International Journal of
Engineering Studies and Technical Approach
IJESTA
ISSN No. 2395-0900

Application of Microwave in Food Drying

Yashwant Kumar

Assistant Professor, Department of Food Processing & Technology, Bilaspur University, Chhattisgarh, India

ABSTRACT

Microwave is the machine, which is very helpful for the food sector. The modern age of life as well as the increasing number of working women requires simplified routines and standardization of foods with lesser preparation time and convenience in usage. The demands of the consumers are the real factor for the success or failure of any food items in the present scenario. The increasing consumer demands for food which offer more convenience in use and time savings in preparation of food, microwave is the novel tools to achieve this goal. Due to volumetric heating of food by the electromagnetic waves in the microwave, the cooking time drastically reduces. This makes a faster processing in domestic as well as in commercial. The objective of this paper is to present the recent research in microwave processing and how it has been utilized for the preservation of foods.

Key-words:-*Microwave oven, thermal processing, emerging technology, microwave heating, food drying.*

INTRODUCTION

Mass production of dry food is often accomplished through the use of convective dryers. The products dried by these methods are often poor in colour, flavour (taste and aroma), texture and rehydration qualities. Case hardening (the formation of hard outer shell) and shrinkage are also two major problems with conventional drying processes. In recent years, improvement of quality retention by dried products (rehydrability etc.), by altering process conditions and/or pretreatments, has been a major research goal (Cohen and Yang, 1995). Water molecules are polar, which means that they can rotate under the influence of an alternating electrical field. Foodstuffs usually contain 52 to 99 % water, and hence are very well suited for heating and drying with microwave energy. Now a day's microwave drying is used mainly for drying of pasta and post baking of biscuits. Microwave drying of fruits and vegetables is hardly carried out at an industrial scale.

APPLICATIONS OF MICROWAVE OVEN IN FOOD DRYING

There are various fruits and vegetables are dried using microwave oven. Some of them are given in this paper. Carrots and onion were dried by microwave radiation after pretreatment with hot air blast and the products were compared to those of traditional drying process i.e. freeze drying, hot air blast and vacuum drying. Test panel assessments of onion showed that freeze-dried product became softer than microwave dried one. There were few differences in colours between different drying methods for carrots. Textural studies of dried product examined by scanning electron microscopy have relevated a greater degree of shrinkage in the microwave-dried sample of both the vegetables. The advantages of using microwave energy in the drying of carrots and onion have been described by Torringa *et al*. (1993).

Wang *et al*. (2010) reported that a rotary device was built in a home microwave oven, where wet soybean was dried in a dynamic moving state to improve the microwave drying uniformity. Experiments were conducted to investigate the relative water removal ratio which was defined to characterize the electromagnetic field distribution in microwave oven, and to compare the drying characteristics between static and rotary microwave drying. It is concluded that the kernel cracking ratio is lower when microwave drying of soybean was carried out in rotary state. MW ovens, commercialized applications of MW/RF heating include blanching, tempering, pasteurization, sterilization, drying, rapid extraction, enhanced reaction kinetics, selective heating, disinfestations, etc.

Dehydration characteristics of carrot cubes were evaluated in a domestic microwave oven (600 W) modified to allow passage of air at constant flow rate and a given air temperature. The parameters included inlet air at two temperatures (45 and 60 °C), and microwave oven operation at two power levels. Conventional air drying with microwave off served as the control. Microwave drying resulted in a substantial decrease (25–90 %) in the drying time and the product quality was better when dried at the lower power level (Prabhanjan *et al*., 1995).

Walde *et al*. (2004) observed that wheat samples of approximately 20 g each were dried in a domestic microwave oven for different time periods ranging from 15 to 150 s with different moisture contents ranging from 0.11 to 0.23 kg of water/kg of dry weight of solids. The microwave-dried samples for 120 s were crisp and consumed less energy for grinding compared to the control samples. The interior temperature of dried microwave-heated food is higher than the surface temperature and moisture is transferred to the surface more dynamically than during convective drying (Ohlsson, 1990; Torringa *et al*., 2001).

Souza *et al*. (2006) studied the effect of air parameters on microwave-assisted drying of bananas, focusing on sensory quality and found that high sensory quality could be achieved by using air temperature higher than 40 ºC. Medeni Maskan (2000) reported that Banana samples (4.3±0.177, 7.4±0.251 and 14±0.492 mm thick) were dried using the following drying regimes; convection (60 °C at 1.45 m/s); microwave (350, 490 and 700 W power) and convection followed by microwave (at 350 W, 4.3 mm thick sample) finish drying. The drying of banana slices took place in the falling rate-drying period with convection drying taking the longest time. Microwave finish dried banana was lighter in colour and had the highest rehydration value.

Pre-fry drying of onion slices using microwaves reduces the oil uptake during subsequent frying (Hansen, 1998). Chemical pretreatment decreased skin resistance to diffusion and microwave pre-drying created a partial puffing of the structure, thereby enhancing the internal moisture diffusion during sun drying (Tulsidas *et al*., 1996).

Microwave drying of mushrooms at low power density in combination with heated air resulted in improve moisture diffusivity, better rehydration properties and improved flavor retention. Agaricus bisporus mushrooms were dried by hot air and combined hot air microwave treatment at different hot air temperatures of 35, 45, 60 and 75 ºC. Quality was assessed by checking rehydration and flavour retention. Results showed that combined pretreatment shortened the process time, yielding a good final quality product without pretreatment when using microwaves the water release rate though the sample surface was quicker. Layer rehydration of dried mushrooms depended on drying temperature and was slightly better and samples dried with combined treatment. Retention of characteristics aroma compound and its oxidation product was positively affected by microwave drying (Riva *et al*., 1991). Microwave-vacuum drying of basil resulted in higher retention of volatiles, better colour and higher rehydration rates in comparison to the conventional hot air method (Yousif, *et al*., 1999).

Kar (2001) observed that microwave assisted convective dehydration of sliced banana resulted in an increase in the energy use efficiency by a factor of 19 and 90 % reduction in drying time as compared to that using convective dehydration alone.

Microwave vacuum dehydration of Thompson seedless grapes was conducted by Clary and Clary and Ostrom (1995). They concluded that dehydrated grapes of excellent integrity, puffed character and colour of fresh grape (without any chemical pre-treatment) could be obtained using an optimum total specific energy of 0.84 to 0.88 W-h/g for 70 to 75 min (microwave drying reduced drying time) in an infrared temperature range of 70 to 80 ºC.

High drying rates in the dry conservation of parsley could be established with combined vacuum-microwave drying (Sobiech, 1980). Leek red and green pepper, onions and potatoes were dried in much shorter time using appropriate level of microwave energy than by high temperature drying alone, without any loss of quality. Tuncer *et al*. (1990) reported that at water removal rates of 7.4 g/min-kg dry rice or less using microwave vacuum drying, the parboiled rice could be dried in a single pass to safe storage levels without any significant decrease in yield. Drying rates could be increased by a factor of 16 using microwaves instead of vacuum drying alone in the dehydration of sliced and mashed bananas by Drouzos and Schubert (1996). For cranberries, microwave-vacuum drying improved the colour and resulted in softer products than the conventionally dried product (Yongswatdigul and Gunasekaran, 1996).

Kim *et al*. (1997) suggested microwave-vacuum drying of yoghurt at low temperature as a useful alternative to freeze-drying and spray drying in terms of survival of starters and cost.
Prasad *et al*. (2004) reported that microwaves when used for drying, reducing time and bacterial contamination, thus resulting in improved appearance in the product quality without influencing the chemicals composition of dried products. The process of drying also gets accelerated by the use of microwave in fruits as observed in case of plums' dehydration.

Strawberries were microwave dried after a pretreatment; is dipping in a 2 % ethyle oleate solution in 0.5 % NaOH and then microwave power applied at 0-2 g/W. The product obtained was comparable to freeze dried product in terms of color, texture and rehydration characteristics. Dipping in ethyl oleate alters the skin coating (Prasad *et al*., 2004).

Rao *et al*. (1998) reported heavy loss of volatile oil during the drying of Rosemary using microwaves. Microwave heating was found to contribute to appreciable loss (approximately 30-40 %) of vitamin B_{12} in food like raw beef, pork and milk.

Hussain *et al*. (2010) observed to establish optimum conditions for microwave drying of ginger in terms of aroma quality. The lowest drying temperature (40 ºC) did not result in best product quality. Most of the aroma was lost at low drying temperature due to a long drying time. The longer drying times also made the process energy consuming. On the other hand, high-temperature drying (70 ºC), though more energy efficient and less time consuming, rendered the dried product unacceptable due to the charring of the product and high loss of aroma. From the analysis of aroma profiles and the results of quality assessment (rehydration ratio, surface color) it can be concluded that the best product quality was achieved by drying at 60 ºC.

Microwave Drying is not only faster but also requires less energy consumption than conventional drying (Tulsidas, 1994). In the drying of osmotically pre-treated strawberries or blueberries, it has been showed that microwave drying required shorter drying time than freeze drying, while maintaining the same final product quality (Venkatachalapathy, 1998). Also it has been reported that the use of microwaves in freeze-drying could substantially increase drying rate and consequently, decrease drying time (Sanga *et al*., 2000). It has been compared hot air-drying, freeze-drying, vacuum drying and a combination of hot air and microwave drying of cranberries (Beaudry, 2001). It was concluded that microwave-assisted hot air drying resulted in the shortest drying time and acceptable color, taste and texture.
It has been dried flowers with microwave energy in conjunction with a color- protecting treatment, which offered a number of advantages over conventional methods (Liang *et al*., 2003). It was observed that in microwave drying of wood strands with proper selections of power input, weight of drying material, and drying time, microwave drying could increase the drying rate, save up to 50 % of energy consumption, and decrease volatile organic compound (VOC) emissions when compared with the conventional drying method (Guanben *et al*., 2005).

St. Joseph, Michigan (2008) reported that an increase in air temperature from 45 to 75 °C resulted in 77 to 90 % reduction in drying time. The microwave drying technique was more efficient than conventional hot air drying and resulted in savings to an extent of about 95-98 % of drying time. The microwave dried leaves exhibited less shrinkage and thus had better rehydration characteristics. The dried leaves were safe and stable with respect to microbial growth, chemical/biochemical reaction rates and physical properties based on water activity (www.asabe.org).

Majumdar (2000) observed that much invention has been accomplished over the past two decades as far as understanding and development of drying technologies are concerned for food and agro-products.

According to Askari *et al*. (2006) microwave treatment, even at a low microwave power and short time, can have major effect on the quality of dried apple slices. The type of coating material has been a significant effect on textural quality such as texture strength. Starch (in suspension form) and pectin with $CaCl_2$ had the best quality characteristics (more porosity, less apparent density and more rehydration capacity).

Bouraoui *et al*. (2007) reported that potato slices were dried using microwave drying, combined microwave and convective drying, and convective drying. Rehydration kinetics was also studied. Drying rates of the different drying methods were determined and microwave drying was compared with convective drying. Microwave drying has a potential for producing better quality dried products while considerably reducing drying duration (i.e. 10 min vs 10 h). Effective moisture diffusivity profiles were calculated using Fick's diffusion model in one dimension.

Microwave (MW)-related combination drying is a rapid dehydration technique that can be applied to specific foods, particularly to fruits and vegetables. Increasing concerns over product quality and production costs have motivated the researchers to investigate and the industry to adopt combination-drying technologies. The advantages of MW-related combination drying include the following: shorter drying time, improved product quality, and flexibility in producing a wide variety of dried products. MW-related combination drying takes advantages of conventional drying methods and microwave heating, leading to better processes than MW drying alone.

Another major drawback is the penetration depth of the MW field into the products. Although MW power at 915 MHz penetrates to a greater depth than does at 2450 MHz, in large-scale drying applications (Wang *et al*., 2003).

It was also noticed that products with an acceptance rate higher than 7 were obtained with a drying air flow rate within the range from 1.10 to 1.65 m^3/min and drying air temperatures higher than 30 °C. It was concluded that it is possible to dry bananas with the assistance of microwave energy by using drying air within pre established temperature and flow rate limits (5 °C and 0.8-1.8 m^3/min, respectively).

Sousa *et al*. (2004) observed that increasing microwave power during the final drying of banana slices increases the drying rate and consequently decreases drying time. However, higher microwave power also causes a rapid rise in product temperature (temperature runaway) and consequently charring of the dried product. Thus, it is necessary to control the microwave power during the final drying phase in order to avoid temperature runaway and quality deterioration of the product. Air temperature and air velocity also have a positive effect on drying time, although the reductions with higher temperatures and velocities are not as great as those associated with microwave power.

In this study, the germination percentage of wheat samples collected from hot spot and normal heating zones after microwave treatment was determined. Canadian wheat samples (50 g in each experiment) at four moisture levels (12, 15, 18, and 21 % wet basis) were subjected to microwave treatment at five power levels (100, 200, 300, 400, and 500 W) and two exposure times (28 and 56 s) in a laboratory scale, continuous type, industrial microwave dryer (2450 MHz). After microwave treatment, the germination percentage was near zero at 300 W for the samples collected from the hot spot, when the exposure time was increased to 56 s and the initial moisture content was 18 and 21 %. At 400 and 500 W power and 56 s exposure, the germination percentage was almost zero for samples collected from both normal and hot-spot regions.

Alibas *et al*. (2004) reported that spinach leaves with 50 g weight and 9.01 humidity on dry basis were dried in microwave oven using eight different microwave power levels ranging between 90 and 1000 W, until the humidity fell down to 0.1 on dry basis. Drying processes were completed between 290 and 4005 s depending on the microwave power level. Energy consumption remained constant within the power range of 350–1000 W, whereas 160 and 90 W resulted in significant increase in energy consumption. The best quality in terms of colour and ascorbic acid values were obtained in the drying period with 750 W microwave powers.

Heating takes place volumetrically and water is heated, vaporized within the whole volume of the food product. The rapidly formed water vapor creates a large pressure gradient, which is drying force in microwave drying (Dorin Bolder, 2003).

The colour, re-hydration capacity and macaroni cooking quality, related to cooked weight, cooking loss and firmness of drying of short-cut macaroni were evaluated. The textural properties of uncooked and cooked macaroni samples were measured using a texture analyzer. Protein denaturation of dried samples increased significantly with microwave power level. Firmness of samples increased while cooking loss decreased generally with microwave application after hot air drying i.e., hot air/microwave combination shortened the drying time and improved many of the physical, textural and cooking properties of macaroni samples (Alibas *et al*., 2004).

According to Dar *et al.* (2010) microwave is new technologies in food processing. This requires special equipment to generate and control their energy. The electromagnetic spectrum between frequencies of 300 MHz is represented by microwaves (Decareau, 1995). Microwave can pass through materials like glass, paper, plastic and ceramic and be absorbed by metals. Once microwave energy absorbed, polar molecules and ions inside the food will rotate or collide according to the alternating electromagnetic field and heat is subsequently generated for cooking. Dielectric properties i.e. dielectric constant and loss factor, of food materials play a critical role in determining the interaction between the electric field and foods (Buffler, 1993). Microwave heating is quicker than conventional heating and there is better nutrients retention (Felton *et al*., 1994).

Preliminary studies were made to develop pilot scale microwave processing equipment to produce-detoxified soybean, which could be used for cottage level processing. Among the heat labile anti-nutrients trypsin inhibitor activity is required to be reduce below 10 %. The urease activity, which is also one of the anti-nutrients of soybean, is required to be reduced to 0.05. The microwave heating experiment was conducted using 17 liters capacity rotating platform domestic microwave oven. The average time required at 100, 200 and 200 g/cm^2 spreading density were 7.3, 9.3 and 14 min respectively (Saxena *et al*., 2006).

Kar *et al*. (2007) reported that the quest for novel technologies in the area of food processing and preservation has led to the application of ionizing radiation into enhance the process capabilities, energy efficiencies and the retention of the wholesomeness of food. The applicability has infinite dimensions. The microwave indeed has proved to be boons for its effective utilization in different operations the food industries in order enhance the overall process and palatability of the stakeholders.

OTHER APPLICATIONS OF MICROWAVE IN FOOD PROCESSING

(1). Cooking: With the increase in the number of domestic microwave ovens and reduced time availability of the working women today, lots of research is carried out in order to find out of the optimum cooking procedure for various foods.

Potato slices were dried using microwave heating; combined microwave & convective heating and convective drying. Final products were compared and found that microwave drying had potential for producing better quality dried product with considerably reducing drying duration. Production of fat-free potato chips with the characteristics of fried chips without the use of oil using a microwave system has also been designed by Kloos (1990).

Shrimps cooked at 240 W microwave power for 140 s and with a 120 s holding before serving was found to have the best consumer acceptability in terms of colour, flavour, texture, juiciness and overall acceptability (Gundavarapu *et al*., 1998). Sharma and Lal (1998) reported that there was no significant change on the loss of B-complex vitamins during microwave boiling of cow and buffalo milk in comparison to conventional heating. Microwave cooking reduces cooking times of common beans and chickpeas (Marconi *et al*., 1998). In addition microwave treatment reduced cooking losses, increased the soluble: Insoluble and soluble: total dietary fiber ratio, but didn’t modify in-vitro starch digestibility.

A higher protein concentration in soya milk was obtained by microwave heating of soya slurry than by the conventional methods of heating such as the use of boiling water (Ashida *et al*., 1998). Microwave oven heating of soya slurry, which was effective for protein extraction, also made the prepared tofu more digestible.

IIlow *et al*. (1995**)** reported that microwave cooking resulted in minimum loss of vitamin C in white cabbage, cauliflower, brussels sprouts and French beans in comparison to the traditional method of cooking. It also had a positive effect on the organoleptic quality of these vegetables. Microwave roasting of soaked soyabean produced full-fat soya flour with high vitamin E without burnt colour and browning (Yoshida and Takagi, 1996). Variation in the organic acids, sugars and minerals of raw and microwave cooked beetroot, broccoli, antichokes, carrots, cauliflower, fennel, potatoes, chillies, celery, spinach and courgettes have been reported by Plessi (1995).

In contrast to the above observations, microwave cooking was found to be unsuitable or to be having an insignificant effect on the processing of some of the products. Mascova *et al*. (1996) reported suggested that microwave processing was not effective for the treatment of beans, peas and soybeans due to high losses of water-soluble nutrients and practically no saving of time and energy.

(2). Enzyme inactivation (blanching): Blanching is usually done in hot water or in steam. In water blanching, the product is submerged in water at 85 ºC to 100 ºC. In steam blanching, the product is carried on a wire mesh belt through a hooded section where steam is injected. By controlling the time and temperature of the process, enzymes are inactivated throughout the product. Water blanching usually results in a greater loss of nutrients but takes less time then steam blanching. After blanching, the vegetables are quickly cooled to at least 25 ºC. Onions, green peppers, and mushrooms can be dried without blanching.

The emerging technologies being developed are mainly aimed to reduce energy, processing time, and wastewater. Efficient thermal processing, steam recycling, intelligent process control and alternatives to conventional water and steam processing.

Microwave energy is one of the most efficient thermal processing methods being used in some food industries as a method to blanch vegetables. The advantages of microwave heating over conventional blanching are more uniform volumetric heating, minimal oven temperature gradients, and no blanching residual products, reduced energy costs, and reduced processing time. The primary barrier to implementing microwave blanching is the high cost of equipment.

Microwave due to their inherent capacity of rising the temperature quickly, helps in the inactivation of enzymes thereby enhancing the quality of the product in the subsequent processes. Blanching freshly picked vegetables in a microwave not only speeds of the freezing process but also maintains the food nutritional value better than traditional blanching does. Microwave treatment led to considerable inactivation of lipase and complete inactivation of lipoxigenase in freshly milled rice bran (Vertimani *et al*., 1992). This led to the stabilization of rice bran as measured by lower increase in FFA content of treated samples after storage for one month. Boyes, *et al*. (1997) found microwave blanching to be significantly more efficient, than water blanching on corn kernels in terms of thermolability of soluble peroxidase and soluble protein when blenched at 85 ºC. Szabo *et al*. (1998) successfully inhibited the activity of anti-nutritional enzymes, urease and tripsin inhibitors in soyabeans using microwave heating.

Microwave heating was found to be substantially more effective in inactivating pectin methyl esterase (PME) in orange juice than the conventional continuous flow pasteurization (Tajchakavit and Ramaswamy, 1997). They also comparative hot air foam mat drying tests were conducted using orange juice concentrate (44 % TS) as test material. Sample layers of thickness 3.2, 6.3 and 12.7 mm were studied. The results showed that the microwave process considerably increased the drying rate and increased the layer thickness, which may be dried efficiently with no adverse effect of microwave processing on quality (colour and rehydration properties) of the product.

(3). Pasteurization and sterilization: The energy absorption from microwaves raises the temperature of the food high enough to inactivate the microorganisms, which could be utilized for effective pasteurization. A number of studies have proven that the thermal effect is the essential contributor to the destruction of microorganisms as well as the degradation of vitamin B_1, thiamin (Welt and Tong, 1993).

Industrial microwave pasteurization and sterilization systems have been reported for more than three decades. Studies on the implications of commercial pasteurization and sterilization have also been widely reported (Tang, 2001).

Researchers have also reported the use of home microwave ovens for pasteurization or for increasing shelf-life (Thompson and Thompson, 1990).

Significantly reduction in microorganisms in a non-thermal flow process using microwave energy in water, 10 glucose solution and apple juice was reported by Kozempel *et al*. (1998). However, there was only a slight decrease in microorganisms in tomato juice, pineapple juice, apple cider and beer; and no effect in skimmed milk using the process. However, microwave, heating in combination with standard pasteurization at 85 ºC resulted in milk and yoghurt having a prolonged keeping quality (Gasincova and Burdova, 1993). Microwave treatment resulted in the reduction in the drying time and bacterial contamination of

medicinal plants thereby resulting in improved appearance in product quality, without influencing the chemical composition (Horsten and Kartnig, 1999).
In spite of the multifaceted advantages, there has been lack of success in commercial operation due to complexity, expenses, non-uniformity of heating, inability to ensure sterilization of the entire package, lack of suitable packaging materials and unfavorable economics when compared to prepared frozen foods.

(4). Tempering (Tempering frozen food with microwaves): Tempering is an important operation for many production processes where the incoming raw material is frozen. Invariably the first operation on the material usually is to dice, slice or separate individual sections into smaller pieces.
The tempering process with microwaves offers lower overall cost and high product quality (i.e. no drip, colour, flavour losses). However, the high capital investment, careful control required for the processes are major limitations for the process. Further, products such as corned beef and whole chicken require greater care, corned beef because of packets of salt which create localized heating; whole chicken because it has both voids and dense areas.

(5). Other applications: Fishman (2001) has found a way to use microwave technology to extract pectin. In the traditional method of extraction method of extraction of pectin, the heating process takes an hour or more per batch. Overheating sometimes breaks down the pectin, reducing its quality. However, this faster, non-destructive method can reduce the cost of processing.
Microwave surface treatment has been found to contribute significantly to extending the keeping quality of cottage cheese (Herve *et al*., 1998).

HOW DOES MICROWAVE COMPARE TO CONVENTIONAL HEATING?

In conventional or surface heating, the process time is limited by the rate of heat flow into the body of the material from the surface as determined by its specific heat, thermal conductivity, density and viscosity. Surface heating is not only slow, but also non-uniform with the surfaces, edges and corners being much hotter than the inside of the material. Consequently, the quality of conventionally heated materials is variable and frequently inferior to the desired result. Conversely, with microwaves, heating the volume of a material at substantially the same rate is possible. This is known as volumetric heating. Energy is transferred through the material electro-magnetically, not as a thermal heat flux. Therefore, the rate of heating is not limited and the uniformity of heat distribution is greatly improved. Heating times can be reduced to less than one percent of that required using conventional techniques (www.industrialmicrowave.com).

2450 MHz versus 915 MHz ? (www.industrialmicrowave.com)

- 915 MHz generators can provide up to 100 kW from a single magnetron. Although the cost is similar, the largest commercial 2,450 MHz units available use 30 kW magnetrons.
- 915 MHz generators lose about 15 % efficiency in producing electromagnetic energy from electric power. However, the conversion of that energy into useful heating or drying is often greater than 95 % using IMS technology so that the total system

efficiency usually exceeds 80 %. This compares with 55 to 70 % total system efficiency obtainable from 2,450 MHz generators.

- The depth of penetration of microwave energy at 915 MHz is about three times as great as that at 2,450 MHz.
- With their higher total system efficiencies, 915 MHz heaters and dryers tend to have lower running costs than comparable 2,450 MHz units.
- One 100 kW 915 MHz generator will be about 50 % cheaper than seven 15 kW 2,450 MHz units.
- The low power 2,450 MHz magnetrons developed from the proliferation of domestic microwave ovens are inexpensive and readily available. This makes them ideal for low flow capacity R & D applications.
- The size of magnetrons and wave-guides for a 2,450 MHz system is considerably smaller than those used in 915 MHz units. This makes them suitable for small-scale installations.
- 2,450 MHz is efficient where fast product expansion.

Effects of microwave on food and nutrients

According to Anahad O'Connor (2006) any form of cooking will destroy some nutrients in food, but the key variables are how much water is used in the cooking, how long the food is cooked, and at what temperature. Microwave ovens do convert vitamin B_{12} from the active to inactive form, making approximately 30-40 % of the B_{12} contained in foods unusable by mammals (Watanabe *et al*., 1998).

Spinach retains nearly all its folate when cooked in a microwave (Watanabe *et al*., 1998); in comparison, it loses about 77 % when cooked on a stove, because food on a stove is typically boiled, leaching out nutrients. Steamed vegetables tend to maintain more nutrients when cooked on a stovetop than in a microwave. Bacon cooked by microwave has significantly lower levels of carcinogenic nitrosamines than conventionally cooked bacon (Globe and Mail, 2003).

CURRENT RESEARCH

Some of the current research activity on microwave application in the international arena includes:

- More use of home microwave ovens
- Product and package developments
- Industrial advancement for specific applications
- Mathematical modeling techniques to better understand the electromagnetic factors affecting microwave sensing probes including open ended coaxial probes suitable for convenient sampling of microwave properties.
- Use of computer programs and hardware in order to analyze interpret the information provided by microwave sensors.
- Use of microwave heating to find the best way to deactivate enzymes.

One of the major areas of future research would be the improvement of uniformity of microwave heating. Many techniques have been tried to improve the uniformity of heating. These include rotating and oscillating the food package, providing an absorbing medium (such as hot water) surrounding the product, equilibrating after heating and cycling the power. In the past success of these processes has been limited due to the tremendous dependence of temperature and its distribution on food and oven factors. Use of the 915 MHz and radio frequencies to improve uniformity of heating may have potential for the future (Lau *et al*., 1999). Future possibilities to improve the uniformity of heating include variable frequency microwave processing and phase control microwave processing. Although these two techniques have been applied to microwave heating of non-food materials, they are yet to be applied to food in a significant way. Combinations of microwave and conventional heating in many different configurations have also been used to improve heating uniformity. The critical process factor in combination heating or any other novel processes would most likely remains the temperature of the food at the cold point, primarily due to the complexity of the energy absorption and heat transfer processes.

In the future, microwave may be combined with conventional; heating or chemical treatments for surface treatment, for example, meat processing (KSU, 1999) or food contact surface (Anonymous, 1996).

CONCLUSION

Microwave processing is expected to tremendous increase in the world wide due to raising consumer demands for newer types of convenience foods having more nutritional as well as sensory attributes. It's processing results in excellent retention of nutritional and sensory value besides having either advantage like saving in energy, cost, time etc. through it had a limited applicability in the past, microwave processing is a boon to the food industry and it has a tremendous potential if explored properly. The modern life as well as the increasing number of working industries requires simplified routines and standardization of foods with lesser preparation time and convenience in the use and saving.

FUTURE ASPECT OF MICROWAVE DRYING

In the past few years there has been a surge of interest in the application of microwave heating for industrial purposes. This is primarily due to the worldwide energy crisis and the growing acceptance of and familiarity with microwave ovens. It is well known that conventional means of heat processing irreversibility alter the flavour, colour, and texture of many foods. From the point of flavour alone, it is desirable to improve our present methods of processing foods. Some improvements have been made in the direction with a number of food products by use of high-temperature short time processing. Research has been conducted in recent years to ascertain whether it is possible to improve the colour, flavour and retention of nutrients in processed foods by means other than heat for processing. Among the alternative means that have been considered to obtain this objective in the food processing is the utilization of several of the radiations of the electromagnetic spectrum.

REFERENCES

i Alibas Ozkan, Alibas Ozkan, Altan A. and Maskan M., 2004. Microwave Assisted Drying of Short-Cut Macaroni: Cooking Process and Textural Properties, *Food Science and Technology International*, 10(3), 187-196.

iv Anahad O'Connor, 2006.The Claim: Microwave Ovens Kill Nutrients in Food.

v Ashida, Y., Itou, J., Takai, C.,Miyakita, H., Ikawa, Y. And Sato, K. 1998. Praparation of tofu using microwave oven heating process and go (soy slurry) and in vitro digestability of the prepared tofu. *J japan Societ of Nutirtion Food Sci*., 51(3), pp. 135-139.

vi Askari G. R., Emam-Djomeh Z. and Mousavi S. M., 2006. Effect of combined coating and microwave assisted hot-air drying on the texture, microstructure and rehydration characteristics of apple slices, *Food Sci Tech*, 12(1), pp. 39-46.

vii Beaudry C "Evaluation of drying methods on osmotically dehydrated cranberries". MS Thesis. Montreal QC: McGill University, Department of Agriculture and Biosystem Engineering. 2001.

viii Bouraoui M., Richard P. and Durance T., 2007. microwave and convective drying of potato slices, *Journal of Food Process Engineering*, 17(3), pp.353 – 363.

ix Boyes, S., Chevis, P., Holden, J. and Parera, C. 1997. Microwave and water blanching of corn kernels: control of uniformity of heating during microwave blanching. *J Food Proc. Presv*., 21(6), pp. 461-484.

x Buffler, C.R. 1993. Prediction of dielectric properties in solid foods of high moisture content at ultra high and microwave frequencies. *J. Food. Proc. Presev*. 13, pp. 119-151.

xi Clary, carter D. and Ostrom, Gwynn A. sawyer 1995. Use of microwave vacuum for Dehydration of Thompson seedless grapes. *California Agriculture Technology Institite Publication* #950405.

xii Cohen, J.S. and Yang, T.C.S. 1995. Progress in Food Dehydration. *Trends Food Sci. Technol*., 6, pp. 20-25.

xiii Dar B. N., Ahsan Hafiza, Wani S. M., Kaur D. and kaur S., (2010). Microwave heating in food processing: A review, *Beverage & Food World*, p. 36.

xiv Decareau, R. V. 1995. The microwave sterilization process. *Microwave world* 16(2), pp.12 15.

xv Dorin Bolder, Temperature control of the continuous peanut drying process using Microwave Technology, Ph.D. thesis-2003.

xvi Drouzos, A.E. and Schubert, H. 1996. Microwave Application of Vacuum drying of Fruits. J. Food Engng., 28, pp. 203-209.

xvii Felton, J. S., Fulty, E., Dolbeare, F. A. and Kruize, M. G. 1994. Effect of microwave pre traetment on hetrocyclic aromatic amine mutagens/carcinogens in fried beef patties. *Food Chemical Toxicology*, 40, pp. 1213-1221.

xviii Fishman, marshall L. 2001. Using microwave to extract pectin. Agricultural research magazine, june 2001.

xix Gasincova, E. and Burdova, O. 1993. Microwave heating of milk products. *Slovensky veterinarsky Casopis*, 18(3-4), pp. 36-65.

xx Globe and Mail, 2003, Microwaving destroys nutrients, study finds by S Strauss.

xxi Guanben Du, Siqun Wang and Zhiyong Cai, 2005. Microwave Drying of Wood Strands. *Drying Technology*, 23, pp. 2421–2436.

xxii Gundavarapu, S., hung, Y.C. and Reynolds, A.E.1998. Consumer acceptance quality of microwave-cooked shrimp. *J Food Quality*, 21(1), pp. 71-84.

xxiii Hansen, S.L.1998. Effect of prefry drying methods on the quality of deep fat fried onion slices. *J Food Quality*, 21(5), pp. 433-433.

xxiv Herve, A. G., Tang, J., Luedecke, L. and feng, H. 1998. dielectric properties of cottage cheese and surface treatment using microwaves. *J Food Engng.*, 37(4), pp. 389-410.

xxv Horsten, D. Von and Kartning, T.1999. Processing of medicinal plants using microwaves. *Landtechnik*, 54(4), pp. 206-207.

xxvi Hussain A.; Li Z.; Ramanah D. R.; Niamnuy C.; and Raghavan G. S. V. 2010. Microwave Drying of Ginger by Online Aroma Monitoring. *Drying Technology*, 28, pp. 42–48.

xxvii IILow, R., Regulska, I.B. and Szymozak, J. 1995. Evaluation of losses of vitamin C in some vegetables cooked by use of conventional procedures and in a microwave oven. *Bromatologia i Chemia Toksykologiczna*, 28(4), pp. 317-321.

xxviii Kar Abhijit 2001. Studies on Microwave Assisted Convective dehydration of Banana. Unpublished Ph. D. Thesis submitted to the Indian Agricultural research Institute, New Delhi, India.

xxix Kar Abhijit, Rao K. H., Chandra Pitam and Dash Sanjaya K., 2007. Microwave: A potential applied technology for food preservation, *Agricultural Engineering Today* 31(1), pp. 25-36.

xxx Kim, S.S., Shin, S.G., Chang, K.S., Kim, S.Y., Noh, B. S. and Bhowmik, S. R. 1997. Survival of lactic acid bacteria during microwave vacuum-drying of plain yoghurt. *Lebensmittel Wissenschaft Technologie*, 30(6), pp. 573-577.

xxxi Kloos, K. 1990. No-fat, no-cholestrol, salt-free potato cooking process. US Patent 4, 906,483.

xxxii Kozempel, M.F., Annous, B.A., Cook, R.D., Scullen, O.J. and Whiting, R.C.1998. Inactivation of microorganisms with microwaves at reduced temperatures. *J Food Protection*, 61(5), pp. 582-585.

xxxiii KSU 1999. KSU microbiologist uses microwave, acid treatments to kill pathogens, maintain colour in meat. *KSU Press Release.* June 15 1999.

xxxiv Lau, M.H., tang, J., Taub, I.A., Yang, T.C.S., Ewwards, C.G. ang Younce, F.L. 1999. HTST processing of food in microwave pouch using 915 MHz microwaves. AIChE Annual Meeting.

xxxv Liang L., Z.Mao, Y. Cheng, “Study on the Application of freeze-drying and microwave drying to flowers.” ASAE paper No. 036075 St. Joseph, Mich.: ASAE, 2003.

xxxvi Majumdar A.S. (2000). Drying technology in agricultural and food science. Plymouth, UK: science Publishers, Inc., pp. 61-98, 253-286.

xxxvii Marconi, E., Ruggeri, S., Paoletti, F., Leonardi, D. and Carnovale, E. 1998. Physico-chemical and Structural modifications in chickpea and common bean seeds after traditional and microwave cooking processes. Paper in 3rd European Conference on grain legumes. Opportunities for high quality, healthy and added value crops to European demands. Valladolid, Spain, 14-19 November, 1998. pp. 358-359.

xxxviii Mascova, E., Rysova, J., Fielderova, V., Holasova, M. and Vavreinova, S. 1996. Stability of selected vitamins and minerals during culinary treatment of legumes. *Potravinarske Vedy*., 14(5), pp. 321-328.

xxxix Medeni Maskan, 2000. Microwave/air and microwave finish drying of banana, Journal of Food Engineering 44(2), pp. 71-78.

xl Ohlsson, T. (1990). Microwave processing in the food industry. European Food and Drink Review, 7, pp. 7–11.

xli Plessi, M. 1995. estimation of organic acids, sugars and minerals in widely consumed vegetables: effect of microwave cooking. *Rivista della Societa Italiana dell Alimentazione*, 24(1), pp. 23-33.

xlii Prabhanjan D. G.; Ramaswamy H. S. and Raghavan G. S. V., 1995. Microwave-assisted convective air drying of thin layer carrots, *Journal of Food Engineering*, 25(2), pp. 283-293.

xliii Prasad K, Pratibha, Singh S. K. and Prasad K. 2004. Technological aspects of microwave applications in Fruits and Vegetables Processing. *Processed Food Industry, June*, pp. 18-24.

xliv Rao, L.J., Singh, M., Raghvan, B. and Abraham, K.O.1998. Rosemary (Rosemarinus officinalis L.): impact on drying on its flavour quality. *J Food Quality*, 21(2), pp. 107-115.

xlv Riva, M., Schiraldi, A. and Di Cesare, L.F. 1991. drying of Agaricus bisporus mushrooms by microwave-hot air combination. *Lebensm. Wiss. U-Technol*, 24, pp. 479-483.

xlvi Sanga, E., A. S. Mujamdar and G. S. V. Raghavan, “Principals and application of Microwave Drying”. In: Drying technology in agriculture and food sciences. Edited by A. S. Mujumdar. Enfiled N. H.: Science publishers. Inc. 2000.

xlvii Saxena Alok; Chaturvedi Brijesh; Patil R. T. and Singh L. K (2006). Impact of Microwave Heating on Detoxification of Soybean. *Beverage & Food World*, pp. 58-61.

xlviii Sharma, R. and Lal, D. 1998. Influence of various heat processing treatments on some B vitamins in buffalo and cow’s milk. *J Food Sci. and Technol*., 35(6), pp. 524-526.

xlix Sobiech, W. 1980. Microwave-vacuum Drying of Sliced Parsley Root. *J. Microwave Power*, 15, pp. 143-154.

l Sousa, W. A., Marsaioli Jr, A. & Rodrigues, M.I. 2004. Optimizing a microwave assisted banana drying process. In: Silva, M.A. & Rocha, S.C.S. (Eds.), Proceedings of the 14th International Drying Symposium. Sa˜o Paulo, Brazil, Vol. C, 1938–1945.

li Souza, W. A., Pitombo, R. M. N., Da Silva, M. A. A. P., & Marsaioli, A. Jr,. 2006. Sensory evaluation of dried bananas obtained from air dehydration assisted by microwaves. In M. Willert-Porada (Ed.), Advances in microwave and radio frequency processing. 8th International conference on microwave and high-frequency heating (pp. 289–302). Germany: Bayreuth.

lii St. Joseph, Michigan, 2008. Microwave Drying - A promising alternative for the herb processing industry, American Society of Agricultural and Biological Engineers.

liii Szabo, G., Rajko, R., Kovacs, E. and Vidal, V.C. 1998. Optimization of microwave treatment for reducing enzyme activity of soyabean. *Acta Horticulture*, 476, pp. 141-147.

liv Tajchakavit, S. and Ramaswamy, H.S. 1997. Continuous-flow microwave inactivation kinetics of pectin methyl esterase in orange juice. *J Food Proce*, *Presev*., 21(5), pp. 365-378.

lv Tang, T. (2001). Scientists work to improve Army food. Washington State University Today, On line edition, November 2, 2001.

lvi Thompson, J.S. and Thompson, A. 1990. In-home pasteurization of raw goat's milk by microwawv treatment. *International J Food Microbiol*., 10, pp. 59-64.

lvii Torringa, E., Esveld, E., Scheewe, I., van den Berg, R., & Bartels, P. (2001). Osmotic dehydration as a pre-treatment before combined microwave-hot-air drying of mushrooms. *Journal of Food Engineering*, 49(2–3), pp. 185–191.

lviii Torringa, H.M., Nijhuis, H.H., Van Remmen, H.H.J. and Bartels, P.V. 1993. IN: Proceedings of the 4th International Congress on Food Industry, Cesme, turkey, (Seygin E, Mucuncun M and Gowenc M eds), pp. 331-344.

lix Tulsidas, T. N. "Combined convective and microwave drying of grapes. Ph.D. thesis, Montreal QC: McGill University: Departmental of Agriculture Engineering. 1994.

lx Tulsidas, T.N., raghavan, G.S.V. and Norris, E.R. 1996. Effects of dipping and washing pretreatments on microwave drying of grapes. *J Food Process Engng*., 19, pp. 15-25.

lxi Tuncer, I.K., Zeren, Y., Yildiz, M.T., Ozcan, E. and Guzel, A. 1990. Characterization and drying of vegetables by hot air and microwave energy. International Congress on Mechanization and Energy in Agriculture. Proceedings of a conference held in Adana, turkey, 1-4 october. pp. 472-480.

lxii Venkatachalapathy, K "Combined osmotic and microwave drying of strawberries and bluebarries". Ph.D. Thesis. Montreal, QC: McGill University Department Agriculture and Biosystems Engineering. 1998.

lxiii Vertimani, R., Jyothimayi, N., Rao, P.H. and Ramadoss, C.S. 1992. Inactivation of lipase and lipoxigenase in cereal bran, germ and sorbean by microwave treatment. *Lebensmittel Wissenschaft Technologie*, 25(6), pp. 532-535.

lxiv Walde Wander A. Sousa, Antonio Marsaioli Jr. and Maria I. Rodrigues. Optimising A Microwave Assisted Banana Drying Process, *Drying 2004* – Proceedings of the 14th International Drying Symposium (IDS 2004).

lxv Wang, Ruifang; Li, Zhanyong; Su, Weiguang; and Ye, Jingsheng (2010). "Comparison of Microwave Drying of Soybean in Static and Rotary Conditions," *International Journal of Food Engineering*: 6(2), Article 2.

lxvi Wang, S., Tang, J., Johnson, J. A., Mitcham, E., Hansen, J. D., Hallman, G., *et al*. (2003). Dielectric properties of fruits and insect pests as related to radio frequency and microwave treatments. *Biosystems Engineering*, 85, pp. 201-212.

lxvii Watanabe, F., Abe, K., Fujita, T., Goto, M., Hiemori, M. and Nakano, Y. 1998. Effects of microwave heating on the loss of vitamin B_{12} in foods. *J Agril. Food Chem*., 46(1), pp. 206 210.

lxviii Welt, B.A. and Tong, C.H. 1993. Effects of microwave radiation on thiamin degradation kinetics. *J Microwave Power Electromagnetic Energy*, 28(4), pp. 187-195.

lxix www.asabe.org

lxx www.industrialmicrowave.com/faqs.htm

lxxi Yongswatdigul, J. and Gunasekaran, S. 1996. Microwave-vacuum drying of Cranberries: Part II. Quality Evaluation. *J Food Proc. Preserv*., 20, pp. 121-156.

lxxii Yoshida, H. and Takagi, S. 1996. Vitamin E and oxidative stability of soyabean oil prepared from beans at various moisture contents roasted in a microwave oven. *J Sci. Food Agriculture*, 72(1), pp. 239-246.

lxxiii Yousif, A.N., Scanman, C.H., Durance, T.D. and Girard, B. 1999. Flavour volatile and physical properties of vacuum-microwave and air dried sweet basil *J Agril.Food Chem*., 47(11), pp. 4777-4781.