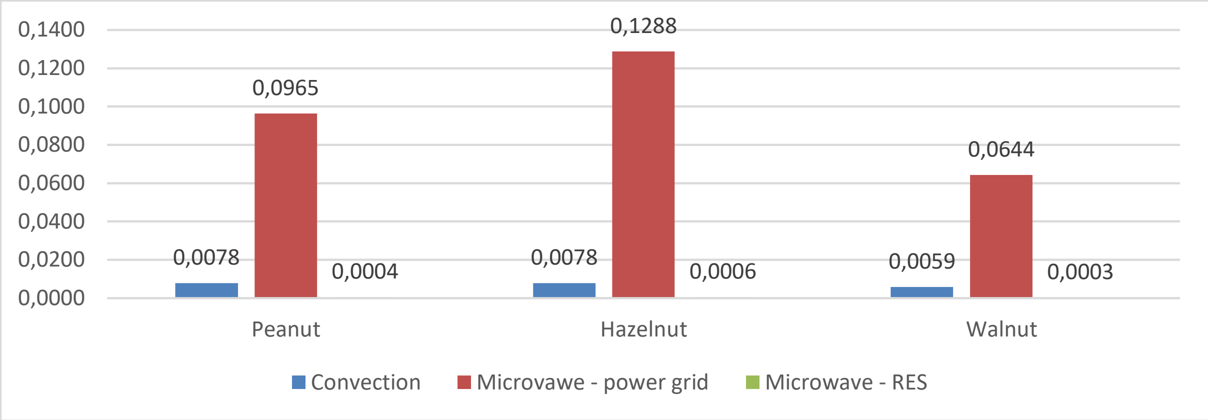

Fig. 6. Total environmental impact of roasting methods of nuts [points / kg of raw nuts]

Regardless of the nut type, the convectional roasting and microwave roasting powered with RES contribute to a smaller number of categories than microwave roasting (Table 3). Out of 17 impact categories, conventional and microwave roasting from RES have an impact on climate change, and thus on ecosystems and health. Microwave roasting powered from the power grid affects 9 additional categories, including human toxicity. This is mainly due to the structure of electricity production in Poland, based in over 80% on hard coal and lignite, and related toxic pollutions emitted by power stations [29]. On the other hand, all roasting methods are resource-neutral.

Table 3. Impact of the roasting methods of raw nuts on the environment by categories (green - no impact; red - maximum observed impact)

Impact category	AK20	AM86_grid	AM86_RES	LK20	LM68_grid	LM68_RES	WK15	WM64_grid	WM64_RES
ecosystem quality (agricultural land occupation)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ecosystem quality (climate change, ecosystems)	0.0035	0.0008	0.0000	0.0035	0.0011	0.0001	0.0026	0.0006	0.0000
ecosystem quality (freshwater ecotoxicity)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ecosystem quality (freshwater eutrophication)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ecosystem quality (marine ecotoxicity)	0.0000	0.0008	0.0000	0.0000	0.0011	0.0000	0.0000	0.0006	0.0000
ecosystem quality (natural land transformation)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ecosystem quality (terrestrial acidification)	0.0000	0.0006	0.0000	0.0000	0.0008	0.0000	0.0000	0.0004	0.0000
ecosystem quality (terrestrial ecotoxicity)	0.0000	0.0001	0.0000	0.0000	0.0002	0.0000	0.0000	0.0001	0.0000
ecosystem quality (urban land occupation)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
human health (climate change, human health)	0.0044	0.0011	0.0000	0.0044	0.0014	0.0001	0.0033	0.0007	0.0000
human health (human toxicity)	0.0000	0.0754	0.0001	0.0000	0.1007	0.0002	0.0000	0.0503	0.0001
human health (ionising radiation)	0.0000	0.0001	0.0000	0.0000	0.0002	0.0000	0.0000	0.0001	0.0000
human health (ozone depletion)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
human health (particulate matter formation)	0.0000	0.0175	0.0002	0.0000	0.0233	0.0002	0.0000	0.0117	0.0001
human health (photochemical oxidant formation)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
resources (fossil depletion)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
resources (metal depletion)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ecosystem quality (total)	0.0035	0.0023	0.0000	0.0035	0.0032	0.0001	0.0026	0.0017	0.0000
human health (total)	0.0044	0.0941	0.0003	0.0044	0.1256	0.0005	0.0033	0.0628	0.0002
resources (total)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
total	0.0079	0.0964	0.0003	0.0079	0.1288	0.0006	0.0059	0.0645	0.0002

Impact

Replacing conventional roasting technologies with microwave methods results in a significant, positive technological, environmental and economic impact.

Technological impact

New, gentle methods of processing dried fruits and nuts are based on the reduction of processing time and temperature needed to carry out the process. The lower temperature may limit the formation of Maillard compounds above 140 °C. However, the microwave roasting is more energy-intensive/ consuming than conventional roasting. Nevertheless, thanks to using renewable energy sources, the impact on the environment may be 14 ÷ 28 times lower than conventional roasting (depending on the raw material) and 231 times less than microwave roasting powered from the power grid. Thus, the introduction of microwave technologies in the food industry causes the technological snowball effect - prompts and stimulates to search for new technological solutions that enable lower energy costs.

Economic impact

Shortening the roasting time thanks to microwave technologies can impact on the economic aspects. Shorter roasting time increases productivity while maintaining high quality products.

Environmental impact

Traditional roasting processes use fossil fuels, most often natural gas, to power bakery ovens. Therefore, the emission of greenhouse gases resulting from the combustion of gas (butane) is undesirable for the natural environment. The introduction of integrated technological solutions - microwave roasting of dried fruits and nuts, powered by RES energy [30], will have a positive impact on environmental issues. Due to the drive to increase the share of energy from renewable sources related to EU policy, the use of microwave roasting installations in the factory will have a positive impact on environmental issues.

Conclusions

The results of microwave processing depend on the generation of microwave energy, its transfer through the media, penetration into the product and conversion into heat. The proposed physical model allows to choose the rational characteristics of the microwave heating process, that is, regulate the radiation power, surface areas and the thickness of the product. Data available to date indicate that roasting with the use of microwaves positively influences on properties of food. Convection roasting is a proven and frequently used method of processing dried fruits and nuts, while microwave roasting has never been used on a large scale. The type of roasting method affects the sensory properties of peanuts, hazelnuts and walnuts. Evaluation of unroasted, microwave and convectional roasted samples showed that convection roasting had increased intensity of the smell and taste. Microwave roasting did not diminish the sensory quality of the product expressed in general consumer preferences. The highest rated peanuts, roasted with microwaves, had the highest notes of nutty and sweet taste. On the other hand, according to experts' comments, microwave-roasted hazelnuts have been described as similar to nuts made of high-quality hazelnut chocolate, which is a positive feature. In the case of walnuts, microwave roasting significantly increased the overall acceptance of microwave-roasted nuts for 4 minutes at 600 W, they were rated as tastier and sweeter. There were none statistically significant differences between judges regarding sensory attributes observed. Furthermore, microwave roasting powered from RES has significantly lower environmental impact than convectional roasting.

Conflict of Interest

There are no conflicts to declare.

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