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MICROWAVE HEATING PROCESS – CHARACTERISTICS, BENEFITS, HAZARDS AND USE IN FOOD INDUSTRY AND HOUSEHOLDS – A REVIEW®

Ogrzewanie mikrofalowe – charakterystyka, korzyści i zagrożenia oraz zastosowanie w przemyśle spożywczym i gospodarstwach domowych – przegląd®

Key words: microwave heating, food industry, household, nutritional value, food safety, hazards.

The article presents the advantages and disadvantages of using microwave heating in the food industry and in households. A review of the literature in this field revealed many positive aspects of microwave heating. The microwave oven enables fast heat transfer, which translates into a short heating time and high energy efficiency compared to a conventional heating process. The efficiency of the process depends on many factors, including the shape and size of the product, the properties and position of the food during heating, and the process parameters used. However, the challenge for producers is still uneven temperature distribution, and hence uneven heating of the product. In summary, the quality of food prepared in a microwave oven differs from that of food prepared with conventional heating. The authors report both the highest and average sensory quality of vegetables prepared in a microwave oven and good nutrients retention. However, microwave heating also raises concerns among consumers due to the penetration of waves into the product and among other the possibility of acrylamide formation, as well as the safety of people operating the devices. Based on the research, it is known that the combination of microwave heating and conventional methods significantly improves the efficiency of the process, affecting the higher product quality, including the microbiological quality of the products obtained in this way.

Słowa kluczowe: ogrzewanie mikrofalowe, przemysł spożywczy, gospodarstwa domowe, wartość odżywcza, zagrożenia.

W artykule przedstawiono zalety i wady stosowania ogrzewania mikrofalowego w przemyśle spożywczym oraz w gospodarstwach domowych. Przegląd literatury z tego zakresu wykazał wiele pozytywnych aspektów ogrzewania mikrofalowego. Kuchnia mikrofalowa umożliwia szybki transfer ciepła, co przekłada się na krótki czas nagrzewania, wysoką efektywność energetyczną w porównaniu z konwencjonalnym procesem ogrzewania. Wydajność procesu zależy od wiele czynników, m.in. kształtu i wielkości produktu, właściwości i położenia żywności podczas ogrzewania a także zastosowanych parametrów procesu. Wyzwanie dla producentów wciąż jednak stanowi nierównomierny rozkład temperatury, a co za tym idzie nierównomierne nagrzewanie się produktu. Podsumowując, jakość żywności przygotowanej w kuchence mikrofalowej różni się w porównaniu z żywnością przygotowywaną za pomocą ogrzewania konwencjonalnego. Autorzy donoszą zarówno o najwyższej, jak i przeciętnej jakości sensorycznej warzyw przygotowanych w kuchni mikrofalowej oraz o dobrym zachowaniu składników odżywczych. Jednakże ogrzewanie mikrofalowe budzi też obawy wśród konsumentów ze względu na wnikanie fal w głąb produktu i m.in. możliwość tworzenia się akryloamidu, a także bezpieczeństwo osób obsługujących urządzenia. Na podstawie badań wiadomo, że połączenie ogrzewania mikrofalowego i metod konwencjonalnych znacznie poprawia wydajność procesu, wpływając na wyższą jakość produktu, w tym jakość mikrobiologiczną tak uzyskanych produktów.

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INTRODUCTION

Microwaves (MWs) are electromagnetic (EM) waves, which are synchronized perpendicularly oscillations of electric and magnetic fields that propagate at the speed of light in a free space. MWs are characterized by the frequency (between 300 MHz and 300 GHz) and the wavelength (ranging from 1m to 1mm). According to the countries and regions, five frequencies (433, 896, 915, 2375, and 2450m MHz) are authorized for MW heating operations. The 2450 MHz is the exclusive frequency for home appliances [42].

The process of heating food in microwave ovens differs from conventional methods in which heat is transferring from the outer surface of the product to its interior. Microwave heating causes vibrations of molecules with polar properties, mainly water, and causes direct heating of the interior, without any additional heat transfer medium. As the microwave propagate to the surface of the dielectric material, the energy will be divided into three parts i.e., the transmitted part, the reflected part, and the absorbed part. The absorbed microwave energy is converted into heat by polarizing the solid dipoles in dielectric materials and then used to improve the internal energy of the charge. The frequency of microwave wave radiation is in the range from 300 MHz to 300 GHz. Microwave heating also depends on the electrical properties of the food, which in turn affects the degree of energy conversion [13].

The aim of this study is to characterize microwave heating and present the benefits of its use in terms of the protection of nutrient and maintaining food safety, but also the concerns related to its use in food preparation and processing.

DATA COLLECTION

All data presented in this review were summarized from the references, including scientific journals and book chapters. These references were systematically searched against databases: PubMed, Web of Science, Scopus and Google Scholar with a keywords: microwave heating, microwave, microwave oven, technological process. To search for maximum relative references, the keyword was set as "microwave oven and microwave heating" and restricted to 1998–2022 years. The statistical data concerning the equipment of Polish households with microwave ovens in the years 1995–2021 was analyzed.

CHARACTERISTIC OF MICROVAWE HEATING

A microwave oven works by absorbing energy by dipolar molecules in the ionic components of the raw material, and then generating energy, which is then converted for heating [61]. The generation of heat therefore depends on the dielectric properties of the food. The dielectric properties are dependent on the temperature, humidity and composition of the food, as well as the microwave frequency [59]. Another important factor is the packaging material of the food being treated, as it can serve as a strong or weak absorber, or reflect microwaves without generating heat [14].

Compared to other heating methods (e.g. hot air heating, infrared heating etc.), microwave heating is more efficient and faster due to the volume heat [36, 45, 89]. Due to the uneven heating and the difficulty in obtaining browning, the optimal parameters of the microwave heating process are still sought, adapted to the form of the raw material, taking into account the appropriate power and time while maintaining the highest quality [51]. The uneven temperature distribution during the process has been widely discussed by many authors. Uneven distribution of the electromagnetic field in dielectric materials causes uneven temperature and humidity, e.g. the appearance of "cold" or wet points, which causes the survival of pathogens and accelerates food spoilage. On the other hand, the appearance of hot or dry places causes charring, cracking or hardness of the food materials [45, 68,72]. This variation in heating capacity sometimes raises questions about food quality and safety, as the microorganisms are not inactivated in cold places [85]. The heterogeneity of the heating process may be related to the texture, geometry and dielectric properties of the food, and the packaging used. These issues represent challenges for microwave ovens manufacturers as well as technologists who develop food products intend for the microwave oven [16, 23, 91].

Research on the relationship between parameters, e.g. temperature or humidity, and process variables, e.g. size, shape or dielectric properties, is of key importance in better understanding the microwave heating process and obtaining high quality of the obtained product. Process efficiency is influenced by many factors, including shape or size, properties and position of food in microwave ovens, as well as attributes of microwave ovens. Modifying the design of microwave devices, combining with other heating methods, optimizing the process and designing heated semi-finished products increase the heating efficiency in a microwave oven. Designing the appropriate shape and distribution of ingredients in a multi-element dish, intended to be prepared in a microwave oven, can affect even heating and higher quality of the product [9, 10, 30, 91, 92, 93, 98]. The conducted research shows that the shape and size of the raw material, especially the thickness, affect the heating efficiency, which is higher in the case of samples with small volumes and weights [7, 10, 11, 30, 73, 88, 95]. It was shown that the shape of a vertical cylinder has the highest uniform temperature distribution [9]. The concentration of microwave energy occurs in the center or on the corners of products of various shapes subjected to the heating process [10,13].

THE USE OF MICROVAWE HEATING IN FOOD INDUSTRY

Microwave heating is successfully applied in many areas of food processing, including drying processes (e.g. dry potatoes chips, pasta and snacks), lyophilization, pasteurization, extraction of bioactive compounds and enzyme inactivation, as well as microbiological disinfection [14, 15, 47, 54, 55, 66, 72, 75], due to the beneficial effects on many properties of the final products [41, 71, 77].

Microwave (MW) drying

When drying with the use of microwave heating of a product with high humidity, the microwave energy is supplied directly to the entire volume of the product, which causes a rapid increase in product temperature and immediate evaporation of water inside the product [47]. The internal pressure increases, bringing the water to a liquid state towards the product surface. This reduces drying time for many products - up to five times compared to air drying. The increase in internal pressure prevents the food from shrinking and hardening the surface during drying, positively influencing the texture of the microwave-dried product. It also affects the greater porosity of the product and increases the rehydration capacity [47]. In the case of microwave drying, an additional preservative effect can be observed due to the rapid increase in temperature of products rich in water, causing thermal shock in thermally sensitive microorganisms. The authors [46] found that by drying onions with air and using microwave, they found a tenfold greater reduction in total microbial count with microwave drying (a reduction approximately one to two logs).

This is an important advantage of microwave drying compared to conventional drying. However, due to the rapid saturation of the surrounding air, the efficiency of microwave drying is limited, therefore, in order to improve water transfer over the product surface, MW drying is often combined with a flow of hot air. When drying MW, excessive surface temperature may also occur, especially at the edges. This can carbonize the product and produce unpleasant off-flavors, especially in the final stages, as opposed to hot air drying where the surface temperature does not exceed a controlled ambient air temperature, e.g. when drying aromatic plants at 30-40°C. In combination with other conventional methods, microwave drying improves the drying efficiency and the quality of the dried product. Combined drying applications are mainly MW assisted hot air (HA) drying, MW vacuum drying and MW freeze drying [47].

Dried foods, including vegetables, fruits, seafood and meat, have an extended shelf life, a lower weight-to-volume ratio, which makes them easier to store or transport over long distances. In many studies, researchers focus on the use of microwave ovens for microwave drying, due to the speed and uniformity of the process, energy efficiency and obtaining a higher quality product compared to conventional hot air drying [17, 25]. Zielińska and Michalska (2016) [99] report that the berries vacuum-dried in a microwave (1.3 W / g microwave power at a pressure of 4-6 kPa, 6 rpm) showed a significant increase in color intensity change, as well as density and chewiness, which were desirable qualities of the fruit. The authors also report an improvement in color when using a domestic microwave oven with a rotating system for the drying process to improve uniformity (1000 W and a frequency of 2450 MHz) [58].

Extraction with the use of microwave heating

Microwave Assisted Extraction (MAE) is an attractive alternative in functional food development [49].

Functional food contains bioactive compounds such as antioxidants, antimicrobials, immunomodulators, enzymes, probiotics, prebiotics, fibers, phytosterols, peptides, proteins, isoflavones, saponins, and others [4]. Traditional techniques for the extraction of bioactive compounds, such as the Soxhlet method, or liquid-liquid or solid-liquid extraction, are time consuming and less efficient than microwave assisted extraction. Therefore, MAE may have the potential to be used in the extraction of fluid-soluble products from a wide variety of food matrices with minimal use of solvents [4, 8].

Microwave pasteurization and sterilization

To extend the shelf life of most food products, the pasteurization and sterilization processes are commonly used. This is due to the destruction of vegetative pathogenic microorganisms and the deactivation of certain enzymes in food. The pasteurization temperatures and the treatment time used vary depending on the pH and nature of the product and the type of microorganism. In pasteurization, most processes heat food to 60-85°C for a few seconds to an hour [2]. In semi-solid or solid products, heat transfer mainly takes place by conduction from the surface to the center, known as the "cold" point. Reaching the target temperature at the "cold" point can be demanding and may result in overcooking the surface and deterioration of quality. Maximizing bacterial inactivation while minimizing nutrient degradation is a challenge for producers and technologists. The use of microwaves seems to be a good solution to the limitations of slow thermal diffusion of conventional processes due to the direct and volumetric interaction between microwave heating and food.

Microwave sterilization of food is caused by the heat generated as a function of the food medium and the temperature achieved in the various parts of the food. De-La Vega et al. (2012) demonstrated good product quality (no loss of color) and inactivation of 5.1 log cycles of Salmonella Typhimurium, after inoculating fresh jalapeño peppers with it, then immersing them in water and subjecting them to a 950 W (2450 MHz) microwave temperature 63°C (25s) before cooling [21].

In another study [52] reduced by 2 logarithmic cycles the population of Salmonella enterica in tomatoes using microwaves (700W for 59s). Also in the case of eggs, the use of microwaves resulted in a reduction of *Salmonella enteritidi*s by 2 log cycles without any significant negative impact on the quality [48]. On the other hand, Zeinali et al (2015) [90] reported a reduction of 6 log cycles of L. monocytogenes inoculated in chicken thighs after 60 s exposure in a domestic microwave oven.

In summary, many studies have shown the effectiveness of using MW heating for pasteurization and sterilization of food [31, 65, 70]. Various strains of microorganisms have been inactivated by the use of microwaves: *Bacillus cereus, Campylobacter jejuni, Clostridium perfringens, Escherichia coli, Enterococcus faecalis, Listeria monocytogenes, Staphylococcus aureus and Salmonella* [27, 97].

A serious problem, however, is the heterogeneity of heating, which can lead to incomplete inactivation of the microorganisms. Several studies have shown the survival of pathogens in microwave-heated food, np. *Salmonella spp.* [37] and *L. monocytogenes* [24]. Non-uniform heating also deteriorates the quality of the product. Local overheating often results in irreversible color changes, where the temperature is highest, mainly at the corners and edges due to wave reflection [78]. The localization of "cold" points can also be a problem when using microwaves. In a conventional thermal process, the "cold" point is well-defined and is often at the center of the product. During MW pasteurization, single-point monitoring of the temperature in the product is not sufficient to ensure complete food safety [34]. Schnepf & Barbeau [67] investigated the inactivation of *Salmonella* in poultry and showed that the measurement of the internal temperature during the MW treatment did not reflect the inactivation of the surface, the temperature of which was lower. However, the method of chemical markers can be used to locate a "cold" point [12, 43, 62]. In combination with experimental research, numerical simulations are recommended to find cold spots and obtain accurate research to develop a reliable decontamination process for explosives [33, 34, 56].

The food industry is constantly looking for new solutions that are characterized by greater efficiency and effectiveness, ensuring food safety while maintaining product quality. One such solution is the use of microwave assisted thermal sterilization (MATS), developed by Washington State University [78]. Worldwide license for this technology is owned by 915 Labs. The development of the MATS method at Washington State University has shown great potential in providing commercial sterilization and pasteurization with minimal nutrient loss [79]. Microwave Assisted Heat Sterilization (MATS) is becoming an increasingly popular technology for sterilizing packaged food. In this system, packaged food is sterilized by simultaneous heating to 120°C via a pressure hot water bath and microwave energy at 915 MHz, and then rapidly cooled [78]. This method has been approved by the Food and Drug Administration (FDA) for the sterilization of mashed potatoes (2009), processed meats (2010), and salmon fillets (2012) [6, 78]. The MATS system differs from conventional microwave technology in that it primarily uses water as an interface for heating followed by the heating process in a microwave oven. The combination of technology and the use of water as a medium allows for more uniform heating and at the same time reduces the time of exposure to high temperature compared to conventional sterilization [6, 78].

THE USE OF MICROVAWE HEATING IN HOUSEHOLDS

Due to its wide range of applications, microwave heating has gained a lot of interest from food producers now, but it was not until the 1940s that the possibility of using a microwave oven for cooking was discovered [74]. A domestic microwave oven is the most common device among consumers that uses the thermal effect of an electromagnetic wave, and its common operating frequency is 2.45 GHz [45, 68, 72].

Microwave heating is used in gastronomy and at home, mainly for such processes as: cooking and thawing [14, 15, 54, 55, 66, 72, 75].

The microwave oven allows for quick heat transfer, which translates into a short heating time, high energy efficiency and ease of use compared to the conventional heating process, as well as the ability to immediately turn off the device to stop the process [65, 96]. Changing the lifestyle of consumers and limiting the time for preparing meals contributed to the popularization of the use of microwave ovens in households. In recent years, consumer interest in microwave ovens has increased in Poland. In 1994, only about 3% of households were equipped with them, while in 2020 it was 64.6% (Figure 1) [29]. By comparison, according to the US Bureau of Labor Statistics in 1994 67% of American household owned a microwave oven, and now it is 90% of households [84].

Food safety and safety of use microwave oven

Food cooked in a microwave oven is as safe as food cooked in a traditional cooking methods, but it raises concerns for consumer safety. The main difference between the two cooking methods is that microwave energy penetrates deep into the food and reduces heat conduction in the food, thus reducing the overall cooking time [83]. Consumer knowledge about the safe use of microwave ovens is low causing food safety concerns, especially microbiological hazard of microwaved heated food. This is confirmed by a study conducted among Malaysian consumers (n = 329) on the knowledge and practice of microwave oven safety and attitudes towards food safety. As many as 57.4% of respondents showed a low level of knowledge about the safety of a microwave oven, despite the knowledge of microwave oven usage standards. In addition, consumers also demonstrated a low level of practice of microwave safety [60].

Studies indicated that microwave heating at a high-power level can cause more acrylamide formation in food than traditional heat treatment due to differences in its formation during microwave heating and conventional methods. In contrast, short-term exposure to microwaves (during blanching and thawing) at low power may even reduce acrylamide formation during the final heat treatment [57].

In the research conducted by Czarniecka-Skubina et al. (2016), most respondents assessed the quality of food prepared in the microwave as good or average, but the taste as worse than in traditionally prepared dishes. Most of the respondents (73.6%) considered the microwave oven safe for health, and only a small percentage of respondents were afraid of radiation and the possibility of developing cancer [20].

Some authors report that the safety of microwave ovens is related to the

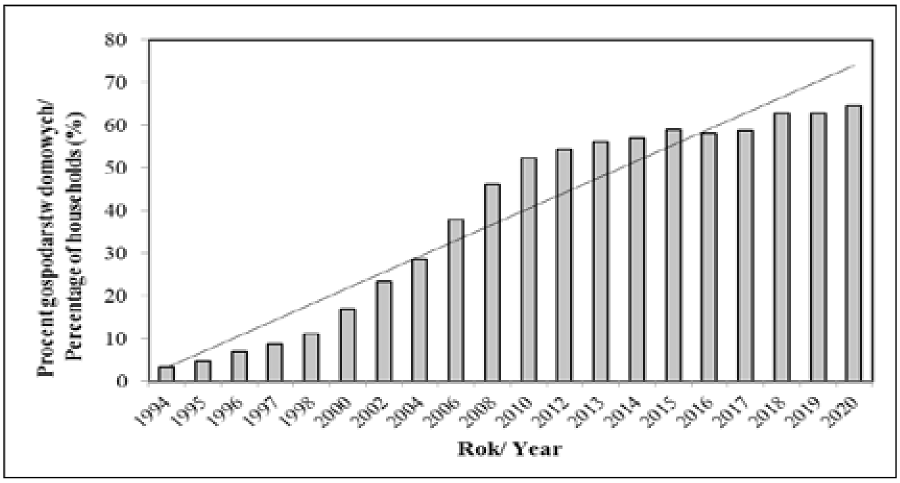

Fig. 1. Percentage of Polish households equipped with microwave ovens.
Rys. 1. Procent polskich gospodarstw domowych wyposażonych w kuchenki mikrofalowe.

Source: Own elaboration based on literature [29]

Źrodło: Opracowanie własne na podstawie literatury [29]

Table 1. Advantages and disadvantages usage of microwave heating in household and food industry

Tabela 1. Wady i zalety stosowania ogrzewania mikrofalowego w gospodarstwie domowym i przemyśle spożywczym

Household		Food industry	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
– cooking time is short / krótki czas gotowania – limited nutrients destruction / ograniczone straty składników odżywczych – no physical change of food / brak fizycznej zmiany żywności – the melting process is easy / łatwy proces topienia – possibility to obtain a sterilization effect / możliwość uzyskania efektu sterylizacji – the heat treatment is easy / obróbka cieplna jest łatwa	– the constraint uses a metal container / oraniczone użycie metalowego pojemnika – heat force control is difficult / utrudniona kontrola siły grzewczej – big water evaporation from food / duże parowanie wody z żywności – a closed container is dangerous because it could be burst / zamknięty pojemnik w trakcie użycia może pęknąć – surface toasting is impossible / niemożliwe opiekanie powierzchni – attention in using a microwave oven is needed / należy zachować ostrożność w trakcie użycia – if it is used improperly, they can leak harmful radiation, posing a risk of cancer and other diseases / jeśli jest używana niewłaściwie, może przepuszczać szkodliwe promieniowanie, stwarzając ryzyko zachorowania na raka i inne choroby	– positive effect on the texture of the dried product / pozytywny wpływ na teksturę suszonego produktu – fast heating efficiency / wysoka wydajność ogrzewania – reduction energy consumption of the process / zmniejszenie energochłonności procesu – inactivation of microorganisms / inaktywacja mikroorganizmów – the use of combined methods to obtain a high-quality product / stosowanie łączonych metod w celu uzyskania wysokiej jakości produktu – no limitation of heat diffusion can be used for many processes i.e., pasteurization, sterilization, drying, cooking, extraction / brak ograniczenia dyfuzji ciepła – może być stosowana w wielu procesach tj. pasteryzacja, sterylizacja, suszenie, gotowanie, ekstrakcja	– uneven temperature distribution / nierównomierny rozkład temperatury – local overheating of food / lokalne przegrzanie jedzenia – difficult localization of "cold" points / trudna lokalizacja „zimnych" punktów – the need to modify microwave ovens / konieczność modyfikacji kuchenek mikrofalowych – the need to optimize process parameters / konieczność optymalizacji parametrów procesu

Source: Own elaboration based on literature [22].

Źródło: Opracowanie własne na podstawie literatury [22]

leakage of waves and thus the health risk to the people who operate them. The effects of electromagnetic radiation from microwave ovens on the health of the workers (n = 28) who are exposed to microwave radiation during their work at cafeterias in four higher educational institutions in northern part of Palestine were studied. Measurable health parameters (heart pulse rate, blood oxygen saturation, tympanic temperature, systolic and diastolic blood pressure) were used to detect the effect on workers' health. The authors indicated that there is no dangerous health effects of microwave radiation from microwave ovens used in university cafeterias [32].

Quality of the products obtained and nutritional value

A literature review suggests that the quality of food prepared in a microwave oven differs from that of food prepared with conventional heating. The authors report both the highest and average sensory quality of vegetables prepared in a microwave oven [44] and good maintenance of nutrients [18]. Microwave-heated tea also had a higher sensory quality than oven-heated tea [39].

Research on the effect of microwave heating on the quality of prepared raw materials took into account the effect on the content of vitamin C, reporting significant losses of up to 40% [50, 86]. Cooking in a microwave oven helps to preserve vitamin C due to the short processing time and the limitation of the amount of water used. By carrying out the process in a microwave oven, intensive boiling of the solution is additionally eliminated, which protects the tissue and vegetable cells from tearing. This results in a reduction in the amount of leached vitamins and minerals into the solution [18].

In the case of microwave baking, the product may show a lower sensory quality by reducing the Maillard reaction products by 50%, but with a higher nutritional value by reducing the formation of heterocyclic aromatic amines and polycyclic aromatic hydrocarbons [80].

Moreover, cooking in the microwave oven changes in the content of chemical impurities in root vegetables [18, 19, 26], as well as the effect on the change in the content of substances antinutritional in legume sprouts [5].

Losses of B vitamins and minerals in microwave-cooked chickpeas were lower than in conventional cooking or autoclaving. The improvement in vitamin retention when cooking in the microwave oven could have been the result of the shorter cooking time. Chickpea protein is rich in essential amino acids such as isoleucine, lysine, total aromatic amino acids, and tryptophan, so it is a good complement to those protein sources that are low in lysine and tryptophan. It was shown that the conventional cooking process and microwave cooking resulted in a slight increase in the total amount of essential amino acids, in addition to the autoclave thermal process. Conventional cooking and autoclaving lowered lysine concentrations, with the exception of microwave cooking [3].

Results of studies confirms the possibility of using microwave treatment as an alternative to conventional oven heating, as demonstrated with flaxseed. The influence of microwave heating and conventional heating in an oven on the amount of hydrogen cyanide, properties of oil and protein, and volatile compounds in linseed were assessed. It was shown that all the heating treatments effectively reduced the content of hydrogen cyanide.

Microwave heating (860 W for 8 minutes) also slightly increased the peroxide value, while heating in an oven (150°C for 30 minutes) increased it more than 10 times. Both methods of heating significantly increased the types and amounts of volatile substances such as pyrazines, alkanes and aldehydes. Further comprehensive quality analysis using principal component analysis (PCA) showed similar properties [38].

Moreover, changes in the quality of poppy seeds were shown, including the content of bioactive compounds, fatty acids, tocopherols and phenol composition [28]. Microwave heating, due to different process conditions, such as time, power, and amount of added water, resulted in the composition of vegetables in different ways [50]. An example is reducing the glucosinolate content of broccoli [42, 86], caused by the high rate of water evaporation, which affected the leaching of glucosinolates [50]. Microwave cooking also had a differential effect on high aliphatic glucose losses as well as indole / aromatic nolana levels, both of which high decreases in broccoli [86] and increases in red cabbage (by 78%) were determined during microwave heating [87].

The authors [82, 94] noticed that with increasing microwave heating time of broccoli and cabbage, the content of polyphenols and their antioxidant activity decreased, which was comparable to conventional cooking. Other authors [76] report that cooking in a microwave oven caused both an increase in the content of flavonoids in juices from various apple varieties, greater than as a result of traditional cooking, and a comparable level of these compounds in both methods.

In conclusion, changes in the content of nutrients, including polyphenols, due to microwave heating are product dependent [81]. The total content of phenolic compounds after culinary treatment was for: pepper – 126%, green beans – 129%, broccoli – 125%, spinach 109%, pumpkin 67%, peas – 83%, leek – 82% in relation to fresh vegetables. Similarly, in the case of antioxidant activity in vegetables, except for peas, an increase was found (from 106% to 188%) [81], as well as a decrease in antioxidant activity in potatoes by 11% [69]. In contrast, microwave-heated fennel seeds were richer in fatty and phenolic acids and had a higher antioxidant activity than after oven treatment [35]. Microwave heating resulted in the even solubility of the protein and minimized the activity of enzymes responsible for the "bean flavor" [35, 40].

The combination of microwave heating (5.7 kW at 180° C) with baking in a steam oven (35 kW at 180°C) reduced the heating time and improved the tenderness and color of beef compared to conventional baking [64].

It was also shown that microwave heating (20 kW, 120°C for 12 s) compared to the pasteurization process (90°C for 15 min) resulted in better preservation of the quality of strawberry puree [54]. Conventional pasteurization resulted in greater degradation of total polyphenols (7%), anthocyanins (20%) and vitamin C (48%) compared to microwave treatment at 120° C. However, no color change was shown. In addition, a product with better "freshness" attributes was obtained in the microwave oven [54].

Other authors have come to similar conclusions [63]. During the microwave assisted pasteurization of carrots (915 MHz) compared to conventional pasteurization, they found no significant differences in texture and carotenoid retention in carrots, but the processing time was significantly reduced, which had a positive effect on the quality attributes. Moreover, the influence of high-frequency radiation on the quality in terms of mechanical strength of bakery products with a low moisture content was demonstrated. Biscuits baked in a convection oven compared to biscuits baked in the same way and additionally subjected to microwave treatment (power 700 W for 30 seconds) had a worse structure, which deteriorated during storage. It has also been found that biscuits which are additionally heated in a microwave oven are less susceptible to the effects of high ambient humidity [1].

SUMMARY

Conventional heat treatment for preserving food generally reduces the quality of the product. Additionally, these methods are not optimized for solid foods due to the slow transfer of heat from the surface to the "cold" point that often occurs in the center of the product. The goal of modern food processing technologies is undoubtedly to improve the organoleptic properties, while obtaining the minimum loss and nutritional value of food in combination with food safety. Microwave (MW) heating has advantages that allow it to break down barriers such as the slow thermal diffusion of conventional heating. This technology is also characterized by fast heating efficiency, at the same time meeting the needs of the industry. It can be successfully used for drying and disinfecting food. However, the main disadvantage of this technology is the heterogeneity of heating, which still poses challenges for technologists and producers. However, the combination of MW heating with other conventional methods significantly improved both microbiological safety and drying efficiency which resulted in higher quality of various products. The use of physical models and simulations as well as further research on an industrial scale to optimize the MW heating process remains a challenge.

CONCLUSIONS

1. The quality of the product subjected to microwave heating depends on the type of product, its shape and size.
2. Microwave (MW) heating overcomes the limitation of slow thermal diffusion compared to conventional heating.

3. Microwave heating technology is also characterized by fast heating efficiency, which meets the needs of the industry.
4. Due to high heating efficiency, microwave heating can be used for pasteurization, sterilization, cooking, extraction, drying. The combination microwave heating with other conventional methods improves process efficiency and higher product quality, as well as microbiological safety.
5. Consumers' interest in microwave ovens and their equipment in households is growing. In 1994, only about 3% of households in Poland had a microwave oven, while in 2020 it was 64.4% of households. While 90% of US households equipped with a microwave oven.

WNIOSKI

1. Jakość produktu poddanego ogrzewaniu mikrofalowemu zależna jest od rodzaju produktu, jego kształtu i wielkości.
2. Ogrzewanie mikrofalowe (MW) przezwycięża ograniczenie powolnej dyfuzji cieplnej w porównaniu do konwencjonalnego ogrzewania.
3. Technologia ogrzewania mikrofalowego charakteryzuje się również szybką wydajnością grzewczą, wpasowując się w potrzeby przemysłu.
4. Ze względu na wysoką wydajność grzewczą ogrzewanie mikrofalowe może być stosowane do pasteryzacji, sterylizacji, gotowania, ekstrakcji, suszenia. Połączenie ogrzewania mikrofalowego z innymi konwencjonalnymi metodami poprawia wydajność procesu, wpływa na wyższą jakość produktu, a także bezpieczeństwo mikrobiologiczne.
5. Wzrasta zainteresowanie konsumentów kuchenkami mikrofalowymi i ich wykorzystaniem w gospodarstwach domowych. W 1994 roku tylko około 3% gospodarstw domowych w Polsce posiadało kuchenkę mikrofalową, podczas gdy w 2020 roku było to już 64,4% gospodarstw domowych. Natomiast 90% amerykańskich gospodarstw domowych jest wyposażonych w kuchenkę mikrofalową.

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