Microwave Applications in Food Processing: An Overview

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ABSTRACT

In the recent years, the industrial applications of microwaves have been popular all over the world. Microwave heating has been applied in a wide range in the food processing such as cooking, blanching, drying, thawing, tempering, baking, pasteurization and sterilization. Microwave energy has many advantages than conventional heating. The present review aimed to investigate the heating of microwave and its applications in the field of food processing. Furthermore, focus on the advantages and disadvantages of microwave heating and comparison between the traditional heating methods and the heating using the microwave energy on the quality of the food products will be also highlighted. The advantages of pasteurization and sterilization of fresh juices,food fluids and other food products and their ability to exhibit inhibition for the most microorganisms at lower temperatures than the usual heating methods have been discussed. Also, using the microwave heat in drying food products suchas microwave assisted air drying,freeze drying followed by microwave, vacuum drying combined by microwave and using drying by microwave combined with the conventional drying methods were reviewed.

Keywords: Microwave, drying, cooking, blanching, baking, thawing, and pasteurization.

INTRODUCTION

Microwave was principally used for communication during the Second World War with the development of radar. Presently, the microwave heating had become so accepted all over the world. Microwave oven has become one of the common household appliances which is used for food preheating, cooking, and tempering of frozen foods. The microwave is the novel tool to attain consumer demands for food and more easier in use and saving time in its preparation. Recently, most food industries use microwave to heat, dry and sterilize many food products. Microwaves have been used successfully in many foods processing such as cooking, blanching, drying, thawing, tempering, baking, pasteurization and sterilization. Microwave heating has many benefits as compared to the conventional heating methods. These advantages are;speed of heating, saving energy, short times for start-up and shut down to reach the desired temperatures. The heat is generated throughout the food and has greater penetration depth. Also, about 80% or higher heating efficiency can be obtained. Moreover, the heating is clean,noiseless and no burned out gas is generated. It is suitable for heat- sensitive food products and multiphase fluids. Other advantages include products of good quality in terms of flavour, taste, texture, colour and nutritional contents (Ahmed & Ramaswamy, 2007, Tewari, 2007,Chavan & Chavan, 2010, Kalla & Devaraju, 2017).

The principle of microwave heating:

Microwave is one of the electromagnetic radio wave. The radio wave which has a frequency band ranging from 300 MHz to 300 GHz is known as microwave. Two frequencies (915 and 2450 MHz) are used for microwave processing. The Microwave heating is given by the interaction between dipolar water molecules orcharged ions and electromagnetic field. When food is placed in a microwave oven, the behavior of food contents is different. The water is the principle component that absorbs heat and make food to be heated. The food which has a high level of moisture being the faster in heating. Water acts like a magnet. It has two ends opposite in charge, 2 hydrogen atoms (positive charge) and oxygen molecule (negative charge). So, water in food behaves as a magnet. Therefore, when microwave oscillate the water molecule, it will rotate due to its different poles. This because the positively charged end of water will attracts to the negative end of microwave. Meanwhile, the end of water which has a negative charge will attracts to the microwave positive end. Heat will generate as a result of molecular friction due to the rotation of dipolar molecule. Due to the strong dipole rotation of water, it is the first component which reacts with microwaves and

produce heat. The microwaves rotate at very high speed of 2450 time / sec. So, the water molecules will rotate 2450 time/ sec. The water molecules will crash each other very fast to produce heat as the result of the rotation. This heat flows by convection, conduction or radiation through the food to warm it up (Fig. 1) (Kalla & Devaraju, 2017).

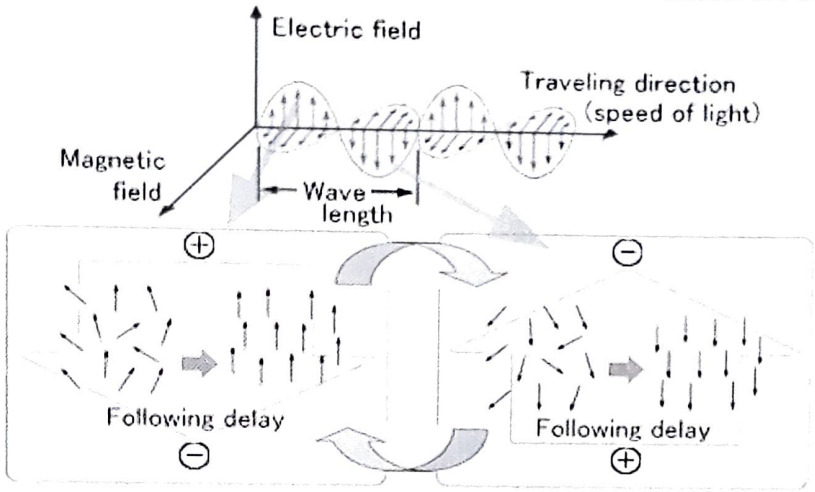

Fig. 1: Microwave heating formula and the dielectric properties of materials (Lehpamer, 2010)

Microwave travel similar to light waves. Microwave heating has some characteristics which are not found in the other conventional heating methods. These are: 1- internal heating. 2- select and rapid heating 3- clean energy and uniformity 4- rapid response and easy to control. (Figs. 2 & 3). (Oliveira &Franca, 2002, Ahmed & Ramaswamy 2007, Marra, *et al*, 2009, 2010).

Microwave applications in food processing:

Cooking

Cooking with microwave is the most familiar application of microwave at the entire world. Microwave heating is very rapid and the food products reach the desired temperature in a short time. Cooking using microwave heating is suitable for the small amounts of foods(Sukhwant, *et al.*, 1992).

The physical and chemical properties of vegetables are changed as a result of cooking in boiling water. Also, some reduction in dietary components were observed in cooked vegetables by microwave heating(Sukhwant, *et al*, 1992, Zia-ur-rehman, *et al*, 2003, Zhang & Hamauzu, 2004).The advantages of cooking by microwave are less loss of moisture content and minimal loss of nutrients of foods. Also, its speed, saving in energy and uniform heating through the food products.Because microwave heating penetrates inside the food materials, so, cooking occurred internally and rapidly through the whole volume of the food, which reduces the cooking time and energy. Moreover, because the transfer of heat is fast, flavour, colour, vitamins and most the food nutrients will be well preserved (Puligundla, *et al.*, 2013).

Many studies on the effect of cooking using microwave heating on the food ingredients were investigated. A reduction in energy consumption was noted due to the benefits of cooking using microwave oven for raw and soaked rice comparing to the cooking in boiling water. The brown rice cooked by microwave retained higher levels of protein, fat, and ash contents as compared to steaming and conventional boiling methods (Lakshmi *et al*, 2007). When the legumes such as common beans and chickpeas

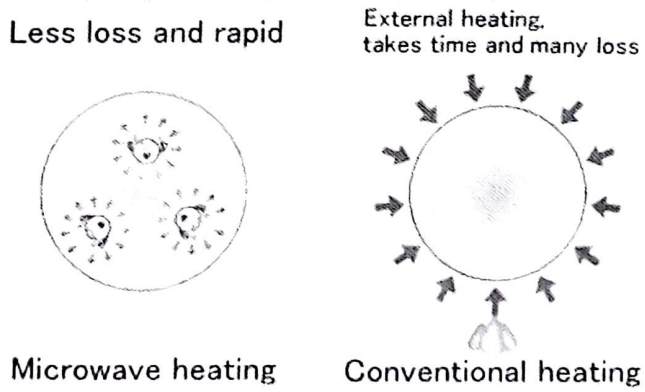

Fig. 2: Microwave heats object internally (Lehpamer, 2010)

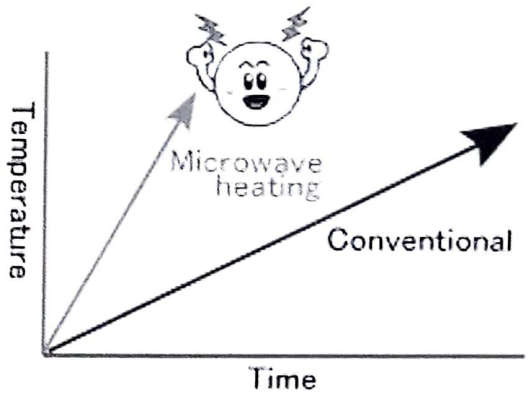

Fig. 3: Microwave heating is fast (Lehpamer, 2010)

were cooked by microwave, the time for cooking was short and they retained higher levels of the major minerals (Ca, Na, K, and Mg) and the minor ones (Fe, Cu, and Zn) comparing with the traditional cooking methods (Marconi, *et al*, 2000, Arab, *et al*, 2010).

Baking

The baking process is the first commercial application of microwave energy. At 2450 MHz, the first bread baking was reported by Ahmed& Ramaswamy(2007). Baking is an important process in bakery industry. The dough expand during the baking process and have high volume, losses in moisture and at the final stage the moisture loss decrease as a result of the falling down of air cells in the dough due to the increased vapor pressure (Mondal, & Datta, 2008).

Many advantages are found for using microwave in baking industry such as short time, small-space, preserves nutrients and save energy as compared to conventional baking. Some problems are noted when baking is carried out using microwave heatingonly such as tough and quite hard texture, dry and loss of flavour and colour. Also, many studies reported that there were some problems related to the microwave bread baking such as the lack of crust formation, surface browning, less firm texture, low volume, lack of colour and rapid staling. Also, some defects were found in cakes baked by microwave such as low volumes, tough textures, lack of colour, high weight loss (Scanlon & Zghal, 2001, Sumnu,2001).

Therefore, recently the combination of microwave with thermal energy (conventional or infrared baking)is investigated by many researchers to produce crust loaf in short time to avoid the absence of crust formation and the brown colour of loaf surface. The combination of traditional heat source with microwave energy succeeded to decrease the baking time by 50 % (Sumnu, 2001, Sumnu, *et al*, 2005,Yolacaner, *et al*, 2017)

The European soft wheat with high ά- amylase can be used with the combined process. This because the microwave heating was uniform to rise in the whole product. Therefore, the inhibition of ά-amylase is fast enough to prevent extensive damaged starch (Tewari, 2007).

Goedeken, *et al* (1997) reported that the power of microwave oven should be adjusted to avoid the water loss during bread baking. Sumnu, *et al*, (2005) reported that doughnut proofing by microwave heating can be completed in 4 min only comparing with 40-60 min by traditional heating methods. Also, using microwave heating in baking cookies at the final stages resulted in producing products without cracking andhave good properties.

During the conventional baking, the conductive and radiant heat heated the products from outer surface. This causes some structural changes in the ingredients of the dough such as the gelatinization of starch, denaturation of protein, increase in the volume and crust formation. While, microwave radiation interacts with water molecules, that results in the structure changes and water movement (Therdthai & Zhou, 2003). The heating mechanism in the microwave differs from the conventional methods. In the microwave the energy absorption results in internal heating and generates internal vapor pressure (Yolacaner, *et al*, 2017).

Ahmad, *et al.* (2001) studied the radiation of high- frequency and their effect on the quality of biscuits which baked in a convection oven, followed by baking immediately in microwave oven for 30 sec. Baking by microwave reduced checking in biscuits to 5 % as compared with 61% in conventional baking and less affected to checking when exposure to high humidity.

Microwave baking do not have the ability to form browning as the conventional methods in baked products (Chavan&Chavan, 2010). Durairaj, *et al.*(2009) reported that ceramic layer is useful in decrease the thermal runaway and enhance the power absorption in food samples by the ceramic layers in the microwave oven.

Some studiesfound that using microwave ovens provide with infrared heating will enhance the quality of the baked products (Datta & Ni, 2002, Sevimli, *et al.*, 2005). Today the most important use of microwave heating is in the final stages of the baking industry, when the conventional processes lead to longer baking times (Kumar, 2015).

Drying:

The food preservation by drying process is used for many products, especially fruits and vegetables to extend self-life (Doymaz, 2006). So, new methods are used to shorten the drying time and decrease of the consumption of energy. The benefits of microwave heating are its penetration depth and the uniform heating. Microwave drying is used

to shorten drying time to an extent of about 90-95%and saving energy consumption as compared with the conventional air drying. Also, only 20-35% of the floor is needed for microwave system (Maskan, 2000, Ahmed &Ramaswamy, 2007).

Microwave drying of food is used in the final stage (falling period) of drying food products because the migration of water from the center of the products is decreased. The mechanism of drying with microwave is different from the traditional hot air drying method. Drying food using microwave heating, the heat is generated through the product causing higher heat transfer. Also, the temperature rises more faster than in conventional drying (Gowen, *et al*, 2008, Chandrasekaran, *et al*, 2013,Gaukel, *et al*, 2017).

The microwave drying cause too much high temperature at the edges of the food products during the final stages of drying which results in production off flavours. So, the use of microwave drying in food processing at a commercially industry was for drying products in the final stage of drying. In the food industry it could be used two – stage drying process involving conventional drying at the initial stage using forced air followed by microwave drying (Ahmed& Ramaswamy, 2007). It was found that the drying time of banana slices reduced by 64% when hot air drying combined with microwave (at 350 W), as compared to the air drying method (at 60°C). The banana samples took place a longest time in the falling rate period by air drying. Meanwhile, the samples were lighter in colour and, the product had excellent taste, no shrinkage and good flavour (Maskan, 2000, Chandrasekaran *et, al*, 2013, Kumar, 2015).

Bouraoui, *et al*,(2007) studied three different methods for drying potato slices (microwave heating, convective drying and combined microwave and convective drying). The results showed that the drying by microwave heating producing dried potato slices of better quality and reducing drying time. Microwave drying at low power have a good effect on the quality of dried apple slices. The coating material affects the textural quality of the slices such as texture strength(Askari, *et al*., 2006).

Pasta is made from semolina by steps include, hydration, mixing, kneading and extruding to obtain the different shapes then drying. The drying step is the difficult and critical to obtain pasta of high quality. It is difficult because the moisture migrates slowly to the surface when hot air is used. Using microwave heating will provide a positive moisture flow to the surface. In many countries, pasta products and noodles are dried successfully by microwave at 915 MHz at a commercial scale (Goksu *et al*., 2005).

Szadzińska, *et al*.(2019) investigated the microstructural alteration, and rehydration properties of the dried raspberry using drying with the application of microwaves (MW) and ultrasound (US) and convective drying (CV) as a reference method. The results showed significantly shorter drying time by 54–64% for CV followed by US and 69% for CV combined by MW comparing to CV. Also, and a lower energy consumption resulting in energy saving of 14to 23% for CV followed by US and 54% for CV combined with MW, as compared to CV.

Ultrasound and microwaves were applied in drying red beetroot using convective drying continuously (hybrid processes) or periodically (hybrid intermittent processes). The drying processes were evaluated in terms of drying time, drying rate, and energy consumption. Furthermore, the total colour change, retention of natural dye (betanin), water activity, texture, and microstructure of dry product were examined. It was found that hybrid intermittent drying reduces the total drying time and energy consumption, enhances both the drying rate and product quality, it was demonstrated that the hybrid intermittent drying can serve as an alternative to conventional hot air drying that could produce a more porous, nice colour, and crispy vegetable products (Szadzińska, *et. al*.,2020).

Microwave assisted vacuum drying, Zhang *et al*. (2006) reported that the thermal efficiency has been improved when microwave was combined with vacuum drying. Microwave vacuum drying was used for various cereal grains, concentration of citrus juice and for production of grape puffs. Many studies reported that microwave applications were used for drying fruits and vegetables (Marra, *et al*, 2010)

Zielinska *et. al*. (2019) investigated hot air convective drying (HACD) and microwave vacuum drying (MWVD) on the drying kinetics and quality of whole cranberries in terms of texture. It was found that drying times were shorter for the samples dried by MWVD as compared to the samples dried by HACD. Moreover, cranberries processed by MWVD were significantly had greater hardness, gumminess, and chewiness as compared

to HACD samples. Also, the texture was hard and crispy and resistance to stress associated with manufacturing, packaging and storage. Meanwhile, HACD produced brittle fruits that were difficult to store and transport and were not fully suitable for direct consumption. Furthermore, when freezing was followed by MWVD the overall appearance of cranberries was improved.

Freeze drying is the method used to preserve the sensitive food products in good quality. It needs a long processing period and consumed great amount of energy. So, microwave can help the freeze drying to produce food products of high quality similar to that of vacuum freeze drying and can shorten the drying period effectively .The drying rate in microwave freeze drying of cabbage was more effective than that of vacuum freeze drying (Kalla&Devavju, 2017)

The falling rate period in the fluidized bed dryers is long drying time. However, using microwave heating combined with fluidized bed dryers can overcome this disadvantage (Chen, 2001, Puligundla*et al*, 2013, Kumar, 2015)

Using vacuum drying can produce a more porous dehydrated products compared by air dried products. Drying by hot air had many disadvantages such as lengthy time and low energy efficiency. This is due to the rapid reduction of surface moisture transfer. This resulted in reducing the quality of food. So, to overcome these disadvantages microwave was combined with hot air drying (Masken, 2001, Sharma & Prasad, 2001).

Botha *et al*, (2012) found that when using osmotic dehydration for drying pre- heated samples of pineapple, they were dried quickly by using microwave at different power conditions and had a good quality.

Carrot slices dried with microwave vacuum drying contained high content of ά - carotene and vitamin C, also had soft texture and good colour than that of air drying. Also, carrot slices dried at 400 W power by microwave retained about 88% of its ß - carotene (Mayer-Miebach, *et al*, 2005).The kinetics and drying properties of potato slices were studied using different microwave powers and vacuum pressure by Song, *et al*, (2009).

Blanching

In the blanching process the food products are exposure to boiling water, steam or boiling solutions containing salts or acids to inactivate the enzymes which catalyze the oxidation of food products and cause undesirable changes in texture, colour and flavour of the food products. This process is an essential step in food processing such as canning, drying and freezing. Also, blanching serves to decrease the microbial load of the food products and eliminate dissolved oxygen from the food (Maskan, 2000, Ahmed & Ramaswamy, 2007).

In general, hot water or steam is commonly used in the blanching step in the food industry. The traditional blanching method is associated with a reduction in weight and leaching some nutritive components such as sugars, water soluble vitamins and minerals (Maskan, 2000, Ramesh, *et al*, 2002).

To keep the nutritional quality of food products, microwave blanching can be used to reduce the leaching of nutrients in water, since it requires little amount of water for efficient heat transfer in food products (Ponne, *et al*, 1994, Ramesh, *et al*, 2002, Lin & Brewer, 2005,Puligundla, *et al*, 2013).

The advantages of blanching using microwave compared with traditional methods include saving consumed energy, speed of operation, no additional water requirement, precise process and faster times for start - up and shut down. The combination of microwave heating with initial hot water or steam could provide an excellent economic benefit. Steam or low cost hot water were used first to raise the temperature, then microwave heating does the more difficult and the high cost of internally blanching stage of food products. Furthermore, blanching by microwave will finish the blanching of the centers quickly regardless to the thick or non-uniform sections (Shaheen, *et al*, 2012).

Also, when using microwave to inactivate enzymes (peroxidase, catalase, polyphenol oxidase and pectinase), a reduction in time and energy were achieved as compared with the traditional methods. Furthermore, the bioactive compounds were enhanced and avoid the leaching effect of water blanching for the phytochemicals due to the short time required by microwave blanching. The food materials blanched with microwave include vegetables, fruits, leaves, tubers, and mushrooms (Dorantes- -Alvares *et al*, 2017, Kalla & Devaraju, 2017).

Using microwave heating in blanching process was preferred than using hot water or steam in blanching step because leafy vegetables can retain its maximum green colour, vitamin C (ascorbic acid)

and chlorophyll contents. Also, it is more effective in retaining water-soluble vitamins and other nutrients as compared to the traditional blanching methods. Microwave heating were carried out for blanching many vegetables like, carrots, mushroom, sweet potato, peas, pepper, beet and green beans. Furthermore, maximum retention of red pigments and total antioxidant activity were found in all the treatments (Severini, *et al*,2016,Wang *et al*, 2017).

However, using the microwave heating can lead to some problems such as non-uniform for heating and distribution of the energy which causes hot and cold points in the product (Chandrasekaran, 2013, Xiao, *et al* , 2017).

Pasteurization and sterilization:

Pasteurization is the process that uses relatively mild heat treatment on foods. The main goals of pasteurization are to destroy pathogenic microorganisms and inactivate some enzymes in foods. It is usual method used to extend the storage period and shelf-life of food products to make food safe for consumption like milk and fruit juices, where minimum process is necessary to minimize health-associated. The absorbed energy from microwave causes a rise in the temperature of the food to be high enough to destroy the pathogenic microorganisms such as bacteria by thermal treatment and to inactivate the undesirable enzymes in foods (Nott & Hall, 1999, Tewari, 2007, Guo, *et al*,2017).

Pasteurization can be achieved by many methods such as ohmic heating, non-thermal technologies (UV light, high hydrostatic pressure, high intensity ultrasound, pulsed electric field and ionizing radiation)(Pereira& Vincente, 2010).

Microwave destroys the microorganisms at sublethal temperatures can be explained by different theories:1-The theory of selective different heating: the microorganisms are selectively heated to higher temperature than the fluid surrounding it and killed very quickly. 2- Electroporation theory: the cell membrane had pores as a result of electrical potential, which causes the drainage of cellular materials. 3- Cell membrane method: the voltage applied causes rupture in the cell membrane. 4- Magnetic field theory: the coupling electromagnetic energy causes disrupted of some components of the cell like protein of the DNA. Also, the polar and / or charged moieties of proteins (COO^- and NH_4) are affected by the electrical component of the microwaves and the disruption of non- covalent bonds by microwaves cause of speedy microorganisms' death (Kozempel, *et al*, 1998, Koulchma, *et al*.2001).

Salazer-Gonzalez, *et al*, (2012) reviewed the using of microwave pasteurization of many liquid foods such as different fruit juices, milk, coconut milk and sweet potato puree and they reported that desired lethality could be obtained. Microwave pasteurization of ready-to-eat meals has also been found to be a commercial success in European countries although US industries are still reluctant to use this technology. Moreover, microwave pasteurization of packaged products is possible for different packaging materials (plastic, paper, and glass).

It was found that pasteurization of eggs shell by microwave can be achieved without losing the shell integrity. Also, the inhibition of Salmonella in the yolk of eggs can be obtained by microwave pasteurization. About 22% reduction of microbes was attained for microwave heating for 15 sec. Whereas, about 36% reduction was obtained using moist heat treatment for 15 min (Dev, *et al*., 2008,Shenga, *et al*., 2010).

Sterilization is a more severe thermal treatment of foods. The process is designed to achieve commercial sterility of the food products, giving it long-term shelf foods. The traditional heat sterilization is mainly carried out by heating and is characterized by slow heat transfer and long sterilization time, which seriously affects the quality of food products. Therefore, microwave heating has the advantage of overcoming the limitation imposed by slow thermal diffusion of conventional heating. Some researchers have claimed non-thermal or enhanced thermal effects, to be associated with microwave heating on the destruction of microorganisms and inactivation of enzymes (Ahmed, & Ramaswamy, 2007, Kalla, & Devaraju, 2017). To preserve fluid foods, the process of high – temperature short- time (HTST) has been used to avoid the thermal degradation in food quality. But for solid foods, the HTST is not suitable due to the slow penetration of heat and overheating of the solid surface during the time of heating. Meanwhile, heating by microwave will overcome the slow heat penetration of traditional heating methods. The heat produced by microwave will shorten the time of heating as compared to the commercial sterilization (Ahmed& Ramaswamy, 2007, Vadivambal & Jayas, 2010).

Sterilization of food products packed in different materials can be achieved by using new techniques like microwave irradiation, Ultra Violet light (UV), cold plasma and ozone. Some packaging materials may migrate into food materials. Benzene may be produce as a result of the high temperature of microwave heating due to the leaking of some polymers or adhesive components of packaging materials. So, paper, glass and ceramics were preferred for using in microwave packaging (Guilard, *et al.*, 2010, Chandrasekaran, 2013). When macaroni packed in pouches with cheese were preserved by sterilization using heat of microwave at 950 MHz, no changes in the taste, texture or flavour of the products were observed (Esteve, *et al.*, 1998). According to U.S. Food and Drug Administration (FDA) (2019) the non-thermal inactivation effect of microwave process on the destruction of microorganisms and inactivation of enzymes is not sufficient to use in sterilization of all types of food. It is recommended to include only thermal effects in the models. The sterilization of potatoes and fish fillet using in pouches was approved recently by the FDA. The process was carried out by dipping the food package in boiling or hot water and usingthe heat of microwave at a frequency of 950 MHz. The food pathogens and spoilage bacteria will be eliminated in 5 to 8 min and the products were safe and have good quality (Brody, 2012).

Several studies demonstrated that the application of microwaves in the sterilization of foods is limited due to the uneven heating of the product during sterilization. Also, the temperature of the product at some locations does not reach the real temperature distribution during microwave heating. Other researchers reported that replacement of the conventional heating by microwave energy as only heating source is impossible without understanding the real heating and inactivation mechanisms, temperature distribution in all layers of foods and other critical factors. To distinguish between thermal and no thermal effects on destroying microorganisms, most studies used the experiments under identical heating conditions to evaluate the inactivation effects of conventional and microwave heating. The major drawback in the microwave sterilization is the lack of availability of actual temperature profiles. Measurement of temperatures at some locations does not guarantee the real temperature distribution in the food product during heating by microwave (Nguyen, *et al* 2013, Peng, *et al*, 2017 Michalak, *et al*, 2020).

Thawing and tempering:

Thawing of frozen food products is the reversal process of freezing. Thawing is the process used for change the frozen products from frozen state to reach temperature of 0°C and be free from ice (unfrozen state) or defrosting. Before cooking the frozen foods should be thawed, to be sure that the food during cooking is sufficiently heated to destroy the spoilage microorganisms. When conventional thawing methods are used, it will take a long time, the outer surface of food product will be the first area which rise in the temperature and results in bacteriological and chemical deterioration. Thawing using hot air or water will subject the outer surfaces of frozen meat blocks to high temperatures for a long time. Microwave heating is usually used for thawing food products because its heat is generated from the center to the surface and the process will be more faster than the conventional thawing (Shaheen, *et al.*, 2012, Kalla & Devaraju, 2017).

The heating of microwave is usually used for thawing frozen bread. It was reported that some bakery products thawed or heated by microwave have low quality, due to presence of some bad properties such as lack of browning, low volume, flavour changes, tough, difficult to chew crumb and bread staling after short time of heating (Sumnu, 2001).

The disadvantagesof using microwave in thawing process are the phenomenon of runaway heating due to the unbalance in heating and the higher amount of power absorption in liquid parts of the materials. So, it is important to adjust the heat produced by the microwave ovens. At commercial practice few quantities of frozen products such as frozen meat, vegetables, fish, fruits and juice concentrates are thawed by microwave heating (Kalla & Devaraju, 2017).

The tempering process is usually carried out at temperature below freezing point (generally bellow- 18°C) and ranged between -5 to -2°C, where the water in the food product is turned to ice but not all the quantity of water changed to ice. At this temperature the product will be strict but not hard. Many studies reported that complete thawing the frozen foods completely by microwave is not practical. Therefore, tempering by microwave showed great benefits and can be used instead or alternative to thawing. At the tempering temperature, the texture and the product firmness are intact and permits

further processing without causing harm. Tempering is more commonly used in the technique for the products that are subsequently required size reduction, and it is quicker than the thawing. Tempering also reduces problems such as drip in the frozen products and bacterial growth that are associated with the thawing. Furthermore, it can handle large amounts of frozen product at small cost, has a high yield, and is accomplished in small spaces with no bacterial growth compared to traditional tempering techniques either with water or air (Chizoba *et al.*, 2017)

In many times it is not important to complete the thawing to save energy, the time will be shorter and obtain products of good quality. The frozen meat is usually found in large pieces. So, in order to cut and slice the frozen meat, it should be tempered firstly. Therefore, the pieces will be tempered from the hard state to a temperature to be easier for cutting without damage the product. The temperature used for tempering will be according to the shapes of pieces, the method used for cutting, slicing and the composition of food product such as moisture, fats, and proteins. Traditional tempering methods usually use hot air and water; in this case the meat surfaces from outside will subject to high temperatures for long periods until the heat reaches the center of the product. Tempering microwave has been carried out for frozen foods such as fish, meat and poultry either in different methods such as batch or continuous systems.

The advantages of microwave tempering are handling large quantities of frozen products, low cost, occupy tempering of bulky products due to its deeper penetration in the product as compared to the frequency of (2450 MHz) (high band) microwave(Ahmed& Ramaswamy 2007, Shahen,*et al.*, 2012, Kalla & Devaraju, 2017).

The main advantages and disadvantages of microwave heating:

In conclusion, microwave heating presents some advantages and disadvantages in comparison to the conventional techniques as reported by some researchers (Salazar-Gonzaler, *et al.*, 2012,Chandrasekaran, *et al.*, 2013, Kumar, 2015, Kalla & Devaraju, 2017, *Szadzinska, et al., 2019*).

The advantages:

1- Faster heating: the microwave heat generates with high heating efficiency (80% or more achieved)

2- The heat is generated throughout the food and has greater penetration depth.

3- Shorter processing time: it uses about a quarter of the time used in the conventional heating and requires short times for start-up and shut down to reach the desired temperatures.

4- Better quality of processed food products: the target temperature reached quickly due to the high heating rate, thus reducing the harmful effects of thermal heating on the food and it is more effective in retaining the nutrients components of the food products.

5- It is suitable for the sensitive, high viscosity, and multiphase fluids.

6- It is safe to handle the packed foods after microwave pasteurization.

7- Ease of operation, small space requirement, and low energy consumption (high efficiency), reduction of noise levels, and low maintenance cost.

8- Environmentally it is clean energy, and does not produce toxics gases or any pollutants wastes.

The disadvantages:

1- The microwave ovens usually use electricity, which is high in costs.

2- It is much expensive to build long towers.

3- To obtain high quality food products, it needs qualified engineers who have experience to develop this novel technology for using at industrial scale.

4- Microwave heating is not suitable for bread baking because bread staling may occur quicker as compared with the conventional baked methods.

5- Microwave drying usually is used only in the falling period of drying many products.

6- Applying microwave heating in drying of some food products may cause too much heating at the edges and corner of the products resulted in off-flavours and unacceptable taste.

7- In order to use microwave heating in the drying of food products, it should combine the drying by microwave with the traditional drying methods to achieve products of high quality.

8- The non uniform temperature distribution, resulting in hot and cold spots mainly in solid and semi-solid products.

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تطبيقات استخدام الميكروويف فى مجال التصنيع الغذائى: نظرة شاملة

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انتشر فى السنوات الأخيرة استخدام تطبيقات الميكروويف العديدة فى جميع أنحاء العالم. تطبيقات استخدام الميكروويف فى مجال التصنيع الغذائى كثيرة مثل استخدامه فى العمليات التصنيعية التالية: السلق- الطبخ – التجفيف للمواد الغذائية – تفكيك المواد الغذائية المجمدة – الخبيز – البسترة والتعقيم. تتميز طاقة الميكروويف بعدة صفات أفضل من التسخين بالطرق التقليدية.

تهدف هذه الدراسة المرجعية الى دراسة مختصرة لطاقة الميكروويف وتطبيقات استخدامها فى مجال التصنيع الغذائى. أيضا القاء الضوء على مميزات وعيوب استخدام طاقة الميكروويف على جودة المواد الغذائية ومقارنتها بطرق التسخين التقليدية. كذلك الإشارة الى مميزات استخدام البسترة والتعقيم على درجة حرارة منخفضة فى تثبيط نمو الأحياء الدقيقة. وأيضا استخدام طاقة الميكروويف فى حفظ الأغذية بالتجفيف ومدى استخدامها كمرحلة مكملة فى الحفظ بالتجفيف بواسطة الهواء الساخن والتجفيف تحت تفريغ وايضا الحفظ بالتجفيد مع المقارنة بالطرق التقليدية.