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Microwave energy and its application in food industry: A reveiw

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ABSTRACT

This paper reviews an overview of microwave heating as one method of thermal food processing. The higher standard of living and soaring income of consumers have lead for the demand for the modern food processing application. The technological revolution and nutritional awareness have increased the popularity of the microwave heating. Microwave heating is known for its operational safety and nutrient retention capacity with minimal loss of heat-labile nutrients such as vitamins B and C, dietary antioxidants, phenols and carotenoids. This review aims to provide a brief update of microwave heating and its application for food processing applications, with special emphasis on its impact on food quality in terms of microbial and nutritional value changes.

Key words: Baking, Blanching, Dipolar rotation, Ionic conduction, Microwave, Sterilization.

The microwave technology was principally used for communication, with the development of radar during the Second World War. It was during 1946, a self taught engineer Dr. Percy Spencer was testing a new vacuum tube called a magnetron, to his surprise the candy bar in his pocket melted. This incident lead to the introduction of microwave energy into the food industry (Fito *et al.,* 2005). In recent years, microwave oven has become one of the most popular home appliances for food processing applications. The consumers have widely accepted the microwave technology due to its wide range of advantages, which has helped them to overcome from the fear and taboos that existed in the beginning. Microwave heating is a volumetric heating process, where heat is generated evenly throughout the entire volume of the food material. This is due to the complete interaction between microwave, polar water molecules and charged ions in food. Microwave energy is selectively absorbed by areas of greater moisture, with more uniform temperature and moisture profiles. The microwave technology has emerged as one of the most promising food processing technology. It has gained popularity due to its considerable advantages over conventional heating methods. It has been applied in various food processing industries such as cooking, pasteurization, sterilization, thawing, baking, blanching and drying of food materials (Decareau, 1985). The reimbursements include high heating rates, lower processing time, more uniform heating, safe handling, easy operation, low maintenance and energy efficiency.

ELECTROMAGNETIC SPECTRUM

Microwaves are form of electromagnetic energy. Microwave energy is a non ionizing radiation that causes molecular motion by migration of ions and rotation of dipoles but does not cause change in molecular structure. Microwave energy occupies a part of electromagnetic spectrum, and is characterized by being situated in the wavelength interval between 1mm to 1m and frequency interval between 300 MHz and 300 GHz (Fig.1). These are normally used for the industrial processing of foods being between 915 and 2450 MHz and, for domestic use, of 2450 MHz

HOW MICRO OVEN WORKS

The most prominent characteristic of microwave heating is volumetric heating, which is quite different from conventional heating. In volumetric heating the materials can absorb microwave energy directly and internally and convert it to heat (Scott jones, 2012). It is this characteristic that leads to advantages using microwaves to process materials. Microwave oven uses electromagnetic waves called micro-waves to heat food. The micro-waves oscillate at a very high speed, normally 2450 times per second. When food is placed in a microwave oven, various food ingredients behave differently. The main ingredient that enables food to be heated by micro-waves is water. The higher the water content of food, the faster is the heating rate. Water in molecular level behaves exactly like a magnet. Water has two oppositely charged ends due to presence of positively charged 2 Hydrogen atoms and a negatively charged Oxygen molecule. Therefore, water in food behaves like a magnet. If a bar magnet is held above another bar magnet, and you rotate the held magnet, the other one also rotates. Similarly, due to two different poles in water, when micro-waves oscillate the water molecules rotate. This is because the negatively charged end of water is attracted to positively charged end of micro-wave,

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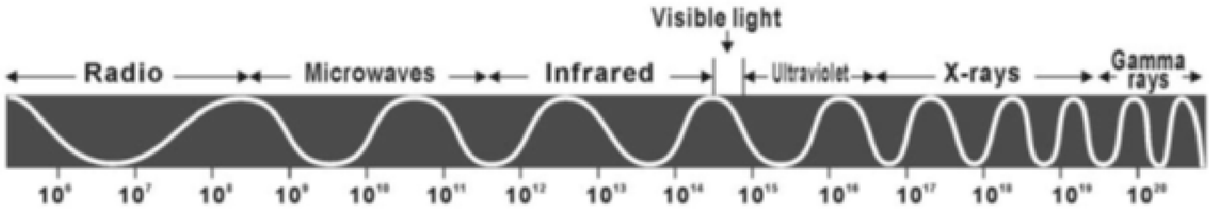

Fig 1: Electromagnetic spectrum

while the positive end of water is attracted to the negative charged end of micro-waves. The micro- waves rotate at extremely high speed of 2450 time per second. This means for every second a micro-wave rotates, the water molecule also rotates 2450 times. This extremely high rotation rate causes water molecules to collide with each other at very fast rate. This creates friction between water molecules. This friction generates heat. The heat flows through the food by conduction, convection or radiation. Therefore food warms up.

DIELECTRIC PROPERTIES

The feasibility of using microwave energy for the heating or drying of any material is dependent on dielectric properties of the food sample (dielectric constant and dielectric loss factor), which determine microwave power absorption as well as microwave energy penetration (To *et al.,* 1974). The heating pattern of a sample, heated with microwave energy will depend upon the dissipation factor (tan δ) of the sample. The dissipation factor is the ratio of samples dielectric loss or loss factor (ε'') to its dielectric constant (ε'). The dielectric constant is the measure of the samples ability to obstruct the microwave energy as it passes through it, and the loss factor measures the sample ability to dissipate the energy, i.e., the amount of input microwave energy being converted into heat. The dissipation factor is finite for absorptive material. The dissipation factor is different for different materials. The greater the dissipation factor of a sample less is the penetration of the microwave energy at a given frequency. Therefore more amount of microwave energy is dissipated as heat (Daniel *et al.,* 1976). Microwave energy is dissipated as heat in the sample by two mechanisms: ionic conduction and dipolar rotation.

Ionic conduction: Ionic conduction is the conductive migration of the dissolved ions in the applied electromagnetic field. The ionic migration is a flow of current that results in I^2R losses (heat production) due to resistance to ion flow. The ionic conduction is affected by ion concentration, ion mobility and solution concentration. All ions in the solution contribute to ionic conduction process. Every ionic solution consist of at least two ionic species (e.g. Na^+ and Cl^- ions) and each species will conduct current according to its concentration and mobility, (the net movement of ions in the electric field generates heat, which increases the temperature of the sample). The increase in concentration increases ionic conduction

Dipolar rotation: Dipolar rotation refers to the alignment of molecules in the sample that have dipole moments, when exposed to the electric field. As the electric field of the microwave energy increases, it aligns the polarized molecules. As the field decreases, thermally induced disorder is restored. The applied micro field causes the molecules temporarily to align in one same direction, when the field is removed, the molecules return to disorder causing agitation and release of thermal energy. At 2450 MHz, the alignment of the molecules followed by their return to disorder occurs 4.9×10^9 times per second and results in very rapid heating (Neas and Collins, 1988).

Industrial application of microwave heating

Pasteurization and sterilization: Microwave assisted pasteurization and sterilization have been motivated by the fast and effective microwave heating of many foods containing water or salts and better quality of product (Shaheen, *et al.,* 2012). Pasteurization is a process applied generally to liquid foods mainly to kill key pathogens and inactivate vegetative bacteria and enzymes to make food safe for consumption (Ahmed and Ramaswamy, 2007). The experiments have showed that microwave pasteurization of milk for 2.5 min resulted in 97.7 % reduction of bacteria Villamiel *et al.* (1996). Microwave heat treatment of milk for 3, 8 and 10 min completely inactivated *C.jejuni*, *Y.enterocolitica and L. monocytogenes,* respectively (Sieber, 1996). The effect of microwave heating of milk was studied on the parameters such as denaturation of â-lactoglobulin and the inactivation of alkaline phosphatase and lactoperoxidase. The results obtained were compared with the conventional heating in a plate heat exchanger, and found that the degree of inactivation in both cases was similar (Lopez-Fandino, *et al.,* 1996). (Nikdel *et al.,*1993) described a continuous-flow microwave system to pasteurize orange juice using PME (pectin methyl esterase (PME) and microbial count as an index of the adequacy of pasteurization. The inactivation of PME and *Lactobacillus plantarum* was found to be more pronounced using microwaves as compared to conventional heating. Microbial destruction thus was much more temperature sensitive under microwave heating than under thermal heating.

Sterilization is a more severe thermal treatment of foods. The sterilization is recognized as a thermal process sufficient to eliminate toxin-producing *C. botulinum* from the food, make the food commercially sterile if adequately packed and stored at room temperature. Microwave sterilization has been studied for potential commercial applications. However, the commercialization has faced several problems with some limited success. A 915-MHz, single-mode, MW sterilization system for processing packaged foods was developed at Washington State University (WSU) to provide the concept of MW technology in pasteurization and sterilization applications (Tang *et al*., 2006). This system has been used for studying the influence of MW sterilization on quality of various foods, Sun *et al.,* 2007 studies demonstrated that asparagus sterilized by microwave-circulated water combination shoed greater antioxidant activity and greener colour than did asparagus processed by conventional method. Guan *et al.,* 2003 study suggest that macaroni and cheese products processed by MCWC showed a reduced microbial count and matched the calculated degree of sterilization (F_0 value). However, microwave sterilization has some problems such as unpredictable and non-uniform energy distribution. Therefore, progress of microwave sterilization at the industrial level has been relatively slow. But continuous studies and researches have overcome this problem.

Thawing and tempering: Thawing is the process of taking a frozen product from frozen state to an unfrozen state (at temperature usually above 0°C) where there is no residual ice, i.e. “defrosting”. Thawing is often considered as simply the reversal of the freezing process (Archer *et al.,* 2008). The frozen foods are thawed before cooking, to ensure that during cooking the food is heated sufficiently to kill harmful bacteria. If large frozen foods are not thawed prior to cooking, it will remain uncooked in the centre whilst being burnt or overcooked on the surface. The major problem of conventional thawing are large space requirements and long time which may result in chemical and bacteriological deterioration. When frozen foods are thawed, the surface area of the food is the first to rise in temperature and bacterial multiplication can recommence which were restricted in frozen foods (Sumnu and Sahin,2005). The use of Microwave energy can overcome this problem, as heat is generated with the food from the center to the surface, hence making microwave thawing a faster process than other methods (Shaheen, *et al.,* 2012). The major disadvantage of microwave thawing is that it does not occur uniformly and this phenomenon is known as runaway heating. Non uniformity in heating arises due to uneven power distributions and the increasing power absorption in liquid regions. Therefore, it is necessary to control the heat generated by the microwaves. (Tong *et al.,* 1993) designed a microwave oven with variable continuous power and a feedback temperature controller to maintain a desired temperature gradient within a model food system. Using this apparatus, thawing time was reduced by a factor of seven compared to convective thawing. In commercial practice the thawing is applied for relatively few products such as frozen meat, fish, vegetables, fruit, butter and juice concentrate. The thawing allowed the seafood product to be easily separated. The microwave thawing of frozen, raw, headless shrimp was noted as advantageous for many reasons; production control was improved; water usage was substantially reduced; ice requirements were reduced, since there was no temperature overshoot, bacteriological quality control was improved and costs were lower than for air or water thawing.

Tempering is the process of taking a product to a temperature where a substantial amount of the water in the product is in the form of ice but not all the water has turned to ice. This temperature must be below the freezing point and is usually between -5 to -2°C. At this state the product is rigid, but not hard and thus easier to cut. The product can either be cooled to this state from a temperature above the freezing point or warmed from a frozen temperature. The idea of microwave tempering as opposed to microwave thawing was studied by many scientists. Early work predicted that complete thawing with microwave was not practical; however, microwave tempering showed great potential. Microwave tempering can be used as an alternative to thawing because in most cases complete thawing is not necessary, and is a waste of energy, affects quality, and increases processing time. Microwave tempering has several advantages over most thawing processes. The microwave tempering process can handle large amounts of frozen product at small cost, has a high yield, and is accomplished in small spaces with no bacterial growth (Metaxas, 1996 and microdry, 1998). In meat processing industry, the meat used is usually obtained in thick frozen blocks below -18°C. The primary operation of meat processing is to separate individual sections into smaller pieces. The mechanical operation requires the blocks be tempered from their solid frozen state to a point where cutting or separation can be carried out easily without damage to the product. Conventional tempering techniques either with water or air, subject the outer surfaces of the product bulk to warmer temperatures for long periods. This results in large temperature gradients. In addition, the conventional tempering process takes a long time (several days) with considerable drip loss especially resulting in loss of protein, which represents an economic loss. Microwaves can easily penetrate the whole frozen product, thus effectively reaching the inner regions within a short time. The process has been successfully used by meat, fish, and poultry industries for further processing while the dairy industry has exploited the technology for tempering of butter and frozen foods (George, 1997) and to reduce the chances of rancidity during bulk freezing of butter. It has been the most successful applications of microwave in the dairy industry.

Pre cooking and cooking: The objective of pre-cooking operations is to reduce preparation time for the consumer. Precooking is recommended for many foods such a cereal flours, parboiling of rice, bacon and dried meats such as beef jerky which is precooked to a safe internal temperature before drying. The combined benefits of convenience, health and variety have increased the market of precooked products. However a second heat treatment is required for cooking of the precooked products. Microwave heating is found to be an ideal system for cooking bacon compared to conventional grilling. It is reported that most of the bacon usage in food services is precooked in microwave ovens. Microwave heating of bacon produces better structure with less shrinkage (Ahmed and Ramaswamy, 2007). Microwave heating has also found a possible application in precooking of various cereal products which helps in treating the starch, basically to reduce its gelatinization time during final preparation of the food product (Chang, 2011). Velupillai et al. (1989) developed a process for parboiling rough rice using microwave technology. Kaasova *et al.,* 2001 found that during parboiling process the gelatinization of rice starch is progressively faster during microwave treatment than conventional treatment.

Cooking is one of the most familiar application of microwave oven. Microwave heating is so rapid that it takes the product to the desired temperature in a short time; hence it is possible to do selective and quick cooking (fito *et al*., 2005). The microwave oven is well suited for cooking the food in small quantities, especially for households (Juliano, 1985), though not convenient for mass cooking. If the sizes of foods are small and the shape of foods is flat, the uniform heating through overall volume is possible. Microwave cooking has advantage of less loss of moisture contents and the greatest energy savings, and the nutrition of foods will be preserved very well (Puligundla et al., 2013). Various studies have been conducted to study the effect of microwave cooking on the food components. The controlled microwave cooking of un-soaked rice and presoaked rice compared with conventional cooking showed a reduction in energy consumption (Lakshmi *et al.,* 2007). The microwave cooking of chickpea flour have shown to retain higher percentage of major minerals (such as K, Ca, Na, and Mg) and minor elements (Cu, Fe and Zn) contrasting to fried cooking and traditional cooking methods (Arab *et al*., 2010). Various studies were conducted to study the effect of microwave cooking on vitamin content of foods. Alajaji and El-Adawy 2006 studies reported that higher concentration of riboflavin, thiamin, and pyridoxine were retained in microwave cooked chickpea seeds than compared with boiling and autoclave cooking. A significant reduction in cooking time was observed with microwave cooking. Marconi *et al.,* 2000 reported that microwave cooking with sealed vessels enabled a drastic reduction in cooking time, for chickpeas and beans compared with conventional cooking. The cooking time is effected by a few components of food (such as water fat etc.). Das and Rajkumar 2011 investigated the effect of various fat levels on microwave cooked goat meat patties. Microwave cooking time was found to reduce with an increase in fat level, as the dielectric constant and loss factor decreases with fat. The nutritious characteristics of the food are quite well retained in microwave cooking, but it does not reach the typical flavor of the cooked dish (fito *et al*., 2005) and cooking of multiple foods containing particles of any shape and size together cannot be achieved(Puligundla *et al.,* 2013). Therefore, new combination techniques, of microwave treatment with conventional technologies would be feasible (Chang *et al.,* 2000).

Baking: Bakery industry has an important place in food industry. Bakery products have now become essential food items of vast majority of population. (Potter and Hotchkiss, 1997). Baking is an important step in manufacturing of all bakery products, where the dough is subjected to heat in a baking oven. Baking process includes expansion of dough, moisture loss, rise in product height and at last rate of moisture loss decreases because the structure of the air cells within the dough medium collapses as a result of increased vapor pressure (Mondal and Datta,2008). The microwave baking of bread has found hopeful, despite of lack of commercial application (Ovadia and Walker, 1995). It is surprising that microwave heating has not met with greater success in the field of baking. This is due to internal heating mechanism of microwave energy which would seem ideal for ever expanding heat insulating foam in dough. Many researchers have addressed various problems related to the microwave baking. These problems include texture, low volume, lack of color, and crust formation, more dehydration and rapid staling. Megahey *et al.,* (2005) observed the influences of different baking conditions on quality in terms of texture of cake using microwave oven at 250 W and conventional oven at 200°C. Microwave baked cake was found to possess high springiness, moisture content and the low firmness as texture attributes compared with the cake that baked in convection method. (Fox and Dungan 1969 and Chamberlain 1973) have noted the importance of the pans used for microwave baking. Baking pans have always posed a problem of non uniform heating. The problem was solved by the use of metal pans (Schiffmans *et al.,* 1981). The metal pans have always proved to be good heat conductors and high heat transfer coefficient can be achieved with air impingement heating technology (Smith, 1975). The air impingement heating reduces the time lag between crumb baking and crust formation. The metal pans have also posed a problem of uneven baking, due to poor microwave permeability. Hence an ideal microwave baking pan must have excellent microwave permeability and thermal conductivity. (Ovadia, 1994) found that modification of existing metal pan could provide solution. He used metal pans with holes on the sides and the bottom, through which microwaves pass through. The amount that will pass depends on diameter of holes. At 2450 MHz the holes need to be more than 3mm in diameter (Constable, 1979) hence increasing the penetration of microwave into dough. To avoid the flow of dough through holes the pan was lined with common baking paper (0.08 mm thick). Results obtained were significantly improved over pan with no holes. Another problem related to microwave baking is the formation of a pale, weak and soggy crust. The solution was to bake the loaf by conventional method in metal pan, then remove it from the pan and complete the baking with microwaves (Broughton, 1974). Lefeuver 1981 suggested an innovative method, where baking was initiated by a combined infrared and microwaves applied simultaneously for one minute followed by infrared baking for 10 minutes thereby reducing the conventional baking time by more than half. Hence to overcome these problems researchers found that combination of infrared-microwave system is best alternative. The combination of microwave with other heating systems has been an interesting area, to reduce processing time and increase the quality of products. The combined heating technique has solved many issues such as low moisture content, the bread formation with firm inside and tougher outside, weak crust formation etc.

Blanching: Blanching is a unit operation practiced in food industry. Blanching serves a variety of functions, one of the main being to destroy enzymatic activity in vegetables and some fruits, prior to further processing. Blanching is not solely a preservation method but acts as a pre-treatment which is normally carried out between the preparation of the raw material and later operations particularly heat sterilization, dehydration and freezing (Fellows, 2000). The two most widely used commercial blanching methods are hot water and steam blanching treatment. However, the conventional blanching method is closely associated with the serious issues like loss of weight, leaching and degradation of nutritive components such as sugar, vitamins and minerals. To retain nutritional quality of food products, several researchers suggested the use of microwave heating as an alternative to conventional blanching method for food products. Microwave blanching requires little or no water for efficient heat transfer in food, and hence reduces the leaching of nutrients compared with hot water immersion (Puligundla *et al.,* 2013). The advantage of microwave blanching over conventional method include speed of operation, no additional water required, energy savings, precise process controls and faster start up and shut down times. The study on microwave blanching was reported by many scientists, Osinboyejo *et al.,* (2003). Studied the effect of microwave blanching (MWB) versus boiling water blanching (BWB) on retention of selected water soluble vitamins in turnip greens and found that BWB lost 16% ascorbic acid, and 100% folic acid, thiamin and riboflavin while MWB lost 28.8% ascorbic acid, 25.7% folic acid 16.9% thiamin and 7.2% riboflavin. In another recent study comparing traditional hot-water and microwave blanching on quality of green beans, the microwave treatment of pods, showed a reduced processing time with better retention of ascorbic acid in addition to an effective peroxidase enzyme inactivation (Ruiz-Ojeda and Penas, 2013). Schirack and co-workers (2007) studied the microwave blanching of peanuts and found that microwave blanching was better than traditional blanching techniques in terms of energy and time savings. The studies comparing microwave blanching versus hot water blanching on three vegetables namely spinach, carrot and bell peppers revealed that there was reduced loss of valuable nutrients and the kinetics of peroxidase inactivation indicated that microwave blanching was comparable to water blanching with higher reaction rate in the case of water blanching (Ramesh *et al.,* 2002).

Drying: Drying is one of the thermal processes, intended to reduce the moisture content of food materials, and it's one of the time-and energy-consuming processes in the food industry. Consequently, new methods are aimed to decrease drying time and energy consumption with preservation of quality (Kassem, *et al.,* 2011). Microwave drying is a newer addition to the family of dehydration methods. The mechanism for drying with microwave energy is quite different from that of ordinary drying. In conventional drying, moisture is initially flashed off from the surface and the remaining water diffuses slowly to the surface. Whereas, in microwave drying, heat is generated directly in the interior of material creating a higher heat transfer and thus a much faster temperature rise than in conventional heating. In microwave system, mass transfer is primarily due to the total pressure gradient established because of the rapid vapor generation within the material (Schiffmann, 2006). Most of the moisture is vaporized before leaving the sample. If the sample is initially very wet and the pressure inside the sample rises very rapidly, liquid may be removed from the sample under the influence of a total pressure gradient. The higher the initial moisture, the greater is the influence of the pressure gradient on the total mass removal. Thus, there is, a sort of ''pumping'' action, forcing liquid to the surface, often as a vapor. This leads to very rapid drying without the need to overheat the atmosphere and perhaps cause case hardening or other surface overheating phenomena. The major disadvantage of microwave drying is difficulty in control of final product temperature. This causes excessive temperature along the corner or edges of food products results in scorching and production of off-flavors especially during final stages of drying. This could be overcome by combination of microwave drying with conventional drying which has various advantages and widespread application in food industry. The combined microwave drying methods include Microwave-Assisted Freezing Drying (MFD), Microwave-Assisted Vacuum Drying (MVD), Microwave-Assisted Hot Air Drying (MHD) and Microwave-Enhanced Spouted Bed Drying (MSD) (Puligundla, 2013).

Microwave assisted drying as final stage for air drying reduces the drying time and increases the thermal efficiency. Maskan, 2000 reported that hot air drying combined with microwave finish drying reduced the drying time by 64% as compared to convective air drying. Microwaves can be combined with vacuum drying which improves the thermal efficiency (Zhang *et al.,* 2006). Vacuum microwave drying of banana slices was examined at a microwave power supply of 150 W and under a vacuum of less than 2500 Pa (Drouzas and Schubert, 1996). It was determined that the drying was achieved in less than 30 minutes without exceeding 70°C and the quality of the product was found to be good and was comparable to that of freeze dried product. Freeze drying can maintain the quality of heat sensitive dried products compared with other conventional techniques but it is a long time processing and brings high energy consumption issue. The microwave assisted freeze drying could be a one of alternatives to be able to avoid these weaknesses. It can produce the same quality as that of conventional freeze drying and can reduce the drying time effectively. In microwave freeze drying of cabbage, the drying rate of microwave freeze drying was twice greater than that of vacuum freeze drying. Fluidized bed dryers are of the most efficient equipments and are suitable for a variety of drying applications. However major disadvantage of fluidized bed dryers is, long drying time during the falling rate period and low energy efficiency (Chen *et al.,* 2001). Assisting conventional fluidized bed dryers by microwave heating provides an effective means of overcoming this limitation. Most of the microwave assisted drying of fruits and vegetables were performed in lab scale and hence more industrial scale applications with optimizations need to be conducted. (Zhang *et al.,* 2006).

CONCLUSION

Microwave ovens are common place in households and are established there as devices of everyday use. Knowledge of dielectric properties is very helpful for designing microwave oven. Microwave heating technology has been successfully applied for processing of various foods in various industries. The microwave pasteurization and sterilization of foods have claimed to effectively destroy pathogenic microorganisms and significantly reduce processing time without serious damage to overall quality of product compared to traditional methods. The microwave heating applied for food processes such as blanching, cooking and baking have the advantages of retaining more taste, color, quality and nutritional value and has a great effect on preservation compared to the conventional methods. The microwave heating has drastically reduced the energy consumption during drying of foods compared to conventional method. The greater advantages have been observed with the combined microwave heating method supplemented with conventional methods. The benefits include uniform heating of particulate foods, increased thermal efficiency, reduction in drying time, higher rehydration capacity and retain heat sensitive components of food material in case of microwave assisted freeze drying. The main obstacle for development of microwave heating applications is the high cost of the process. Electrical power, which is more expensive than combustion energy, is used with low yield. Therefore, the investigation of parameters which can influence the workability of microwave heating such as dielectric, physical, and chemical properties of food products should be carried out.

REFERENCES

Alajaji, S.A. and El-Adawy, T.A. (2006). Nutritional composition of chickpea (*Cicerarietinum* L.) as affected my microwave cooking and other traditional cooking methods. *J Food Compos Anal* **19:** 806-812.

Ahmed, J. and Ramaswamy,S.H. (2007).Microwave paeturization and sterilization of foods. In Handbook of Food Preservation, 2nd Ed, [Rahman, S.M. (Ed)], CRC Press, Taylor and Francis Group, Newyork. 691-709.

Arab, E.A.A., Helmy, I.M.F. and Bareh, G.F. (2010). Nutritional Evaluation and Functional Properties of Chickpea (*Cicerarietinum* L.) Flour and the Improvement of Spaghetti Produced from its. *J Am Sci*, **66:** 1055-1072.

Archer, M., Edmonds, M. and George, M. (2008). Seafood Thawing. Research and Development Department. p.1-41.

Broughton, W. (1974). Improvements in coking and processing. UK Patent 1,376,744.

Chamberlain, N. (1973). Microwave energy in baking of bread. *Food Trade Review*. **43:** 8-12.

Chang, K, Y., Steel, J.C. and Clerici, S.P.T.M. (2011). The Use of Microwave Radiation Energy to Process Cereal, Root and Tuber-based Products, Advances in Induction and Microwave Heating of Mineral and Organic Materials, [Prof. StanisÅ, Grundas (Ed.)], ISBN: 978-953-307-522-8, InTech.

Chen. G., Wang. W. and Mujumdar. S. (2001). Theoretical study of microwave heating patterns on batch fluidized bed drying of porous material. *Chemical Engineering Science* **56:** 6823–6835.

Constable, R.J.W. (1979). Microwave Heating. UK Patent 1,538,851.

Daniel, I.C., Wang, A.S. and goldblith. (1976). Dielectric properties of food. Technical report by Massachusetts Institute technology, Department of nutrition and food science, Cambridge, Massachusetts. P. 1-26.

Das, A.K., and Rajkumar, V. (2011). Effect of different fat level on microwave cooking properties of goat meat patties. *Journal of Food Science and Technology,* **50:**1206-1211.

Decareau, R. V. (1985), Microwaves in the Food Processing Industry. Orlando, Academic Press Inc.

Drouzas, A.E. and Schubert, H. (1996). Microwave application in vacuum drying of fruits. *Journal of Food Engineering*, **28:** 203-209.

Fellows, J.P. (2000). Food processing Technology. Principles and Practices, chapter 10,2nd Ed, Wood Head publishing Limited, Cambridge England, p-234.

Fito, P., Chiralt, A. and Eugenia martin, M. (2005). Current state of microwave applications to food processing, In: Novel Food Processing Technologies (Ed by G.V. Barbosa-canovas, M.S. Tapia, M.P. Cano), Marecel Dekker, New York, CRC Pess, pp 525-537.

Fox, M. and Dungan, A.L. (1969). The speed field feeding system. Technical report 70-11-GP. General Equipment and packaging Laboratory, U.S. Army Natick Laboratories, Natick, MA.

George, M. (1997). Industrial microwave food processing. *Food Review- cape town*. **24:**11-13.

Guan, D., Gary, P., Kang, D.H., Tang, J., Shafer, B., Ito, K., Younce, F. and Yang, T.C.S. (2003). Microbiological validation of microwave-circulated water combination heating technology by inoculated pack studies. *Journal of Food Science* **68:** 1428– 1432.

Juliano, B.O. (1985). Production and utilization of rice. In Juliano BO (ed.) Rice chemistry and technology, (2ndedn.) St. Paul: American Association of Cereal Chemists 1-16.

Kaasova, J., Kadlec, P., Bubnik, Z. and Pour, V. (2001). Microwave Treatment of Rice. *Czech J. Food Sci*., **19:** 62-65

Kassem, A.S., Shokr, A.Z., El-Mahdy, A.R., Aboukarima, A.M. and Hamed, E.Y. (2011). Comparison of drying characteristics of Thompson seedless grapes using combined microwave oven and hot air drying. *Journal of the Saudi Society of Agricultural Sciences* **10:** 33-40.

Lakshmi, S., Chakkaravarthi, A., Subramanian, R. and Singh, V. (2007). Energy consumption in microwave cooking of rice and its comparison with other domestic appliances. *J Food Eng* **78:** 715-722.

Lefeuvre, S. (1981). Bread making. UK Patent 1,583,182.

Lopez-Fandino, R., Villamiel, M., Corzo, N. and Olano, A. (1996). Assessment of the thermal treatment of milk during continuous microwave and conventional heating. *J Food Prot* **59:** 89–92.

Maskan, M. (2000). Microwave/air and microwave finish drying of banana. *J Food Eng* **44:** 71-78.

Megahey, E.K., McMinn, W.A.M. and Magee, T.R.A. (2005) Experimental Study of Microwave Baking of Madeira Cake Batter. *Food Bioprod Process* **83:** 277-287.

Metaxas, A.C. (1996). Foundation of electro heat: A unified approach. Pub by John Wiely & Sons, New York, Chichester, pp. 500

Microdry. (1998). Website: http//www.microdry.com/micro5.htm

Mondal,A. and Datta, A.K. (2008). Bread baking - a review. *J Food Eng* **86:** 465-474.

Neas, D.E. and Collins, J.M. (1988). Microwave heating. In Therotical Concepts and Equipment Design. American Chemical Society. p 7-31

Nikdel, S., Chen, C.S., Parish, M.E., Mackellar, D.G. and Friedrich, L.M. (1993). Pasteurization of citrus juice with microwave energy in a continuous-flow unit. *J. Agric. Food Chem*. **41:** 2116- 2119.

Osinboyejo, M. A., Walker, L. T., Ogutu, S., and Verghese, M. (2003). Effects of microwave blanching vs.boiling water blanching on retention of selected water-soluble vitamins in turnip greens using HPLC. *National Center for Home Food Preservation. Paper 92A-8. Presented at the Institute of Food Technologists Annual Meeting, Chicago, IL, July 15, 2003*

Ovadia, D.Z. (1994). Microwave baking pan. US Patent 5,331,153.

Ovadia, D.Z. and Walker, C.E. (1995). Microwave baking of bread. *Journal of Microwave Power and Electromagnetic Energy*, **30:** 81-89.

Potter, N.N. and Hotchkiss, H.J. (1997). Food Science, Fifth edition, CBS Publication, New Delhi.

Puligundla, P., Abdullah, A.S., Choi, W., Jun, S., Sang-Eun Oh and Ko, S. (2013). Potentials of Microwave Heating Technology for Select Food Processing Applications - a Brief Overview and Update. *J Food Process Technol*. **4:** 1-9.

Ramesh, M.N., Wolf, W., Tevini, D. and Bognár, A. (2002), Microwave Blanching of Vegetables. *Journal of Food Science*, **67:** 390–398.

Ruiz-Ojeda, L. M., and Peñas, F. J. (2013). Comparison study of conventional hot-water and microwave blanching on quality of green bean. *Innovative Food Science & Emerging Technologies*, **20:** 191-197.

Schiffmann, R.F. (2006). Microwave and dielectric heating. In handbook of industrial Drying. [Mujumdar, S.A. (Eds)]. Third edition, CRC Press, Taylor and Francis Publishers, Oxon, UK, p. 687-709.

Schiffmann, R.F., Mirman, A.H. and grillo, R.J. (1981). Microwave proofing and baking bread utilizing metal pans. US patent **4:** 271,203.

Schirack, M.A., Sanders, T.H. and Sandeep, K.P. (2007). Effect of processing parameters on the temperature and moisture content of microwave-blanched peanuts. *Journal of Food Process Engineering*, **30:** 225-240.

Scott jones. (2012). Adavantages of using microwave energy for process heating. Marion mixer, p 1-6.

Shaheen, S.M., El-Massry,F.K., El-Ghorab, H.A. and Anjum, M.F. (2012). Microwave applications in thermal food processing. In: The Development and Application of Microwave Heating. [Wenbin Cao (ed.)], INTECH, Science technology and medicine Access Publisher. DOI: 10.5772/48716.

Sieber, R., Eberhard, P. and Gallmann, P.U. (1996). Heat treatment of milk in domestic microwave ovens. *Int. Dairy J.* 6: 231–246.

Smith, D.P. (1975). Cooking apparatus. US Patent **3:** 884,213.

Sumnu, G. and Sahin, S. (2005). Recent Developments in Microwave Heating. In emerging technologies for food processing. Chapter 16. Da wen-sun (Ed.), Elsevier Acedemic Press, California, USA. p.433.

Sun, T., Tang, J.M. and Powers, J. (2007). Antioxidant activity and quality of asparagus affected by microwave-circulated water combination and conventional sterilization. *Food Chemistry* **100:** 813–819.

Tang, J., Liu, F., Patfiak K. and Eves, E.E. (2006). Apparatus and method for heating objects with microwaves. US Patent 7119313 B2.

To, C.E., Mudgett, E.R., Wang, C.I.D., Goldblith, A.S. and Decareau, V.R. (1974). Dielectric properties of food materials. *Journal of Microwave Power*. **9:** 303-315.

Tong, C. H., Lentz, R. R., and Lund, D. B. (1993). A microwave oven with variable continuous power and a feedback temperature controller. *Biotechnology Progress*, **9:** 488–496.

Velupillai, L., Verma, L. R. and Tsangmuichung, M. (1989). *Process for parboiling rice*. United States Patent 4,810,511

Villamiel, M., Corzo, N., Martinez-Castro, I. and Olano, A. (1996). Chemical changes during microwave treatment of milk. *Food Chem*. **56:** 385–388.

Zhang, M., Tang, J., Mujumdar, A.S., & Wang, S. (2006). Trends in microwave-related drying of fruits and vegetables. *Trends in Food Science & Technology*, **17:** 524-534.