OPTIMIZATION OF PROCESS PARAMETERS DURING PULSED MICROWAVE OSMOTIC DEHYDRATION (PMOD) OF BANANA SLICES BY RESPONSE SURFACE METHODOLOGY

A THESIS

BY

MD. RAKIBUL ISLAM

Student No: 1405198

Session: 2014-15

Semester: July – December, 2015

MASTER OF SCIENCE (MS)

IN

FOOD ENGINEERING AND TECHNOLOGY

DEPARTMENT OF FOOD ENGINEERING AND TECHNOLOGY

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200

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DEDICATED

TO MY

BELOVED PARENTS

ACKNOWLEDGEMENT

Firstly, all praises and deepest sense of gratitude be to the "Almighty Allah", the most compassionate, powerful and supreme creator of the universe, whose blessings have enabled me to carry out the whole research and to complete this thesis successfully.

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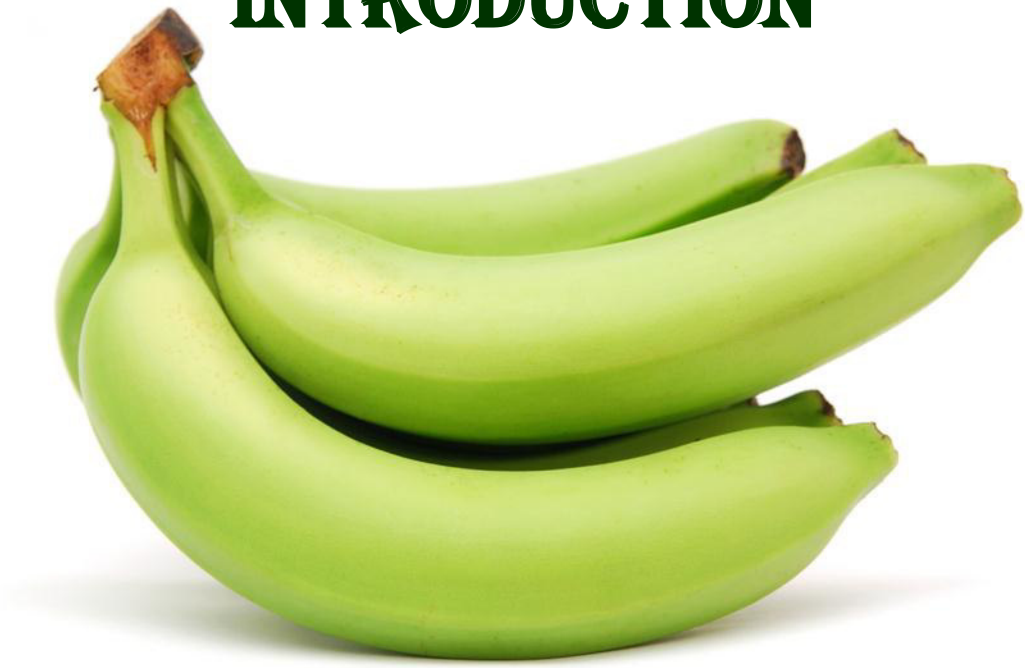
CHAPTER I

INTRODUCTION



CHAPTER I

INTRODUCTION

The product obtained from osmotic dehydration belongs to the class of intermediate moisture foods (IMF). This is because, intermediate moisture foods are basically partially dehydrated products which having the moisture content ranging from 20-50%. Consequently, osmotically dehydrated products contain moisture in the range of 65–75% (Rao 1997; Le Maguer 1988). Moreover, osmotic dehydration (OD) is a partial dehydration process which removed water from food tissues since hypertonic solution acts as a driving force for moisture diffusion (An et al. 2013). It also represents an energy efficient means to obtain an intermediate moisture food product. The energy efficiency characterized because there is no need to supply latent heat to vaporize water whereas water is removed by a physical diffusion process (Azarpazhooh & Ramaswamy 2012). However, OD is a slow and time-consuming process, as a result, it needs to develop novel techniques to accelerate the mass transfer rates without adversely affecting the quality of the product (Rastogi et al. 2002). Thus, a combination of osmotic dehydration with microwave drying techniques may improve the drying rate by reducing the time and efficient means to reduce energy consumption (Raghavan & Silveira 2001; Piotrowski et al. 2004).

Microwave assisted dehydration involves the transformation of electromagnetic energy into heat which generated due to molecular excitation into the food product. This lead to a positive outflow of water resulting faster drying rates (Orsat et al. 2006; Wray & Ramaswamy 2013). However, non-uniform heating of foods during microwave heating is the major drawback it's application in the food industry. This is because of non-uniform temperature distribution and central heating effects. For improving temperature uniformity, the microwave power applied in a pulsed form (Gunasekaran 2008; Sharifian et al. 2012). Several researchers applied microwave energy during osmotic dehydration in either by immersion or spray mode for various food products (Li & Ramaswamy 2006; Azarpazhooh & Ramaswamy 2009). To date, there is no published information founds on optimization of pulsed microwave osmotic dehydration on banana slices. Maskan (2000) reported that application of microwave energy produced a light colored banana product and drying time also reduced about 64.3%.

The banana (*Musa paradisica* L.) is an important fruit crop of the world, especially in the tropical countries. Tropical countries like Bangladesh, banana is available throughout the year but significant amount of it's spoiled due to their high perishability and lack of known preservation techniques. This can lead to a huge financial loss by the grower and country also. However, it can be processed into a product of more shelf stable and convenient form of powder, chips, wine and fig etc. The most important methods that widely practiced for fruits and vegetables are drying and dehydration (Chavan et al. 2010; Taiwo & Adeyemi 2009; Singh et al. 2007).This method can prevent banana from microbial spoilage hence its huge wastage can prevent resulting economically beneficial for Bangladesh. From the above-mentioned literature and to fulfill the research work the following objectives are considered:

1) To quantify the effect of process variables on mass transfer, color change and drying efficiency during pulse microwave osmotic dehydration (PMOD) of banana slices and
2) To optimize the process variables by response surface methodology using a faced centered central composite design (FCCD).

CHAPTER II

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

The goal of this chapter is to collect the available scientific literatures related to osmotic dehydration of banana as well as preparation of solution, effect of temperature, time and concentration. Notably, before the commencement of this research, there was limited information in scientific literature on the optimization of process variables during pulsed microwave osmotic dehydration of banana by response surface methodology was found.

2.1 Banana

Bananas (*Musa paradisica*) belong to the family Musaceae and consist of two genuses: Ensete and Musa. There are 200-500 varieties of bananas and plantains (Sadler et al., 1993). Bananas (*Musa acuminata*) are generally eaten raw, whilst plantain (*Musa paradisiaca*) is cooked (Douglas et al. 1982).

Banana is a fruit for tropical and subtropical regions. Bangladesh land and weather is very suitable for growing different variety of banana round the year. Chilling injury occurs at a temperature below 12^0C. Growth reaches an optimum at 27^0C, then declines and come to a stop at 38^0C. A monthly rainfall of 100mm is ideal for growth of banana. The fruit Banana is variable size in Bangladesh but is usually elongated and curved, with soft flesh rich in starch covered with a rind which may be green, yellow, red, purple or brown when ripe. The Banana fruits grow in clusters hanging from the top of the plant. Almost all modern edible parthenocarpic (seedless) bananas come from two wild species *Musa acuminate* and *Musa balbisiana*. Among different variety, on the basis of local name the most popular & demandable varieties are- Sagor, Sabri, Kobri, Chini Champa, Mehersagar, Agniswar, Gerasundari, Kanthali Kola, BARI Kola-1, Atia Kola, Bichi Kola, Kacha Kola (Islam and Hoque , 2003)

Generally banana plants are found throughout the country in most of the rural homesteads. Major districts of cultivated Banana in Bangladesh are Bogra, Narsingdi, Rangpur, Nator, Pabna, Noakhali, Faridpur, and Khulna. Districts of wild grown Banana are Sylhet, Moulvibazar, Netrokona, Rangamati, Khagrachhari, Bandarban (BBS, 2015)

2.2 Nutrition and chemical compositions of banana.

Bananas are a very nutritious, healthy food because they contain less than 2% fat contain no cholesterol, and are very low in sodium (this is of benefit for people with high blood pressure). In addition, they are a good source of fiber (one banana can supply 16% of daily need of fiber), carbohydrates, vitamins A, C, foliate, B_3; B_1 and B_6 (Sadler et al. 1993 & Wills et al. 1986).

Banana is especially very rich in potassium, helpful in the prevention of heart disease and maintaining healthy cardiovascular muscle. Due to the abundance of potassium and B6 in banana, the fruit is considered as a nutrient for the brain since potassium is needed for proper brain function. Moreover, with a high level of B_2, banana helps the body break down carbohydrates and fat, and is therefore beneficial for weight control.

2.3 Osmotic dehydration

The osmotic dehydration (OD) is such a process that removes water partially from food material when in a hypertonic solution means of food is immersed (i.e. salt and sugar). Normally osmotic dehydration is a slow process depending on the permeability of cell architecture and cell membranes (Anami et al. 2007).

According to Alzamora (2000) osmotic dehydration (OD) is a preservation technique that may be used to decrease water activity (a_w). This method is used as a treatment for further processing and applied to increase product diversity and modify the product sensorial characteristics. Some dehydration techniques, including OD, bring significant changes in the dehydrated material such as membrane alteration or lysis, volume reduction, membrane separation from the cell wall or cell wall deformation among others.

Osmotic dehydration is a process that is used for partial removal of water from foods such as fruits and vegetables. Banana is placed in hypertonic (osmotic) solution in this process. In OD there are three different mass transfer mechanisms occur (i) solute migration from solution to food (ii) water migration from food to the solution and (iii) solute concerning product extracted to solution (Eroglu et al. 2010).

According to Krokida and Kouris (2003) Osmotic dehydration is one kind of the energy efficient means of removing moisture from a food product. In this process, water doesn't have to go through a phase change to be released from the product. In comparison with other drying processes some of the advantages of direct osmosis include less decolonization of fruit by enzymatic oxidative browning and minimized heat damage to color and flavor.

Fernandes et al. (2007) reported that osmotic dehydration is a common pre-treatment that is used before air-drying. In this technique fruit is immersed in a hypertonic solution to remove part of the water from the fruit. The difference in osmotic pressure between the hypertonic solution and the fruit is the driving force for removal of water. For diffusion of water within the fruit the complex cellular structure of the fruit acts as a semi-permeable membrane by creating an extra resistance.

According to Madamba (2003) osmotic dehydration is a water removal operation which involves soaking of foods specially fruits and vegetables in a hypertonic solution such as concentrated salt syrup or sugar syrup. During osmotic dehydration two major simultaneous counter-current flows and important water flow out of the food into the solution and a simultaneous transfer of solute from the solution into the food. During osmotic dehydration two major simultaneous counter-current flows occur; solute transfer from the solution into the food and a simultaneous water flows out of the food into the solution. There is also a third flow of natural solutes such as sugars, salts, organic acids, mineral, leaking from the food into the solution. All these mass exchanges may have an effect on nutritional and organoleptic quality of the dehydrated product (Azoubel and Murr, 2004).

Torreggiani (1993) described that Osmotic dehydration is mainly carried out on fruits and vegetables and these products that have cell wall membranes which are alive, and can stretch and expand when the product grows or generates pressure from within. An ideal osmotic dehydration situation would be for a semi-permeable membrane to be permeated by the molecules of the solvent but not by those of the solute. The cellular membranes will freely allow molecules of the solvent to pass through them, but they also allow a small amount of the solute molecules to pass through; this is shown in Figure 2.1. This type of membrane should be classified as permeable, as opposed to semi-permeable membrane.

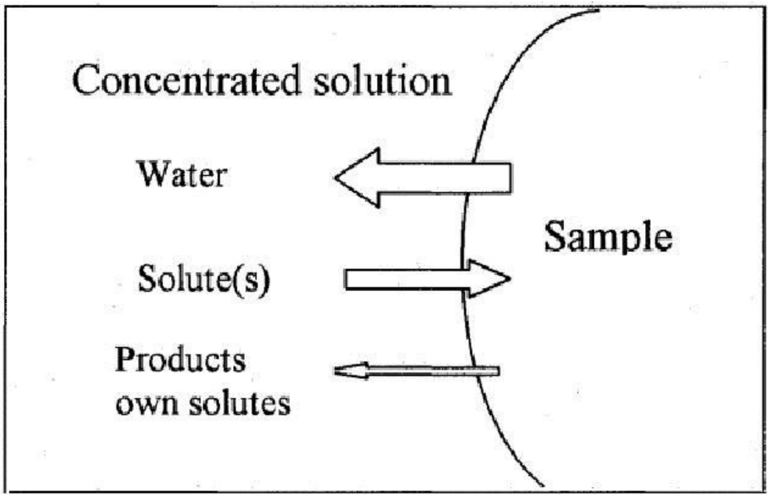


Figure 2.1: Mass transfers during the soaking process (Raoult-Wack, 1991).

2.4 Factors influencing osmotic dehydration

Over the last few decades, the factors that influence the osmotic dehydration process have been studied extensively. Apart from the influence of solid structure, mass transfer depends on operating variables: such as osmotic temperature, time duration, solute concentration, composition of the solution (i.e. Solute molecular weight and nature, presence of ions), pressure, and the product: solution ratio (Raoult-Wack et al., 1991). The factors influencing osmotic dehydration are briefly reviewed below:

2.4.1 Temperature

Osmotic diffusion is a temperature-dependent phenomenon. Higher process temperatures generally promote faster water loss through swelling and plasticizing of cell membranes, faster water diffusion within the product and better mass transfer characteristics on the surface due to lower viscosity of the osmotic medium (Lazarides et al. 1995). Conway et al. (1983) reported that for every 10°C increase in temperature, there was a corresponding 5% increase in the percentage final moisture loss from the produce. Bakalis et al. (1994) observed that temperature had a positive effect on moisture diffusivity in apples within a range of 24°C to 38°C. Nieuwenhuijzen et al. (2001) reported different sizes apple slices moisture loss and solids gain generally increased with increasing temperature of osmotic solution. The best processing temperature depends on the food, for example for green beans (Biswal et al. 1991), 40°C is too high, and a temperature 20°C gives better results.

2.4.2 Time

The rate of moisture loss and solid gain is highest within the first hour of osmosis followed by drastically lower rates for the rest of the time. On average, moisture loss rates drops to 20% of the initial rate during the first hour of dehydration and kept decreasing at a much slower rate to nearly level off at ea 10% of the initial rate within 3 h. Solid gain rates show a similar decrease trend. The rate of solid gain drops to 25% of the initial rate within the first hour and leveled off at 15% of the initial rate within 3h of dehydration (Farkas et al. 1969; Raout-Wack et al. 1992; Lazarides et al., 1995 and Kowalska et al. 2001). Rapid loss of water in the beginning is due to the large osmotic driving force between the dilute sap of the fresh fruit and the surrounding hypertonic solution. On the other hand, rapid drop of the water loss rate within the first hour seems to result from a serious disturbance of the initial osmotic concentration difference due to superficial sugar uptake.

2.4.3 Osmotic solution to fruit ratio

The ratio of osmotic solution to fruit expresses the mass of solution required per unit mass of treated food. On an industrial scale, the ratio must be as low as possible to restrict plant size and the costs of solution regeneration. However, the use of a low ratio leads to significant changes in the solution composition. Most laboratory and pilot plant studies are carried out using a large excess of solution so as to ensure negligible variation in the solution composition, which makes the interpretation and modeling easier. The weight ratio of solution to product is generally in the range 20-30.

2.4.4 Agitation during osmotic dehydration

In early works Ponting et al. (1966), the effect of agitation was studied by comparison of agitated and non-agitated treatments. It was reported that agitated samples exhibited greater weight loss than non-agitated ones and thus agitation was found to be another process parameter. Raoult-Wack et al. (1989) studied the effect of agitation on both water loss and solid gain and reported: agitation of the osmotic solution resulted in higher mass transfer co-efficient values for solutions of higher concentration and higher viscosity. Agitation has a good influence on weight loss (especially for the concentrated solutions) and on the exchange speed. The agitation ensures that the concentrated solutions are renewed around the particle and therefore, a concentration difference favorable to mass transfer is recreated. As a corollary, dilution of the boundary layer increases solute gain-since agitation provide lower sugar gain (Raoult-Wack et al. 1989). In some cases, intermittent agitation or short time duration may be sufficient.

2.4.5 Nature of the fruit

Water loss and solid gain are mainly controlled by the raw material characteristic (Torreggiani et al., 1987; 1993), certainly influenced by the possible pre-treatments. The great variability observed among the different fruits is mostly related to the tissue compactness (Giangiacomo et al, 1987), initial insoluble and soluble solid content (Lenart & Flink, 1984), intercellular spaces, presence of gas, ratio between the different pectin fractions (water soluble pectin and protopectin) (Forni et al., 1986) and jellification level of pectin of the fruit. Ponting et al. (1966) reported that osmotic dehydration is not suitable for citrus fruits and tomatoes because of their excessive loss of juice during the process. Fruits that are very porous e.g. pineapples are better suited to vacuum treatment during osmotic dehydration (Shi & Maupoey, 1993).

2.4.6 Size and shape of fruit

The higher the ratio of surface area to volume, the higher is the osmotic dehydration rates. Islam and Flink (1982) reported that the size and geometry of the food had some influences on the extent of final solute concentration, especially during short dehydration times, and at such times, dehydration was primarily a transport phenomenon related to surface area. According to Nieuwenhuijzen et al., (2001), moisture loss and solids gain increased as particle size decreased under same processing conditions.

2.4.7 Type of Osmotic Agent

The choice of the solute and its concentration depends upon several factors. The solutes are the inorganic salts: calcium chloride, sodium chloride, mono hydroxyl ethanol and the polyhydroxyl organics such as sucrose, lactose, maltodextrin, and high fructose corn syrup.

2.4.7.1 Sucrose

Carbohydrates have been a part of the human diet since antiquity. In addition to sweetness, they provide valuable functions in food systems, which inc1ude structure, mouth-fee1, texture and flavor enhancement. Before the development of the sugar refining industry, sweetening agents were largely limited to fruits, honey, maple syrups etc. Sucrose suppresses bitter, acid and salty tastes, but the sweet taste of sucrose is not much suppressed except at high concentration of the other tastes (Goodshall, 1990).

2.4.7.2 Calcium Chloride

Ponting et al., (1972) reported that calcium treatment of apples was the logical and historical method for increasing firmness. The effect of a calcium dip was effective in preserving texture over an extended storage period, as well as having a synergistic effect with ascorbic acid or sulfur dioxide in preventing browning. However, Ponting and Jackson (1972 b) observed that it should be used in small quantity below 0.5% otherwise it was found to cause bitterness.

2.4.7.3 Sodium chloride

For products osmo-dehydrated with sodium chloride, drying can be completed to the required water activity at higher final moisture content than that achieved when sucrose is used (Islam and Flink, 1982). In order to have an acceptable product from a sensory viewpoint, the salt concentration of the osmotic agent should not exceed 10%. The saltiness of sodium chloride limits its usage in fruit processing. Using a mixture of sodium chloride and sucrose resulted in higher rates of osmotic dehydration than if sucrose were used alone (Hawkes and Flink, 1978).

2.5 Microwave theory and characteristics

Microwaves are part of the electromagnetic spectrum (Figure 2.2) and are located between 300 MHz and 300 GHz. Microwave wavelengths range from 1mm to 1m.The terms "dielectric" and "microwave" are used inter-changeably and in somewhat confusing manners and must be defined. The term "dielectric heating" can be applied logically to all electromagnetic frequencies up to and inc1uding at least the infrared spectrum. The lower frequency systems operated at frequencies through at least two bands: HF (3-30 :MHz) and VHF (30-300 :MHz).Thus, the names high frequency (HF), dielectric, radio frequency and microwave (MW) heating can often be used interchangeably. However, it is generally accepted that dielectric heating is done at frequencies between 1 and 100 MHz, whereas microwave heating occurs between 300 MHz and 300 GHz (Schiffmann, 1987; Dibben, 2002). Microwave heating is defined as the heating of a substance by the electromagnetic energy operating in that frequency range.

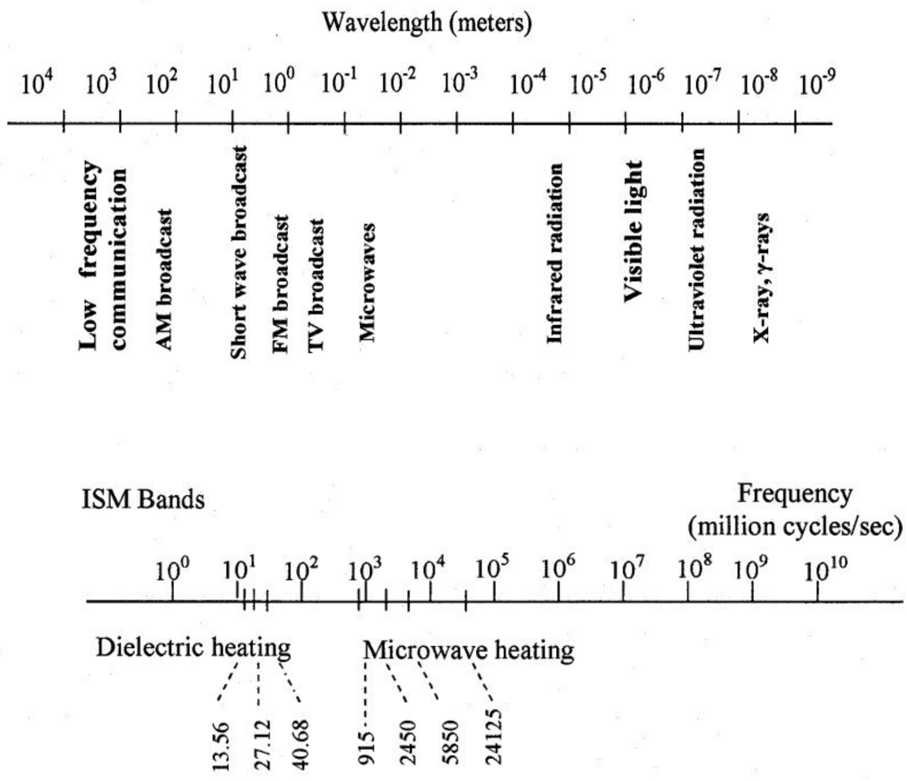


Fig: 2.2 Electromagnetic Spectrum

2.5.1 Microwave Drying

Drying has become an important procedure in almost all areas of industrial processing. When using conventional driers, with hot air or infrared, the speed of drying is limited by the rate at which water or solvent diffuses from the interior to surface from which it is evaporated. Microwave drying employs a completely different mechanism. Because of the internal heat generated by microwave field, there is an internal pressure gradient, which effectively pumps water to the surface. The usual means of applying microwaves to a drying process is at the end of the falling rate period (Figure 2.3), in which case this is referred to as finish drying. A good example of this is the finish drying of chips and cookies. Microwaves can also be applied throughout the drying process at low power levels to "boost drying" by constantly

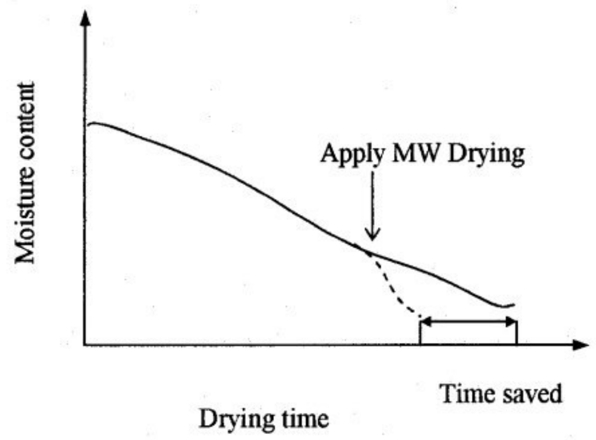


Fig 2.3 Microwave finishes drying. Conventional hot air drying employed first and microwave energy is added near the end of the falling rate period to rapidly remove the last traces of moisture.

pumping water to the drying surface. This technique is sued for the microwave drying of pasta. There is also the possibility of applying microwave heating prior to hot air drying, thereby preheating the product to the drying temperature. This has been tried with cake batters (Schiffmann, 1987).

2.5.2 Microwave Drying Mechanisms

Microwaves themselves do not represent heat, but the absorbed energy is converted into heat inside the product. There are many factors affecting how food is heated in a microwave field and this makes the heating mechanism very complicated to understand.

When a microwaveable product is to be developed, the fundamental mechanisms of microwave heating and the interaction of microwaves with materials should be understood (Dibben, 2002).

The heating of foods by microwave energy is accomplished by the absorption of microwave energy both by dipolar water molecules and ionic components of the food. Thus, both the water content and the dissolved ion content (often salt) are dominating factors in the microwave heating of foods. When the dipolar water molecule is subjected to a microwave field, with the field rapidly changing its direction, the dipole tries to align itself with the field direction. There is a time lag, as some response time is required for the water molecule to overcome the inertia and the intermolecular forces in the water. The electric field thus provides energy for the water molecule to rotate into alignment. The energy is then lost to the random thermal motion of the water and results in a temperature rise. When ionized compounds are subjected to a microwave field, they randomly collide with non-ionized groups in an electric field. The kinetic energy of these ions is transmitted into heat during the collisions (Schiffmann, 1987).

The most obvious direct effect of microwave heating is embodied in the volumetric heating that will quickly raise the temperature and alter the temperature profile depending on the moisture profile in the drying material. Microwaves are absorbed by polar molecules and other ionic compounds but are reflected by metals while glass and plastic allow the microwaves to pass through them. Materials are roughly divided into three kinds according to their interaction with electromagnetic fields: transparent, reflecting and absorbing.

Transparent materials, such as air, quartz glass and water-free ceramic bodies, allow the waves to pass through unhindered, as glass does with light (Figure 2.4a). In the microwave field, these materials do not heat. Reflecting materials, such as metals or graphite, ideally permit no rays to penetrate them. The waves hit the surface and are thrown back almost unchanged into space (Figure 2.4b). These materials also remain cold in the microwave field. Absorbing materials, such as foods, fresh wood and moist ceramic bodies, are able to absorb microwave energy and convert it into heat (Figure 2.4c). How deeply the rays penetrate the interior varies, depending on the material and its specific dielectric properties.If a material consists of several components, and at least one component is a good absorber, then it can be heated well.

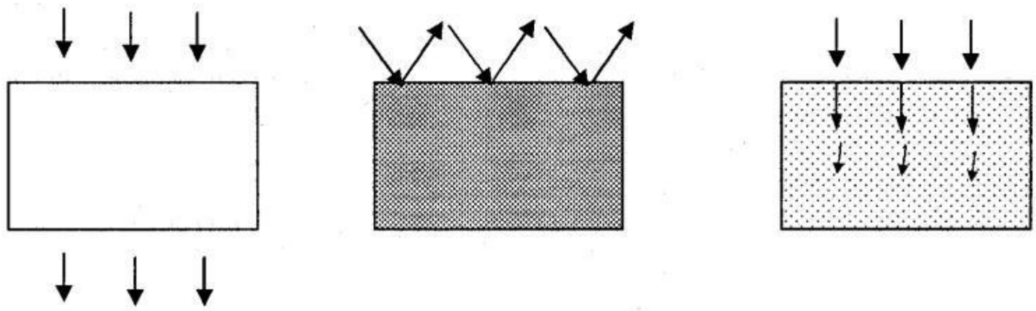


Fig: 2.4a Fig: 2.4b Fig: 2.4c

There are several energy conversion mechanisms by which heat is generated by microwaves. These inc1ude: ionic conduction, dipole rotation (entire molecule quantized, twisted or bent), interface polarization ferroelectric hysteresis, electric domain wall resonance, electro-restriction, piezoelectricity,nuclear magnetic resonance, ferro and ferri-magnetic resonance. For microwave heating in foods, only ionic conduction and dipolar rotation are of primary interest (Owusu-Ansah, 1991).

2.6 Response Surface Methodology (RSM)

Response surface methodology (RSM) explores the relationships between several explanatory variables and one or more response variables. The main idea of RSM is to use a set of designed experiments to obtain an optimal response. Box and Wilson suggest using a first-degree polynomial model to do this. They acknowledge that this model is only an approximation, but used it because such a model is easy to estimate and apply, even when little is known about the process Wilson, (1951). Response surface methodology or RSM is a collection of mathematical and statistical technique that are useful for the modeling and When a microwaveable product is to be developed, the fundamental mechanisms of microwave a response of interest is influenced by several variable and the objective is to optimize this response. Response surface methodology (RSM), used to optimize the process parameters for osmotic dehydration of mushroom samples, is a collection of certain statistical techniques for designing experiments, building models, evaluating the effects of the factors and searching for optimal conditions for desirable responses. It uses quantitative data from an appropriate experimental design to determine and simultaneously solve multivariate problems. Equations describe the effect of test variables on responses, determine interrelationships among test variables and represent the combined effect of all test variables in any response. This approach enables an experimenter to make efficient exploration of a process or system. Therefore, RSM has been frequently used in the optimization of food processes (Shi *et al.,* 2008).

2.7 Recent Study on Osmotic Dehydration of Banana

Orsat et al. (2006) study the effects of osmotic dehydration on mass transfer properties as water loss, solids gain, and weight reduction during osmotic dehydration in order to determine the usefulness of this technique as pre-treatment for further drying of bananas slices. Banana slices, 10mm thick, were immersed in sucrose solutions with concentrations of 45,55 and 65°Brix at 30, 40 and 50°C for 20,40,60,120 and 240 minutes. Water loss, weight reduction and solids gain increased with treatment time. Longer time in high concentrations of sucrose resulted in a very soft product, which is difficult to handle and unsuitable for further drying. Increasing concentration at the same temperature did not cause significant increments in weight change. Higher concentrations of sucrose caused higher rates of water removal. About 50% of the water loss occurred between 40–120 minutes for most of the conditions. Results obtained suggest that a product for further drying could be obtained by treating the slices at temperatures not more than 30°C and using osmotic solutions at 55 or 65° Brix.

Pereira et al., (2006) reports on a study of the final stage of microwave-hot air drying of osmotically dehydrated bananas, focusing on the effects of microwave power, air temperature and air velocity on drying kinetics and product quality, evaluated in terms of color, apparent volume and porosity. The drying process was divided into three periods: phase I (760 W; 2kg moisture/kg dry matter); phase II (380 W; 0.67 kg moisture/ kg dry matter); and phase III (0 W, 76W, 150W or 230W up to the final sample moisture of 0.17 kg water/kgdm). Three conditions for the hot air were tested: 50 C and 3.3 m/s; 70 C and 3.3 m/s; 70 C and 5.7 m/s. The results show that increasing the microwave power in phase III increased the drying rate, thus making the drying time shorter. However, higher microwave power also caused temperature runaway leading to charring on the dried product. Air flow cools the product surface and improves product quality by reducing charring.

2.8 Optimization of process parameters during osmotic dehydration by response surface methodology (RSM)

Kaur and Singh (2013) investigated the mass transfer kinetics and optimization during osmotic dehydration of beetroot. The samples were osmotically treated in different hypertonic sugar solution (55, 65 and 75°Brix) with salt concentration of 5% (w/v), at different solution temperature (30, 45 & 60°C). It was found that the magee's model was appropriate for predicting water loss (WL) and solute gain (SG), while Azuara's model fitted water loss as well as solute gain (SG) data represented more accurately the condition of the complete process close to equilibrium. Quadratic regression equations describing effects of process variables on water loss, solute gain and weight reduction were developed and optimization of osmotic dehydration was done using response surface methodology (RSM). The regression analysis revealed that linear terms of all process parameters have a significant effect on all the responses. The optimum conditions were found to be as sugar of 75°Brix with 5% salt, solution temperature of 47.70°C and immersion time of 120 min at constant osmotic solution to sample ratio of 4:1. At these optimum values, water loss, solute gain and weight reduction were observed as 28.78, 4.42 and 24.36 (g/100 g of initial mass) respectively.

Narang and Pandey (2013) used RSM for quantitative investigation on water and solids transfer during the osmotic dehydration process of the grapes in sucrose solution using Box-Behnken experimental design. Effects of temperature (35–55°C), sucrose concentration (40–60°Brix) and processing time (100–200 min)), on osmotic dehydration of grapes were estimated. Quadratic regression equations describing the effects of these factors on the water loss, solids gain, rehydration ratio and sensory score were developed. It was found that effects of concentration and temperature were more significant on the water loss than that of processing time. As for solids gain processing time and temperature were the most significant factors. The osmotic dehydration process was optimized for water loss, solute gain, rehydration ratio and sensory score. Optimum conditions obtained by numerical optimization were temperature 36.92°C, processing time 160.57 minutes and sucrose concentration 60°Brix solution to achieve maximum water loss, rehydration ratio and sensory score, and lower solute gain. Corresponding to these optimum conditions, the predicted value for water loss was 40.54 (g/100 g initial sample), 10.06 solid gain (g/100 g initial sample), 3.05 rehydration ratio and 7.63 sensory score.

Response surface methodology was used to investigate the effect of sugar concentration (50-70°Brix), solution temperature (30-60°C), solution to fruit ratio (4:1-8:1) and immersion time (60-180 min) on the water loss, solute gain, rehydration ratio, vitamin-C loss, color change and sensory overall acceptability of Indian gooseberry (aonla) slices. The optimum process parameters obtained by computer generated response surfaces, canonical analysis and contour plot interpretation were: sugar concentration, 59°Brix solution temperature 51°C, solution to fruit ratio 4:1 and immersion time of 60 min (Alam et al. 2010).

Mehta et al. (2013) reported the use of RSM for osmotic dehydration of button mushrooms. During the research work, The effect of brine concentration in the range of

10-20%; solution temperature in the range of 35-55°C and duration of osmosis in the range of 30-60 min on water loss (WL) and salt gain (SG) using the response surface methodology at constant solution to sample ratio of 5/1 (w/w) were investigated. The brine concentration, temperature of brine and duration of osmosis with respect to water loss and solid gain were analyzed for linear, quadratic and interaction effects. Second order polynomial models were developed using multiple regression analysis and the adequacy and accuracy of the fitted models were checked by analysis of variance (ANOVA). The response surfaces and contour maps showed the interaction of process variables provided optimum operating as solution temperature of 36.36°C, brine concentration of 15.11% and duration of osmosis of 41.45 min. At this optimum point, water loss and salt gain were predicted to be 35.04% and 2.31%, respectively.

Process temperature (30, 40 and 50 °C), syrup concentration (50^0, 60^0 and 70^0 Brix) and process time (4, 5 and 6 h) for osmotic dehydration of papaya (*Carica papaya*) cubes were optimized for the maximum water loss and optimum sugar gain by using response surface methodology. The cubes were removed from bath at pre-decided time, rinsed with water and weighed. Initial moisture content of papaya samples were 87.5-88.5% (wb), which was reduced to 67.6-81.1% after osmotic dehydration in various experiments showing mass reduction, water loss and sugar gain in the range of 20.6-36.4, 23.2-44.5 and 2.5-8.1%, respectively. The weight reduction, water loss and sugar gain data were statistically analyzed and regression equation of second order were found the best fit for all the experimental data. Maximum water loss of 28% with optimum sugar gain of 4% was predicted for the 60°Brix syrup concentration at 37°C for syrup to fruit ratio as 4:1 in 4.25 h of osmotic dehydration (Jain et al. 2011).

CHAPTER III

MATERIALS AND METHOD

CHAPTER III

MATERIALS AND METHOD

The experiment was conducted in the laboratories of the faculty of Engineering, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, Bangladesh. The methodology of the conduction of the study are discussed in this chapter in details.

3.1 Materials

Banana (*Musa paradisica*) fruits of good quality and well matured and ready for ripening was procured from the local farmer's banana garden and allow ripening under natural conditions. Fully ripe, the yellowish colored banana was used for conducting the research. The refined sugar was used for preparing the osmotic solution which collected from the local market also.

3.2 Osmotic solution preparation

The osmotic solutions were prepared by dissolving the required quantity of sugar in distilled water (w/w), under the conditions given by the face-centered central composite experimental design (FCCD). The total soluble solids (^{o}Brix) content of the solution was measured using a digital Refractometer (model-HI96801).

3.3 Experimental design

The pulsed microwave osmotic dehydration in immersion (PWOD) experiments were conducted using an FCCD with four factors [sample thickness (A), sucrose concentration (B), microwave power (C), and contact time (D)] at three levels to take into account the individual and interaction effects of the factors. The variable levels were chosen on the basis of previous experiments conducted by the several authors (Chavan et al. 2010; Athmaselvi et al. 2012; Azarpazhooh & Ramaswamy 2012). The experimental design included 30 experiments with sample thickness in the range of 5-10 mm, sucrose concentration in the range 40-60^{o}Brix, microwave power in the range 100-1000W, and contact time in the range 10-50 min. The sample to solution ratio of 1:30 was kept constant throughout all of the experiments (Azarpazhooh & Ramaswamy 2011). The original values of all variables in terms of coded and actual units are shown in Table 3.1.

Table 3.1 Process variables and their three levels of experimental design

Variable	Name	Units	Levels		
			-1	0	1
A	Sample thickness	mm	5	7.5	10
B	Sucrose concentration	^{o} Brix/%	40	50	60
C	Microwave power	Watt	100	550	1000
D	Contact time	min	10	30	50

All these variables were closely controlled and accurately measured during experimentation. Response surface methodology was used to determine the relative contributions of A, B, C and D to various responses under study such as water loss (WL), solid gain (SG), drying efficiency, and color change (ΔE) of osmotically dehydrated banana. The second order polynomial response surface model was fitted to each of the response variables (Y_k).

$$Y_k = b_{k0} + \sum_{i=1}^{3} b_{ki} X_i + \sum_{i=1}^{3} b_{kii} X_i^2 + \sum_{i \neq j=1}^{3} b_{kij} X_i X_j \quad ....(3.1)$$

Where b_{k0}, b_{ki}, b_{kii}, and b_{kij} expressed are the constant, linear, quadratic, and cross product regression coefficients, respectively, and X_is are the coded independent variables of A, B, C, and D.

3.4 Experimental Setup

A domestic microwave oven (Panasonic Model NN-GD5705) with a nominal output of 1100W at 2450 MHz was used for osmotic dehydration of banana slices. Microwave heating allows faster heat transfer in the food materials resulting thermal damage of the product. This results in a reduction in drying time up to 25–90% and a four- to eightfold increase in drying rate compared to convective drying during microwave heating of plant foods. Thus, drying at various microwave power was found to be more suitable for drying of plant foods (Ahrné et al. 2007; Wang et al. 2014). During osmotic dehydration of banana slices, variable microwave power of 100 to 1000W was used. Moreover, in pulsed drying, the drying time was considered in two ways that were total time and power on time. The total time was the total duration of time that was required for complete drying. In addition to, the power on time was referred to as the duration over which energy was supplied for complete drying. When a longer power on time setting was used, food materials dried faster and improves energy utilisation (Gunasekaran 1999). For that reason, microwave energy was supplied in pulsed form during the total drying time of 10 to 50 min. Basically, the microwave oven was operated at a pulsing ratio of two. In this technique, the energy for drying was periodically turned on and off for 5 min.

3.5 Experimental procedure

Osmotic dehydration of banana slices was carried out in a batch system. The experiments were conducted at various combinations of slice thickness, sucrose concentration, microwave power, and time as per the experimental design. The glass beaker containing the osmotic solution and banana slices was placed inside the microwave cavity in a sample to solution ratio of 1:30. During experimentation, agitation was not performed because it increases the cost of processing. After completion of total drying time as per experimental design, samples were withdrawn from the solution, quickly rinsed, gently blotted with paper towel to remove adhering solution, and then analyzed. Experiments were run in triplicate and the data are given an average of these results. The reproducibility of the experiments was within the range of ±1.63%. The water loss (WL) and solid gain (SG) were determined using a mass balance method as described by El-Aouar et al. (2006).

$$WL(\%) = \frac{(w_i X_i - w_f X_f)}{w_i} \times 100 \qquad \text{......................................(3.2)}$$

$$SG(\%) = \frac{(w_f(1 - \frac{X_f}{100}) - w_i(1 - \frac{X_i}{100})}{w_i} \times 100 \qquad \text{..............................(3.3)}$$

Where w_i and w_f are initial and final samples weights (g) at time (t), respectively; X_i and X_f are initial and final moisture content at time (t), respectively, (g/100g initial wet of banana slices).

3.6 Drying efficiency

Drying efficiency is defined as the energy required to evaporate a unit mass of water (MJ/kg). The equation used for calculation of drying efficiency is given by Yongswatidigul & Gunasekaran (1996) described as-

$$DE = \frac{t_{on} \times P \times (1 - m_f) \times 10^{-6}}{M_i \times (m_i - m_f)} \quad \text{.........................(3.4)}$$

Where DE is the drying efficiency (MJ/kg); t_{on} is the total power on time (s); P is the microwave power input (W); m_i and m_f is intial and final moisture content after OD, respectively.

3.7 Color change

Color change or total color difference (ΔE) of fresh and osmotically dehydrated banana slices was measured with a Hunter Lab color meter (USA), Model 45/0-L. The instrument was caliberated using standard white tile before taking measurements of each sample. The color of fresh and dehydrated carrot slices was assessed in terms of 'L', 'a', and 'b' after making a paste of the sample. For determining the color of the dehydrated sample, the paste was completely filled in Petri dish hence no light can pass during the measuring process. The obtained values were recorded and compared with the values of fresh carrot sample. The color change (ΔE) was calculated by the equation given by Giri & Prasad (2007)

$$\Delta E = \sqrt{[(L - L^*)^2 + (a - a^*)^2 + (b - b^*)^2} \quad \text{................(3.5)}$$

Color change (ΔE) indicates the degree of overall color change of a osmotically dehydrated sample in comparison to color values of a fresh sample having color values of L^*, a^* and b^*, respectively.

3.8 Data analysis and Optimization

The experiments were conducted according to face-centred central composite design (FCCD). Moreover, the response surface methodology was applied to the experimental data in Table 3.2, using a commercial statistical package, Design Expert,version7.0 (Stat-Ease Inc.,Minneapolis,MN).

Table 3.2: Treatment combinations for osmotic dehydration under pulsed microwave conditions

Uncoded process variables					Responses			
Run	Sample thickness, mm	Sucrose concentration (%)	Microwave power (W)	Contact time (min)	Water loss (%)	Solid gain (%)	Drying efficiency, (MJ/kg)	Color change, (ΔE)
1	10	60	100	50	18.2	4.48	30.13	12.77
2	10	60	100	10	10.7	3.82	8.70	9.91
3	7.5	50	100	30	13.7	7.19	29.44	24.14
4	5	60	1000	10	10.2	5.15	84.81	14.74
5	5	40	1000	50	22.8	31.71	107.09	15.17
6	7.5	60	550	30	18.2	25.87	59.14	22.8
7	5	60	100	50	18.2	2.19	31.81	24.04
8	10	60	1000	10	14.1	12.08	77.15	23.69
9	5	50	550	30	17.1	26.80	57.02	26.29
10	7.5	50	550	30	17.0	24.67	58.52	25.2
11	7.5	50	550	30	13.3	19.31	67.44	25.98
12	5	60	100	10	8.6	0.54	17.92	13.91
13	10	50	550	30	17.8	26.37	51.68	29.9
14	7.5	50	550	30	16.1	25.16	47.33	26.95
15	7.5	50	550	50	21.5	29.36	83.99	25.84
16	10	60	1000	50	30.7	65.30	77.74	38.03
17	10	40	1000	50	17.8	45.62	97.17	32.32
18	7.5	50	550	10	7.3	11.45	35.01	22.15
19	5	40	1000	10	10.96	3.05	90.38	9.54
20	7.5	50	1000	30	23.01	33.86	87.67	30.9
21	5	60	1000	50	30.02	53.99	86.27	26.06
22	7.5	50	550	30	14.6	22.17	60.60	23.85
23	5	40	100	10	6.01	3.01	18.24	12.70
24	10	40	1000	10	9.4	4.69	75.52	21.83
25	10	40	100	10	5.2	2.35	15.79	8.01
26	7.5	50	550	30	16.6	24.37	52.84	28.55
27	10	40	100	50	10.05	4.49	33.11	10.85
28	5	40	100	50	10.7	3.81	70.67	8.86
29	7.5	40	550	30	9.5	20.90	74.15	18.01
30	7.5	50	550	30	15.2	23.31	50.11	27.92

Analysis of variance (ANOVA) was conducted to fit the model represented by eq. (3.1) and to examine the statistical significance of the model terms. The adequacy of the model was determined using model analysis, lack-of-fit tests, and co-efficient of determination (R^2). The co-efficient of variance (CV) was calculated to find the relative dispersion of the experimental points from the predicted values of the model. Response surfaces and numerical optimization were generated using the same software.

Numerical optimization technique was used for simultaneous optimization of the various responses. The possible goals for responses were maximize, minimize and target whether the independent variables were kept within range. In order to search a possible solution, the goals were combined into an overall composite function, D(x), called the desirability function (Myers & Montgomery 2002), which is defined as:

$$D(x)= (Y_1 \times Y_2 \times ....\times Y_n)^{1/n} ....(3.6)$$

Where Y_i (i=1,2,......,n) are the responses and n is the total number of responses in the measure. Desirability is an objective function that ranges from zero to one and reflects the desired ranges for each transformed response. The numerical optimization sort out a point that maximizes desirability function.

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

The present study was conducted to evaluate the mass transfer, drying efficiency, and color change parameters during pulsed microwave osmotic dehydration (PMOD) of banana slices and to optimize PMOD process by response surface methodology (RSM). The data was analyzed by using multiple regression techniques to develop a response surface model. Moreover, the results of the experiments were handled based on the experimental design. The statistical significance of linear, quadratic, and interaction effects was calculated using ANOVA for each response. The multiple regression coefficients for each response were obtained by employing a least square technique to predict the polynomial models.

4.1 Influence of pulsed microwave heating on water loss (WL)

The co-efficient of WL regression model with coded variables are listed in Table 4.1. The co-efficient of determination for water loss was 0.97; the lack of fit was non-significant at 95% level of confidence, which all implied that the quadratic model was adequate for predicting water loss (WL). Additionally, the co-efficient of variation was calculated 9.98% which is less than 10% thus confirmed the adequacy of the model (Giri & Prasad 2007). The p and β value in Table 4.1 indicates that the medium contact time was the most significant variable for WL followed by microwave power and sucrose concentration. It implies that increased water loss with the increase of contact time. Azarpazhooh & Ramaswamy (2012) reported similar findings during microwave osmotic dehydration of apples. The interaction term ' microwave power and contact time' have the most significant effect on WL followed by ' sucrose concentration and contact time' at 5% level of significance. The quadratic effect of all process parameter has no significant effect on WL except sucrose concentration which explains that in an increment of that variable significantly decreased in water loss. Therefore, the regression equations for describing the effects of process variables on WL of banana slices in terms of coded variables are given as:

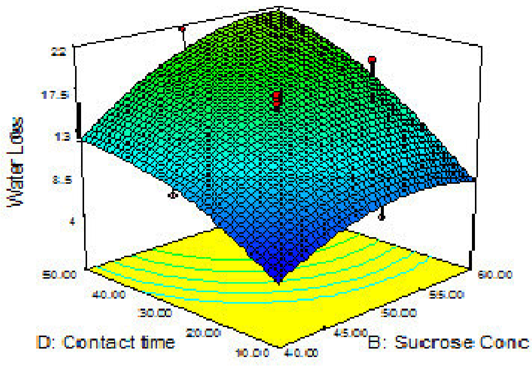
$$WL = 15.90 - 0.036A + 3.14B + 3.76C + 5.42D + 0.92AB - 0.16AC - 0.54AD + 0.020BC + 1.48BD + 1.88CD + 1.13A^2 - 2.47B^2 + 2.03C^2 - 1.92D^2 \quad \text{.............................(4.1)}$$

The combined effects of the two factors on WL can be observed graphically from the response surfaces and contour plots generated for each of the models by keeping two other variables at the center levels. Figure 4.1 (a) indicates that as the sucrose concentration and time of osmosis increased water loss also increased. Similar findings were reported in previous studies (van Nieuwenhuijzen et al. 2001; Li & Ramaswamy 2006). It is also observed from Fig 4.1 (b) that as the microwave power and contact time increased significantly increased water loss from the banana slices. In addition to, the higher water loss with an increment of time could be explained by the fast and uniform heating effect of microwave heating on water molecules resulting in a pressure buildup within the product thereby accelerating the water loss (Ramya & Jain 2016).

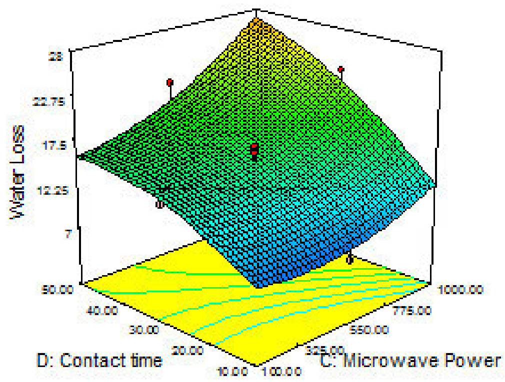
Table 4.1 : ANOVA showing the effects of the variables on WL and SG during pulsed microwave osmotic dehydration of banana slices

Source	df	Water loss				Solid gain			
		β	**Sum of square**	**F- value**	**P level**	**β**	**Sum of square**	**F- value**	**P level**
Model	14	15.90	1108.12	34.65	0.0001^{S}	24.01	7643.05	54.30	0.0001^{S}
Sample thickness (A)	1	-0.036	0.0227	0.0099	0.9218	2.16	84.29	8.39	0.0111^{S}
Sucrose conc. (B)	1	3.14	177.34	77.64	0.0001^{S}	2.99	160.69	15.99	0.0012^{S}
Microwave power (C)	1	3.76	254.10	111.24	0.0001^{S}	12.42	2777.11	276.34	0.0001^{S}
Time (D)	1	5.42	528.12	231.19	0.0001^{S}	10.82	2108.29	209.79	0.0001^{S}
AB	1	0.92	13.50	5.91	0.0280^{S}	0.51	4.23	0.42	0.5261
AC	1	-0.16	0.429	0.19	0.6709	1.76	49.70	4.95	0.0419^{S}
AD	1	-0.54	4.62	2.023	0.1753	1.06	18.07	1.80	0.1999
BC	1	0.020	0.0064	0.003	0.9585	3.38	182.83	18.19	0.0007^{S}
BD	1	1.48	35.22	15.42	0.0013^{S}	1.99	63.36	6.31	0.024^{S}
CD	1	1.88	56.32	24.66	0.0002^{S}	10.40	1730.59	172.21	0.0001^{S}
A^2	1	1.13	3.29	1.44	0.2489	1.73	7.79	0.78	0.3924
B^2	1	-2.47	15.85	6.94	0.0188^{S}	-1.47	5.60	0.56	0.4670
C^2	1	2.03	10.69	4.68	0.0471	-4.32	48.46	4.82	0.0442^{S}
D^2	1	-1.92	9.59	4.20	0.0584	-4.45	51.28	5.10	0.0392^{S}
Lack of fit	10		24.71	1.29	**0.4097^{NS}**		127.19	2.70	**0.1423^{NS}**
R^2			**0.97**				**0.98**		
C.V. %			**9.98**				**16.77**		

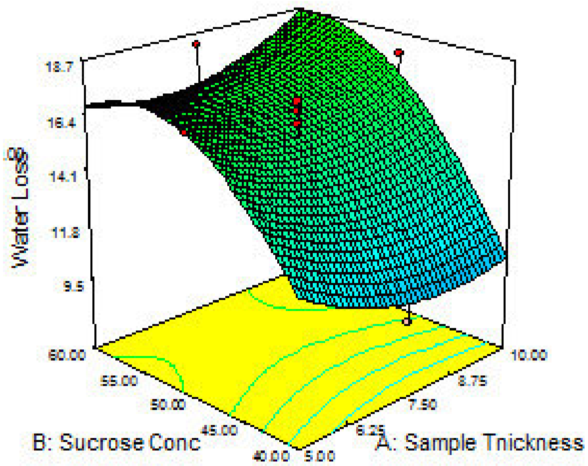
- S=significant at 5% level of significance ($p<0.05$)
- NS= nonsignificant at 5% level significance ($p>0.05$)



(a)



(b)



(c)

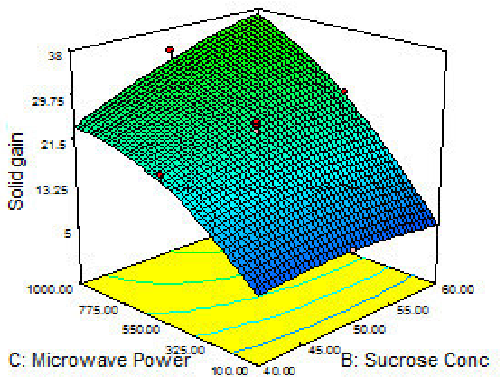
Fig. 4.1 (a-b): Response surface and contour plots for water loss

4.2 Influence of pulsed microwave heating on solid gain (SG)

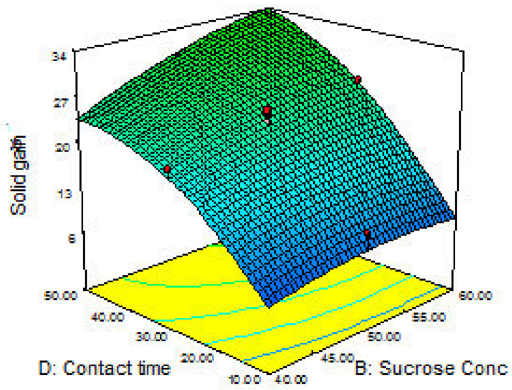
The coefficient of the solid gain regression model is given in Table 4.1. The lack of fit was nonsignificant at 5% level of significance, the R^2 (coefficient of determination) was 0.98; the CV was 16.77%, which all revealed that the quadratic model was adequate for predicting solid gain. The p and F values indicated that the microwave power has the most pronounced effect on SG followed by the time of osmosis, sucrose concentration and slice thickness. This result describes that as the microwave power increased significantly increased in the SG during pulsed microwave osmotic dehydration of banana slices. This linear effect can be explained by the greater exposure to microwaves thus in higher SG. This is due to a decrease in the viscosity of the solution with increased microwave power over time thereby temperature rising and facilitating greater mobility. This result agree with the findings of several studies where increased temperature also increases the solids gain of the product (Azarpazhooh & Ramaswamy 2012; Lazarides et al. 1995; Sutar et al. 2012; Azarpazhooh & Ramaswamy 2010). The quadratic terms of all process variables have a negative effect on SG except slice thickness. Therefore, the mathematical expression of relationship to the response with coded variables of solid gain is given below:

$$SG = 24.01 + 2.16A + 2.99B + 12.42C + 10.82D + 0.51AB + 1.76AC + 1.06AD + 3.38BC + 1.99BD + 10.40CD + 1.73A^2 - 1.47B^2 - 4.32C^2 - 4.45D^2 \qquad (4.2)$$

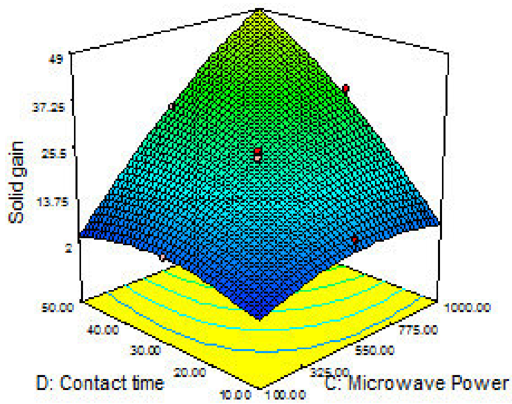
It is noted from Table 4.1 that the interaction term ' microwave power and time of osmosis' have the most significant effect on SG followed by 'sucrose concentration and microwave power', and 'sucrose concentration and time of osmosis' at $p<0.05$. The response surface and contour plots [Fig. 4.2 (a-c)] are generated for the fitted model to visualize the combined effect of different process variables on the solid gain. Fig 4.2 (a) explains that when the sucrose concentration and microwave power increases resulting in increasing solid gain. The possible explanation for higher solid gain is due to the effect of microwave power absorption by the water molecules in the system (both fruit and syrup) and therefore rapid heating of water molecules and leading to more efficient water and solute transfer from fruit to the syrup (Azarpazhooh & Ramaswamy 2009). From Fig. 4.2 (b) it is noticed that as the time of treatment and sucrose concentration increases SG also increases. This gaining of soluble solid content as a function of time also reported by Chandra & Kumari (2015). Fig 4.2 (c) shows that when the interaction effect microwave power and contact time increases resulting in increasing of SG of banana slices during PWOD. This is because of higher temperature which increased as a result of increment of microwave power application over time. Moreover, higher temperatures cause individual cells in the sample to swell hence increase the cell membrane permeability to sucrose molecules (Lazarides et al. 1997; Wray & Ramaswamy 2013).



(a)



(b)



(c)

Fig 4.2 (a-c): Response surface and contour plots for solid gain

4.3 Influence of pulsed microwave heating on drying efficiency (DE)

The regression model for DE is given in Table 4.2. Multiple regression analysis showed that the lack of fit was highly insignificant at $p>0.05$, the coefficient of determination (R^2) was 0.90 which explained that fitted linear model was accounted for more than 90% of the variation in the experimental data. The Model F-value of 60.13 implies that the model is significant ($p<0.01$). The coefficient of variation (CV) is 15.25% which show that the deviations between experimental and predicted value are also low. The p and F values indicated that the microwave power was the most significant influential variable for drying efficiency followed by the time of osmosis. In addition to, at lower microwave power levels and shorter time of osmosis can offer lower energy consumption since exhibited increased drying efficiency. This phenomenon is in line with the results of Sunjka et al. (2008) and Giri & Prasad (2007). However, sucrose concentration and slice thickness has significant negative effect on DE. This explains that increase of those variable results in the decrease in drying efficiency. Thus, the final equation for drying efficiency in terms of coded values is:

Drying efficiency (DE)=57.91-5.40A-6.03B+29.33C+10.80D........................(4.3)

4.4 Influence of pulsed microwave heating on color change (ΔE)

The co-efficient of the color change regression model is listed in Table 4.2. The "lack of fit F value" of 1.41 implies that the Lack of Fit was nonsignificant ($p>0.05$). The R^2 value was calculated by least square technique and found to be 0.96 showing the good fit of the model to the data. Moreover, the coefficient of variation (CV) describes the extent to which the data were dispersed. The value of CV for color change was found to be 9.27% which all indicated that the model was adequate for predicting color change (ΔE). The F value, p values and β values in Table 4.2 indicate that the color change was mostly affected by microwave power, contact time, sucrose concentration, and sample thickness ($p<0.05$). This finding revealed that decrease in color of osmotically dehydrated banana slices with an increase of these linear process variables. This may be due to the dielectric breakdown which occurs when the electric field intensity in the drying chamber is above a threshold value and leads to burning of the product surface hence color changes of osmotically dehydrated banana slices (Wang et al. 2014). Therefore, after solving second order polynomial equations the final equation for color change is given in below:

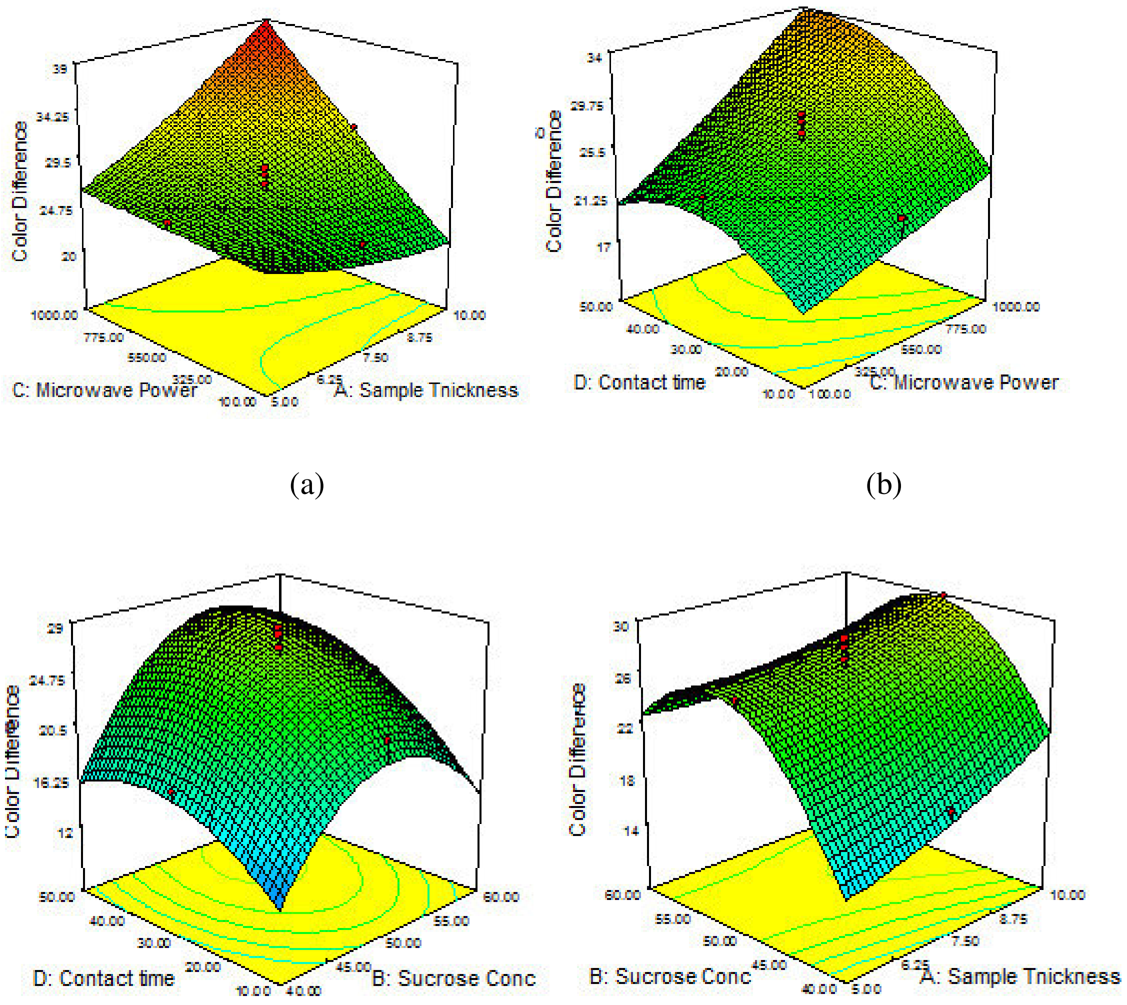
Color change (ΔE) $=26.85+2.00A+2.70B+4.84C+3.19D-1.32AB+4.27AC+0.46AD+0.22BC+1.47BD+1.86CD+0.81A^2-6.88B^2+0.23C^2-3.29D^2$..............................(4.4)

Table 4.2 : ANOVA showing the effects of the variables on drying efficiency and color change during pulsed microwave osmotic dehydration of banana slices

Source	df	Drying efficiency				df	Color change			
		β	**Sum of square**	**F- value**	**P level**		**β**	**Sum of square**	**F- value**	**P level**
Model	4	57.91	18768.13	60.13	0.0001[S]	14	26.85	1774.67	32.34	0.0001[S]
Sample thickness (A)	1	-5.40	525.05	6.73	0.0156[S]	1	2.00	72.02	18.37	0.0006[S]
Sucrose conc. (B)	1	-6.03	653.65	8.38	0.0078[S]	1	2.70	131.57	33.56	0.0001[S]
Microwave power (C)	1	29.33	15489.03	198.50	0.0001[S]	1	4.84	421.42	107.50	0.0001[S]
Time (D)	1	10.80	2100.39	26.92	0.0001[S]	1	3.19	183.39	46.78	0.0001[S]
AB						1	-1.32	27.81	7.09	0.0177[S]
AC						1	4.27	291.77	74.43	0.0001[S]
AD						1	0.46	3.33	0.85	0.3716
BC						1	0.22	0.74	0.19	0.6698
BD						1	1.47	34.62	8.83	0.0095[S]
CD						1	1.86	55.48	14.15	0.0019[S]
A^2						1	0.81	1.68	0.43	0.5224
B^2						1	-6.88	122.79	31.32	0.0001[S]
C^2						1	0.23	0.14	0.035	0.8537
D^2						1	-3.29	28.12	7.17	0.0172[S]
Lack of fit	20		1672.70	**1.504**	**0.3457[NS]**	10		43.45	**1.41**	**0.3686[NS]**
R^2			**0.90**					**0.96**		
C.V. %			**15.25**					**9.27**		

- S=significant at 5% level of significance ($p<0.05$)
- NS= nonsignificant at 5% level of significance ($p>0.05$)

The interaction term ' sample thickness and microwave power', 'microwave power and time of osmosis', and 'sucrose concentration have the positive and significant effect ($p<0.05$) on color change even though 'sample thickness and sucrose concentration' have the negative effect. This reflects that with the increase of sample thickness and sucrose concentration there is significant change in color of the samples. It is observed from Table 4.2 that the quadratic terms of sucrose concentration and time of osmosis have the negative and most influential effect on the color change of the sample while other two variable has the positive effect.



(a) (b)

(c) (d)

Fig 4.3 (a-d): Response surface and contour plots for color change

It is noticed from Fig 4.3 (a-d) that microwave power, sample thickness and time of osmosis has the most pronounced effect on the color change of the sample. This explains that changes of these variables significant change in the color of the osmotically dehydrated banana slices sample. This is possibly due to higher microwave power absorption over time on the slices and solution, which influenced the temperature of the sucrose solution thereby burns on the product surface and leads to purple light color.

4.5 Optimization of the responses during PMOD of banana slices and experimental validation

Numerical optimization was performed using the developed models for water loss, solid gain and color change. The slice thickness, sucrose concentration, microwave power and osmosis time were set in the range while the response WL was set at maximum, SG and color change were set at minimum. The Design Expert program was run for the optimum conditions and the solutions obtained are presented in Table 4.3. The best solution was found with a maximum desirability value selected as the optimum conditions for PMOD of banana slices.

Table 4.3: Solution for optimum conditions

Solution No.	Slice thickness (mm)	Sucrose Conc. ^{o}Brix	Microwave power (Watt)	Time (min)	WL (%)	SG (%)	CC (ΔE)	Desirability
1.	**9.76**	**60.00**	**100.00**	**50.00**	**19.30**	**6.58**	**15.17**	**0.725**
2.	9.96	60.00	108.77	50.00	19.53	7.69	15.26	0.724
3.	10.00	59.52	100.00	49.70	19.50	7.19	15.59	0.722
4.	9.51	60.00	114.50	50.00	19.59	8.25	15.37	0.721

Pulsed microwave osmotic dehydration (PMOD) of banana slices were performed for validating the predicted data. Moreover, the experimental values of various responses were calculated by using the predicted values of various independent variables. The experimental values (mean of two measurements), as well as predicted values of various responses are presented in Table 4.4

Table 4.4 Comparison of experimental values with predicted values

Response	Predicted value	Experimental value ±SEM
Water loss (%)	19.30	19.54±0.19
Solute gain (%)	6.58	6.92±0.174
Color change (ΔE)	15.17	16.98±1.36

CHAPTER V

SUMMARY AND CONCLUSION

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In this study, the pulsed microwave osmotic dehydration (PMOD) of banana slices was carried out by immersing in sucrose solution according to the face-centered central composite experimental design (FCCD). Additionally to optimize PMOD process response surface methodology was used to predict the optimum operating conditions that yield maximum water loss (WL), minimum solid gain (SG) and color change. The experimental data was analyzed by using multiple regression techniques to develop a response surface model. In order to obtain a better understanding of different process variables for the developed models was studied for analysis of variance (ANOVA) and the second-order polynomial model was solved for predicting various responses.

The time of osmosis/contact time has the most significant effect on WL followed by microwave power and sucrose concentration. It implies that when the time of osmosis increased WL also increased linearly. However, for SG the microwave power has the most pronounced effect. This is because of the greater exposure to microwave hence rapid and uniform increment of the temperature of sucrose solution resulting in a decrease in the viscosity of the solution thereby facilitating greater mobility. For drying efficiency and color change, microwave power was found also as a most influential linear variable followed by the time of osmosis, sucrose concentration and sample thickness at 95% level of confidence. This revealed that increase in power consumption and the decrease in color of osmotically dehydrated sample with the increase of microwave power level. The change in color of the product due to the breakdown of dielectric properties of the sample and solution simultaneously which occurs when the electric field intensity in the drying chamber is above a threshold value. Moreover, leads to burning of the product surface since the appearance of light purple color on the product surface and solution also. The desirability function technique was used for finding the optimum conditions during pulsed microwave osmotic dehydration (PMOD) of banana slices. By numerical optimization technique, the optimum solution was found to be 19.49 % (wb), 6.96% (wb) and 15.06 for water loss, solid gain and color change, respectively. After obtaining optimum conditions for various responses and independent process variables, PMOD experiments of banana slices were carried out to validate predicted values. The experimental responses were found in close proximity to the predicted values from fitted models.

Therefore, pulsed microwave osmotic dehydration (PMOD) process is suitable for obtaining intermediate moisture food products. Moreover, pulsed microwave heating can be applied to the osmotic dehydration process to improve mass transfer rates during the process. This is because osmotic dehydration under pulsed microwave heating made possible to obtain a higher diffusion rate of water transfer at lower solution concentration and temperatures as well as limit the intake of soluble solids of banana slices.

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