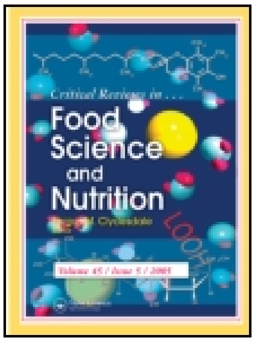

Critical Reviews in Food Science and Nutrition

ISSN: 1040-8398 (Print) 1549-7852 (Online) Journal homepage: http://www.tandfonline.com/loi/bfsn20

Emerging Trends in Microwave Processing of Spices and Herbs

Ismail Rahath Kubra, Devender Kumar & Lingamallu Jagan Mohan Rao

To cite this article: Ismail Rahath Kubra, Devender Kumar & Lingamallu Jagan Mohan Rao (2016) Emerging Trends in Microwave Processing of Spices and Herbs, Critical Reviews in Food Science and Nutrition, 56:13, 2160-2173, DOI: 10.1080/10408398.2013.818933

To link to this article: https://doi.org/10.1080/10408398.2013.818933

Accepted author version posted online: 09 Mar 2015.
Published online: 09 Mar 2015.

Critical Reviews in Food Science and Nutrition, 56:2160–2173, (2016)

ISSN: 1040-8398 / 1549-7852 online
DOI: 10.1080/10408398.2013.818933

Emerging Trends in Microwave Processing of Spices and Herbs

ISMAIL RAHATH KUBRA, DEVENDER KUMAR and LINGAMALLU JAGAN MOHAN RAO

Plantation Products, Spices and Flavor Technology Department, Central Food Technological Research Institute, Mysore, India (A Constituent Laboratory of Council of Scientific and Industrial Research, New Delhi, India)

Today, spices are integral part of our food as they provide sensory attributes such as aroma, color, flavour and taste to food. Further their antimicrobial, antioxidant, pharmaceutical and nutritional properties are also well known. Since spices are seasonal so their availability can be extended year round by adopting different preservation techniques. Drying and extraction are most important methods for preservation and value addition to spices. There are different techniques for drying of spices with their own advantages and limitations. A novel, non-conventional technique for drying of spices is use of microwave radiation. This technique proved to be very rapid, and also provide a good quality product. Similarly, there are a number of non-conventional extraction methods in use that are all, in principle, solid–liquid extractions but which introduce some form of additional energy to the process in order to facilitate the transfer of analytes from sample to solvent. This paper reviews latest advances in the use of microwave energy for drying of spices and herbs. Also, the review describes the potential application of microwave energy for extraction of essential oil/bioactive components from spices and herbs and the advantages of microwave-assisted process over the other extraction processes generally employed for extraction. It also showcases some recent research results on microwave drying/extraction from spices and herbs.

Keywords Spices, microwave energy, drying, extraction, antioxidants

INTRODUCTION

Thermal technology dictates the quality, economics and environmental impact of any processing industry. The increasing number of regulations calls for more efficient energy usage and more environment friendly raw materials as well as effluents (Allen and Shonnard, 2002). Microwave, infrared and radio frequency are the fast emerging electromagnetic heating technologies. Among these, microwave heating is an alternative to conventional heating techniques and as an environmentally benign process. Microwave energy for heating has been in commercial use since 1950 in telephone channels (Edgar, 2001). But it is only recently that its benefits as an environmentally friendly source of thermal energy have been widely appreciated.

Drying is the most popular preservation method which makes ensuring of the microbiological safety of biological products. The main purpose of drying food products is to allow longer periods of storage to preserve and make them available to consumers for the whole year without substantial loss of flavor, taste, color and nutrients (Okos et al., 1992; Maroulis and Saravacos, 2003). Sun drying allows for the production of a product rich in color and translucent in appearance, but it has some disadvantages e.g., it is a time-consuming process, weather depended, labor demanded and it is greatly exposed to possible environmental contamination (Maskan, 2001). Nevertheless, sun and oven drying methods are still widely used to produce dried products because of their low costs (Soysal and Oztekin, 2001). Convective drying has been commonly selected technique to dry fruits and vegetables, including herbs. However, this method has several disadvantages and limitations; for instance, it has been seen that the temperature used during the process involves a loss of cell functionality and consequently results in changes in nutritional and sensory qualities (Spiess and Beshnilian, 1998).

New and innovative techniques that increase the drying rate and enhance product quality have achieved considerable attention in the recent past. Microwave drying is a

Address correspondence to Dr. L. Jagan Mohan Rao, Senior Principal Scientist, Plantation Products, Spices and Flavor Technology Department, Central Food Technological Research Institute, Mysore, India. E-mail: ljnatpro@yahoo.com; ljnatropro@cftri.res.in.

new addition in the existing drying techniques, versus convective air-drying (cabinet, flat bed, tunnel), spray, vacuum, foam mat and freeze-drying (Prabhanjan et al., 1995; Vega-Mercado et al., 2001). The conversion of microwave energy into heat in the food is mainly because of the presence of water.

Majority of the extraction processes have traditionally been based either on different liquid extraction methods or on vapor-phase extraction methods (Starmans and Nijhuis 1996). Extraction methods, such as sonication, super/sub-critical fluid extractions, etc. possess capabilities and also limitations owing to their inherent and unique features. Use of microwave irradiation is another way of increasing the efficiency of conventional extraction methods. Microwave assisted extraction (MAE) consists of heating the solvent in contact with the sample by means of microwave energy. The process involves disruption of hydrogen bonds, as a result of microwave-induced dipole rotation of molecules, and migration of the ions, which enhances the penetration of the solvent into the matrix, allowing dissolution of the components to be extracted (Hudaib et al., 2003). Thus, MAE process is a high-speed method used to selectively extract target compounds from various raw materials.

The characteristic feature of MAE is accelerated dissolution kinetics as a result of the rapid heating processes that occur when a microwave field is applied to a sample. The main advantages of MAE over the conventional extraction techniques are moderately high recoveries, with reduced solvent consumption and shorter operational times, in addition to good reproducibility and minimal sample preparation for extraction process. MAE is a viable candidate for performing extractions due to its applicability over a wide range of sample types because the selectivity can be easily manipulated by altering solvent polarities. This method uses energy of microwave radiation to heat solvents quickly and efficiently (Mandal et al., 2007). MAE can be performed at higher temperatures using a closed system, and also the extraction times are reduced significantly. It is an innovative solvent-extraction technology, offers a superior alternative to several thermal applications owing to its efficient volumetric heat production and has many advantages over conventional solid liquid extraction methods. MAE can therefore be employed for the extraction of bioactive compounds from natural sources.

Spices are the building blocks of flavor in various foods. Edible spices serve many functions in food products. Their primary functions are to flavor food and to provide aroma, texture, color and sometimes mask undesirable odors (Peter, 2001). Spices also provide secondary effects, such as preservative, nutritional, and health functions. Herbs and spices have tremendous importance in our daily life as ingredients in food, alcoholic beverages (Ravindran et al., 2002), medicine (Shylaja and Peter, 2004), perfumery, cosmetics and coloring as well as garden plants. Spices and herbs are used in foods to impart flavour, pungency and color. These also have antioxidant (Lee and Shimbamoto, 2002), antimicrobial (Arora and Kaur, 1999; Sagdic and Ozean, 2002), pharmaceutical and nutritional properties (Farrell, 1990). In addition to the known direct effects, the use of these plants can also lead to complex secondary effects such as salt and sugar reduction, improvement of texture and prevention of food spoilage (Peter, 2004). These are essential ingredients in beauty care as cleansing agents, infusions, skin toners, moisturizers, eye lotions, bathing oils, shampoo /hair conditioners, cosmetic creams, antiseptic and anti-tanning lotions and creams, improvement of complexion and purifying blood (Ravindran et al., 2002).

Spices are consumed in fresh form and their processed value added products are available. Spice extractives are highly concentrated forms of spices and they contain both the volatile and nonvolatile oils that give each spice its characteristic flavour. The spice extracts such as essential oils and oleoresins from leaves and flowering tops of various herbal spices can be recovered using steam distillation, water cum steam distillation, supercritical carbon dioxide extraction and solvent extraction using low-boiling organic solvents. The microwave assisted processing is another such a technique, which can be used for processing of spices.

This paper provides a general review and a brief introduction on the current applications of microwave heating in spice processing. It explores the possibility of using microwave energy for heating and also for extraction of bioactive components from spices and herbs. It presents a brief discussion regarding microwave, their general methods of extraction, microwave-assisted extraction and quantification, and finally discusses the possible benefits obtained by microwave extraction for the separation of bioactive compounds from spices.

Microwave Energy

Microwave is an electromagnetic wave in the frequency range of 300–30000 MHz (Decareau, 1985). It is the combination of electrical and magnetic fields, with only the former being engaged in the conversion process when waves interact with the non-magnetic materials (Ohlsson, 1989; Prabhanjan et al., 1995; Sutar and Prasad, 2008). The water molecules are bipolar and rotate in the rapidly changing electromagnetic field, heat is evolved within the foodstuff due to friction between the water molecules. The waves penetrate directly into the material and therefore heating is volumetric (from inside out) and provides fast and uniform heating throughout the product. The quick absorption of energy by water molecules causes rapid evaporation of water, resulting in high drying rates of the food (Bouraoui et al., 1994). This creates an outward flux of rapidly escaping vapor. In addition to improving the rate of drying, this outward flux helps to prevent the shrinkage of tissue structure, which prevails in most convective drying techniques (Feng et al., 2001). The two narrow bands of microwave allocated for use in industrial food processing applications are 915 and 2450 MHz. The most widely commercially used frequency is 2450 MHz as the lower band creates interference with mobile phones (900 MHz) and computers (Nijhuis et al., 1996).

When microwaves are interacted by dielectric materials like food, they interact with the dielectric material, giving up energy which results in an increase in temperature of the material. This can be attributed to two phenomenon i.e., Ionic polarization, where ions move and collide with each other in response to alternating electric field; Dipole rotation, where dipole molecules like water rotate with respect to changing electric field and produces frictional heat. In simple words, frequency of 2450 MHz, the electric field swings the orientation of water molecules 2.45×10^9 times every second. Thus, creating an intense heat that can escalate as quickly as several degrees per second (estimated as 100°C/s at 4.9 GHz) (Lew et al., 2002). Among the different factors, dielectric properties and moisture content of foods are critical, but the frequency of the applied alternating field, the temperature of the material and also the density, chemical composition (i.e., fat, protein, carbohydrate and salt) and structure of the material all have an influence on microwave heating (Piyasena et al., 2003; Tang, 2005).

Microwave Drying

Although the microwave got various areas of application in processing of food but in case of spices, it limited mostly to drying and extraction. Drying is essential operation in order to ensure the expected shelf-life of the product, while extraction of principle components from spices is a value addition process. Besides, this technique also has a role in blanching and sterilization of spices. Drying of spices inhibits microbial growth and prevents certain biochemical changes. However, it gives rise to other alterations such as changes in appearance and alterations in aroma due to loss in volatiles or the formation of new volatiles as a result of reactions e.g., oxidation, dehydration, rearrangement, esterification etc. In recent times, applications of microwave drying were increased abundantly due to its advantages such as higher drying rate, shorter drying time, rapid and volumetric heating, decreased energy consumption, and better quality of the dried products (Zhang et al., 2006).

Microwave drying is an energy efficient dehydration method and can improve product quality in some cases (Prabhanjan et al., 1995; Gunasekaran, 1999). This method has been combined with hot air drying, vacuum drying, freeze drying, etc., and applied in numerous drying practices in recent decades (Drouzas and Schubert, 1996; Raghavan et al., 2005; Zhang et al., 2006; Vadivambal and Jayas, 2007). Drying temperature and microwave power are the two most important factors in microwave drying of agricultural products. These two factors significantly influence the drying parameters such as drying time, drying curve, drying speed, drying efficiency, and the final product quality. To improve microwave drying, a number of studies have been conducted to investigate the effects of different microwave power levels and drying temperatures, different prediction models have been established (Soysal, 2004; Ozbek and Dadali, 2007; Therdthai and Zhou, 2009; Arslan et al. 2010; Li et al., 2010).

Garlic (*Allium sativum*) is used for seasoning of foods because of its typical pungent flavour. It is a high-moisture commodity and requires mild heat treatment for shorter period of time during drying. This necessitates developing an efficient drying technique that reduces the drying time, energy consumption and can produce good quality dehydrated product. Sharma and Prasad (2001) investigated the use of combined microwave-convective drying technique for processing of garlic cloves in an experimental dryer. Combined microwave-hot air drying experiments were carried out at temperatures of 40–70°C at air velocities of 1–2 m/s using continuous microwave power of 40 W; this resulted in a reduction in the drying time to an extent of 80–90% in comparison to conventional hot air drying method. Later, the same group of authors (Sharma and Prasad 2006a; Sharma and Prasad 2006b) optimized the process parameters for microwave-convective drying of garlic cloves. In another study (Baysal et al., 2003), garlic dehydration process using microwave drying was found to be superior compared to infrared drying methods for retention of color, while there was no significant difference in rehydration characteristics of the product.

Cui et al. (2003) compared the combined microwave-vacuum drying and air drying of garlic with conventional hot air drying and advanced freeze drying methods. In combination of microwave-vacuum drying and air drying, the sample was dried by microwave-vacuum until the moisture content reached 10% (wet basis, wb), and then by conventional hot-air drying at the temperature of 45°C to final moisture content less than 5% (wb). Pungency, color, texture, and rehydration ratio of dried garlic slices were evaluated and compared with those dried by freeze-drying and conventional hot-air drying. The comparison showed that the quality of garlic slices dried by microwave-vacuum drying method was close to that of freeze dried garlic slices and much better than that of conventional hot-air dried ones. Microwave-vacuum drying resulted in acceleration of the drying rate and water evaporation at a lower temperature in the early stage of drying, however in the later stage (moisture content less than 10% wb) air-drying at the temperature of 45°C was a feasible alternative way to avoid hot-spots and product damage. The power output of magnetron should be decreased with the reduction in moisture content in microwave-vacuum drying.

Rao et al., (2007) found that the microwave assisted drying reduced the moisture content of garlic powder from 1.55% to 0.057% within 0.25 h, while comparing with cabinet tray drier which took 8 h for reducing the same to 0.093%. The yields of essential oils decreased by 25% and 65% in cabinet-dried samples and microwave-dried sample, respectively, as compared to fresh garlic. The drying times were reduced from 8 h to 0.25 h for bringing down the moisture contents to similar levels. While comparing the two drying processes (microwave drying and cabinet tray drying), it was found that the drying rates in microwave drying were considerably high as compared to that in cabinet tray drier. The reduction in volatile fraction in the microwave-dried product may be attributed to two reasons, namely, the heat generated within the garlic would have driven out the flavour volatiles, or the enzyme *alliinase* would have been partially inactivated in the microwave dryer, which resulted in reduced formation of volatile sulphur components (Rao et al., 2007). The HOCl scavenging ability of garlic was eliminated when garlic was subjected to microwave heating indicating that the compound /compounds involved in HOCl scavenging, which remain to be determined, are sensitive to microwaving. Interestingly, the $O_2^{\bullet\,-}$, H_2O_2, $OH^{\bullet}$ and $ONOO^{-}$ scavenging properties and the ability of garlic to inhibit low density lipoprotein (LDL) oxidation were not eliminated by microwaving (Pedraza et al., 2004, 2007). These results suggest that the compound / compounds involved in HOCl scavenging is / are different to those involved in $O_2^{\bullet\,-}$, H_2O_2, $OH^{\bullet}$ and $ONOO^{-}$ scavenging. Yu et al. (2007) prepared garlic powder by microwave-vacuum technology. This technology can provide high allicin content with the quality of the finished product as good as the product prepared by freeze drying. The optimal condition was 3 min drying time under the microwave output power 376.1 W. The thiosulfinates retention after drying was about 90.2% which is comparable with freeze drying (93.6%). Sharma et al., (2009) reported that microwave drying of garlic cloves resulted in a better quality product with respect to color and flavour when compared to commercial sample. The retention of volatile oils in microwave assisted dried sample was more than commercially available dried sample.

Dry **ginger (*Zingiber officinale*)** is a value added product and utilized for manufacturing of ginger powder, ginger oil, ginger essence, ginger oleoresins and soft drinks. Dehydration of ginger is a vital requirement to reduce the postharvest losses with minimum changes in physical, chemical and organoleptic properties. Liu (2007) compared microwave drying of fresh ginger with that of hot air drying. It was reported that the dehydration of more than 65% water of fresh ginger was always accomplished during the first half drying time in either hot air drying or microwave drying. However, the energy cost through hot air drying was 1.6 times that of the microwave drying, and the time was 28–30 times that of microwave drying. The quality of the end product was found to be better in microwave drying than hot air drying.

The effect of microwave drying of ginger slices at different power levels (PL 40, 60, 80, and 100 with microwave output power 385, 525, 660 and 800 W, respectively) with reference to yield and chemical composition of essential oil was studied (Kubra and Rao, 2012a). It was observed that the drying time was reduced significantly from 720 min for convective drying (CD) to 25 min for MW. One of the microwave-dried samples at selected power level (PL 100, 800 W) retained the maximum volatile fraction (3% v/w) and it was near to that of the fresh sample (3.2% v/w) and was higher than CD dried (2.9% v/w). Seventy-six compounds were identified using GC and GC-MS analyses. The GC analysis of the essential oil from convection dried ginger (CGO) showed decrease (15%) in hydrocarbon content (2582 to 2193 μl/100 g dry weight); whereas the oxygenated compounds (588 to 648 μl/100 g) increased (10%) when compared to fresh ginger oil (FGO). It was observed that in CGO, the relative percentage of monoterpenes and related compounds increased (21%) significantly, while sesquiterpenes and related compounds decreased (26%) compared to FGO. Both fresh and dried ginger oils contained zingiberene, a sesquiterpene, as the major compound but in different quantities. The concentration of zingiberene was marginally higher in the microwave-dried sample at selected power level (PL 100, 800 W) when compared to fresh sample. However, the major sesquiterpene (viz., zingiberene) content decreased by 43% in CGO, possibly owing to long exposure of ginger flakes to oxygen in convection dryer, which might have resulted in the degradation of sesquiterpenes to monoterpenes.

The authors (Kubra and Rao, 2012b) also evaluated the effects of microwave (MW) drying on the total polyphenol content (TPP) and antioxidant properties of ginger extract and the results were compared to that of the conventional drying (CD) method. Extract yield, TPP content (59–80 mg GAE/g) of the MW dried samples increased with increase in MW power levels (PL 40, 60, 80, and100 with microwave output power 385, 525, 660 and 800 W respectively), which might be as a result of intense heat/MW energy causing the release / breakdown of cellular constituents, thus causing more TPP to be extracted. Higher quantity (1.5 fold) of TPP, [6]-gingerol content and antioxidant activity was observed for MW-dried (PL100, 800 W) extract, when compared to the CD extract. Hence, it was reported that the 800 W was the optimal MW power level for drying of ginger slices with respect to retention of non-volatiles.

The effects of drying methods (viz., oven, microwave, and silica gel) on the degree of dehydration and volatile components of Chinese ginger were studied (Huang et al., 2012). The volatile components of ginger were extracted by head-space solid-phase micro extraction. Sixty compounds were identified using GC-MS analysis. The major volatile compounds were zingiberene (26.4–37.1%), β-phellandrene (7.4–12.9%), β-sesquiphellandrene (10.2–12.8%), and geranial (6.6–8.1%). The volatiles of silica gel–dried ginger were similar to those of fresh ginger. Microwave-dried ginger had a higher content of zingiberene and satisfactory dehydration efficiency. It was reported from the results that microwave and silica gel could be used in drying of ginger to maintain the taste and appearance of fresh Chinese ginger.

Onion (*Allium cepa*) has been widely used since ancient times as seasonings, foods and for medicinal use. Arslan and Ozcan (2010) reported drying of onion slices by different methods viz., sun, oven (50 and 70°C) and microwave oven (210 W and 700 W). The drying kinetics and quality degradation of the product was monitored. Fresh and dried onion slices had high amounts of K (696.82–16357.55 mg/kg), Ca (69.64–340.03 mg/kg), Na (37.72–1895.43 mg/kg), Mg (3.31–964.77 mg/kg) and P (46.47–3384.07 mg/kg) minerals. The highest mineral values were determined in oven dried samples. Sun (L* 58.00, *a** 0.27, *b** 14.36) and microwave oven drying at 210 W (L* 54.78, *a** −0.71, *b** 13.17) revealed optimum color values in the dried products. The phenolic contents of microwave oven dried samples (1664.3 and 1623.5 mg/100 g for 210 W and 700 W, respectively) were higher than those of the other dried onion slices. The shorter time required for microwave drying might have increased the phenolic content of microwave oven dried samples. More release of phenolics is due to the breakdown of cell matrix during the microwave drying process.

Red bell pepper (*Capsicum annuum* L.) is in high commercial demand by the global food industry, based on its aromatic, coloring, and flavoring properties. It is eaten as a raw and cooked as vegetable and also used commonly in making paste, pickle, and sauce. The drying behaviors of red bell-pepper slices were investigated (Arslan and Ozcan, 2011). Effects of these drying methods (sun, oven, microwave) in terms of color indices and antioxidant activity of pepper slices were also studied. By using oven drying method (50°C and 70°C), the drying time [up to the moisture content of approximately 9.3 g/100 g (wb)] could be shortened by 8.2% and 55.7%, when compared to sun drying, respectively. For microwave oven drying at 210 W and 700 W, the drying times to reach the 8.5 g/100 g (wb) moisture content were 16 min and 9 min, respectively. Sun dried and followed by microwave oven (700 W) dried samples revealed the highest L*, *a** and *b** color values than the other dried samples. The antioxidant activities of the dried samples were higher than those of fresh samples. Microwave dried (210 W) and oven dried (50°C) samples exhibited lower Trolox equivalent antioxidant capacity (μmol TEAC/100 g DM) and DPPH free radical scavenging activities than the microwave (700 W) dried and oven (70°C) dried samples, which showed that long dehydration times were more destructive than high temperatures applied during drying in terms of antioxidant activity.

The quality characteristics (texture, color and sensory properties) of red pepper dried at continuous and intermittent application of microwave energy combined with convective air drying were investigated (Soysal et al., 2009) and the results were compared with convective air dried and commercially convective air dried (belt dryer) red peppers. The microwave drying treatments were done both in the intermittent and continuous modes at two different microwave output powers (597.2 and 697.8W) using two identical microwave–convective dryers. Results showed that the intermittent microwave–convective drying conducted at lower drying air temperature and microwave power level with relatively long power-off time resulted in more stable and gentle drying process concerning dried product quality. The intermittent microwave–convective drying at 35°C with a pulse ratio (PR) of 3.0 at 597.2 W resulted in considerable savings in drying time and could be used to produce high quality dried red pepper with better physical (color and texture) and sensory attributes.

Cumin (*Cuminum cyminum*) seeds were subjected to heating by microwaves (using various power levels) and conventional roasting at different temperatures (Behera et al., 2004). The volatile oils distilled were analyzed using GC and GC–MS. The results indicated that the microwave-heated samples showed better retention of characteristic flavor compounds, such as aldehydes, than did the conventionally roasted samples. The optimum condition for conventionally roasted were 125°C for 10 min and for microwave roasted samples was 730 W for 10 min. Under these conditions, the yields of the volatile oils were similar in both cases. There was no significant difference in the refractive indices of both oils. However, changes were observed in the optical rotation values, which indicated differences in the chemical compositions. GC and GC-MS analysis of optimized condition samples showed that microwave heated samples revealed better retention of characteristic flavour compounds of cumin (i.e., total aldehydes), than conventionally-roasted cumin samples.

Salah (2004) assayed fenugreek **(*Trigonella foenumgraecum* L.)** for trypsin and α-chymotrypsin inhibitor activities. The trypsin and α-chymotrypsin inhibitors activities of fenugreek were 45.8 and 7.1 unit/mg protein, respectively. Heating the extract in autoclave (120°C, 80 min) destroyed 53% of the trypsin inhibitor activity, whereas only 20% of the activity of this inhibitor was destroyed by microwave heating (850 W, 2450 MHz, 130°C, 8 min). α-Chymotrypsin inhibitor activity in fenugreek flours was much more heat labile compared to trypsin inhibitors activity. Autoclave (100 min) and microwave (8 min) heating inactivated 30% and 100% of α-chymotrypsin inhibitors activity respectively.

Coriander leaves (*Coriandrum sativum* L.) are one of the most popularly used plants for culinary and medicinal purposes. Microwave drying characteristics of coriander leaves at various power outputs were investigated (Sarimeseli, 2011). The effect of microwave power output on effective moisture diffusivity, color parameters and rehydration characteristics of coriander leaves was studied. No significant differences in the color parameters between the fresh and dried samples were observed; and the changes in their values were not dependent on the power outputs of the microwave drier. The highest rehydration capacity was recorded for the samples dried at 180 W and lowest at 900 W.

Divya et al., (2012) investigated the effect of microwave drying on carotenoids, their bio-efficacy and stability during drying, with the main emphasis on β-carotene (vitamin-A precursor) analysis by HPLC-MS in coriander leaves. Coriander leaves were wrapped in blotter sheetsand drying was done at five power levels (180–850 W) for five different periods (30–150s). Microwave drying at different power levels for different periods indicated that drying at 850 W for 90s was found ideal for drying coriander foliage to match with the moisture content equal to that of oven-dried. The oven drying of coriander foliage, even at a very low temperature of 45°C resulted in substantial loss of both chlorophylls (65%) and carotenoids (35%). Further experiments with various power levels and drying time indicated that in case of microwave drying, there was an increase in the retention of chlorophylls a and b, as well as total carotenoids at all power levels up to 90 s. It was concluded that microwave drying of foliage was rapid with better retention of pigments, high intactness of trans-β-carotene and higher extractability of pigments when compared with oven drying.

Parsley (*Petroselinum crispum* Mill.) is a widely used culinary, medicinal and aromatic plant. The fresh or dried leaves, roots and seeds of this plant are used in the food, cosmetic and pharmaceutical industries to produce spice, essential oils and drugs respectively. Soysal, (2004) studied drying of parsley leaves in a domestic microwave oven and determined the effects of microwave output power on drying time, drying rate and the dried product quality in terms of color. Seven different microwave output powers (360 to 900 W) were used in the drying experiments. Drying took place mainly in constant rate and falling rate periods. After a short heating period, a relatively long constant rate period was observed. Approximately 40.5% of the water was removed in this period. The rapidly decreasing falling rate period followed the constant rate period. As the drying progressed, the loss of moisture in the product caused a decrease in the absorption of microwave power and resulted in a fall in the drying rate. Increasing the microwave output power resulted in a considerable decrease in drying time. No significant differences were observed between the color parameters of fresh and microwave-dried leaf materials, except for some decrease in whiteness 'L' value ($p > 0.05$). The change in color values was not dependent on the microwave output power. Although some darkening occurred, microwave drying maintained a good green color close to that of the original fresh parsley leaves. At 900 W, the drying time was reduced by 64% with a good quality product. The same authors reported (Soysal et al., 2006) optimization of microwave drying through different experiments with varying material loads ranging from 64.3 to 128.5g at microwave power cycle of 9s on/9s off at 900 W microwave output power. The microwave oven power was set to cyclic heating with 50% rating, which provided an intermittent heating for a period of 9 s, followed by a pause for 9s. Increasing the material load resulted in a considerable increase in drying efficiency and a significant decrease in specific energy consumption. About 9.5% increase in drying efficiency and about 18% (0.92 MJ kg^{-1} [H_2O]) decrease in specific energy consumption could be obtainable by increasing the material load from 64.3 to 128.5 g.

Mint (*Mentha cordifolia Opiz* ex Fresen) is one of the popular Thai kitchen herbs due to its unique aroma and it also helps to relieve from colds, flu, fever, motion sickness and poor digestion. Therdthai and Zhou (2009) reported drying of mint using microwave vacuum drying and hot air drying. For microwave vacuum drying, three microwave intensities (i.e., 8.0 W/g, 9.6 W/g and 11.2 W/g) were applied with pressure controlled at 13.33 kPa. For hot air drying, two drying temperatures (60°C and 70°C) were examined. Lewis's, Page's and Fick's models were used to describe drying kinetics under various drying conditions. The microwave vacuum drying could reduce drying time of mint leaves by 85–90%, compared with the hot air drying. In addition, color change during drying was also observed. Lightness, greenness and yellowness of the microwave vacuum dried mint leaves were higher than those of the hot air dried mint leaves. From scanning electron micrographs (SEM), the microwave vacuum dried mint leaves had a more porous and uniform structure than the hot air dried ones. From rehydration test at 30°C, rehydration rate constants of the dried mint leaves by the microwave vacuum drying at 9.6 W/g and 11.2 W/g microwave intensity were significantly ($p < 0.05$) higher than those by the hot air drying at 60°C and 70°C.

Peppermint (*Mentha x piperita* L.) leaves are used either as fresh or dried for flavouring several dishes. Arslan et al. (2010) reported drying of peppermint leaves using different drying methods [sun, oven (50°C) and microwave oven (700 W)]. Page, Modified page, Midilli and Kucuk models adequately described the oven, sun and microwave oven drying behaviours of peppermint leaves. Fresh and dried herbs had high amounts of K, Ca, P, Mg, Fe and Al minerals. Microwave oven drying method lead to the lowest increase in Ag, Al, B, Na, Mn, Mg and Zn values than the other drying methods. The convective mode of energy and wave strength of the oven drying method could cause more increase in the solubility of the elements than the microwave drying. The changes in the concentrations of minerals were dependent on the method and the drying temperature. Microwave oven drying shortened the drying time, revealed the highest phenolic content and optimum color values. The phenolic concentration was found to be ˜53% lower in the oven dried samples, while 16% higher in the sun dried and 45% higher in the microwave oven dried samples compared to fresh leaves. The increase in total phenolics might be attributed to the liberation of phenolic compounds from the matrix during the drying process. The high temperature of oven drying might be the reason for the lowest phenolic content of the oven dried samples.

Mint leaves (***Mentha spicata*** L.) are used for flavouring, tea infusions and spicing. It is also used as a medicinal and aromatic plant. It helps to relieve cold, flu, fever, poor digestion, motion sickness, food poisoning, rheumatism, hiccups, stings, ear aches, flatulence and for throat and sinus ailments. The effect of microwave drying technique on moisture content, moisture ratio, drying rate, drying time and effective moisture diffusivity of mint leaves were investigated (Ozbek and Dadali, 2007). The microwave drying process, which reduced the moisture content of mint from 6.33 to 0.1 g water g dry $base^{-1}$ took 6.6–16 min as the sample amount increased from 25 to 100 g, respectively. By increasing the microwave output powers from 180 W to 900 W the drying time decreased from 12.5 to 3.0 min. To determine the kinetic parameters, the drying data were fitted to various models based on the ratios of the differences between the initial and final moisture contents and equilibrium moisture content versus drying time. Among the models proposed, the semi-empirical Midilli model gave a better fit for all drying conditions applied. Drying process for mint leaves took place both in the constant rate and falling rate period after a short heating period. Average drying rates of mint leaves at constant rate period ranged from 0.571 to 3.083 g water g dry base^{-1} min^{-1} at various microwave output powers (from 180 to 900 W) and followed by falling rate period which was the dominant period during drying.

Sweet basil (*Ocimum basilicum* L.) is used extensively to add a distinctive aroma and flavor to food, such as salads, pizzas, meats and soups. Yousif et al. (1999) compared the two methods for drying (conventional hot air and vacuum-microwave dryers) of basil. The major volatile compounds of basil (linalool and methyl chavicol) were found to retain higher amount in vacuum-microwave dried samples (approximately 2.5-fold for linalool and 1.5-fold for methyl chavicol) as compared to air-dried samples. This may be due to the rapid rate of vacuum-drying that reduced the time for diffusion of volatiles out of the tissue. Overall, the vacuum-microwave treated samples exhibited a higher concentration of volatiles than fresh basil. The effect of each drying method on leaf structure was observed under the SEM. After air drying, basil leaves exhibited severe shrinkage of their cuticle layer. Internally, the epidermis and mesophyllic cells of the palisade layer were extremely affected and collapsed. The structure of cuticle of vacuum-microwave dried samples was less affected by heat as judged from the extent of shrinkage to that layer and cells of the epidermis and palisade layers looked "stretched" or "puffed." It was concluded that vacuum-microwave-drying to be very rapid drying process (0.4 vs. 11.5 h for air-drying) that resulted in a better quality product in terms of flavor, color, rehydration and appearance than conventional hot-air-drying.

Luigi et al. (2003) found that microwave drying allowed a larger retention of chlorophyll pigments than air-drying and freeze-drying irrespective of blanching treatment prior to drying and hence preserved the color of the raw basil. Microwave drying required a much shorter treatment and implied the simultaneous blanching of the raw material. Microwave dried basil leaves showed higher retention of both volatile compounds and chlorophyll pigments when compared to the leaves dried by traditional techniques.

Demirhan and Ozbek (2009) reported the color change kinetics of basil during microwave drying. The parameters for the color change were quantified by Hunter system. These values were also used for calculation of the total color change (ΔE), chroma, hue angle, and browning index. The microwave-drying process changed color parameters of "L," "a," and "b," causing a color shift toward the darker region. The mathematical modelling study of color change kinetics showed that 'a' and 'b' fitted to a first-order kinetic model, while L and ΔE followed a zero-order kinetic model. However, chroma and browning index (BI) followed a first-order kinetic model, whereas hue angle followed a zero-order kinetic model.

Sanchez et al., (2011) evaluated the influence of drying method on aroma compounds of sweet basil. Convective (CD) and vacuum-microwave (VMD), as well as a combination of convective pre-drying and VM finish-drying (CPD-VMFD) were employed for drying of sweet basil. Volatile compounds from basil samples were extracted by hydro distillation and analyzed by GC-FID and GC-MS. Forty compounds were identified, with methyl eugenol, eugenol, eucalyptol, and linalool being the major components. The total quantity of volatiles of fresh sweet basil (32.1 g/kg) decreased considerably during both CD and VMD (14.4 g/kg and 14.4 g/kg db), respectively. The CPD-VMFD (40°C and 360 W) resulted in reduced drying time (≈250 min), total volatile concentrations of 16.7 kg^{-1} db, and aroma quality as observed by sensory analysis.

Dried **rosemary (*Rosmarinus officinalis* L.)** leaves are used in fried chicken, salads, baked products, condiments, perfumes and soaps. Rao et al. (1998) studied the impact of drying on flavour quality of rosemary. Fresh rosemary leaves subjected to convection heat drying at 45°C and also to microwave heating (175W, 385W and 595W) and the effect on flavour components was evaluated by comparison of the GC profile of volatiles of fresh and dried leaves. The results reveal that despite faster drying and good color retention. The microwave drying was not useful to dry and preserve the herb due to heavy loss of volatile oil during drying. Arslan and Ozcan (2008) compared the different drying methods for rosemary leaves. The leaves were dried using sun, oven (50°C) and microwave oven (700 W, 2450 MHz) drying methods. Microwave oven drying shortened the drying time (more than 99%) when compared to the sun and oven drying methods. The most abundant minerals in the rosemary samples were K, Ca, Na, Mg and P. The mineral content of oven dried rosemary leaves was higher than that of the sun and microwave dried samples. The solubility of the elements is more in convective mode than in the microwave drying as described earlier. Microwave oven drying revealed optimum color values. Oven drying resulted in a considerable decrease in the color quality of the rosemary leaves.

Szumny et al., (2010) studied the influence of the drying method on volatile compounds of rosemary leaves. Convective (CD) and vacuum-microwave (VMD), as well as a combination of convective pre-drying and VM finish-drying (CPD-VMFD) were used for drying. Rosemary drying kinetics was described by a simple exponential model for CD and VMD, while VMFD kinetics consisted of two periods: linear until a critical point and exponential beyond that point. Volatile compounds were extracted by steam-hydro distillation and analyzed by GC–MS. Thirty-four compounds were identified, with α-pinene, bornyl acetate, camphene and 1,8-cineole being the major components. The total volatiles concentration of fresh rosemary (135 g/kg) decreased considerably during both CD (87.2 g/kg) and VMD (61.9 g/kg). CPD–VMFD was reported to be the best method for drying of rosemary in relatively short time (30 min), total volatiles concentration (100 g/kg) with good aroma quality as analyzed by sensory evaluation. Sanchez et al., (2011) optimized the drying of rosemary using vacuum–microwave. Different conditions for the microwave power intensity and the vacuum level were assayed to optimize the drying conditions on the basis of the volatile composition. Drying kinetics was also studied. The time needed to dry rosemary was shorter for high values of microwave power and vacuum intensity. Volatile compounds were extracted by steam–hydro distillation and analyzed by GC–MS. Thirty-one compounds were identified and α-pinene, verbenone and 1,8-cineole being the major monoterpenoids. The total quantity of volatiles of fresh rosemary (27.2 g/kg) decreased during drying, independent of treatments, to a mean of 14.8 g/kg. Highest concentrations of volatiles and the best sensory quality were obtained at 72–74 kPa and 360 W. From the above reports, it may be observed that CPD-VMFD could be best method for the retention of volatiles during drying of rosemary.

Oregano (*Origanum vulgare*) is an important herb rich in phenolic compounds with strong antioxidant and antibacterial activity. Figiel et al. (2010) evaluated the influence of the drying method on volatile compounds of oregano. The drying methods such as convective (CD) at 60°C and vacuum-microwave (VMD), as well as a combination of convective pre-drying and VM finish-drying (CPD-VMFD) were evaluated. The volatile compounds of fresh and dried oregano were extracted by steam-hydro distillation and analyzed by GC-MS. Thirty-four compounds were identified, with carvacrol, thymol, and γ-terpinene, being the major components. The total volatiles concentration of fresh oregano (33.0 g/kg) decreased significantly during drying, independently of the method used (10.2, 13.1 and 27.9 g/kg for CD, CPD-VMFD and VMD respectively). Thus, VM dehydrated oregano was of better aromatic quality than that of hot air dried.

Extraction of Volatiles Using Solvent-free Microwave Extraction

Solvent-free microwave extraction (SFME) is a green technology and employed as a good alternative for the extraction of essential oils from aromatic plants and spices. Lucchesi et al. (2004) compared SFME (a combination of microwave heating and dry distillation, performed at atmospheric pressure without addition of solvent or water), with a conventional technique, hydro distillation (HD), for the extraction of essential oil from aromatic herbs like **basil and thyme**. The essential oils extracted by SFME (30 min) were quantitatively (yield) and qualitatively (aromatic profile) similar to those obtained by conventional hydro-distillation (4.5 h). It was reported that substantially higher amounts of oxygenated compounds and lower amounts of monoterpene hydrocarbons are present in the essential oils extracted by SFME in comparison with HD. Monoterpene hydrocarbons are less valuable than oxygenated compounds in terms of their contribution to the fragrance of the essential oil. Conversely, the oxygenated compounds are highly odoriferous and hence, the most valuable. The greater proportion of oxygenated compounds in the SFME essential oils was probably due to the diminution of thermal and hydrolytic effects, compared to hydro distillation, which uses a large quantity of water and time and energy consuming. Linalool and eugenol were the main components in the essential oil extracted from basil but the relative amounts differed in extraction methods employed. Eugenol was the most abundant component of the SFME extract (43%) followed by linalool (25%), whereas the HD extract was dominated by linalool (39%) and then by eugenol (11%). The essential oil of thyme isolated by SFME and HD contained thymol (51% and 41%), γ-terpinene (17% and 23%), and p-cymene (7.5% and 11%) respectively. It was thus concluded that SFME method yields an essential oil with higher amounts of more valuable oxygenated compounds, and allowed substantial savings of costs, in terms of time, energy and plant material.

The essential oils from dried ***Cuminum cyminum* L.** were extracted using an improved solvent-free microwave extraction (SFME) by adding microwave absorption solid medium (carbonyl iron powders; CIP) without any pretreatment. Improved SFME was compared with conventional SFME, microwave-assisted hydro distillation (MAHD) and conventional hydro distillation (HD) for the extraction of essential oil from dried cumin. The chemical composition of essential oils extracted using the above extraction methods were identified by GC–MS analysis. HD had the highest (79.6%) content of oxy-compound, followed by conventional SFME (75.6%), MAHD (66.6%), and lowest in improved SFME (60.8%). The improved SFME was completed in 30 min at a microwave power of 85W, with carbonyl iron powders in water. The compositions of essential oil obtained by different extraction methods were same, which indicated that improved SFME was an alternative and was suitable for the extraction of essential oil (Wang et al., 2006).

Lucchesi et al. (2007) optimized the conditions for SFME of essential oil from **cardamom (*Elletaria cardamomum* L.)** and compared the potential of the SFME technique with the conventional hydro-distillation method. For SFME, it was found that the 1,8-cineole content decreased with time, power and moisture content while the opposite was true for α-terpinyl acetate. The quantity of α-terpinyl acetate was greater in HD extract. Thus, the parameters such as extraction time, irradiation power or moisture content were optimised so as to obtain a high yield of essential oil, or to obtain essential oils of differing composition. However, they reported the optimal conditions for efficient extraction were 75 min at 370 W power and 67% moisture content. Since, the extraction was being facilitated due to rupture of the cells, the extraction time was lower in SFME as compared to the HD. SFME gave the essential oil with more quantities of oxygenated compounds which are of higher importance as these contribute much towards flavour of essential oils.

From GC-MS analysis of the essential oils *of* ***Piper nigrum*** **L. and** ***Piper longum*** L., it was reported that microwave distillation and headspace solid-phase micro extraction (MD-HS-SPME) has a high extract efficiency and good precision as compared to conventional solid phase micro extraction (Liu et al., 2007). More volatile oil components were extracted with MD–HS-SPME method compared to conventional HS-SPME. The result showed that MD–HS-SPME yielded significantly higher relative content for most of the compounds than conventional HS-SPME. In addition, no degradation of main compounds occurred by MD-HS-SPME, suggesting that microwave distillation was suitable for extracting essential oils.

Extraction of Non-volatiles Using Microwave Energy

Spices comprises of various compounds, which are responsible for their functional properties. Preservation and processing are important considerations as these determine the quality of end product. Extraction is an important step for separation of constituents from the spices. By adopting the selected scientific method of processing and preservation, the end product will be of superior quality and can be stored for longer periods of time. The development of new separation techniques for the chemical, food and pharmaceutical industries has lately received a lot of attention. Conventional techniques for the extraction of active constituents are time and solvent consuming, thermally unsafe and sometimes have lower efficiency. Compared with the traditional method of extraction using conventional heating such as the microwave heating can be another alternative. Microwave heating technique is a simple, inexpensive and valuable tool in applied chemistry where lesser amount of solvent, simplified manipulation and higher purity of final product with lower cost (Kormin et al., 2006).

Raman and Gaikar (2002) reported microwave assisted extraction to be an effective technique for rapid and selective extraction of piperine from **black pepper (*Piper nigrum* L.)**. In comparison to conventional solvent extraction techniques, a "one spot" microwave extraction technique provides higher extraction efficiencies, less labour intensive, and rapid. It can also be used as a quality control tool for the rapid screening of raw pepper. Optimized conditions for extraction of piperine using petroleum ether as a solvent were found to be: microwave radiation power of 150 W, exposure time of 2 min and solid to solvent ratio of 1:100, resulted in the isolation of piperine to the extent of 94% with a purity of 85%. Rapid energy transfer was observed between the polar molecules, coupled with the microwaves and the non-polar solvent. The results provided an effective mechanism for introducing non-polar solvents as good extraction solvents. Cell rupture was facilitated by dielectric heating and coalescence of the constituents within the cellular matrix. Extraction of piperine from black pepper was, therefore, complete and rapid using non-polar solvents.

Williams et al. (2003) investigated the applicability of microwave irradiation to assist the extraction of capsaicinoids from **capsicum fruit**. Samples in a closed-vessel were irradiated and then performed the gas chromatography of capsaicinoids derivatives. The optimum conditions for extraction were determined to be, the use of acetone as solvent at 30% power (maximum power 300 W) for 7 min irrespective of ground or whole tissue. The yield of the compounds extracted was significantly greater using microwave-assisted extraction compared to traditional reflux and shaken flask methods. A single extraction step was sufficient in recovering approximately 95% of the total capsaicinoids fraction in 15 min compared to 2 h for the reflux and 24 h for the shaken flask methods. Due to the considerable savings in time and energy as well as reliability, this technique was suitable for fast extraction of capsaicinoids from large samples.

Paprika red pigment was obtained by extracting the red pepper with organic solvent. The extractive rate at different temperature and time was testified to determine the optimum extractive conditions. At the same time the technology of paprika extraction was studied using yield as an index by microwave-assisted method. The optimum extraction conditions of microwave-assisted extraction method were found to be: solid to solvent (1:8 w/v) with 12 min of extraction time, at microwave power level of 600 W. Compared with traditional extraction method, microwave-assisted technique improved the yield in shorter extraction time (Chen et al., 2006).

Nazari et al., (2007) reported the extraction of capsaicin from Capsicum frutescens using microwave-assisted extraction procedure. The influence of experimental variables (viz., irradiation power, extraction temperature and dynamic extraction time before reaching the selected extraction temperature) on the extraction procedure was studied using a Box–Behnken experimental design followed by a conventional central composite design approach. Quantity of capsaicin was estimated using ^{1}H-NMR spectrometry. Optimum extraction conditions were: 120°C, 150 W, 15 min with acetone as solvent. The optimized MAE method provided extracts that can be quantitatively analyzed using ^{1}H-NMR without any preliminary clean-up or derivatisation steps. In ^{1}H-NMR spectrum of the crude extracts the doublet signal in the range of δ 4.349–

4.360 ppm was well separated from other signals. The quantity of capsaicin was calculated from the relative ratio of the integral value of the target peak to that of a known amount of dimethylformamide as internal standard. MAE showed higher extraction yield, selectivity, drastic reduction of extraction time and solvent consumption when compared to both conventional soxhlet and sonication methods.

Microwave-assisted liquid-phase extraction of **ginger (*Zingiber officinale*)** was optimized (Alfaro et al., 2003). The results obtained showed that by controlling the amount and the density of the energy applied to the extraction system it was possible to produce extracts in greater quantity and of similar quality to those obtained by soxhlet much more rapidly. The optimum conditions reported were: extraction time - 2 min; power - 150 W by using ethanol as solvent and water as modifier. This technique found to give better yield than conventional 2h soxhlet extraction using ethanol as solvent. Tian and Yang (2006) studied the influence of microwave irradiation on the extraction of antioxidants from ginger. The most satisfying results were observed using pre-treatment of ginger by microwave irradiation under output power (480 W) with irradiation time 6 min. The results indicated that the microwave irradiation treatment favours the extraction of antioxidants in ginger. In contrast to the traditional extraction process, the extraction ratio was raised by 10% and the antioxidants activity was improved as well.

Dandekar and Gaikar (2002) conducted the experiments for optimizing the parameters for microwave-assisted extraction of curcuminoids from **turmeric (*Curcuma longa* L.)**. The extraction process was optimized at 20% power level (Max 750 W) giving 60% extraction of curcuminoids with 75% purity within 1 min. Compared to other classical extraction techniques, MAE gave an efficient and rapid extraction, and was less labour intensive. Amongst the solvents (viz., Dichloroethane, isopropyl alcohol, 95% ethyl alcohol and acetone), acetone gave the highest extraction (around 60%) of curcuminoids in less than 1 min with 74% purity of curcuminoids. Microwave radiation directly affected the cells of natural raw material. The internal fast heating of cells lead to dielectric heating and coalescence of cellular matter, ultimately caused the rupture of cell wall. These changes in cellular structure and solid matrix facilitated transport of the solvent into the solid structure and faster extraction of curcuminoids.

A study conducted by Tang, (2005) on curcumin extraction by microwave radiation indicated that the optimum conditions for microwave extraction were: 75% (v/v) ethanol as solvent, a ratio of 1:30 of material to solvent, microwave power 360 W and microwave radiation time 60s. The crude curcumin was purified by adsorption separation with S-8 macroporous resin, and pure curcumin was obtained. On comparing to the traditional extraction method, microwave assisted extraction method has the advantages of simple technology, improved yield with reduced extraction time. Li et al. (2007) conducted a study to establish a new method for the extraction of turmeric oil and curcumin by supercritical CO_2 and microwave combined technique. They suggested that the pre-treatment of turmeric powder with supercritical CO_2 to obtain turmeric oleoresin and then microwave was used to extract curcumin. The optimum conditions of curcumin extraction were found to be: temperature 45°C, ratio of material to liquor 1:11, 80% ethanol as extracting solvent, time 2 min, yield of 3.22%.

Mandal et al. (2008) reported an extraction method using microwaves for the extraction of curcumin from turmeric. The duo-heating mechanism was based on simultaneous heating of sample matrix and extracting solvent under microwave energy. Methanol was used as modifier; plant material was soaked in it to bring about selective and effective heating of the sample under microwave. Acetone was used as the extracting solvent, which had excellent curcumin solubilising capacity and heats up under microwave owing to its good dissipation factor. The optimum extraction conditions reported were as follows: 20% microwave power, 4 min irradiation time, particles screened through sieve 20 and 8 ml of modifier. Microwave assisted extraction under the influence of dual heating mechanism showed better precision and dramatically higher yield with significant reduction in extraction time under optimum extraction conditions, when compared to conventional approaches.

Wakte et al., (2011) studied the extraction efficiency of soxhlet, microwave, ultra-sonic and supercritical carbon dioxide assisted extraction techniques, which was established in terms of percent curcumin yields and extraction rate constants. The effect of pre-irradiation and soaking solvent on the curcumin yield were studied. Prior to extraction, microwave and ultra-sonic irradiation of dry curcuma powder resulted in 68.5 and 40.0% curcumin yield, respectively. The MAE of water soaked irradiated curcuma powder recovered a maximum of 90.47% curcumin, whereas UAE resulted in 71.4% of curcumin with acetone as the extraction solvent during a total extraction period of five minutes.

The extraction of flavonols from different **onion (*Allium cepa*)** varieties (red, yellow, white and grelot onion) was carried out by solvent free microwave hydro diffusion and gravity (MHG) technique (Zill-e-Huma et al., 2011) and compared to that of conventional solvent extraction (CSE). The extracts obtained were analyzed for their phenolic content, antioxidant activity and flavonoids. The highest antioxidant capacity was observed for red onion, followed by yellow, white and grelot onion. MHG was the preferred extraction method in comparison to the conventional method, as all the samples obtained under microwave-assisted extraction (MAE) exhibited the highest antioxidant activities in all the tests. Also, the microscopic observations of extracted tissues showed that at cellular level, microwaves induced disruptions of vacuoles and cell walls thus promoting the effectiveness of this method.

Kaufmann et al. (2007) developed microwave-assisted extraction method for the extraction of diosgenin from **fenugreek (*Trigonella foenum-graecum*)** seeds, air-dried and fresh leaves and air-

Table 1 Optimized parameters for microwave drying of selected leafy spices

Leafy spices	Optimum condition	Quality parameters	Reference
Parsley (Petroselinum crispum Mill.)	Microwave oven drying 900 W (3.5min)	Drying rates, Color	Soysal, 2004
Mint leaves (Mentha spicata L.)	Microwave drying 900 W (3min)	drying kinetic, activation energy	Ozbek and Dadali, 2007
Rosemary (Rosmarinus officinalis L.)	Microwave oven drying 700 W (3.7 min)	drying kinetics, mineral content and color	Arslan and Ozcan, 2008
Mint (Mentha cordifolia Opiz ex Fresen)	Microwave vacuum drying 1920 W (12min) & 2240 W (10min)	Drying rates, Color, Rehydration capacity, SEM	Therdthai and Zhou, 2009
Peppermint leaves (Mentha x piperita L.)	Microwave oven drying 700 W (5.3 min)	Drying time, total phenolics, color values & mineral content	Arslan et al., 2010
Rosemary (Rosmarinus officinalis L.)	Convective pre-drying and VM finish-drying (CPD–VMFD) 480 W, 46°C (84 min)	Drying kinetics, Volatile compounds, sensory data	Szumny et al., 2010
Rosemary (Rosmarinus officinalis L.)	Vacuum–microwave drying 72–74 kPa and 360 W (39 min)	Drying kinetics, Volatile compounds, sensory data	Sanchez et al., 2011
Oregano (Origanum vulgare)	Vacuum-microwave drying 360 W, 4–6 kPa (24 min)	Drying kinetics, Volatile compounds, sensory data	Figiel et al., 2010
Coriander leaves (Coriandrum sativum L.)	Microwave drying 180 W (14 min)	Drying rates, Color, Rehydration capacity	Sarimeseli 2011
Sweet basil (Ocimun basilicum L.)	Convective pre-drying and VM finish-drying (CPD–VMFD) 360 W, 40°C (~250 min)	Drying kinetics, Volatile compounds, sensory data	Sánchez et al., 2012

dried roots. Extraction time, microwave power applied and percentage of 2-propanol in the extraction mixture as well as their interactions were studied in order to optimize the extraction efficiency. Response surface modelling was used to predict the extraction yield of diosgenin in selected matrices. The analysis of diosgenin in crude extracts was carried out using capillary GC-MS. It was reported that the percentage of 2-propanol must be maintained at a low value (40%) for all matrices, except seeds. The extraction times could be short for leaves (fresh and air-dried i.e. 5–8 min.), while for the other two (roots and seeds), longer periods (>20 min) are preferred.

Chemat et al. (2005) performed the microwave-assisted extraction of monoterpenes (carvone and limonene) from **caraway (*Carum carvi* L.)** seed and compared the process efficiency with conventional solvent extraction technique. The microwave-assisted extraction was carried out at 120 W for 60 min and found that yield of carvone had reached a steady state value of approximately 18 mg/g at 30 min. For limonene, the situation was slightly different, with a small spread of steady state yields (16–18 mg/g). Carvone and limonene have a different behaviour when microwaves were applied. Carvone, an oxidized terpene, absorbed better microwave radiation; thus, released rapidly. They concluded that the microwave procedure helps in rapid extraction and yielded an extract rich in carvone.

Di Cesare et al. (1995) used the microwave for extraction of aroma compounds from **basil (*Ocimum basilicum* L.)**. The aroma compounds were extracted through an *in situ* distillation. The aroma profile established using GC-MS revealed linalool, cineole, camphor, eugenol and methoxyeugenol are the main compounds in the extract. The extraction yield was dependent on the irradiation time and the microwave power used. Antonelli et al. (1998) studied the modifications of dried basil leaf oil by using gamma and microwave irradiation in comparison to the blank sample. The dried basil leaves were irradiated with gamma rays and microwaves. Forty-seven peaks were identified using capillary GC-MS. Contents of linalool and estragole increased with radiation and decreased with microwaves. They concluded that gamma radiation caused more evident changes in the composition profiles than the microwave treatment. Subsequently, a sensory test confirmed significant differences between the extracts. The panellists preferred the gamma radiation treated sample, while the microwave treated sample was the least appreciated.

Sui et al., (2012) reported an efficient microwave pretreatment (MP) method to sustain the quality of postharvest rosemary leaves. Carnosic acid (CA) and rosmarinic acid (RA) content in MP rosemary leaves was investigated under four storage conditions (sunlight, shade, −20°C, 55°C). Rosemary leaves after MP (800 W, 15 min) had much lower degradation rates of CA and RA than those of non-treatment samples during the storage period. Microwave pretreatment enabled higher retention of CA and RA in rosemary during storage. Pretreatment and essential oil extraction processes were simultaneously carried out. No differences were reported in yield or composition between essential oils obtained by MP and hydro distillation.

Applications of microwave radiation in the drying of leafy spices are summarized (Table 1). Isolation of essential oils and bioactive components from spices are tabulated in Table 2.

Table 2 Application of MAE in isolation of essential oils bioactive components from spices

Spices	Bioactive components	Method*	Optimum conditions	Reference
Piper nigrum L.	Piperine	MAE	150 W, non-polar solvents	Raman and Gaikar, 2002
Basil, mint, thyme	Essential oil	SFME	500 W, 100°C, 30 min	Lucchesi et al., 2004
Cuminum cyminum seeds	Essential oils	microwave heating	730 W for 10 min	Behera et al., 2004
Cuminum cyminum	Essential oils	Solvent-free (but adding microwave Absorption medium)		Wang et al., 2006
Capsicum Frutescens	Capsaicinoids	MAE	Ethanol, 5 min	Barbero et al., 2006
Elletaria cardamomum seeds	Essential oil	SFME	390 W, 100°C, 75 min	Lucchesi et al., 2007
Capsicum frutescens	Capsaicin	MAE	120°C, 150 W, 15 min with acetone as extractant	Nazari et al., 2007
Piper nigrum L. and Piper longum L.	Essential oil	microwave distillation and headspace solid-phase micro extraction (MD-HS-SPME)	DVB/CAR/PDMS fiber, 400 W, 4 min	Liu et al., 2007
Allium cepa	Polyphenols/ flavonoids	Solvent free microwave hydrodiffusion and gravity (MHG)	500 W, 1W/g, 23 min	Zill-e-Huma et al., 2011
Curcuma longa dried rhizomes	Curcumin	MAE	140 W, 5 min, acetone	Wakte et al., 2011

*SFME (solvent-free microwave extraction), MAE (Microwave assisted extraction), MD–HS-SPME (microwave distillation and headspace solid-phase micro extraction), MHG (microwave hydrodiffusion and gravity).

CONCLUSION

Generally spices undergo different processing techniques in order to achieve a high value added finished product. Conventional heating is characterized by surface heating, limited by heat transfer modes, heat surrounding the product unused. Whereas microwave heating is characterized by volumetric heating, fast and controllable, energy is directed to product and eco friendly. Microwave processing has different advantages that include high speed & short time of operation, high quality of product, higher power density, instant heating, no fouling of product, high efficiency and compatibility with other techniques. This technique has got different areas of applications like microwave assisted heating, drying, extraction and as well as a hybrid with the existing conventional techniques.

Despite of certain limitation of applicability it has got tremendous future prospects as this makes the processing conditions less destructive, more efficient and simultaneously highly economical. Many studies reveal its diverse application to produce a quality product, which is need of the hour. Lack of awareness among food manufacturers is the major stumbling block in liberal adoption of this technology. More research has to be carried out and more analytical data should be generated to widen its areas of applicability and standardization of various processing conditions. Microwave heating is so different from conventional heating and its use should be borne in mind, when technical problems arise with products and processes. It should also provide new thinking that may sometime results in improved traditional techniques. But also generate new ideas for future needs.

ACKNOWLEDGMENTS

Authors are thankful to Director, Central Food Technological Research Institute, Mysore, India and Head, Plantation Products Spices and Flavour Technology Dept. CFTRI, Mysore, India, for providing the facilities.

REFERENCES

Alfaro, M. J., Belanger, J. M. R., Padilla, F. C. and Pare, J. R. J. (2003). Influence of solvent, matrix dielectric properties, and applied power on the liquid-phase microwave assisted processes (MAP)^{TM} extraction of ginger (*Zingiber officinale*). *Food Res. Int.* **36**:499–504.

Allen, D. T. and Shonnard, D. R. (2002). Green engineering. Environmentally Conscious Design of Chemical Processes, Prentice Hall, Upper Saddle River, NJ.

Antonelli, A., Fabbri, C. and Boselli, E. (1998). Modifications of dried basil (*Ocinum basilicum*) leaf oil by gamma and microwave irradiation. *Food Chem.* **63**:485–489.

Arora, D. S. and Kaur, J. (1999). Antimicrobial activity of spices. *Int. J. Antimicrobial. Agents.* **12**:257–262.

Arslan, D. and Ozcan, M. M. (2008). Evaluation of drying methods with respect to drying kinetics, mineral content and color characteristics of rosemary leaves. *Energ. Convers Manage.* **49**:1258–1264.

Arslan, D. and Ozcan, M. M. (2010). Study the effect of sun, oven and microwave drying on quality of onion slices. *LWT - Food Sci Technol.* **43**:1121–1127.

Arslan, D. and Ozcan, M. M. (2011). Dehydration of red bell-pepper (*Capsicum annuum* L.): Change in drying behavior, color and antioxidant content. *Food Bioprod Process*. **89**:504–513.

Arslan, D., Ozcan, M. M. and Menges, H. O. (2010). Evaluation of drying methods with respect to drying parameters, some nutritional and color characteristics of peppermint (*Mentha x piperita* L.). *Energ Convers Manage*. **51**:2769–2775.

Barbero, G. F., Palma, M. and Barroso, C. G. (2006). Determination of capsacinoids in peppers by microwave assisted extraction high performance liquid chromatography with fluorescence detection. *Anal. Chimca. Acta.* **578**:227–233.

Baysal, T., Filiz I., Seda, E. and Hasan, Y. (2003). Effects of microwave and infrared drying on the quality of carrot and garlic. *Eur. Food Res. Technol.* **218**:68–73.

Behera, S., Nagarajan, S., and Jagan Mohan Rao, L. (2004). Microwave heating and conventional roasting of cumin seeds (*Cuminum cyminum* L.) and effect on chemical composition of volatiles. *Food Chem.* **87**:25–29.

Bouraoui, M., Richard, P. and Durance, T. (1994). Microwave and convective drying of potato slices. *J. Food Process Eng.* **17**:353–363.

Chemat, S., Amar, H. A., Lagha, A. and Esveld, D. C. (2005). Microwave-assisted extraction kinetics of terpenes from caraway seeds. *Chem. Eng. Process*. **44**:1320–1326.

Chen, X., Zhou, X., Li, B., Shao, H. and Zuo, Z. (2006). The extraction paprika red pigment by microwave-assisted technique. *Food Res. Dev.*, ISSN:1005-6521.0.2006-10-030.

Cui, Z., Xu, S. and Sun, D. (2003). Dehydration of garlic slices by combined microwave-vacuum and air drying. *Dry. Technol*. **21**:1173–1184.

Dandekar, D. V. and Gaikar, V. G. (2002). Microwave assisted extraction of curcuminoids from *Curcuma longa*. *Sep. Sci. Technol.* **37**:2669–2690.

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

Demirhan, E. and Ozbek, B. (2009). Color change kinetics of microwave-dried basil. *Dry. Technol.* **27**:156–166.

Di Cesare, L. F., Riva, M. and Schiraldi, A. (1995). Microwave extraction of basil aroma compounds. *Dev. Food Sci.* **37**:857–868.

Divya, P., Puthusseri, B. and Neelwarne, B. (2012). Carotenoid content, its stability during drying and the antioxidant activity of commercial coriander (*Coriandrum sativum* L.) varieties. *Food Res. Int.* **45**:342–350.

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

Edgar, R. H. (2001). Handbook of Microwave Technology for Food Applications, pp. 215, Datta, A. K. and Anantheswaran, R. C. Eds., Marcel Dekker, Inc., New York.

Farrell, K. T. (1990). Spices, Condiments and Seasonings, 2nd ed., AVI book, Van Nostrand Reinhold, New York, United States.

Feng, H., Tang, J., Cavalieri, R. P. and Plumb, O. A. (2001). Heat and mass transport in microwave drying of hygroscopic porous materials in a spouted bed. *AIChE J.* **74**:1499–1511.

Figiel, A., Szumny, A., Ortiz, A. G. and Angel A. C.-B. (2010). Composition of oregano essential oil (*Origanum vulgare*) as affected by drying method. *J. Food Eng*. **98**:240–247.

Gunasekaran, S. (1999). Pulsed microwave-vacuum drying of food materials. *Dry. Technol*. **17**:395–412.

Huang, B., Wang, G., Chu, Z. and Qin, L. (2012). Effect of oven drying, microwave drying, and silica gel drying methods on the volatile components of ginger (*Zingiber officinale* Roscoe) by HS-SPME-GC-MS. *Dry. Technol.* **30**:248–255.

Hudaib, M., Gotti, R., Pomponio, R. and Cavrini, V. (2003). Recovery evaluation of lipophilic markers from Echinacea purpurea roots applying microwave-assisted solvent Extraction versus conventional methods. *J. Sep. Sci.* **26**:97–104.

Kaufmann, B., Rudaz, S., Veuthey, J. L. and Christen, P. (2007). Influence of plant matrix on microwave-assisted extraction process. the case of diosgenin extracted from fenugreek (*Trigonella foenum*-graecum L.) *Phytochem. Anal.* **18**:70–76.

Korminn, Z., Ahmed, I., Yunus, R. M. and Yusof, Z. M. (2006). The potential of modified microwave extraction system to extract bioactive components from ferns. *Intl. J. Eng. Technol.* **10**:7–21.

Kubra, I. R. and Jagan Mohan Rao, L. (2012a). Effect of microwave drying on the phytochemical composition of volatiles of ginger. *Intl. J. Food Sci. Technol.* **47**:53–60.

Kubra, I. R. and Jagan Mohan Rao, L. (2012b). Microwave drying of ginger (*Zingiber officinale* Roscoe) and its effects on chemical composition and antioxidant activity. *Intl. J. Food Sci. Technol.* DOI: 10.1111/j.1365-2621.2012.03104.x.

Lee, K. and Shimbamoto, T. (2002). Determination of antioxidant potential of volatile extracts isolated from various herbs and spices. *J. Agric Food Chem*. **50**:4947–4952.

Lew, A., Krutzik, P. O., Hart, M. E. and Chamberlin, A. R. (2002). *J. Combinatorial. Chem.* **4**:95–105.

Li, X., Zhang, Y., Zhang, J. and Luo, Z. (2007). Study on extraction of active ingredient of turmeric by supercritical CO_2 and microwave combined technique. *Sci. Silvae Sinicae* **43**(5).

Li, Z., Raghavan, G. S. V. and Orsat, V. (2010). Temperature and power control in microwave drying. *J. Food Eng.* **97**:478–483.

Liu, L. (2007). Comparison study between hot air drying and microwave drying of fresh ginger. *Food Sci.*, ISSN:1002.

Liu, L., Guoxin, S. and Yaoming, H. (2007). GC–MS analysis of the essential oils of *Piper nigrum* L. and *Piper longum* L. *Chromatographica* **66**:785–790.

Lucchesi, M. E., Smadja, J., Bradshaw, S., Louw, W. and Chemat, F. (2007). Solvent free microwave extraction of *Elletaria cardamomum* L.: a multivariate study of a new technique for the extraction of essential oil. *J. Food Eng.* **79**:1079–1086.

Lucchesi, M. E., Chemat, F. and Smadja, J. (2004). Solvent-free microwave extraction of essential oil from aromatic herbs: comparison with conventional hydro-distillation. *J. Chromatogr. A*, **1043**:323–327.

Luigi, F. D. C., Elisabetta, F., Daniela, V. and Renato, C. N. (2003). Changes in the chemical composition of basil caused by different drying procedures. *J. Agric. Food Chem.* **51**:3575–3581.

Mandal, V., Mohan, Y. and Hemalatha, S. (2008). Microwave assisted extraction of curcumin by sample-solvent dual heating mechanism using Taguchi L9 orthogonal design. *J. Pharma Biomed. Anal.* **46**:322–327.

Mandal, V., Mohan, Y. and Hemalatha, S. (2007). Microwave assisted extraction- an innovative and promising extraction tool for medicinal plant research. *Pharmacognosy Rev.* **1**:7–18.

Maroulis, Z. B. and Saravacos, G. D. (2003). *Food Process Design*, 1st ed. Marcel Dekker, Inc., New York.

Maskan M. (2001). Drying, shrinkage and rehydration characteristics of kiwi fruits during hot air and microwave drying. *J Food Eng*. **48**:177–182.

Nazari, F., Ebrahimi, S. N., Talebi, M., Rassouli, A. and Bijanzadeh, H. R. (2007), Multivariate optimisation of microwave-assisted extraction of capsaicin from Capsicum frutescens L. and quantitative analysis by ^{1}H-NMR. *Phytochem. Anal.* **18**:333–340.

Nijhuis, H. H., Torringa, E., Luyten, H., Rene, F., Jones, P., Funebo, T., et al. (1996). Research needs and opportunities in the dry conservation of fruits and vegetables. *Dry. Technol*. **14**:1429–1457.

Ohlsson, T. (1989). Dielectric properties and microwave processing. In *Food Properties and Computer-Aided Engineering of Food Processing Systems* (eds.) Singh R. P. and Medina, A. G. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Okos, M. R., Narasimhan, G., Singh, R. K. and Witnaurer, A. C. (1992). Food dehydration. In Hedman, D. R. and Lund, D. B. (eds.). *Hand Book of Food Engineering*, Marcel dekker, New York.

Ozbek, B. and Dadali, G. (2007). Thin-layer drying characteristics and modelling of mint leaves undergoing microwave treatment. *J. Food Eng*. **83**:541–549.

Pedraza-Chaverri, J., Gil-Ortiz, M., Albarran, G., Barbachano-Esparza, L., Menjivar, M. and Medina-Campos, N. (2004). Garlic's ability to prevent in vitro Cu^{2+}-induced lipoprotein oxidation in human serum is preserved in heated garlic: effect unrelated to Cu^{2+}-chelation. *Nutrition J.* **3**:10.

Pedraza-Chaverrı, J., Campos, O. and Murillo, S. (2007). Effect of heating on peroxynitrite scavenging capacity of garlic. *Food Chem. Toxicol.* **45**:622–627.

Peter K. V. (2004). *Handbook of Herbs and Spices 2*. Woodhead Publishing Ltd., Cambridge, England and CRC press, United States.

Peter, K. V. (2001). *Handbook of Herbs and Spices*. Woodhead Publishing Ltd., Cambridge, England and CRC press, United States. pp 17–23.

Piyasena, P., Dussault, C., Koutchma, T., Ramaswamy, H. S. and Awuah, G. B. (2003). Radio frequency heating of foods: Principles, applications and related properties-A review. *CRC-Reviews Food Sci. Nutrit.* **43**:587–606.

Prabhanjan, D. G., Ramaswamy, H. S. and Raghavan, G. S. V. (1995). Microwave-assisted convective air drying of thin layer carrots. *J. Food Eng*. **25**:283–293.

Raghavan, G. S. V., Orsat, V. and Meda, V. (2005). Microwave processing of foods. *Stewart Postharvest Rev.* **3**:1–7.

Raman, G. and Gaikar, V. G. (2002). Microwave-Assisted Extraction of Piperine from *Piper nigrum*. *Ind. Eng. Chem. Res.* **41**:2521–2528.

Rao, L. J.M, Singh, M., Raghavan, B. and Abraham, K. O. (1998). Rosemary *(Rosmarinus officinalis* L.): Impact of drying on its flavor quality. *J. Food Qual.* **21**:107–115.

Rao, P. P., Allani N., Rao, L. J. M. and Rao, D. G. (2007). Studies on the effects of microwave drying and cabinet tray drying on the chemical composition of volatile oils of garlic powders. *Eur. Food Res. Technol*. **224**:791–795.

Ravindran, P. N., Johny, A.K and Nirmakbabu, K. (2002). Spices in our daily life. *Satabdi Smaranika*, Vol. **2**. Arya Vaidya Sala, Kottakkal, India.

Sagdic, O. and Ozean, M. (2002). Antibacterial activity of Turkish spice hydrosols. *Food Control*. **14**:141–143.

Salah, A. A. (2004). Inactivation of trypsin and chymotrypsin inhibitors in fenugreek (*Trigonella foenumgraecum* L.) defatted seed flour. Food Science and Agricultural Research Center, King Saud University, Saudi Arabia, **130**:5–17.

Sánchez, A. C., Lech, K., Szumny, A., Figiel, A. and Ángel A. C.-B. (2012). Volatile composition of sweet basil essential oil (*Ocimum basilicum* L.) as affected by drying method. *Food Res. Intl.* **48**:217–225.

Sanchez, A. C., Szumny, A., Figiel, A., Jałoszynski, K., Adamski, M. and Barrachina, A. A. C. (2011). Effects of vacuum level and microwave power on rosemary volatile composition during vacuum–microwave drying. *J. Food Eng.* **103**:219–227.

Sarimeseli, A. (2011). Microwave drying characteristics of coriander (*Coriandrum sativum* L.) leaves. *Energ. Convers Manage.* **52**:1449–1453.

Sharma, G. P. and Prasad, S. (2001). Drying of garlic (*Allium sativum*) cloves by microwave-hot air combination. *J. Food Eng.* **50**:99–105.

Sharma, G. P. and Prasad, S. (2006a). Optimization of process parameters for microwave drying of garlic cloves. *J. Food Eng.* **75**:441–446.

Sharma, G. P. and Prasad, S. (2006b). Specific energy consumption in microwave drying of garlic cloves. *Energy* **31**:1921–1926.

Sharma, G. P., Jain, S. K., Verma, R. C., Chahar, V. K. and Bakal, S. (2009). An economic analysis of microwave drying of garlic cloves. *Indian Food Ind.*. **28**:45–52.

Shylaja M. R. and Peter K. V. (2004). The functional role of herbal spices, In: *Handbook of Herbs and Spices 2*. pp 25–35, Peter K. V., Ed., Woodhead Publishing Ltd., Cambridge, England and CRC press, United States.

Soysal, Y. (2004). Microwave drying characteristics of parsley. *Biosystems. Eng*. **89**:167–173.

Soysal, Y., Ayhan, Z., Esturk, O., and Arıkan M. F. (2009). Intermittent microwave–convective drying of red pepper: Drying kinetics, physical (color and texture) and sensory quality. *Biosystems Eng*. **103**:455–463.

Soysal, Y. and Oztekin, S. (2001). Comparison of seven equilibrium moisture content equations for some medicinal and aromatic plants. *J. Agric. Eng. Res*. **78**:57–63.

Soysal, Y., Oztekin, S. and Eren, O. (2006). Microwave drying of parsley: Modelling, kinetics, and energy aspects. *Biosystems Eng*. **93**:403–413.

Spiess, W. E. L., Beshnilian, D. (1998). Osmotic treatments in food processing. Current state and texture needs. In: *Proceedings of the 11th International Drying Symposium (IDS'98)*, vol. A. Ziti Editions, pp. 47–56, Akritidis, C. B., Marinos-Kouris, D., Saravacos, G. D. Eds., Thessloniki, Greece.

Starmans, D. A. J. and Nijhuis, H. H. (1996). Extraction of secondary metabolites from plant material: a review. *Trends Food Sci. Technol*. **7**:191–197.

Sui, X., Liu, T., Ma, C., Yang, L., Zu, Y., Zhang, L. and Wang, H. (2012). Microwave irradiation to pretreat rosemary (*Rosmarinus officinalis* L.) for maintaining antioxidant content during storage and to extract essential oil simultaneously.*Food Chem.* **131**:1399–1405.

Sutar, P. P. and Prasad, S. (2008) Microwave drying technology-recent developments and R&D needs in india. In proceedings of 42nd ISAE Annual Convention, February 1–3.

Szumny, A., Figiel, A., Ortiz, A. G. and Barrachina, A. A. C. (2010). Composition of rosemary essential oil (*Rosmarinus officinalis*) as affected by drying method. *J. Food Eng.*. **97**:253–260.

Tang, J. (2005). Dielectric properties of foods. In: *The Microwave Processing of Foods*. pp. 22–40, Schubert, H. and Regier, M., Eds., Woodhead Publishing, Cambridge, United Kingdom.

Therdthai, N. and Zhou, W. (2009). Characterization of microwave vacuum drying and hot air drying of mint leaves (*Mentha cordifolia* Opiz ex Fresen). *J. Food Eng.* **91**:482–489.

Tian, D. and Yang, R. (2006). Influence on the extraction of antioxidants in ginger by microwave irradiation treatment. *China Condiment.* SUN: ZGTW.0.2004-02-00

Vadivambal, R. and Jayas, D. S. (2007). Changes in quality of microwave-treated agricultural products-a review. *Biosystems Eng.* **98**:1–16.

Vega-Mercado, H., Gongora-Nieto, M. M. and Barbosa-Canovas, G. V. (2001). Advances in dehydration of foods. *J. Food Eng.* **49**:271–289.

Wakte, P. S., Sachin, B. S., Patil, A. A., Mohato, D. M., Band, T. H. and Shinde D. B. (2011). Optimization of microwave, ultra-sonic and supercritical carbon dioxide assisted extraction techniques for curcumin from *Curcuma longa*. *Sep. Pur. Technol.* **79**:50–55.

Wang, Z., Ding, L., Li, T., Zhou, X., Wang, L., Zhang, H., Liu, L., Li, Y., Liu, Z., Wang, H., Zeng, H. and He, H. (2006). Improved solvent-free microwave extraction of essential oil from dried *Cuminum cyminum* L. and *Zanthoxylum bungeanum* Maxim. *J. Chromatogr. A.* **1102**:11–17.

Williams, O. J., Raghavan, G. S. V., Orsat, V. and Dai, J. (2003). Microwave-assisted extraction of capsaicinoids from capsicum fruit. *J. Food Biochem.* **28**:113–122.

Yousif, A., Scaman, C., Durance, Y. and Girard, B. (1999). Flavor volatiles and physical properties of vacuum-microwave and air-dried sweet basil (*Ocimum basilicum* L.). *J. Agric. Food Chem.* **47**:11.

Yu, Li., Xu, S. Y. and Sun, D. W. (2007). Preparation of garlic powder with high allicin content by using combined microwave-vacuum and vacuum drying as well as microencapsulation. *J. Food Eng.* **83**:76–83.

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

Zill-e-Huma , Vian, M. A., Tixier, A. S. F., Elmaataoui, M., Dangles, O. and Chemat, F. (2011). A remarkable influence of microwave extraction: Enhancement of antioxidant activity of extracted onion varieties. *Food Chem.* **127**:1472–1480.