MICROWAVE-INFRARED COMBINATION DRYING OF EGGPLANTS

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

MICROWAVE-INFRARED COMBINATION DRYING OF EGGPLANTS

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The objective of this study was to investigate the effects of hot-air drying and microwave-infrared combination drying on drying characteristics and quality parameters of eggplants. Eggplant slices were dried by using microwave-infrared combination oven at different microwave powers (30%, 40% and 50%) and different infrared (IR) powers (10%, 20% and 30%). Hot air drying was performed in tray dryer at 50°C with an air velocity of 1.5 m/s. As quality parameters, color, rehydration ratio, shrinkage, microstructure and pore size distribution of dried eggplants were chosen.

Microwave-IR combination provided significantly shorter drying time than hot air drying. Osmotic dehydration also reduced drying time in microwave-IR combination oven. In addition, increase in microwave and IR powers increased drying rates so decreased drying time. Effective diffusivity of hot air drying (5.07×10^{-10} m^2/s) was found to be lower than that of microwave-IR drying (7.099×10^{-9}-1.445×10^{-8} m^2/s). Higher microwave and IR powers increased but osmotic pretreatment decreased effective diffusivity.

Microwave-IR dried eggplants had more porous structure than hot air dried ones. Therefore, these eggplants had lower shrinkage and higher rehydration ratio than hot air dried ones. Osmotically dehydrated eggplants had higher shrinkage and lower rehydration ratio than untreated ones. Decrease in IR power and increase in osmotic dehydration increased L* but decreased a* values.

Eggplants dried in microwave-IR combination at 20% IR power and 50% microwave power without any pretreatment had higher rehydration ratio but lower shrinkage as compared to hot air dried ones.

Keywords: microwave, infrared, drying, eggplant, osmotic drying

ÖZ

PATLICANIN MİKRODALGA-KIZIL ÖTESİ KOMBİNASYONU İLE KURUTULMASI

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Bu çalışmanın amacı, sıcak hava ile kurutma ve mikrodalga-kızıl ötesi kombinasyonu ile kurutmanın patlıcanın kuruma özellikleri ve kalite parametreleri üzerindeki etkilerinin incelenmesidir. Patlıcan dilimleri mikrodalga-kızıl ötesi kombinasyonlu fırının farklı mikrodalga güçleri (%30, %40 and %50) ve farklı kızıl ötesi güçleri (%10, %20 ve %30) kullanılarak kurutulmuştur. Sıcak hava ile kurutma, 4 saat boyunca 50°C sıcaklıktaki 1,5 m/s hızındaki hava ile tepsili kurutucu kullanılarak yapılmıştır. Kurutulmuş patlıcanlarda kalite parametreleri olarak renk, rehidrasyon oranı, büzülme, mikroyapı ve gözenek boyutu dağılımı seçilmiştir.

Mikrodalga-kızıl ötesi kombinasyonu, sıcak hava ile kurutmaya göre önemli ölçüde daha kısa sürede kurutma sağlamıştır. Ozmotik kurutma da mikrodalga-kızıl ötesi kombinasyon fırındaki kuruma süresini azaltmıştır. Ek olarak, mikrodalga ve kızıl ötesi güçleri arttıkça, kuruma hızı artmış bu yüzden kuruma zamanı azalmıştır. Sıcak hava ile kurutmada etkin yayınma katsayısının ($5{,}07\times10^{-10}$ m^2/s), mikrodalga-kızıl ötesi ile kurutmanınkinden daha düşük olduğu bulunmuştur ($7{,}099\times10^{-9}$-$1{,}445\times10^{-8}$ m^2/s). Etkin yayınma katsayısını, yüksek mikrodalga ve kızıl ötesi güçleri arttırırken, ozmotik ön işlem azaltmıştır.

Mikrodalga-kızıl ötesi ile kurutulmuş patlıcanların sıcak hava ile kurutulmuş patlıcanlardan daha gözenekli bir yapıya sahip olduğu bulunmuştur. Bu yüzden, bu patlıcanlarda daha az büzülme ve daha yüksek rehidrasyon oranı gözlenmiştir. Ozmotik olarak kurutulmuş patlıcanlarda ön işlem görmemiş patlıcanlara göre büzülme daha fazla, rehidrasyon oranı daha az olmuştur. Kızıl ötesi gücünün azaltılması ve ozmotik kurutmanın arttırılması L* değerlerini arttırırken a* değerlerini azaltmıştır.

Ön işlem uygulanmadan, %20 kızıl ötesi güç ve %50 mikrodalga gücünde mikrodalga-kızıl ötesi kombinasyonu ile kurutulan patlıcanlar, sıcak hava ile kurutulanlara göre daha yüksek rehidrasyon oranına ama daha az büzülmeye sahip bulunmuştur.

Anahtar Kelimeler: Mikrodalga, kızıl ötesi, kurutma, patlıcan, ozmotik kurutma

To my family…

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INTRODUCTION

1.1 Eggplant

Eggplant (*Solanum melongena L.*) is an important market vegetable of Asian and Mediterranean countries. According to Food and Agriculture Organization of the United Nations, annual production of eggplants in the world has been around 46,825,331 tons in 2011. Turkey is one of the world's largest growers, whose annual production has been around 821,770 tons in 2011 (http://faostat3.fao.org/faostat-gateway/go/to/download/Q/QC/E. Last visited: October, 2013).

The vitamin and mineral composition of eggplant (per 100 g) was shown in Table 1.1. Eggplant is a good source of vitamins and minerals, especially in potassium and phosphorus. It contains a variety of phytochemicals such as phenolics and flavonoids (Akanitapichat et al., 2010). It is ranked amongst the top ten vegetables in terms of antioxidant capacity due to the phenolic constituents (Cao et al., 1996). There are several researches that describe the health benefits of the phenolic compounds extracted from eggplant (Han et al., 2003; Matsubara et al., 2005; Li, 2008). Matsubara et al. (2005) demonstrated that eggplant extracts suppressed the formation of blood vessels required for tumor growth and metastasis. Han et al. (2003) showed anti-inflammatory effect of eggplant. Also, eggplant can be used for the treatment of rheumatism, cardiovascular illnesses, obesity, high cholesterol and constipation (Li, 2008).

Table 1.1 Vitamin and mineral content of eggplant (100 g basis) Derived from http://nutritiondata.self.com/facts/vegetables-and-vegetable-products/2443/2. Last visited: October, 2013.

Vitamins	Amount per 100 gr	Minerals	Amount per 100 gr
Vitamin A	27 IU	Calcium	9.0 mg
Vitamin C	2.2 mg	Iron	0.2 mg
Vitamin E	0.3 mg	Magnesium	14.0 mg
Vitamin K	3.5 mcg	Phosphorus	25.0 mg
Niacin	0.6 mg	Potassium	230 mg
Vitamin B6	0.1 mg	Sodium	2.0 mg
Folate	22.0 mcg	Zinc	0.2 g
Pantothenic Acid	0.3 mg	Copper	0.1 mg
Choline	6.9 mg	Manganese	0.3 mg

1.2 Osmotic Dehydration

The thermodynamic state of water in foods is expressed by water activity which is zero for absolutely dry material and one for pure water. The lower water activity means that food is more stable. Therefore, decreasing water activity of foods is an important issue for the stability of foods (Lewicki & Lenart, 2007).

Osmotic dehydration is the process in which water is partially removed from the cellular materials by immersion of them in a concentrated solution of soluble solute (Singh & Gupta, 2007). In osmotic dehydration, there are two major simultaneous counter-current flows which are significant amount of water transfer from the food into the solution and transfer of solute from the solution into the food. In addition, natural soluble solutes such as sugars, minerals etc. leach from the food into the solution which is generally negligible (Falade & Igbeka, 2007). Phase change does not occur during osmotic dehydration. The concentration gradient between the osmotic solution and food is the driving force for removing of water. Natural cells of food provide semipermeable membrane so osmotic dehydration does not result in disintegration of texture of product (Shukla & Singh, 2007). Several osmotic agents such as sucrose, glucose, fructose, corn syrup, sodium chloride and their different combinations have been used for osmotic dehydration. In most cases, sucrose solutions are used for fruits and sodium chloride solution is used for vegetables. The rate of diffusion of water from food depends on temperature and concentration of the osmotic solution, the size and geometry of the food, the mass ratio of solution to food, and the level of agitation of the solution (Ade-Omowaye et al., 2002).

The osmotic dehydration cannot reduce water activity of food sufficiently to avoid microbial activity. Therefore, after osmotic dehydration, application of other preservation methods such as freezing, pasteurization or drying is necessary to reach the final moisture content in which shelf stability can be achieved (Lewicki & Lenart, 2007).

When osmotic dehydration is used as a pretreatment for drying process, it provides several advantages (Torringa et al., 2001; Pan et al., 2003);

- Providing more economical drying than thermal drying
- Producing unique products with better taste
- Improving flavor characteristic and nutritional value
- Prevention of oxidation of the product and providing color stabilization
- Improvement of the texture of the product.

1.3 Drying

Drying is one of the oldest and most frequently used methods of food preservation. Wu et al. (2007) defines drying as a removal of moisture from the food materials to prevent the growth and reproduction of spoilage microorganisms and to slow down the action of enzymes and minimize many of the moisture mediated deteriorative reactions. In order to improve shelf life, reduce packaging costs, lower shipping weights, enhance appearance, encapsulate original flavor and maintain nutritional value, food products are dried (Chou & Chua, 2001).

Okos et al. (1992) summarized the goals of drying process in food industry as three-fold;

a. Process economics: To minimize product loss and to reduce cost with improving capacity per unit amount of drying equipment that is reliable and needs minimal labor requirement, and to develop a stable process.
b. Product quality: To minimize chemical and biochemical degradation reactions, to reduce the change in product structure, to control density and to obtain the desired product color and storage stability.
c. Environmental aspects: To minimize environmental impact by reducing loss in waste and energy consumption during drying process.

Drying methods can be divided with respect to mode of operation, as continuous or batchwise. Another group of drying methods, which is based on heat supply method, are convective, conductive, radiative and dielectric (Keey, 1972).

Most thermal dryers represent convective heating in which the heat is supplied with the hot gas generally air, to direct contact with the drying substance. Tray dryer is the most common example of convective dryer. Electromagnetic radiation whose wavelengths range from solar radiation to microwaves can be used for drying. IR heating is an example of radiative heating which is used in drying films, coatings and sheet materials. Dielectric heating is generated throughout the whole material when dielectric material is placed in an electric field which is very rapidly oscillating (Keey, 1972).

In general, drying involves two simultaneous processes which are heat transfer for evaporation of water and mass transfer of water vapor (Berk, 2009). There are interactions both between heat and mass transfer processes occurring within the food itself and also between the food and the drying medium around the solid matter (Margaris & Ghiaus, 2008). Since the products to be dried have different shapes, moisture contents and temperature sensitivity, the drying conditions such as drying time, drying temperature, amount of heat to be supplied, and amount of water vapor to be removed can be changed (Margaris & Ghiaus, 2008). Heat and mass transport phenomena affect the quality of dehydrated foods. Texture, appearance, color, flavor, taste and nutritional value are affected from drying process conditions. Therefore, deciding suitable drying system is very important for food products. While drying conditions has been selected, type of feed, amount of moisture, drying kinetics, heat sensitivity, physical structure of the material to be dried and quality requirements of a dried food should be regarded (Jangam, 2011).

Fruits and vegetables are valuable sources of essential dietary nutrients, vitamins and minerals. However, they are very perishable because of having high moisture content (above 80 % wb) (Margaris & Ghiaus, 2008). The main aim of drying of fruits and vegetables is to minimize postharvest losses and to extend shelf lives. Keeping more of original characteristics is an important issue for consumers. Therefore, minimizing the adverse effects of drying processing has been recently a critical concern. To obtain healthy, fresh-like and convenient foods, the process must be in optimum condition (Nijhuis, et al., 1998). The significant properties that are used for evaluation of the quality of dehydrated products are the thermal, structural, textural, sensory, optical, microbiological and rehydration properties (Giri & Prasad, 2009). In developed countries, 12-25% of the industrial energy consumption is assigned for drying industry (Garcia-Perez et al., 2011). In food industry, dried vegetables and fruits are used for many processes. Dehydrated vegetables such as mushrooms, carrots, onions etc. are used for instant soups, snack seasonings, stuffing, pasta, salads and meat and rice dishes (Torringa et al., 2001).

1.3.1 Sun Drying

Sun drying method is widely used to dry grains, vegetables, fruits and other agricultural products (Togrul & Pehlivan, 2004). In Turkey, sun drying is commonly used for drying of vegetables. In open sun drying, solar radiation directly affects the foods. The heat results in vapor formation with increasing temperature and evaporation of water from the surface of food (Togrul, 2003).

In literature, there are a number of studies on open sun drying of food products (Soysal & Oztekin, 2001; Kumar & Tiwari, 2007; Sobukola et al., 2007; St.George & Cenkowski, 2009). Sobukola et al. (2007) investigated the thin layer drying characteristics of leafy vegetables using open sun drying method. Kumar & Tiwari (2007) studied drying of onion flakes under open sun and solar dryer. Although sun drying is one of the drying methods with the lowest cost, it has the disadvantages of lack of control of the drying process, loss of product quality, lack of uniformity in drying, risk of contamination by molds, bacteria, rodents, birds and insects, long drying times and dependence on climate (St.George & Cenkowski, 2009). Furthermore, sun drying has the inability to handle the large throughput of harvester and consumer. Intensive solar radiation causes some quality problems such as vitamin losses, and color changes (Soysal & Oztekin, 2001).

1.3.2 Convective Drying

For convective drying, hot and dry gas (usually air) is used to generate heat for evaporation of water inside food. Since air is mostly used as a gas, convective drying is known as air drying. The most common equipment for drying is tray dryer which is also called shelf, cabinet, or compartment dryers. A typical tray dryer contains removable trays set in a cabinet. In tray drying process, the food is put on a tray, and heated air is recirculated by a fan and then hot air is contacted with the food (Geankoplis, 2003). Heat is transferred from air to food product by convection. In addition, there are two main mass transfers which are the transfer of water to the surface of the dried food and the removal of water vapor from the surface (Jayaraman & Das Gupta, 2007).

In conventional drying, drying curve of a food generally consists of three periods. The first period is constant rate period in which drying rate is constant. At high moisture contents, liquid flows due to dominating capillary forces. The surface is wet due to the constant capillary-driven flow of water within the particle. After almost all water at the surface has been finished, the moisture is diffused from internal parts of the food to the surface (Sokhansanj & Jayas, 2007). During drying, the surface that evaporation occurs is drawn more through the center of material so the distance of both water and heat transport becomes longer. Therefore, drying rate decreases sharply in the next period which is called as "first falling rate period" (Erle, 2005). After first falling rate period, there is almost no free water and only slow diffusion is observed in second falling rate period (Erle, 2005).

During the early stages of drying, convective hot air drying is certainly the most efficient method. However, as the process continues, drying hardly progresses and slows down so it requires more energy (Argyropoulos et al., 2011). During drying process, the rate of evaporation is faster than the rate of water movement to the surface. Thus, the outer skin is too dry which is called "case hardening" and it is a significant problem in vegetable drying (Vadivambal & Jayas, 2007). During hot air drying, food is exposed to heat for longer time that causes problems related to quality parameters such as unacceptable color, flavor, texture, sensory characteristics, loss of nutrients, shrinkage, reduction in bulk density and rehydration capacity (Maskan, 2001a).

There are numerous studies in literature about usage of hot air drying method for drying of foods (Ratti, 2001; Doymaz & Pala, 2002; Telis & Sobral, 2002; Piga et al., 2004; Kotwaliwale et al., 2007; Orikasa et al., 2008; Sturm et al., 2012). Piga et al. (2004) dried figs with hot air at 25°C. Drying proceeded 54 hour and a significant loss of ascorbic acid was reported. For drying of kiwifruit, Orikasa et al. (2008) used hot air drying at four temperatures ranging from 40 to 70°C and stated that when hardening of the sample surface was avoided, it accelerated the drying rate of kiwifruit. Doymaz & Pala (2002) dried red pepper with hot-air method and stated that drying rate increased with increasing the surface area exposed to heated air. Sturm et al. (2012) optimized the drying conditions such as air temperature, dew point temperature and velocity of air. Kotwaliwale et al. (2007) reported textural (hardness, cohesiveness, springiness and chewiness) and optical properties of mushroom during hot air drying. Ratti (2001) compared hot air and freeze drying of high value foods and high quality foods were obtained by freeze drying. Telis & Sobral (2002) stated that glass transition temperature of air dried tomatoes was lower than freeze dried ones due to the structural differences between air and freeze-dried product. Some other studies on drying of fruits and vegetables exist in literature such as drying of banana (Cano-Chauca et al., 2002), eggplant (Kavak Akpinar & Bicer, 2005), potato (McLaughlin et al., 1998; Caixeta et al., 2002; Hassini et al., 2007), cauliflower (Mulet et al., 2000), apple (Bai et al., 2002; Lewicki & Jakubczyk, 2004; Velic et al., 2004; Srikiatden & Roberts, 2005; Menges & Ertekin, 2006), tomato (Demiray et al., 2013), mango slices (Madamba & Jose, 2005), grapes (Azzouz et al., 2002).

1.3.3 Microwave Drying

1.3.3.1 Mechanism of Microwave Heating and Drying

Microwaves are electromagnetic waves in frequencies between 300 MHz and 30 GHz (Figure 1.1). Microwaves are non-ionizing radiations because they are placed between radio frequency range at lower frequencies and IR and visible light at higher frequencies. The frequency of microwaves borders to range of radio frequencies used for broadcasting. Therefore special frequency bands are stated by International Telecommunications Union for industrial, scientific and medical (ISM) to prevent interference with radio systems (Regier & Schubert, 2005).

For industrial applications, 2.45 GHz or 915 MHz are used but domestic microwave ovens work at 2.45 GHz (Dibben, 2001).

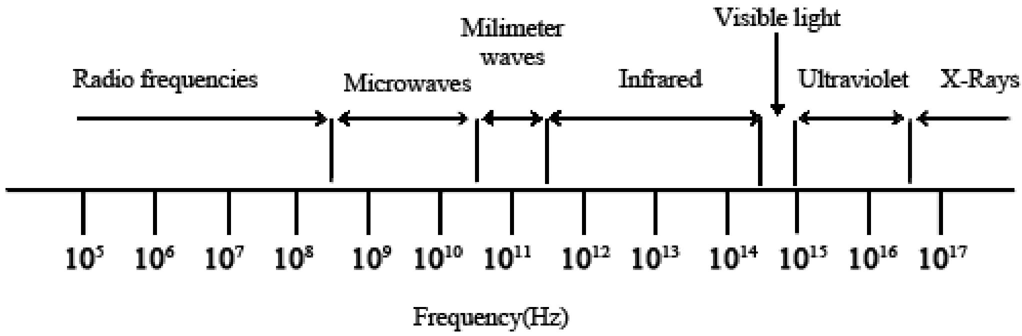

Figure 1.1 The electromagnetic spectrum (Sahin & Sumnu, 2006)

The basic components of microwave heating are generator and applicator. Generator is used to convert the alternating current of 50 or 60 Hz to the high frequency energy. A microwave generator composed of a magnetron or a klystron. After generating the microwave energy, it must be focused upon the load and it is transported to the applicator which is usually waveguides or coaxial cable for lower power (Schiffmann, 2007).

Heat transfer equation for a food material being heated by microwave is;

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T + \frac{Q}{\rho C_p} \quad (1.1)$$

where, “T” is temperature (°C), “t” is time (s), “α” is thermal diffusivity ($m^2.s^{-1}$), “ρ” is density ($kg.m^{-3}$), “C_p” is specific heat of the material ($J.kg^{-1}.°C^{-1}$) and “Q” is the rate of heat generated per unit volume of material per unit time ($J.m^{-3}.s^{-1}$).

Heat generation is a function of field frequency and absorbed power foods. The heat generated per unit volume can be written as,

$$Q=2\pi\varepsilon_0\varepsilon'' f E^2 \quad (1.2)$$

where ε_0 is the permittivity of free space (8.85×10^{-12} F/m), f is the microwave frequency (Hz) and E is the electrical field strength (V/m) in the material (Meda et al., 2005).

Microwave heating mechanism is based on dipolar rotation and ionic interaction. Because of existing molecular friction from dipolar rotation of polar solvents and the conductive migration of dissolved ions, a volumetric heating occurs (Sakiyan et al., 2007). The major component of foods is water which is polar. In microwave oven, magnetron produces electric field. In the presence of electric field, water molecules rotate in the direction of electric field and they collide with other water molecules. When the direction of electric field is reversed, water molecules reverse themselves and move to the other direction. Thus, kinetic energy releases from the oscillating electric field by the dipoles and is transferred to other molecules by the collisions, hence heating takes place. The other heating mechanism is ionic interaction. Charged molecules, such as salt, are composed of positive and negative ions. In the electric field, while one of the particles move in one direction and the oppositely charged particle moves in the other direction. This agitation causes kinetic energy and heating occurs (Decareau, 1992; Sahin & Sumnu, 2006).

Dielectric properties of the food material, which are dielectric constant (ε') and dielectric loss factor (ε''), describes the interactions between microwaves and food material. Dielectric constant shows the ability of a material to store microwave energy and dielectric loss factor shows the ability of a material to dissipate microwave energy into heat. The ratio of ε'' to ε' is called as tangent of loss angle ($\tan \delta = \varepsilon''/ \varepsilon'$) which determines the attenuation of microwave power in foods (Tang, 2005). There are many variables that affect these factors. The basic ones are moisture content, temperature, density, thermal conductivity and frequency. For example, as the moisture content increases, dielectric loss factor increases, too. Therefore, having knowledge over the dielectric properties of food materials, supplies invaluable information about the heating patterns of microwave heating and it helps to develop products, processes and equipment with consistent and predictable properties (Sumnu & Sahin, 2005).

Penetration depth (D_p) of microwaves is defined as the depth where the power is reduced to 1/e =37 % of its value at the surface of the material (Nelson & Datta, 2001). According to Equation (1.3) penetration depth is inversely proportional to the frequency. In order to identify, whether electromagnetic field at a certain frequency can provide uniform heating, penetration depth is an important factor (Tang, 2005).

$$D_p = \frac{\lambda_0}{2\pi\sqrt{2\varepsilon'}} \left[\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2} -1\right]^{-1/2} \quad \text{(Nelson \& Datta, 2001)} \qquad (1.3)$$

where, λ_0 is wavelength of microwave in free space.

In conventional heating, heat is transferred from outside of material to the center of material by conduction. Foods are good heat insulators so conventional heating is so slow. Thus, the center of food is the coolest part and the surface of food is the hottest part. However, in microwave processing volumetric heating occurs. Heating is obtained by the generation of heat within the material itself (Tireki, 2005). Microwave heating has several advantages when compared to conventional heating methods. These are listed as follows;

- Unlike conventional heating, a driving temperature gradient is not necessary for microwave heating and there is notable evaporation inside the material that promotes moisture loss during heating.
- The heating rate of microwave is higher than conventional heating. Therefore, processing time is significantly lower. This can lead to cost and energy saving.

- In microwave heating, energy directly affects the food so there is significant energy saving.
- Due to the internally generated high water vapor pressure, more porous products are obtained which is known as puffing effect.
- With selective heating characteristic of microwave heating, partial heating can be done because moist parts are heated more than the dry ones.
- Better and more rapid process control can be supplied.
- Microwave heating accelerates some processes such as melting and drying.
- Microwave heating overcomes the common problems such as overheating of surface and case hardening in conventional heating since high surface temperatures cannot be generated.
- Less floor space is needed due to more rapid heating (Datta, 2001; Torringa et al., 2001; Schiffmann, 2007).

Due to having significant advantages, microwave heating is used in many areas of food industry. Microwave heating is preferred in tempering, cooking, drying, pasteurization, blanching, baking, packaging and extraction (Orsat et al., 2005).

In conventional drying, heat is transferred from the heating media to the product surface mainly by convection and followed by conduction to the center. Thus, firstly, it is needed to heat the surrounding air in dryer and then conduction occurs (Sablani et al., 1998). It causes low energy efficiency and the long drying time. Microwave drying is different from conventional drying in terms of heating mechanism. In microwave oven, foods are heated by internal heat generation due to the absorption of electrical energy from the microwave field and heat transfer by conduction, convection and evaporation. During microwave drying, microwave energy is rapidly converted to thermal energy in the medium to achieve heating without needing a thermal gradient, so it leads to a rapid increase in temperature of foods (Sumnu, 2001). Microwave energy is transmitted through the food and provides volumetric heating. Microwaves are absorbed more in wet parts of food than dry ones due to having higher dielectric loss factors. Thus, the center of food is warmer than its surroundings which promote the mass transfer (Erle, 2005). In addition, due to the internal heat generation, internal pressure gradients occur which forces the water to the surface.

Microwave heating can be combined with conventional drying methods in three ways; preheating, booster heating and finish heating. In preheating, microwave energy is applied in the entrance of dryer and material is heated to its evaporation temperature. In the booster drying, microwave heating is applied to conventional dryer when drying rate begins to fall. When moisture is concentrated in the center, microwaves supply internal heating and pump water from the center to the surface. This process is used for drying of pasta. In addition, when microwave heating is added at the exit of conventional dryer, which is called as finish drying. To dry cookies and biscuits, finish drying can be used (Schiffmann, 2001; Schiffmann, 2007). Maskan (2001a) investigated that drying time of kiwifruits is reduced by hot air-microwave finish combination to about 40% of the hot air drying. Similarly, hot air-microwave finish drying time of bananas was reduced to 64.3% of convection drying time (Maskan, 2000). In another research, Prabhanjan et al. (1995) stated microwave drying of carrots decreased the time of drying.

Advantages of microwave drying can be summarized below:

- Heat penetration directly to the food results quick energy absorption by water molecules and rapid evaporation of water. In general, drying time can be shortened by more than 50% that depends on product and drying conditions such as temperature and power.
- Energy is transferred directly to the product hence there is no resistance for heat flux in the convection.
- Microwave drying is found to be more efficient in the falling rate period as compared to the other drying methods.
- Due to the significantly shorter drying time, energy saving is obtained.
- Energy is not consumed for heating of the walls of oven or the environment hence the operational cost is lower.
- It leads to reduce migration of water soluble constituents.

- The combination with other drying techniques is quite easy.
- It needs less floor space since equipment is more compact due to the higher processing rate.
- The outward vapor flux leads to decreasing the shrinkage of the tissue structure.
- It provides an improvement in product quality by preventing case hardening and supplying puffing to the material. (Nijhuis, et al., 1998; Schiffmann, 2007; Vadivambal & Jayas, 2007; St.George & Cenkowski, 2009).
- Better color, higher rehydration rates (Feng & Tang, 1998) and higher porosity of microwave dried of foods (Krokida & Maroulis, 1997) have been reported in literature.

Microwave drying has also some disadvantages.

- Non-uniform heating is observed during microwave drying. The release of heat depends on the shape of foods. Too high temperature in the center or in the corners causes tissue destruction. The superposition of the sinusoidal microwaves causes uneven microwave field in the cavity. The composition and dielectric properties of the food material affect the temperature distribution. The location of dried food is also important for uneven heating.
- In order to control the mass transport, controlling the power input is needed however in some cases, the mass transfer rate is too high and controlling it is so difficult. Therefore, rapid mass transport causes undesirable puffing and damages the food texture.
- In general, microwave drying of foods is not suggested when food has high moisture content (over 20% moisture) because it is not economical. Water has very high specific heat so conventional drying is more effective to remove water than microwave drying at initial stages of drying.
- The investment cost is quite high because of expensive and low life-span magnetrons (Owasu-Ansah, 1991; Nijhuis, et al., 1998; Tireki, 2005; Motevali et al., 2011).

1.3.3.2 Studies on Microwave Drying of Foods

The first industrial microwave heating success is the finish drying of potato chips. Schiffmann (1986) and Krokida & Maroulis (1999) analyzed porosity and color of microwave-dried apples, bananas, carrots and potatoes and concluded that microwave drying increased product porosity and improved color. There are successful microwave drying applications in industry such as finish drying of potato chips, pasta drying, snack drying, finish drying of biscuits and crackers and cereal drying (Schiffmann, 2001). A number of studies have been conducted on microwave drying of fruits and vegetables such as mango ginger (Murthy & Manohar, 2012), banana (Maskan, 2000), apple (Askari et al., 2006; Wang et al., 2007), potato (Khraisheh, et al., 2004; Wang et al., 2004), spinach (Alibas et al., 2007). It has been proved that microwave drying offers higher drying rate and shorter drying time, more porous structure, higher rehydration ratio and lower shrinkage.

Although microwave drying is a good way to overcome the problems of conventional drying methods, if it is not appropriately applied, low quality products are obtained. Therefore, microwave drying has usually been combined with other drying techniques to obtain high quality foods with more uniform, fast and effective drying (Soysal et al., 2009).

Microwave- hot air combination has been the most commonly used drying method for fruits and vegetables (Khraisheh et al., 1997; Venkatachalapathy & Raghavan 1998; Sharma & Prasad, 2001; Beaudry et al., 2004). Khraisheh et al. (1997) dried potatoes under combined microwave and convective air conditions and stated that by using microwave heating, better quality finished products were obtained. Beaudry et al. (2004) dried osmotically dehydrated cranberries with four drying methods which are hot air drying, microwave-assisted convective drying, freeze drying and vacuum drying. It was reported that the shortest drying time was obtained using microwave-assisted drying. Venkatachalapathy & Raghavan (1998) dried blueberries by combination of hot air and microwaves and obtained products having the same quality as freeze-dried samples in a shorter time. Similarly, when garlic cloves were dried by microwave-hot air combination method, drying time significantly reduced as compared to conventional hot air drying (Sharma & Prasad, 2001). The foods that have been dried by using microwave-convective technique include such as grapes (Tulasidas et al., 1993), pumpkin slices (Alibas, 2007), apple (Funebo & Ohlsson, 1998; Andres et al., 2004), potato (Bouraout et al., 1994; Reyes et al., 1998), carrot (Prabhanjan et al., 1995), mushroom (Torringa et al., 2001; Argyropoulos et al., 2011), and tomato (Durance & Wang, 2002).

Microwave-vacuum combination drying offers an alternative way to eliminate quality problems caused by microwave drying. There are lots of researches about microwave-vacuum combination drying of fruits and vegetables such as bananas (Mousa & Farid, 2002; Mui et al., 2002), carrot slices (Lin et al., 1998), apple (Han et al., 2010), mushrooms (Giri & Prasad, 2007a), tomatoes (Durance & Wang, 2002), garlic slices (Cui et al., 2003), and cranberries (Sunjka et al., 2004).

1.3.4 IR Drying

1.3.4.1 Mechanism of IR Heating and Drying

IR radiation is the part of the electromagnetic spectrum that is predominantly responsible for the heating effect of the sun. IR radiation can be classified as near-IR (0.75-1.4 μm), mid-IR (1.4-3 μm) and far-IR (3-1000 μm) according to wavelengths (Jun et al., 2011). A medium is not needed for transmission of electromagnetic radiation. The wavelength of spectrum of the radiation depends on the nature and temperature of heat source. It is also called as “thermal radiation” since it generates heat.

Like other electromagnetic radiations, the IR radiation may be absorbed and converted to energy, or reflected from the surface or transmitted. This is expressed by the following equation Ratti & Mujumdar (2007);

$$\rho + \alpha + \tau = 1 \quad (1.4)$$

where, ρ is the reflectivity, α is the absorptivity and τ is the transmissivity.

As stated by Equation 1.4 without reflecting or transmitting, a body absorbs the entire incident energy is called as "black body" (α =1) (Ratti & Mujumdar, 2007).

Planck's law of radiation shows the emissive power distribution of the black surface bounded by a transparent medium with refractive index n (Jun et al., 2011);

$$E_{b\lambda}(T,\lambda)=\frac{2\pi h c_o^2}{n^2\lambda^2\left[e^{hc_o/n\lambda kT}-1\right]} \quad (1.5)$$

where k is known as Boltzmann's constant (1.3806×10^{-23} J/K), n is the refractive index of medium, λ is the wavelength (μm), T is the source temperature (K), c_o is the speed of light (km/s), and h is Planck's constant (6.626×10^{-34} J.s).

Although the magnitudes of ρ, α, τ depend on the material, its thickness and surface finish and the wavelength of radiation, the emissivity of electromagnetic waves depend on only the property of material. As the wavelength of the radiation increases, the emissivity, ε of electrical conductors also increases but emissivity of nonconductors decreases (Ratti & Mujumdar, 2007).

IR radiation drying is also called as thermal radiation drying. During IR drying, radiation energy is absorbed by the food surface and converted to heat. While generated heat is transferred to the center of the food, mass flux is transported from the center to the surface of food (Jaturonglumlert & Kiatsiriroat, 2010). The most important feature of IR drying is that a medium for transmission of energy from source to food is not required. In order to get higher drying efficiency, high absorption of IR radiation and coupling of absorbed energy with water in food are significant considerations (Nindo & Mwithiga, 2011). The useful energy for drying rate is affected by some factors such as the properties and thickness of food (Land, 2012).

Hasanati et al. (1988) designed a model for drying by IR energy and stated that IR drying consisted of three parts. The first one was constant drying rate period in which the material was heated. In the second part, water vapor pressure on the surface was equal to the saturated vapor pressure and drying rate decreased at falling rate period. Finally, in the third part, water was transported as vapor.

Solid materials absorb IR radiation in a thin surface layer. Nevertheless, foods, which are mostly composed of water, are penetrated by radiation and the transmissivity of foods depends on the moisture content (Lampinen et al., 1991). During drying, radiation features of the food products are changeable because of decreasing water content. Hence, as reflectivity increases, the absorptivity decreases. At short wavelengths, IR radiation is transmitted through water but at long wavelengths, it is absorbed on the surface. Therefore, although far-IR radiation is effective for thin layer foods, near-IR radiation is effective for thicker foods (Nowak & Lewicki, 2004).

IR heating has often a high temperature (500°C-3000°C). The surface temperature and surface moisture is affected by the penetration depth of IR radiation. Food materials have different penetration depths. The penetration depth depends on moisture content of food and wavelength (Sumnu & Ozkoc, 2011). Datta & Ni (2002) stated that during IR radiation, as penetration depth decreases, the surface temperature increases.

IR radiation sections include a heat source (called radiator or emitter), a reflector, source sockets, electrical connections and a shell. The main part, radiator can be classified based on mode of heating. In electrically heated radiators; the IR radiation is obtained by passing an electric current through a resistance hence temperature raises (Ratti & Mujumdar, 2007). For example, reflector-type IR incandescent lamps (incandescent vacuum lamp, gas filled lamp, tungsten halogen lamp), quartz tube IR emitters, ceramic IR emitters, tubular metal-sheathed elements, and radiant panels are the most common ones (Das & Das, 2011). Gas-fired radiators composed of a perforated plate which is heated by gas flames so the plate raises its temperature and emits radiant energy (Ratti & Mujumdar, 2007). Direct flame IR radiator, ceramic burner, metal fiber burner, high-intensity porous burner and catalytic gas-fired IR emitter are common gas fired IR emitters (Das & Das, 2011). Electrically heated IR emitters have 78%-85% conversion efficiency and gas fired radiators have 40%-46% efficiency (Ramaswamy & Marcohe, 2005).

IR heating is used for many industrial applications such as baking, roasting, drying, thawing, pasteurization, sterilization and blanching in food industry (Hebbar et al., 2004).

IR drying offers many advantages,

- Temperature gradient in the food reduces within the short period since the food material is heated intensely. Therefore energy consumption is less.
- Radiation is focused at the surface of the food so it helps to remove moisture from the surface and to prevent sogginess of the dried product.
- Radiation penetrates directly into the product without heating the surroundings hence drying time is reduced.
- Uniform temperature distribution gives a better quality product.
- Better organoleptic and nutritional value of food.
- Due to the fast response times, easy and rapid process control.
- Easy installation and low capital cost.
- Simplicity in terms of the equipment required (Sharma et al., 2005a ; Ratti & Mujumdar, 2007 ; Kocabiyik & Tezer, 2009 ; Nasıroglu & Kocabıyık, 2009 ; Vishwanathan et al., 2010 ; Nindo & Mwithiga, 2011).

However, there are some limitations about IR drying. The most important one is, IR drying is a surface drying so it should be developed for thick materials. Also, potential fire hazards must be considered (Ratti & Mujumdar, 2007).

1.3.4.2 Studies on IR Drying of Foods

In literature, there are a number studies on IR drying (Namiki et al., 1996; Hebbar et al., 2004; Nowak & Lewicki 2004; Praveen Kumar et al., 2005; Sharma et al., 2005b). When onion slices were dried with thin-layer IR radiation, it was found that drying time was reduced by about 2.25 times on increasing power from 300 to 500 W (Sharma et al., 2005b). Namiki et al. (1996) compared the quality of carrot dried by IR radiation and freeze drying and indicated that both samples have the same carotene content after drying. Nowak & Lewicki (2004) dried apple slices with IR drying and convective drying individually at equivalent parameters and stated that the process time was shortened by up to 50% when IR energy was used. IR can be combined with other heating methods. The most common one is IR-hot air drying combination. IR and hot-air drying of onions was studied by Praveen Kumar et al. (2005) and their study has shown that combination drying resulted in shorter drying time and in better quality when compared to IR and hot-air drying separately. In addition, Hebbar et al. (2004) reported that when IR- hot air combination method was used for drying of carrot and potato, drying time and energy consumption reduced 48% and 63%, respectively as compared to hot-air drying. Several experimental studies on drying of food materials by IR radiation were reported in the literature for apple slices (Nowak & Lewicki, 2005 ; Toğrul, 2005) welsh onion (Mongpraneet et al., 2002), carrot and garlic (Baysal et al., 2003), potato chips (Supmoon & Noomhorm, 2013), carrot (Toğrul, 2006), banana slices (Nimmol et al., 2007), onion slices (Jain & Pathare, 2004; Pathare & Sharma, 2006), and sweet potato (Lin et al., 2005).

1.3.5 Microwave-IR Combination Drying

Microwave-IR combination drying is a new technology which is the combination of two different heating mechanisms: microwave heating and IR heating. The well-known problem of microwave heating is moisture accumulation at the food surface. Datta & Ni (2002) recommended combination of IR heating with microwave heating to remove excess surface moisture and stated that addition of IR heating increased surface temperature and surface evaporation. Also, IR heating promoted the rate of heating and mass transfer throughout the sample. Therefore, microwave-IR combination drying combines the time saving advantages of microwave heating with surface moisture removal advantages of IR heating. In literature, there are limited studies on microwave-IR combination drying (Sumnu et al. 2005a; Tireki et al. 2006). Sumnu et al. (2005a) dried carrot by using microwave-IR combination and hot air drying. It was stated that by using microwave-IR combination drying, drying time was reduced to 98% of hot air drying time. Moreover, when microwave-IR combination drying was applied, less color change and higher rehydration capacity were obtained. Also, Tireki et al. (2006) produced bread crumbs by conventional and microwave-IR combination drying and it was stated that by using microwave-IR combination drying, time of drying was reduced to 96.8–98.6% of conventional drying. Moreover, when the quality parameters were examined, bread crumbs dried by microwave-IR combination drying were acceptable in terms of color and water binding capacity.

1.3.6 Eggplant Drying

Eggplant has a very limited shelf life for freshness and physiological and morphological changes occur after harvest. It is common to dry eggplants to extend shelf lives. By drying, moisture content is reduced to a level which allows safe storage over an extended period (Doymaz, 2011). Dried eggplant can be used as an ingredient in different kinds of meals, instant soups and sauces. Recently, there have been many researches about drying of eggplants (Cruz & Menegalli, 2004; Ertekin & Yaldiz, 2004; Wu et al., 2007; Doymaz & Göl, 2011; Garcia-Perez et al., 2011). Doymaz & Göl (2011) dried eggplants with hot air and investigated the effects of air temperature and sample thickness on the drying kinetics of samples. It was reported that while drying time of thinner slice of eggplant (diameter: 0.5 cm) was 375 min, drying time of thicker one (diameter: 1 cm) was 495 min. In addition, as drying temperature was increased from 50°C to 80°C, drying time was reduced from 330 min to 150 min, respectively. Similarly, Ertekin & Yaldiz (2004) examined drying characteristics, drying time and quality of eggplants which were dried in a laboratory hot air dryer. It was stated that increasing the drying air temperature and velocity reduced drying time. The results showed that increasing drying air temperature decreased the color lightness and increasing drying air velocity increased both color lightness and rehydration ratio. Eggplants were also dried with ultrasonically assisted convective drying and ultrasound technology was recommended to improve the convective drying of eggplant due to the higher internal mass transport (Garcia-Perez et al., 2011). Wu et al. (2007) dried eggplants with vacuum drying technique. It was found that although shrinkage of the eggplants increased with an increase in drying chamber pressure, it was not dependent on drying temperature. Cruz & Menegalli (2004) used osmotic dehydration as a pretreatment before hot air drying of eggplants and reported that osmotic dehydration reduced the time of hot air drying at 70°C in half.

1.4 Objectives of the Study

Eggplants are good sources of vitamins and minerals. They are widely produced and consumed in Turkey and in the world. Since eggplants have limited shelf life, it is common to dry eggplants. Although sun drying method has been used to dry eggplants in Turkey, it has the disadvantages such as contamination of product by bacteria and insects, and long drying times. In industry, hot air drying is the most common method to dry vegetables but it has also some disadvantages such as low energy efficiency, quality loss and long drying time. In order to eliminate these problems, microwave-IR combination drying can be an effective method. It is a novel technology that combines the time saving advantages of microwaves with surface moisture removal advantages of IR heating. In literature, there are few studies related to the microwave-IR combination drying. However, drying of eggplants by microwave-IR combination drying method has not been studied yet. Therefore, in this study, microwave-IR combination drying method was used to dry eggplants in order to make the drying more efficient in terms of drying rate and quality of the final product. In addition, osmotic dehydration was used as a pretreatment to reduce initial moisture content of samples before microwave-IR combination drying.

The main objective of this study was to compare the effects of hot-air drying and microwave-IR combination drying on drying characteristics and quality parameters of eggplants. In addition, it was aimed to investigate the effects of different processing conditions such as osmotic dehydration, microwave power and IR power on drying characteristics and quality parameters of eggplants. Furthermore, the effective diffusivities for both hot air drying and microwave-IR combination drying at different were calculated. Quality parameters were selected as color, rehydration ratio, shrinkage, microstructure analysis and pore size distribution of dried eggplants.

CHAPTER 2

MATERIALS AND METHODS

2.1 Materials

Eggplants (*Solanum melongena L.*) used in this study were obtained from the local market and stored in a refrigerator at 4°C. Prior to drying, samples were washed and cut into slices, having a thickness of about 5 mm using a kitchen slicer. Diameters of the eggplants were 5±0.5 cm. The initial moisture content of eggplant was found to be 14 ∓ 0.314 kg water/ kg dry solid by using moisture analyzer.

2.2 Drying

2.2.1 Osmotic Dehydration

For osmotic dehydration, solutions having 10% and 20% (w/w) concentration were used. Samples were soaked in salt solution at 50°C for 2 hours in a thermostatic bath with agitation. The ratio of sample to osmotic solution was 1:10 (w/w). After osmotic dehydration, moisture content of samples was measured.

2.2.2 Hot Air Drying

Hot air drying was performed in a tray dryer (Armfield Limited, D 27412, Ringwood Hampshire, England). Drying experiments were carried out at 50°C with an air velocity of 1.5 m/s until a moisture content of 0.13∓ 0.002 kg water/ kg dry solid was reached. In each experiment, 100-115 gr of eggplants were dried and weight of samples were recorded at every 1 hour interval.

2.2.3 Microwave-IR Combination Drying

Microwave-IR combination drying experiments were performed in microwave-IR combination oven (Advantium oven™, General Electric Company, Louisville, KY, USA). Halogen lamp at the top was located 15 cm above the food surface while the halogen lamp at the bottom was just under the rotary table. Combinations of different microwave power levels (30%, 40% and 50%) and halogen lamp powers (10% and 20%) were used in drying of eggplants. In drying of osmotically dehydrated ones, the effect of 30% IR power was also studied. In the experiments, powers of halogen lamps at the top and bottom were the same. The powers of the oven was determined as 700W by using IMPI 2 liter test (Buffler, 1993). For both cases, 100-115 g of eggplant was dried until a final moisture content of 0.13 ∓ 0.002 kg water/ kg dry solid was achieved. In every 2 minutes, weight of the samples was recorded by a digital balance (ARD-110 - Single Unit, China).

2.3 Measurement Methods

2.3.1 Moisture Content

Initial and final moisture contents of the samples were determined by using a moisture analyzer (MX-50 AND Moisture Analyzer, Japan). About 1 g of samples were put into the sample holder and dried until the constant weight was obtained. Moisture content data was given in kg water/kg dry solid unit.

2.3.2 Pore Size Distribution

Pore size distribution was determined by using mercury porosimeter (Poremaster 60, Quantichrome Corp., Florida, USA). About 0.5 g of dried eggplants was used for each experiment. Measurements were done at pressure range of 0-50 psia, and for calculations, mercury surface tension was taken as 480 erg/cm^2 and mercury contact angle as 140°.Relation between applied pressure (P) and pore size was expressed by Washburn equation (Russo et al., 2013) which describes a linear relationship between the size of an intrudable circular pore and the applied mercury pressure in the mercury porosimeter;

$$P.r = -2\gamma\cos\theta \tag{2.1}$$

where r is the pore radius, γ is the Hg surface tension, θ is the contact angle and P is the absolute applied pressure.

2.3.3 Color

Color of the samples was measured using a color reader (Minolta, CR10, Osaka, Japan). The color values were expressed by CIE coordinates (L*a*b* system). L*, a* and b* indicates whiteness/darkness, redness/greenness, blueness/yellowness values, respectively. Six color data were taken from different locations for each sample. L* and a* values were used to evaluate color characteristic.

2.3.4 Shrinkage

Volume of samples before and after drying was determined by the rape seed displacement method (Sahin & Sumnu, 2006). Equations (2.2), (2.3) and (2.4) were used to calculate the volume of eggplants.

$$W_{seeds} = W_{total} - W_{sample} - W_{container} \tag{2.2}$$

$$V_{seeds} = W_{seeds} / \rho_{seeds} \tag{2.3}$$

$$V_{sample} = V_{container} - V_{seeds} \tag{2.4}$$

where, W (g) is weight, V(cm^3) is volume, ρ (g/cm^3) is density.

Then, drying shrinkage was calculated by equation (2.5);

$$S=\frac{V_o\text{-}V_f}{V_o} \qquad (2.5)$$

where, V_o is volume of fresh sample, and V_f is volume of dried sample.

2.3.5 Rehydration Ratio

Rehydration capacity of dried eggplants was determined by immersing 10 g samples in 500 ml distilled water in a hot water bath to maintain a water temperature of 50°C. In every 1 hour, sample was taken out; the surface moisture of the sample was removed by wiping off the surface with paper towel, and then reweighed. This procedure was continued until constant weight was obtained which was 4 hour in this study. The rehydration ratio was expressed as percentage water gain, and estimated from the sample weight difference before and after the rehydration as in the following equation (2.6);

$$\text{Rehydration ratio}=\frac{W_t\text{-}W_d}{W_d} \qquad (2.6)$$

where, W_t is the weight of rehydrated sample (g) when constant weight was obtained and W_d is the weight of the dried sample.

To ensure saturation, the samples were then kept in water until no further change in weight was observed.

2.3.6 Microstructural Analysis

For microstructural analysis, firstly samples were cut into pieces and sputter coated with gold-palladium. Then, microstructural images were taken with scanning electron microscope (JSM-6400-NORAN, Tokyo, Japan). Images of were taken at 100× magnification level.

2.3.7 Statistical analysis

Analysis of variance (ANOVA) was used to determine whether there were significant differences between drying methods, pretreatment, microwave and IR powers. SAS software version 9.1 was used (SAS Institute Inc., NC, USA) to apply ANOVA. If significant differences were found, Duncan's Multiple Comparison Test was used for comparisons ($p \leq 0.05$).

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Drying Characteristics

Eggplants having an initial moisture content of 14 ∓ 0.314 kg water/ kg dry solid were dried by using hot air drying and microwave-IR combination drying to a final moisture content of approximately 0.13∓ 0.002 kg water/ kg dry solid.

It was aimed to compare the effects of hot air drying and microwave-IR combination drying on the drying characteristics of eggplants.

Hot air drying was conducted by using tray dryer which was operated using air at 50°C flowing with a velocity of 1.5 m/s. Figure 3.1 shows the drying characteristics of eggplants in hot air and microwave-IR combination drying in which combination of 20% IR power and 50% microwave power was used.

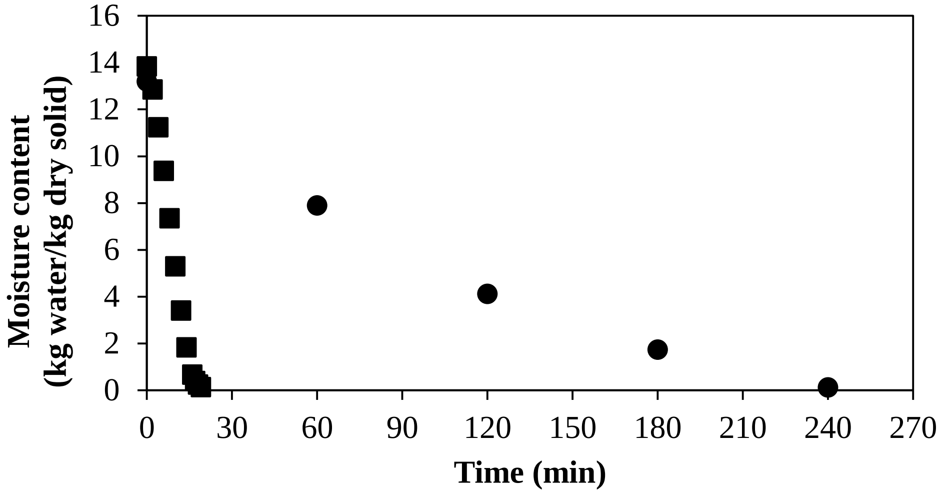

Figure 3.1 Drying curve for hot air drying (●) and microwave-IR combination drying at 20% IR power & 50 % microwave power (■).

As can be seen in Figure 3.1, the drying time of hot air drying was about 4 hours which was significantly higher than microwave-IR combination drying with 19 minutes. Shorter drying time in microwave-IR combination oven can be explained by the rapid mass transfer within the food during microwave heating. Heat is generated within the food due to the absorption of electrical energy from the microwave field and it creates high internal pressure and concentration gradients. Therefore, the flow rate of the liquid through the food to the boundary is increased (Lin et al., 1998 ; Sumnu et al., 2005a). Varith et al. (2007) stated that microwave drying reduced drying time of hot air drying by 64.3% when it was used for drying of peeled longan. Similar results were obtained by different studies in which time of microwave drying was found to be significantly shorter than hot air drying time of fruits and vegetables (Funebo & Ohlsson, 1998 ; Lin et al., 1998 ; Maskan, 2000; Sharma & Prasad, 2001; Sumnu et al., 2005a). Although microwave drying is very effective method with higher drying rate, when it is used alone to dry foods, the surface of the product may remain soggy. The reduction of surface moisture can be achieved by adding IR heating. IR heating increases surface temperature and surface evaporation (Datta & Ni, 2002). Therefore, microwave-IR combination drying supplied higher drying rate and lower surface moisture.

Microwave-IR combination drying was applied to dry both untreated and osmotically dehydrated eggplants at different microwave and IR powers combination. For drying of untreated eggplants, 30%, 40%, 50% microwave powers were combined with 10% and 20% IR powers. Higher IR powers couldn't be tried in drying of untreated samples due to burning problem. However, 30% IR power could be used in combination drying of osmotically dehydrated eggplants.

The weight data obtained during drying was converted into moisture content on dry basis and drying curves were plotted in order to compare the effects of IR and microwave power on drying characteristics. Figures 3.2–3.3 represent the effect of microwave powers on drying behaviors of samples during microwave-IR combination drying at 10% IR and 20% IR powers, respectively.

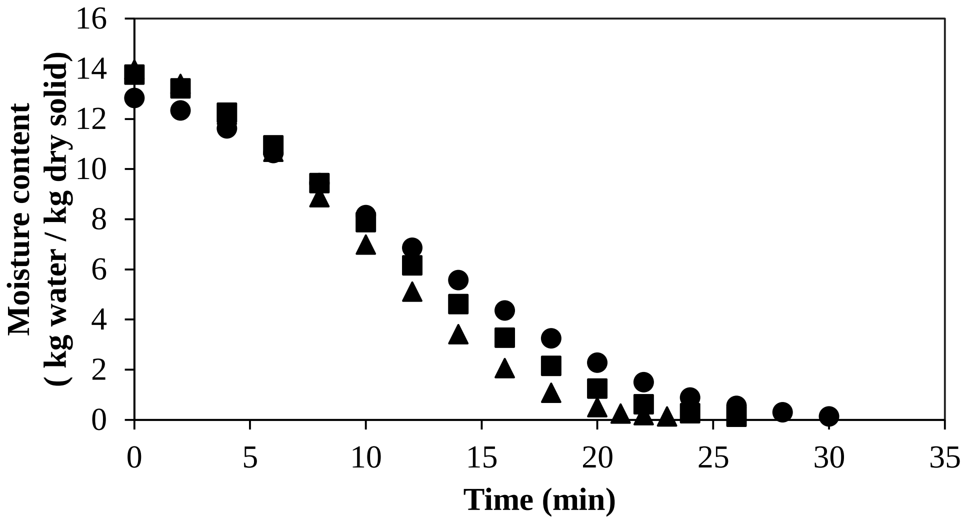

Figure 3.2 Effect of microwave power on moisture content of eggplant dried in microwave-IR combination oven at 10% IR power; (●): 30% microwave power, (■): 40% microwave power, (▲): 50% microwave power.

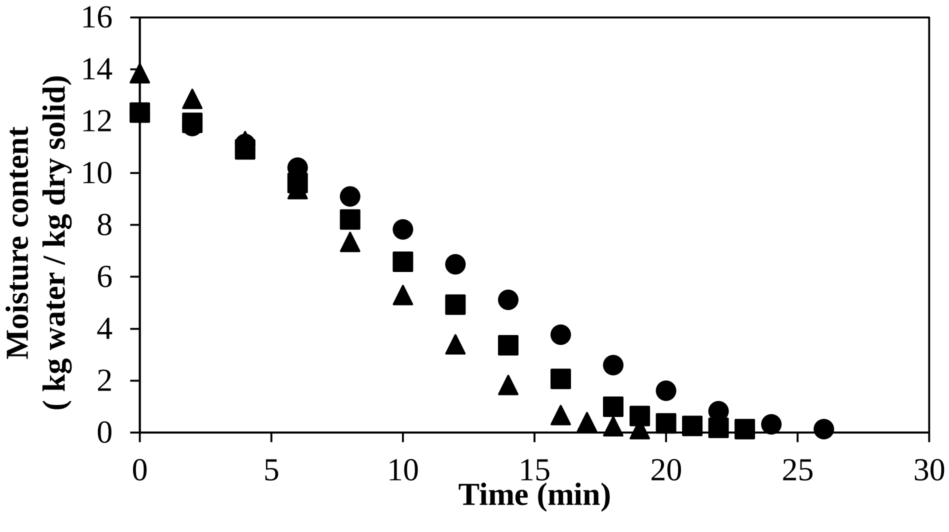

Figure 3.3 Effect of microwave power on moisture content of eggplant dried in microwave-IR combination oven at 20% IR power; (●): 30% microwave power, (■): 40% microwave power, (▲): 50% microwave power.

Drying time decreased as microwave power increased because drying rate increased with the increase in microwave power. When 50%, 40% and 30% microwave power were combined with 10% IR power, eggplants were dried to almost 0.13 kg water/kg dry solid in 23 min, 26 min and 30 min, respectively (Figure 3.2). At higher microwave powers, the rate of mass transfer was higher due to the higher heat generation (Ghanem et al., 2012). Similar results have been observed in the literature for microwave drying of mango ginger (Murthy & Manohar, 2012), carrot (Cui et al., 2004), pumpkin (Alibas, 2007), wild cabbage (Yanyang et al., 2004) and wheat (Kahyaogluet al., 2012).

The effect of IR power on drying characteristic at 30% and 50% microwave powers were shown in Figure 3.4 – Figure 3.5, respectively.

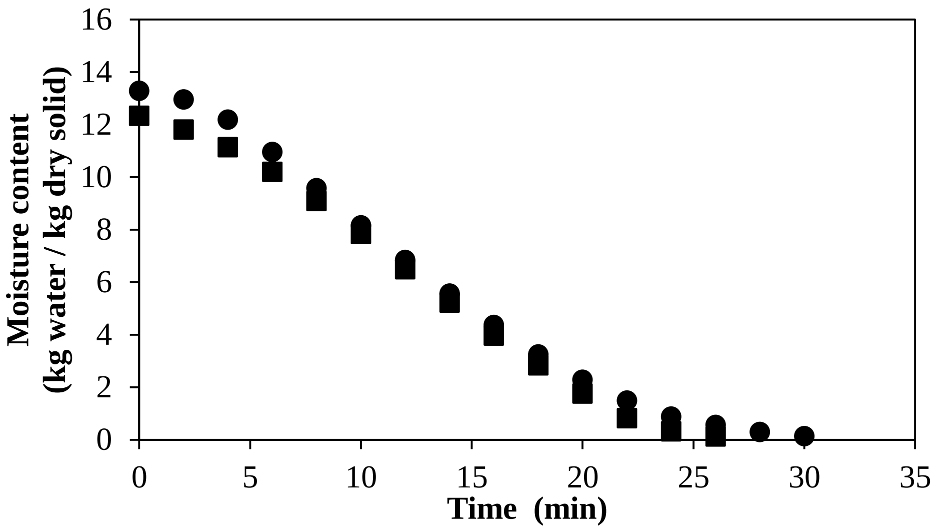

Figure 3.4 Effect of IR power on moisture content of eggplant dried in microwave-IR combination oven at 30% microwave power; (●): 10% IR power, (■): 20% IR power.

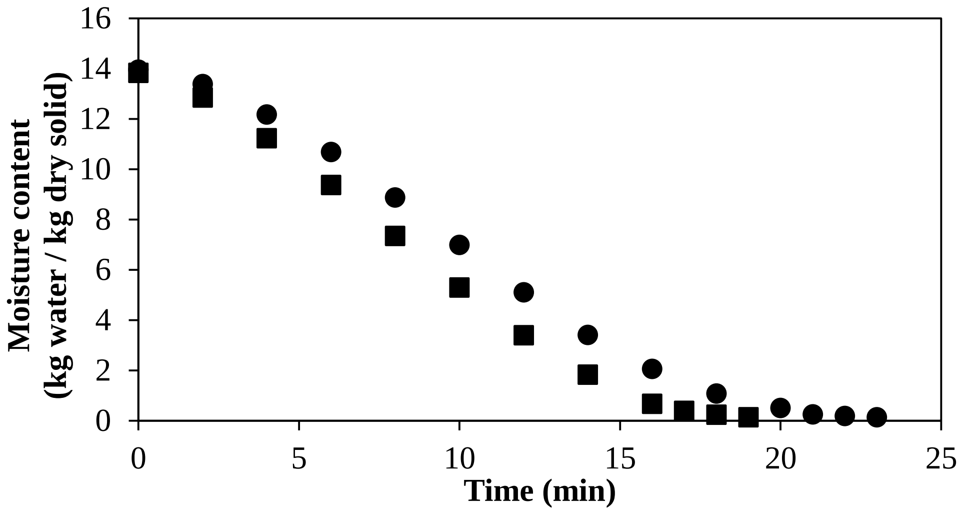

Figure 3.5 Effect of IR power on moisture content of eggplant dried in microwave-IR combination oven at 50% microwave power; (●): 10% IR power, (■): 20% IR power.

It was obvious that drying time reduced with increase in IR power at constant microwave power. The increase in IR power caused a rapid increase in the temperature at the surface and vapor pressure of water inside the product so drying rate increased (Supmoon & Noomhorm, 2013). Similar trend was observed in drying of onion slices (Sharma et al., 2005b) and potato (Afzal & Abe, 1999).

Drying rates were expressed as quantity of moisture removed per unit time per unit dry solids (kg water/kg dry solids min). Drying rates of eggplants dried at different drying conditions were given in Figures 3.6- 3.9.

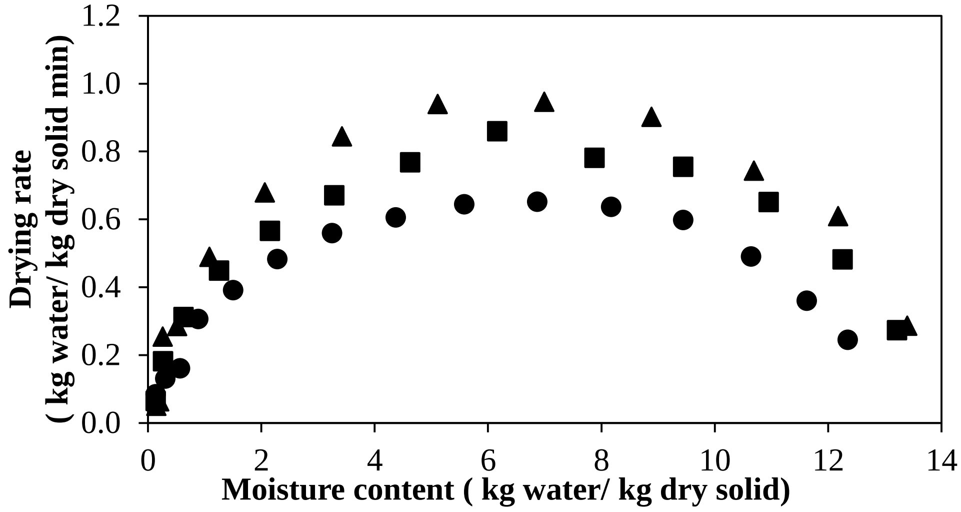

Figure 3.6 Drying rates of eggplant dried in microwave-IR combination oven at 10% IR power; (●): 30% microwave power, (■): 40% microwave power, (▲): 50% microwave power.

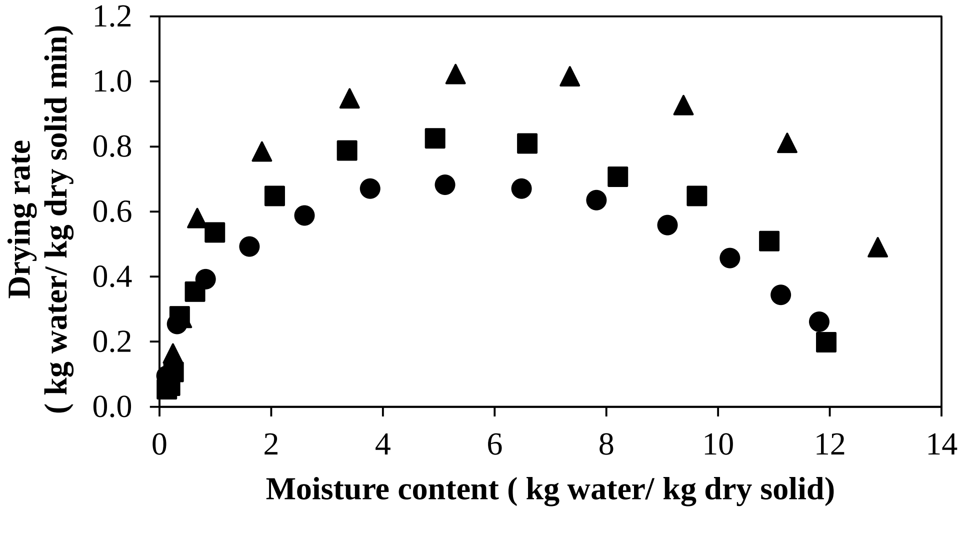

Figure 3.7 Drying rates of eggplant dried in microwave-IR combination oven at 20% IR power; (●): 30% microwave power, (■): 40% microwave power, (▲): 50% microwave power.

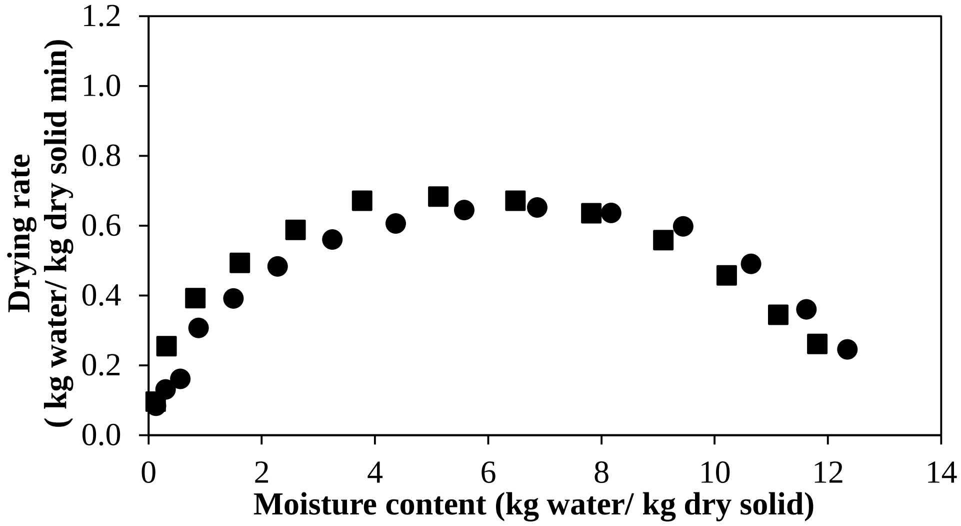

Figure 3.8 Drying rates of eggplant dried in microwave-IR combination oven at 30% microwave power; (●): 10% IR power, (■): 20% IR power.

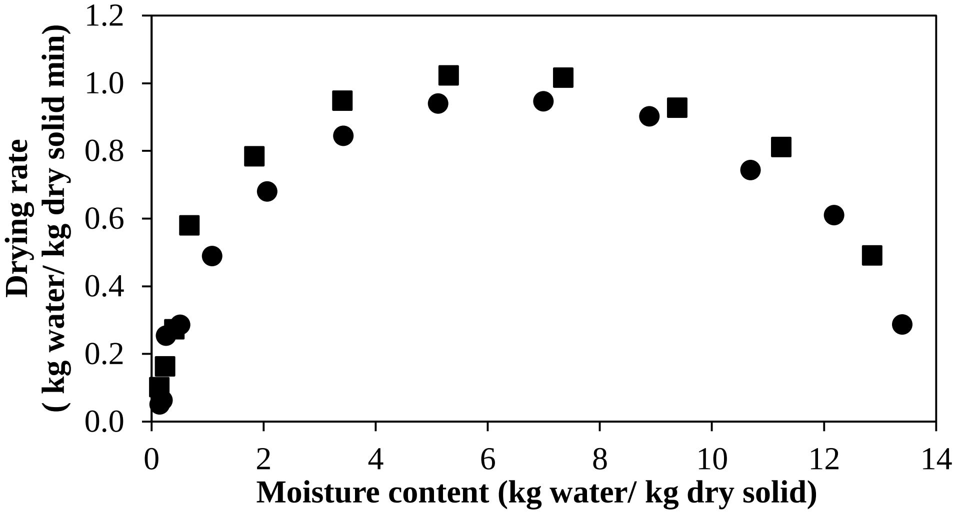

Figure 3.9 Drying rates of eggplant dried in microwave-IR combination oven at 50% microwave power; (●): 10% IR power, (■): 20% IR power.

As can be seen in Figures 3.6-3.9, a constant rate period did not exist during drying of eggplant. This finding is commonly known for drying of fruits and vegetables where a constant rate period is short or does not exist (Varith et al., 2007). Instead of constant rate period, there were two drying rate periods in these curves. In the initial period during microwave-IR combination drying, an accelerating or rising dehydration rate period existed. At the beginning of the drying, the moisture content of eggplants was extremely high (14$\mp$ 0.314 kg water/ kg dry solid). The high moisture content resulted in significant internal heat generation and pressure gradient which increased drying rate. Moreover, at the beginning of drying, dielectric constant and loss factors of eggplants were higher due to higher moisture content of the samples. Therefore, eggplants absorbed more microwave power that leaded to high internal heat generation and higher drying rate (Al-Harahsheh et al., 2009). After rising period, the drying rates were reduced and falling rate period was observed. Murthy & Manohar (2012) investigated microwave drying of mango and observed an accelerating period and no constant rate period. In microwave drying of banana, Pereira et al. (2007) observed a rising period in drying rate curve due to the internal heat generation. In addition, Wang & Sheng (2006) studied far-IR and microwave drying of peach and indicated that samples dried with far-IR drying had a rising rate period. Similarly, Kocabiyik & Tezer (2009) noted that at the beginning of drying process, there was rising period and it was followed by falling rate period in drying of carrot slices using IR radiation.

In drying, first the amount of surface water is decreased so the drying rate is dominated by moisture diffusion from the inside to the surface of samples (Shi, et al., 2008). Moreover, smaller dielectric constant (ε') and dielectric loss factor (ε'') result in a significant reduction in absorbed microwave and a decrease in the driving force caused by concentration and pressure gradients (Pereira et al., 2007). In addition, due to high surface temperature, soluble solids migrate to the surface of the sample and build-up at the surface as water evaporates. As a result, case hardening occurs. Case hardening acts as a barrier to moisture migration during drying and this may be the reason of existence of falling rate period (Feng & Tang, 1998 ; Maskan, 2001a).

When the effect of different microwave and IR power combinations was examined, as microwave and IR power increased, drying rate of eggplant increased. Higher microwave and IR power resulted in more rapid mass transfer within the sample since more heat was generated in sample (Wang & Sheng, 2006). However, Figures 3.6-3.9 shows that the effect of IR power on drying rate was less significant as compared to that of microwave power. The difference between drying rate curves was more distinct when microwave powers were increased at constant IR power. Microwave heating being the dominant mechanism was also reported by Tireki (2005) in microwave-infared drying of bread crumbs.

When 10% and 20% (w/w) NaCI solutions were used for osmotic dehydration, the moisture content of eggplants was lowered from 14∓ 0.314 kg water/ kg dry solid to 5 ∓ 0.043 kg water/ kg dry solid and 3.2 ∓ 0.014 kg water/ kg dry solid after 2 hours, respectively. During osmotic dehydration, eggplants experienced water loss and solid gain. The reason could be stated that the osmotic agent diffused into the samples and water removed from sample to the solution (Tan et al., 2001). In addition, as the concentration of NaCI solution increased, the osmotic pressure in the eggplant also increased so higher water mobility took place.

Figure 3.10 shows the effect of osmotic dehydration as a pretreatment on drying characteristics of eggplants dried using 20% IR power and 50% microwave power in combination. Both pretreated and untreated eggplants were dried at constant microwave and IR power combination and it was concluded that drying time in microwave-IR combination oven was significantly reduced when osmotic dehydration was used. The reason was that osmotically dehydrated eggplants using 10% and 20% osmotic solution had lower initial moisture content, 5 ∓ 0.043 kg water/ kg dry solid and 3.2 ∓ 0.014 kg water/ kg dry solid respectively. When compared to fresh eggplants with initial moisture contents of 14 ∓ 0.314 kg water/ kg dry solid, less moisture was necessary to be removed during drying of osmotically dehydrated eggplants to achieve the same final moisture content.

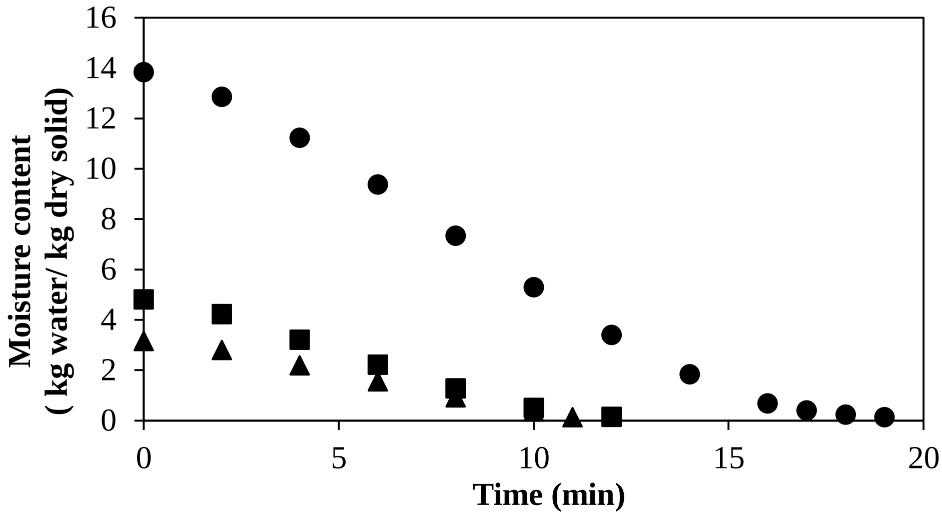

Figure 3.10 Effect of osmotic dehydration on moisture content of eggplant dried in microwave-IR combination oven at 20% IR and 50% microwave powers; (●): untreated, (■):10% osmotic dehydration, (▲): 20% osmotic dehydration.

In order to compare drying rates of both osmotically dehydrated and untreated eggplants in microwave-IR combination drying, the dimensionless moisture ratio (MR=M/M_0) was calculated and drying rate versus moisture ratio was presented in Figure 3.11.

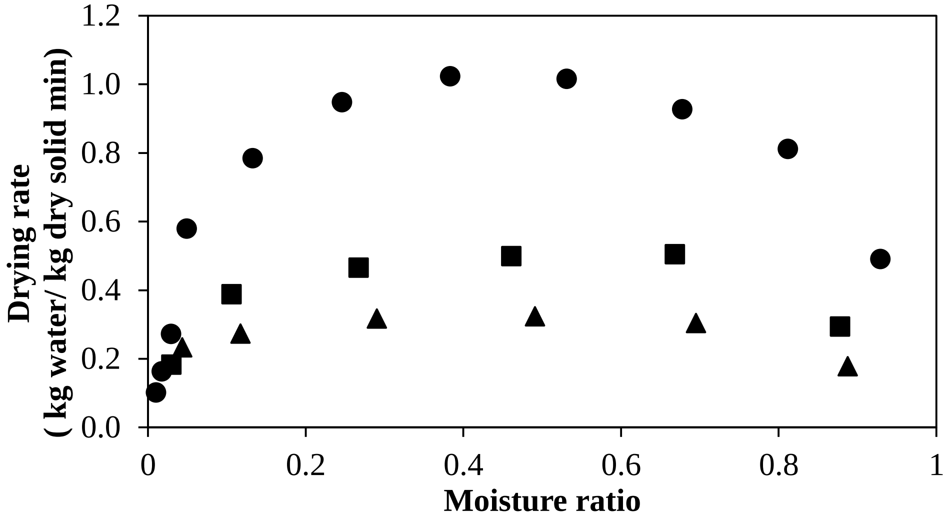

Figure 3.11 Effect of osmotic dehydration on drying rate of eggplant dried in microwave-IR combination oven at 20% IR and 50% microwave powers; (●): untreated, (■):10% osmotic dehydration, (▲): 20% osmotic dehydration.

It was concluded that in microwave-IR combination drying, osmotically dehydrated eggplants had lower drying rates than untreated eggplants due to having lower initial moisture content. Moreover, as the concentration of osmotic solution increased, drying rate of pretreated eggplants decreased. This may be explained by the fact that infused solute inhibited the movement of water during drying which decreased water removal rate (Shi, et al., 2008). Mandala et al. (2005) stated that solute uptake in the osmotic dehydration increased internal resistance to mass transfer during drying. Hence osmotically dehydrated samples had lower rate in further drying process. Similarly, Piotrowski et al. (2004) reported that osmotically dehydrated strawberries had lower drying rate than strawberries not dehydrated osmotically.

The effects of microwave and IR powers on drying characteristic of osmotically dehydrated eggplants were indicated in Figures 3.12- 3.15. It was clear that as the microwave and IR power increased, drying time was significantly lowered due to the higher heat generation.

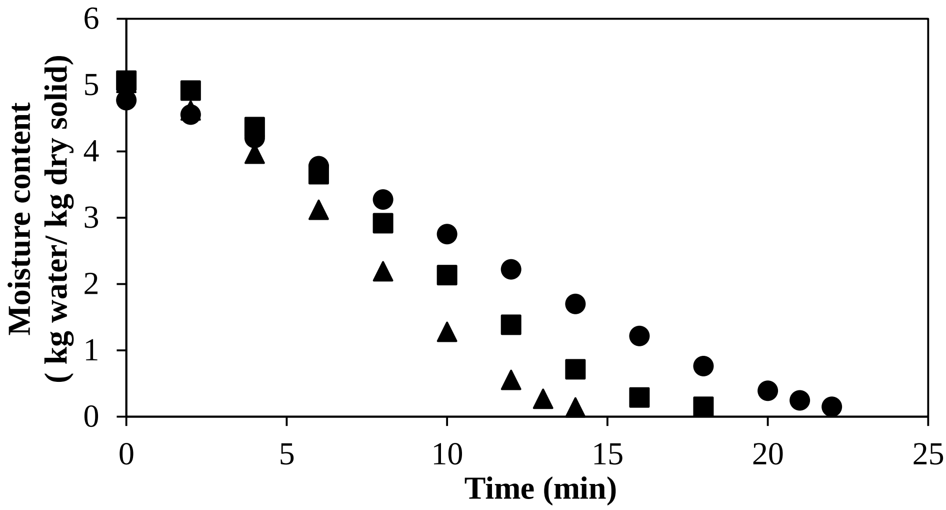

Figure 3.12 Effect of microwave power on moisture content of eggplant pretreated in 10% (w/w) osmotic solution and dried in microwave-IR combination oven at 10% IR power; (●): 30% microwave power, (■): 40% microwave power, (▲): 50% microwave power.

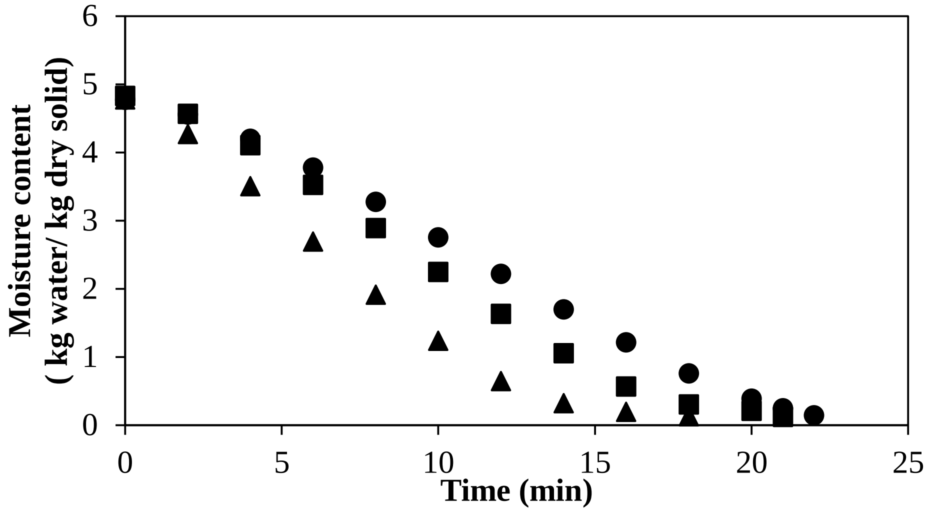

Figure 3.13 Effect of IR power on moisture content of eggplant pretreated in 10% (w/w) osmotic solution and dried in microwave-IR combination oven at 30% microwave power; (●): 10% IR power, (■): 20% IR power, (▲): 30% IR power.

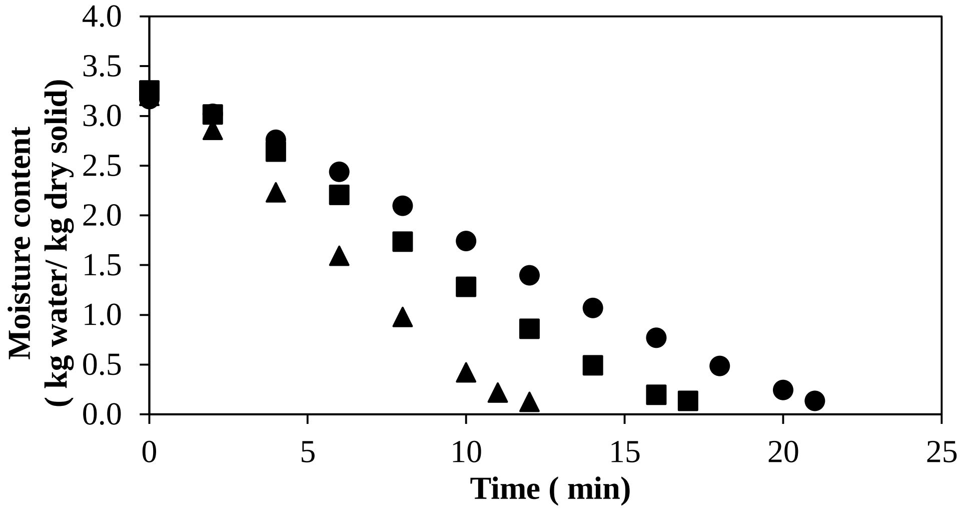

Figure 3.14 Effect of microwave power on moisture content of eggplant pretreated in 20% (w/w) osmotic solution and dried in microwave-IR combination oven at 10% IR power; (●): 30% microwave power, (■): 40% microwave power, (▲): 50% microwave power.

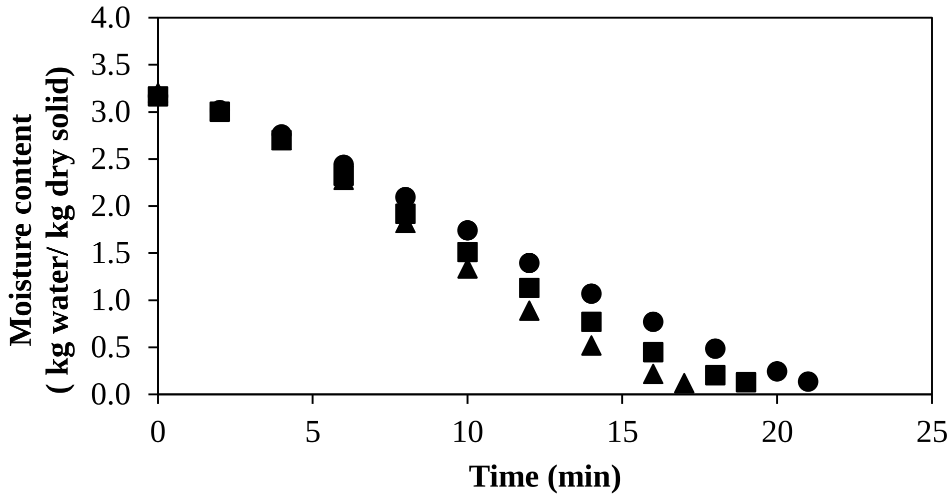

Figure 3.15 Effect of IR power on moisture content of eggplant pretreated in 20% (w/w) osmotic solution and dried in microwave-IR combination oven at 30% microwave power; (●): 10% IR power, (■): 20% IR power, (▲): 30% IR power.

Drying rates of osmotically dehydrated eggplants dried at different microwave and IR power combinations were given in Figure 3.16-3.19. Similar to untreated eggplant, there was a rising and falling rate period during drying of osmotically dehydrated eggplants. As the microwave and IR powers increased, drying rate increased, too.

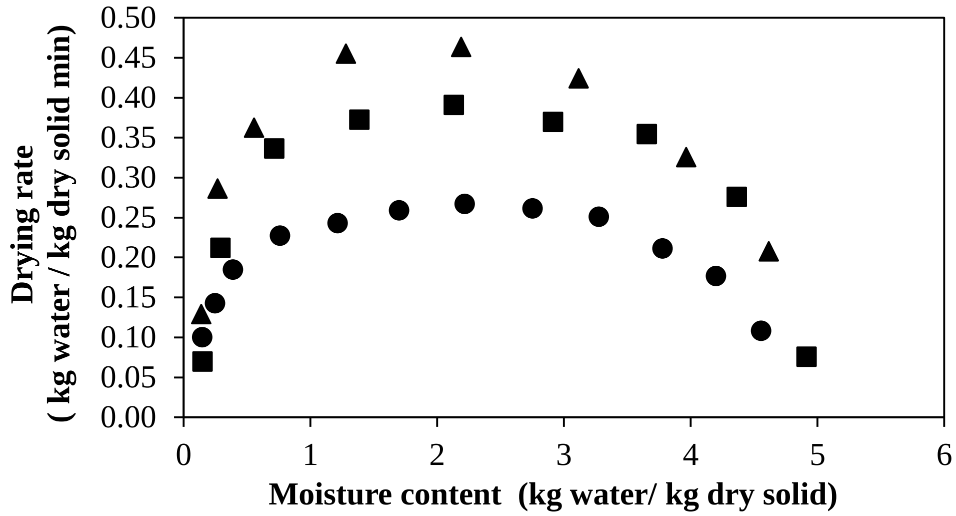

Figure 3.16 Drying rates of eggplant pretreated in 10% (w/w) osmotic solution and dried in microwave-IR combination oven at 10% IR power; (●): 30% microwave power, (■): 40% microwave power, (▲): 50% microwave power.

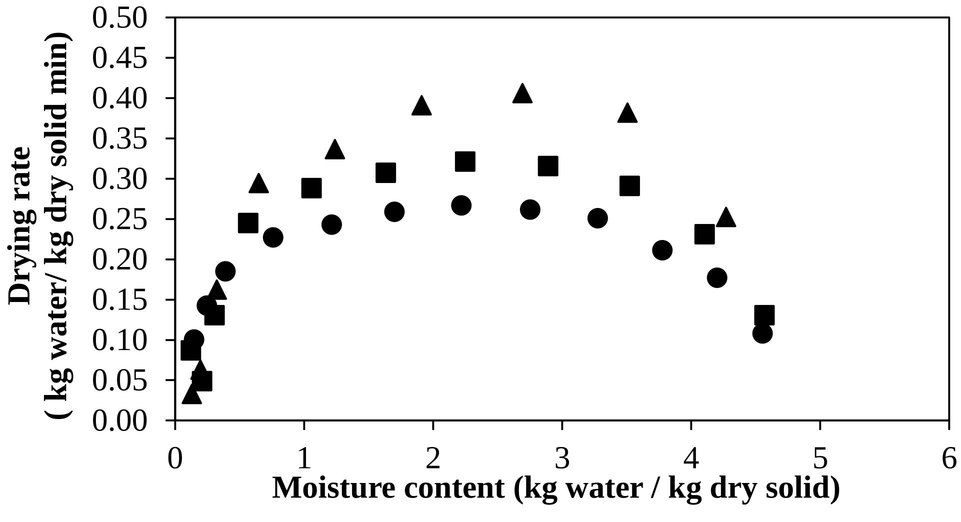

Figure 3.17 Drying rates of eggplant pretreated in 10% (w/w) osmotic solution and dried in microwave-IR combination oven at 30% microwave power; (●): 10% IR power, (■): 20% IR power, (▲): 30% IR power.

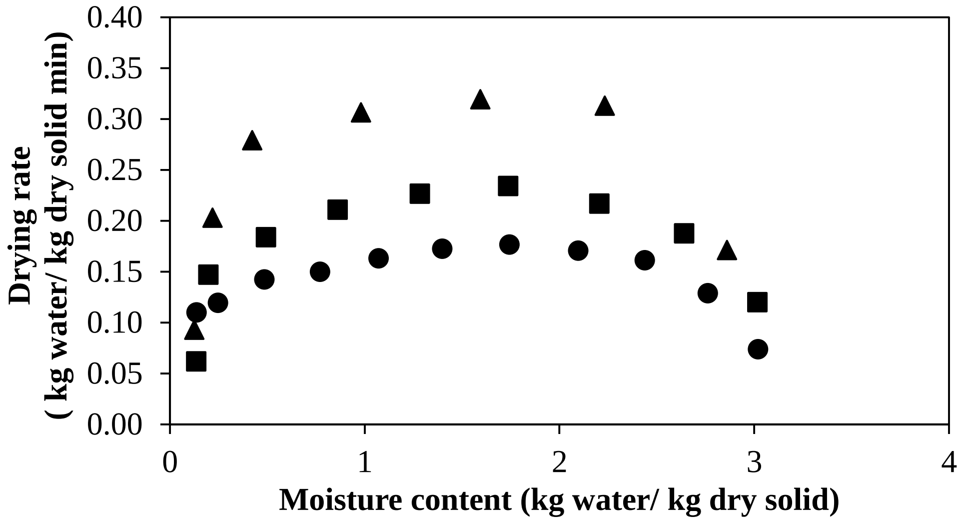

Figure 3.18 Drying rates of eggplant pretreated in 20% (w/w) osmotic solution and dried in microwave-IR combination oven at 10% IR power; (●): 30% microwave power, (■): 40% microwave power, (▲): 50% microwave power.

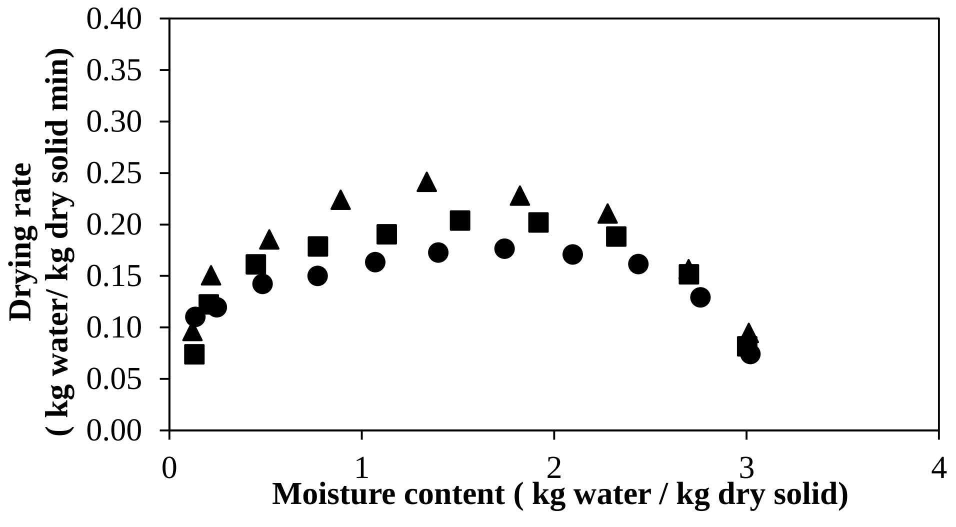

Figure 3.19 Drying rates of eggplant pretreated in 20% (w/w) osmotic solution and dried in microwave-IR combination oven at 30% microwave power; (●): 10% IR power, (■): 20% IR power, (▲): 30% IR power.

3.2 Effective Diffusivity

Eggplant slices were considered as infinite slab because the radius of the slices were much greater than their thickness (larger than 10 times). According to Fick's second law of diffusion in one dimension, the change in moisture concentration can be represented by Equation (3.1) (Geankoplis, 2003);

$$\frac{\partial X}{\partial t} = D_{eff} \frac{\partial^2 X}{\partial x^2} \tag{3.1}$$

where X is the moisture content (kg water /kg dry solid), t is the time (s), x is the distance in the solid (m) and D_{eff} is effective diffusivity (m^2/s).

The solution to Equation (3.1) was developed by Crank (1975) with the following assumptions and given in Equation (3.2)

1. Initially moisture is uniformly distributed throughout the mass of the sample.
2. Mass transfer is symmetric with respect to the center.
3. Surface moisture content of the sample instantaneously reaches equilibrium with the surrounding.
4. Diffusion coefficient is constant and shrinkage is negligible.
5. Resistance to the mass transfer at the surface is negligible compared to internal resistance of the sample.
6. Mass transfer takes place only by diffusion.

$$MR = \frac{X_t - X_e}{X_0 - X_e} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left(- \frac{(2n+1)^2 \pi^2 D_{eff}\, t}{4L^2} \right) \tag{3.2}$$

where D_{eff} is the effective diffusivity (m^2/s), L is the half thickness of slab (m), X_e is the equilibrium moisture content (kg water/kg dry solid), X_0 is the initial moisture content (kg water/kg dry solid), X_t is the average moisture content at time (t) (kg water/kg dry solid) and t is the time (s).

For long drying times, only the first term in Equation 3.2 is significant and the equation becomes (Tutuncu & Labuza, 1996):

$$MR=\frac{X_t-X_e}{X_0-X_e}=\frac{8}{\pi^2}\ \exp\left(-\frac{\pi^2 D_{eff}\,t}{4L^2}\right) \tag{3.3}$$

In order to check the long drying time assumption, dimensionless Fourier number, $\frac{D_{eff}\,t}{L^2}$ should be checked whether it is greater than 0.1 or not.

Equation (3.3) can be written in a logarithmic form as follows;

$$\ln MR = \ln\frac{X_t-X_e}{X_0-X_e} = \ln\frac{8}{\pi^2} - \frac{\pi^2 D_{eff}\,t}{4L^2} \tag{3.4}$$

Equilibrium moisture content of eggplant was assumed to be zero since it was relatively small compared to initial moisture content and moisture content at any time during drying (Diamante & Munro, 1993).

For the effective diffusivity determination, only falling rate period was considered and effective diffusivity values were determined by plotting experimental drying data in terms of ln*MR* versus drying time, *t* in Equation (3.4). Effective diffusivity values were calculated from the slope of the straight line $\frac{\pi^2 D_{eff}}{4L^2}$ and given in Table 3.1.

Table 3.1 Effective diffusivity (m^2/s) values of eggplants dried in microwave-IR combination oven.

Microwave Powers	Untreated IR Powers 10%	Untreated IR Powers 20%	10% osmotic solution IR Powers 10%	10% osmotic solution IR Powers 20%	10% osmotic solution IR Powers 30%	20% osmotic solution IR Powers 10%	20% osmotic solution IR Powers 20%	20% osmotic solution IR Powers 30%
30%	7.0997×10^{-9}	1.0142×10^{-8}	3.6513×10^{-10}	3.7426×10^{-9}	4.2902×10^{-9}	2.7385×10^{-10}	3.1949×10^{-9}	4.1077×10^{-9}
40%	1.0396×10^{-8}	1.2678×10^{-8}	4.38152×10^{-9}	5.11177×10^{-9}	6.9374×10^{-9}	4.01639×10^{-9}	4.9292×10^{-9}	5.5682×10^{-9}
50%	1.2171×10^{-8}	1.4453×10^{-8}	6.9374×10^{-9}	7.11996×10^{-9}	7.4851×10^{-9}	5.2031×10^{-9}	5.6595×10^{-9}	6.4810×10^{-9}

For all effective diffusivities, Fourier numbers were found to be greater than 0.1 therefore long drying time assumption was correct. In addition, coefficients of determination values (r^2) were changed between 0.88-0.97.

Effective diffusivity value of moisture during hot air drying of eggplant was found as 5.07×10^{-10} m^2/s. This value was in agreement with the values in literature. Doymaz (2011) dried eggplant slices with convective hot-air dryer at 50°C and 2.4 m/s air velocity and at this drying condition, effective diffusivity was found as 5.575×10^{-10} m^2/s. It was seen that effective diffusivities of untreated eggplants dried in microwave-IR combination oven were in the range of 7.099×10^{-9} and 1.445×10^{-8} m^2/s which were greater than that of hot air dried eggplant. This was not surprising since microwave-IR combination heating resulted in higher drying rate than conventional heating due to rapid evaporation. Effective diffusivity values are consistent with literature, D_{eff} values for food materials lie in the range of 10^{-11} to 10^{-9} m^2/s (Rivzi, 1986). Arslan & Özcan (2010) dried onion slices in both conventional oven and microwave oven and calculated effective diffusivity as 7.468×10^{-10} m^2/s and 4.009×10^{-8} m^2/s, respectively. Similarly, Walde et al. (2006) stated that effective diffusivity of microwave dried mushrooms (2.721×10^{-4} m^2/s) were much higher than that of tray dried ones (2.609×10^{-6} m^2/s).

The increase in effective diffusivity with microwave and IR power can be seen from Table 3.1. With increasing microwave power, higher drying rates and higher internal pressure were obtained. It enhanced moisture transfer to the surface of samples so diffusion increased. Özbek & Dadali (2007) reported that by increasing the microwave powers from 180 W to 900 W, effective diffusivities increased from 3.982×10^{-11} to 2.073×10^{-10} m^2/s. Similar trend was observed for microwave dried bamboo shoot (Bal et al., 2010) with effective moisture diffusivities of 4.2×10^{-10}-22.8×10^{-10} m^2/s at microwave powers for 140-350 W. Also, Afzal & Abe (1998) showed that IR intensity level affected drying rate and effective diffusivity. Higher IR radiation led to higher inside temperature, higher drying rate and effective diffusivity. Pathare & Sharma (2006) also found that IR intensity was dominant for internal moisture movement and as IR power intensity increased, effective diffusivity increased for the same air temperature and velocity. Similarly, in our experiment, for untreated eggplants, effective diffusivity increased with increasing IR power.

The effect of osmotic dehydration on effective diffusivity was also presented in Table 3.1. According to results, osmotically dehydrated eggplants showed lower effective diffusivity values than untreated ones. Due to the having lower initial moisture content, driving force was lower for osmotically dehydrated eggplants so they have lower effective diffusivity values. In addition, during osmotic dehydration, water removal resistance increased with increase in solid in the samples as a result drying rates and effective diffusivities decreased. Lower effective diffusivities of osmotically dehydrated eggplants were supported by the lower drying rate values for osmotically dehydrated ones compared with untreated ones (Figure 3.11). These results were consistent with the literature. Sankat et al. (1996) concluded that pretreated samples by using sugar solution with highest concentration had the lowest moisture diffusivity. Similar results were found by Rahman & Lamb (1991) who concluded that osmotically dehydrated pineapple slices using sucrose solution with the highest concentration had the lowest effective diffusivity.

3.3 Pore Size Distribution

The data obtained from mercury porosimeter experiments, were converted into graphs as cumulative intrusion curves (Figure 3.20 - 3.28), and pore size distribution curves (Figure 3.29 - 3.37).

3.3.1 Cumulative Intrusion Curves

The plot of cumulative volume of mercury intruded versus pore size or versus pressure is called as cumulative intrusion curve. From the cumulative intrusion curve, the total volume of mercury intruded the pore volume in any pore size range and the threshold diameter (the diameter above which comparatively low mercury intruded) can be determined (Aligizaki, 2006).

The cumulative volumes of mercury intruded as a function of pore size (μm) and pressure (psia) of dried untreated eggplants using different combination of microwave and IR powers were indicated through Figures 3.20 to 3.23. Figure 3.24 was given to show the cumulative intrusion curve of eggplant dried by hot air.

Initially, there was a sharp increase in intrusion volume and then a relatively constant region with increasing pressure in all graphs. Initial step rise indicated that there were macro pores on the surface and the same sized pores existed predominantly. This can be the result of less collapse in the structure due to short drying time. A gradual rise on the slope can be an indication of decreasing pore size through the sample (Rahman et al., 2002).

Pore size ranges for eggplants dried at 10% IR & 30% microwave power, 20% IR & 30% microwave power, 10% IR & 50% microwave power and 20% IR & 50% microwave power combinations were from 227.4 to 4.39 μm; from 201.3 to 4.28 μm; from 235.3 to 4.27 μm; 210.6 to 4.27 μm, respectively (Figures 3.20-3.23). When hot air dried eggplants were compared with microwave-IR combination dried eggplants, pore size range of hot air dried eggplants was narrower. Unlike microwave-IR combination dried eggplants, hot air dried eggplants did not have pores above 200 μm size.

Threshold pore size was the pore diameter where the vertical line was observed and the diameter above comparitively low mercury intruded. Threshold pore size of hot air dried eggplants was 42.47 μm which was lower than the threshold pore size of eggplants dried with microwave-IR combination. This result could be related to higher shrinkage and lower porosity due to higher drying time of conventionally dried eggplants.

Threshold pore size changed for all microwave-IR combination dried eggplants. Threshold pore sizes were 48.86 µm and 55.4 µm for 10% IR & 30% microwave power combination and 20% IR & 30% microwave power combination, respectively. Also, the threshold pore sizes were 64.89 µm and 73.42 µm for 10% IR & 50% microwave power combination and 20% IR & 50% microwave power combinations, respectively. As IR and microwave power increased, threshold pore size increased. This can be attributed to the reduction of shrinkage due to the increased microwave and IR power. Similar pattern was observed for spouted bed drying of wheat (Kahyaoglu, 2009). As the temperature increased, shrinkage was enhanced so threshold pore size decreased slightly.

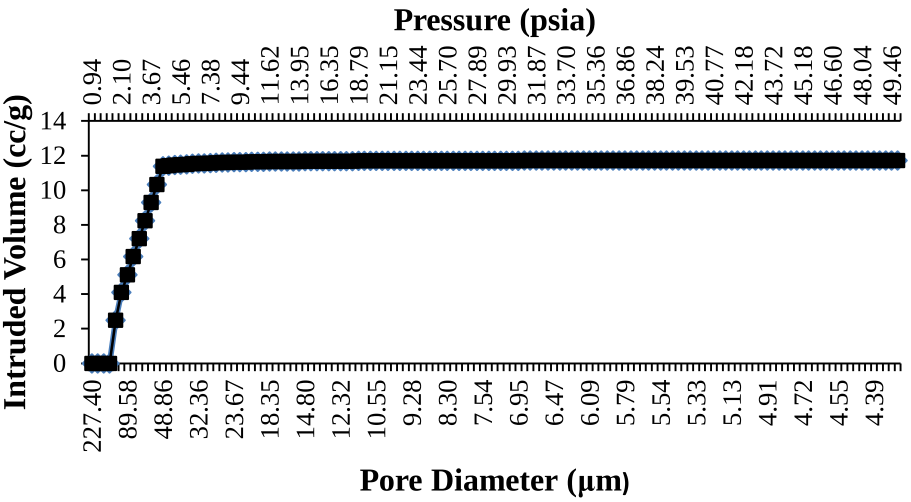

Figure 3.20 Cumulative intrusion curve for untreated eggplants dried in microwave-IR combination oven at 10% IR & 30% microwave powers.

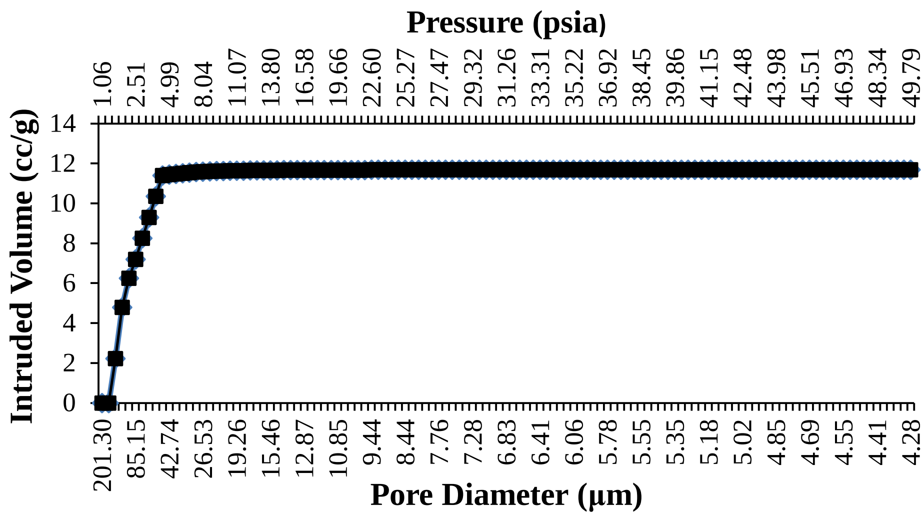

Figure 3.21 Cumulative intrusion curve for untreated eggplants dried in microwave-IR combination oven at 20% IR & 30% microwave powers.

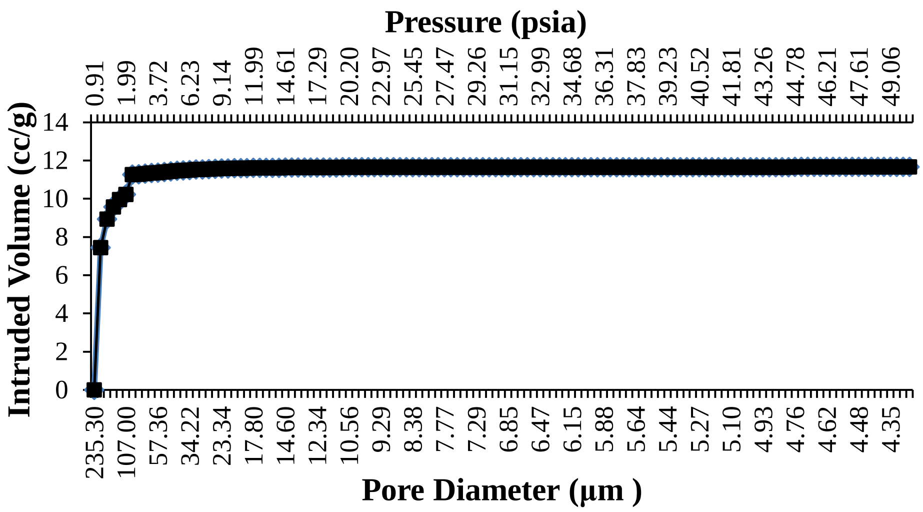

Figure 3.22 Cumulative intrusion curve for untreated eggplants dried in microwave-IR combination oven at 10% IR & 50% microwave powers.

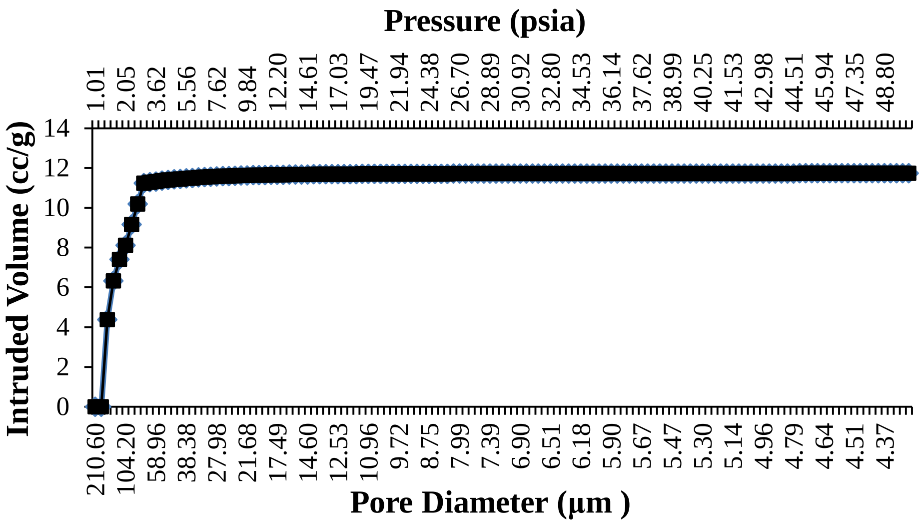

Figure 3.23 Cumulative intrusion curve for untreated eggplants dried in microwave-IR combination oven at 20% IR & 50% microwave powers.

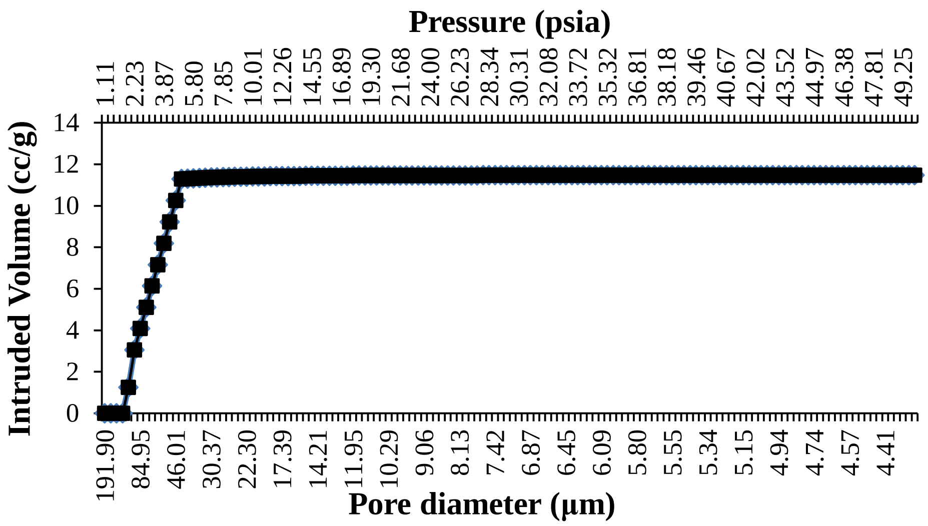

Figure 3.24 Cumulative intrusion curve for eggplant dried in hot air dryer.

The cumulative intrusion curves of eggplants pretreated in 10% (w/w) osmotic solution and dried in microwave-IR combination oven for different powers were shown through Figures 3.25-3.28.

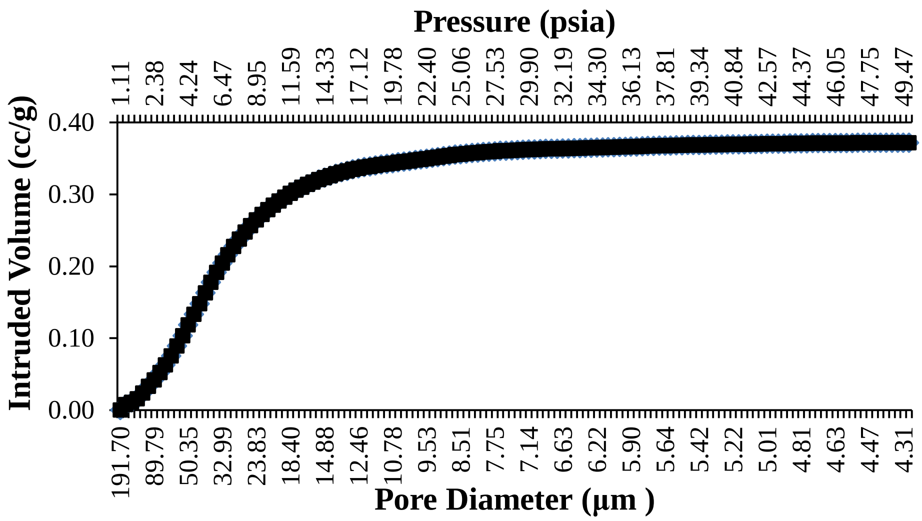

Figure 3.25 Cumulative intrusion curve for pretreated eggplant dried in microwave-IR combination oven at 10% IR & 30% microwave powers.

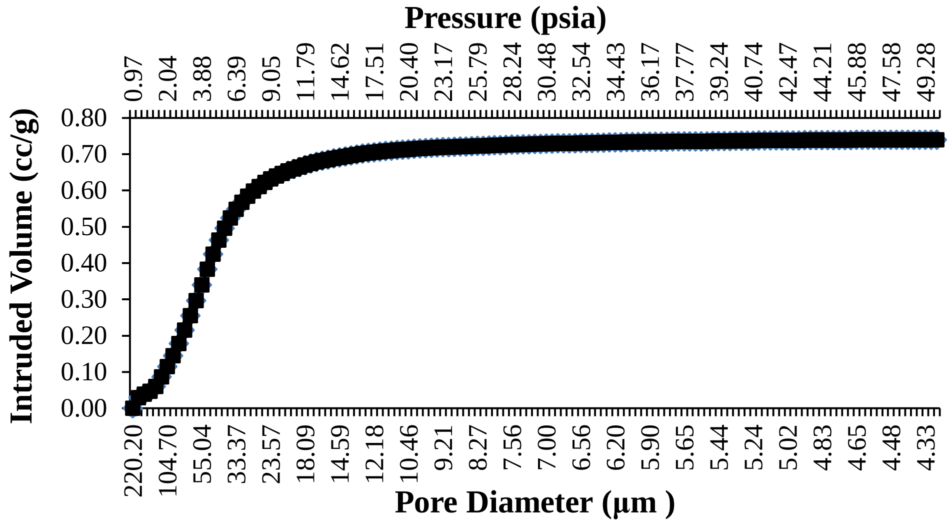

Figure 3.26 Cumulative intrusion curve for pretreated eggplant dried in microwave-IR combination oven at 20% IR & 30% microwave powers.

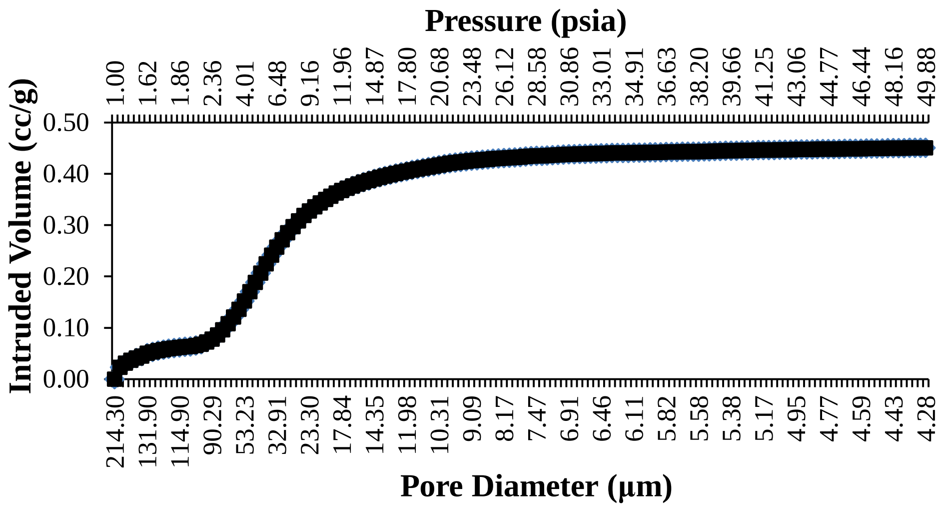

Figure 3.27 Cumulative intrusion curve for pretreated eggplant dried in microwave-IR combination oven at 10% IR & 50% microwave powers.

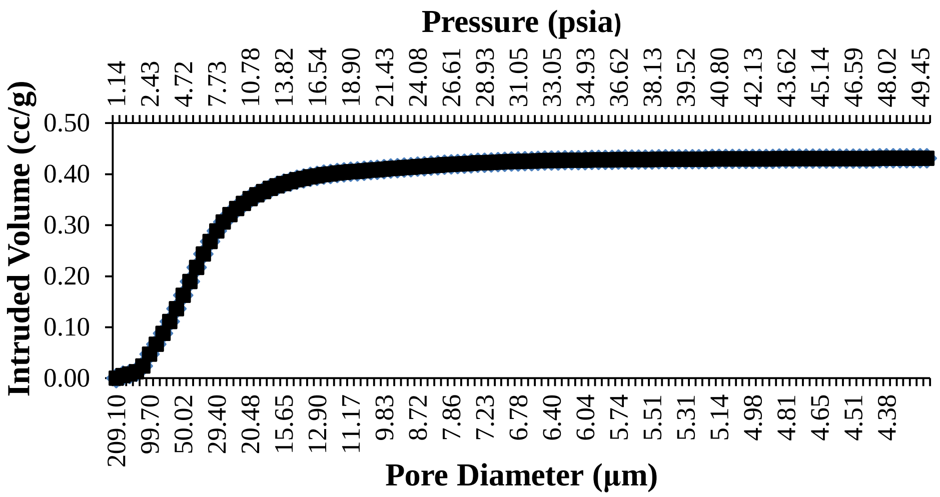

Figure 3.28 Cumulative intrusion curve for pretreated eggplant dried in microwave-IR combination oven at 20% IR & 50% microwave powers.

For the osmotically dehydrated eggplants dried using different combination of IR and microwave power levels, a sharp increase was observed with different slopes. However, this increase was sharper for eggplants dried without osmotic pretreatment (Figure 3.20-3.23). This means that less macro pores existed on the surface of osmotically dehydrated eggplants as compared to untreated ones. The reason could be the existence of more collapse in the structure due to salt particles.

Threshold pore sizes of osmotically dehydrated eggplants changed from 8.82 to 32.75 µm which were lower than threshold pore sizes of untreated ones. This could be due to shrinkage effect of osmotic treatment.

3.3.2 Pore Size Distribution Curves

Pore size distribution was calculated by using the relation between pore radius and pore volume, assuming cylindrical pores (Lowell & Shields, 1984). The pore size distribution can be defined as;

$$D_V = \left(\frac{P}{r}\right)\left(\frac{dV}{dP}\right) \tag{3.5}$$

where D_v is the volume pore size distribution function, defined as the pore volume per unit interval of pore radius (cc/g.μm),*dV* is the volume of intruded mercury in the sample (considered exactly equal to the volume of pores), *dV/dP* is the first derivative of pressure versus intruded mercury volume data. Pore size distribution curves give information about the extent of similar size pores and the more pores at these sizes (Rahman et al., 2002). Pore size distribution curves (D_v versus pore diameter) for untreated eggplants dried with different combination of IR and microwave power and hot air drying were given in Figures 3.29-3.33.

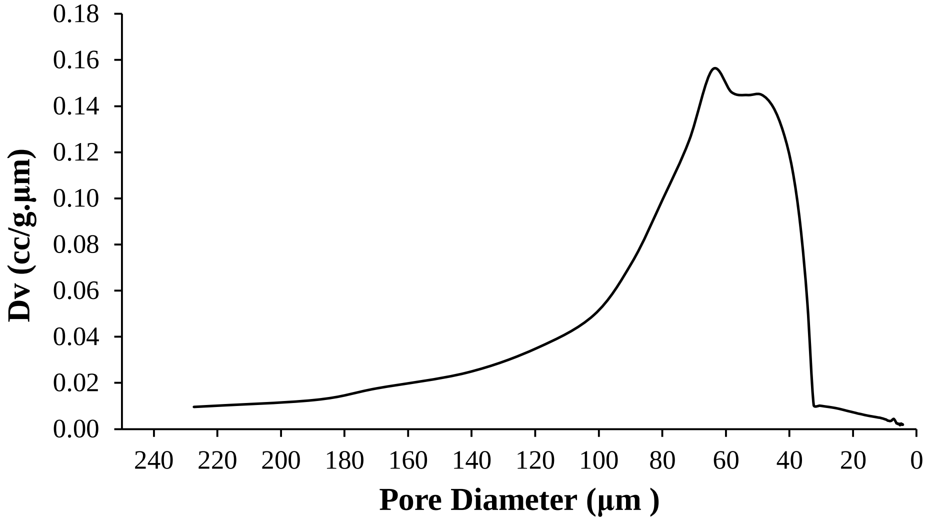

Figure 3.29 Pore size distribution curve for untreated eggplants dried in microwave-IR combination oven at 10% IR & 30% microwave powers.

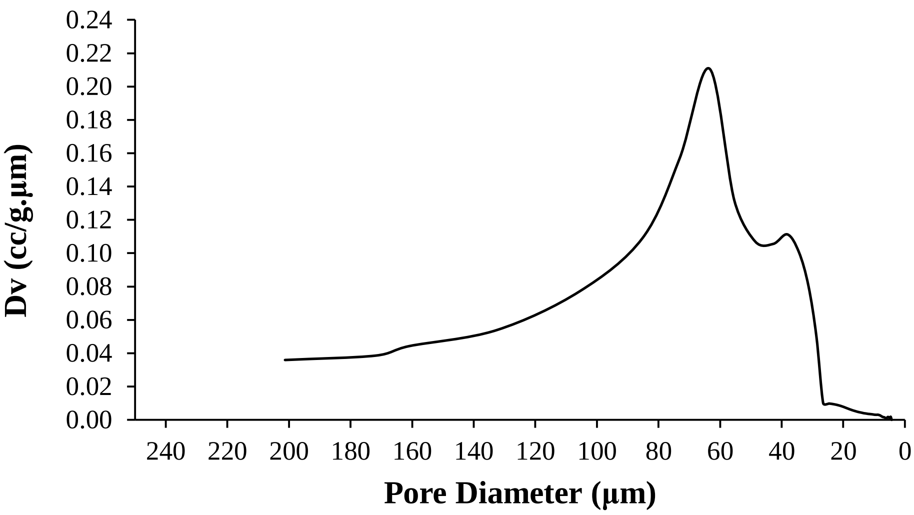

Figure 3.30 Pore size distribution curve for untreated eggplants dried in microwave-IR combination oven at 20% IR & 30% microwave powers.

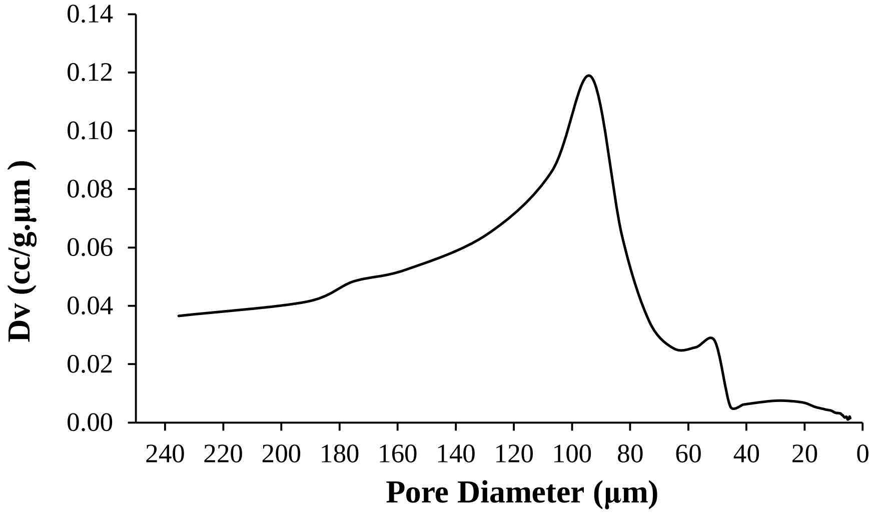

Figure 3.31 Pore size distribution curve for untreated eggplants dried in microwave-IR combination oven at 10% IR & 50% microwave powers.

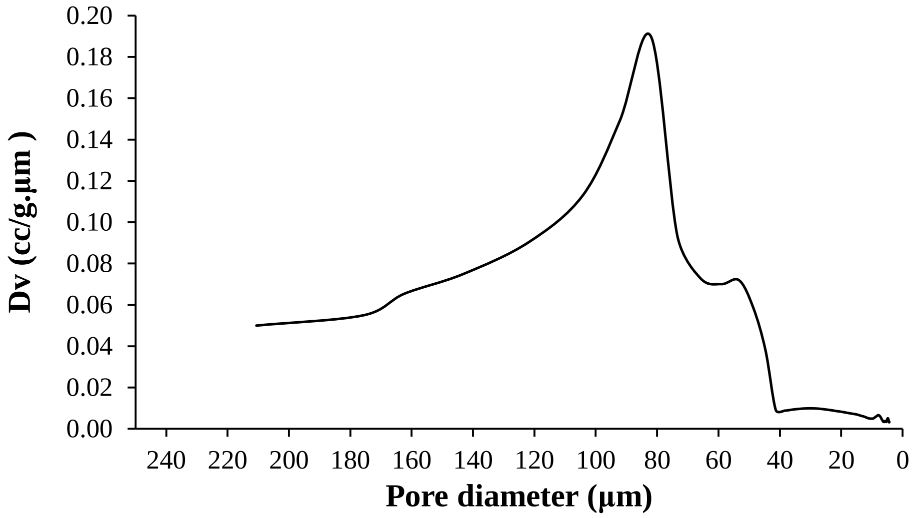

Figure 3.32 Pore size distribution curve for untreated eggplants dried in microwave-IR combination oven at 20% IR & 50% microwave powers.

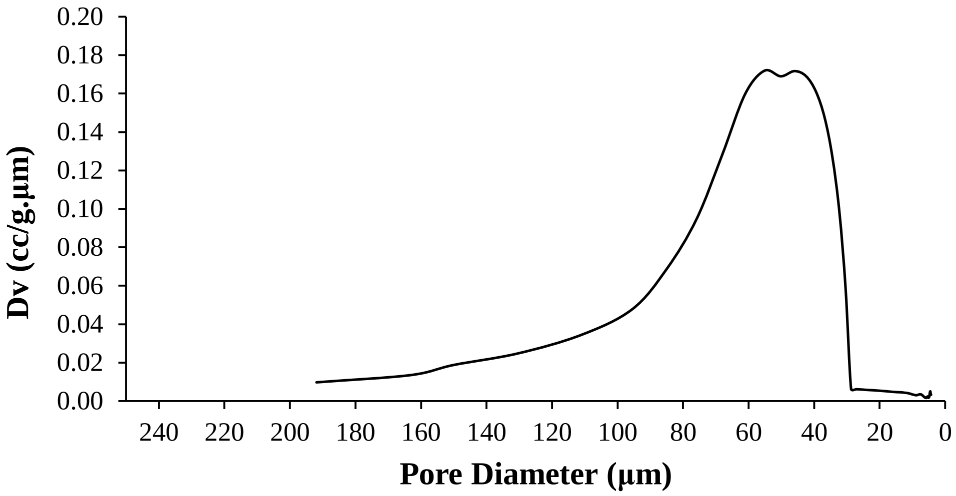

Figure 3.33 Pore size distribution curve for eggplant dried at hot air dryer.

Hot air dried eggplants showed a peak at the pore size of 46.01 µm and the height was 1.72×10^{-1} cc/g.µm. The peak was wider which was an indication of existence both larger and smaller pores. However, the pore size of hot air dried samples was lower than microwave-IR combination dried ones since the drying time was significantly longer that destruct the pore structure. In addition, microwave heating caused higher water vapor pressure inside the samples that resulted in porous structure. Similarly, Karathanos et al. (1996) examined the pore size distribution of air and freeze dried vegetables and stated that pores of air dried samples were smaller than that of freeze dried samples because of the collapse structure during air drying.

While eggplants dried at 10% IR & 30% microwave power showed a peak at the pore size of 64.26 µm and the height was 1.56×10^{-1} cc/g.µm in terms of the unit of Dv, eggplants dried at 20% IR & 30% microwave power showed a peak at the pore size of 63.43 µm and the height was 2.11×10^{-1} cc/g.µm. They were 93.47 µm and 1.19×10^{-11} cc/g.µm; 81.97 µm and 1.90×10^{-1} cc/g.µm for eggplants dried at

10% IR & 50% microwave power and 20% IR & 50% microwave power, respectively. Wider graphs indicated that larger pore segments were followed by smaller ones while the sharp peaks indicated that the most of the pores exist in that pore size range (Rahman et al., 2005). Also, higher height is an indication of existence of more pores at that pore size (Rahman et al., 2002). Although eggplants dried at 20% IR & 30% microwave power showed almost same sized pores with eggplants dried at 10% IR & 30% microwave power, it had large number of pores during drying meaning that IR power increased porosity. Similarly, smaller sized but larger number of pores were also formed for samples dried at 20% IR & 50% microwave power when compared with the samples dried at 10% IR & 50% microwave power. When the effect of microwave power was examined, it was concluded that larger sized pores in smaller number was formed as the microwave power was increased. This may be due to puffing effect of microwave heating. In addition, smaller peaks were observed in Figure 3.29-3.32 but it was not considered for pore size distribution analysis.

The pore size distribution curves for eggplant pretreated in 10% (w/w) osmotic NaCI solution and dried in microwave-IR combination oven were given in Figures 3.34-3.37 for different combinations of microwave and IR powers. When pore size distribution of osmotically dehydrated eggplants were compared with that of untreated ones, both pore size and height were found to be significantly lower. This was an indication that untreated eggplants had higher porosity than osmotically dehydrated ones. During osmotic dehydration, salt diffused into the cells of eggplants that led to less porous structure.

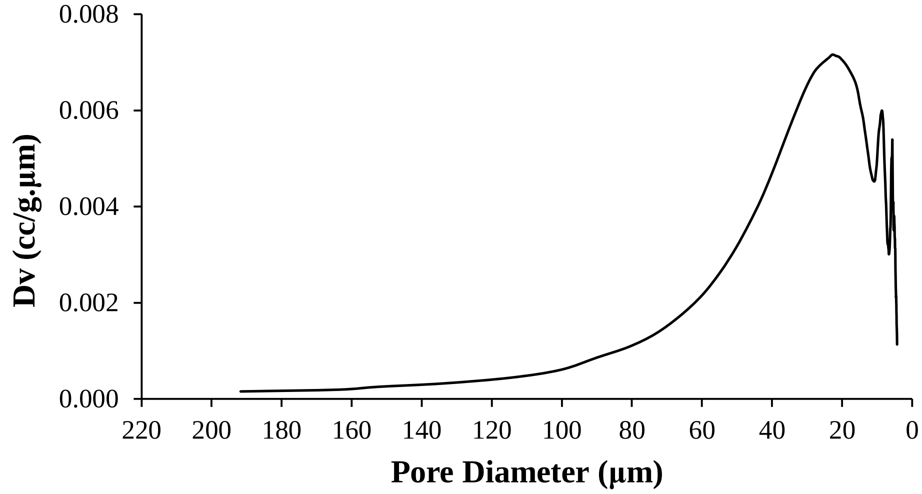

Figure 3.34 Pore size distribution curve for pretreated eggplant dried in microwave-IR combination oven at 10% IR & 30% microwave powers.

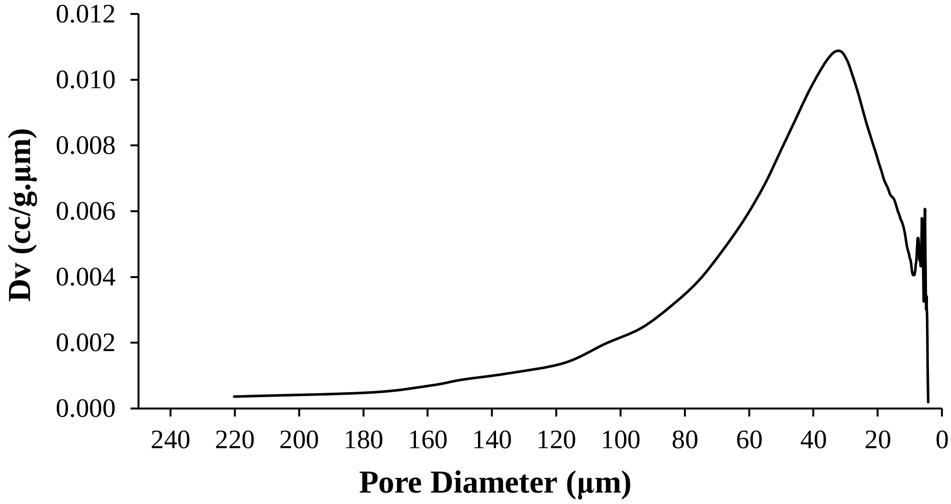

Figure 3.35 Pore size distribution curve for pretreated eggplant dried in microwave-IR combination oven at 20% IR & 30% microwave powers.

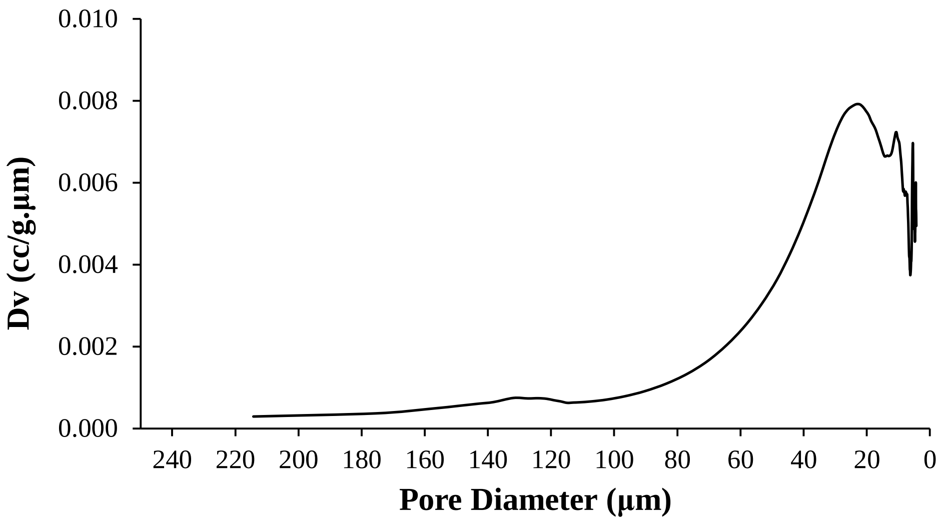

Figure 3.36 Pore size distribution curve for pretreated eggplant dried in microwave-IR combination oven at 10% IR & 50% microwave powers.

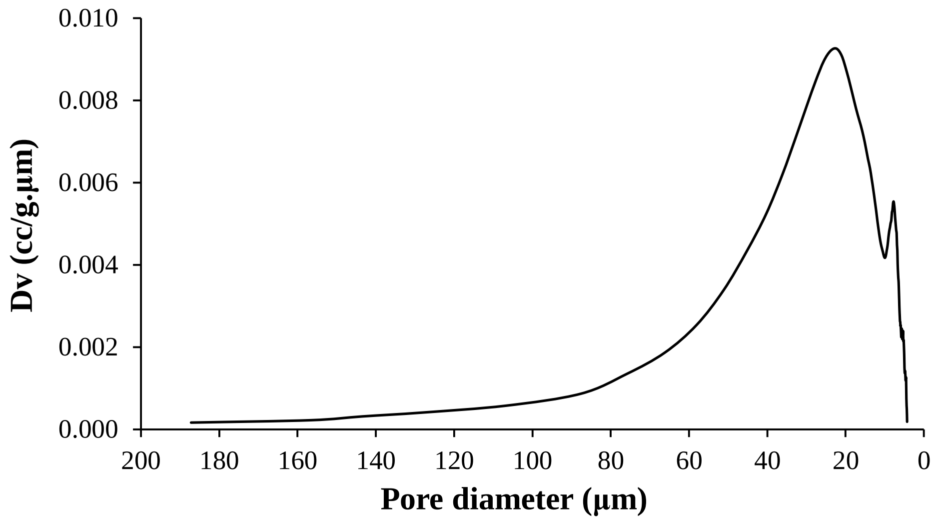

Figure 3.37 Pore size distribution curve for pretreated eggplant dried in microwave-IR combination oven at 20% IR & 50% microwave powers.

3.4 Color Characteristics

Color of a food sample is one of the most important quality indicators to evaluate thermal deterioration. It affects appearance of foods so it influences consumer acceptability since visual appearance is the first impact for the consumer. During drying, there are many reactions that affect color such as pigment degradation and browning reactions (Maskan, 2001b; Dadali et al., 2007). Both enzymatic and non-enzymatic browning reactions take place so color changes occur during drying of fruits and vegetables (Vadivambal & Jayas, 2007).

Color of the dried eggplants were investigated in terms of CIE L* and a* values since no trend was observed for b* values. Nimmol et al. (2007) stated that L* and a* values were significantly affected by both drying temperature and drying methods. L* value shows the lightness and a* value shows redness of the food. Browning reactions caused decrease in L* values and increase in a* values.

When hot air drying method used to dry eggplants, L* and a* values of dried eggplants were recorded as 70.7 and 1.3, respectively. However L* and a* values of eggplants dried in microwave-IR combination oven were ranged between 51.2-57.8 and 8.30-10.1, respectively. It was obvious that eggplants dried with microwave-IR combination drying had lower L* values and higher a* values than eggplants dried with hot air. This could be explained by non-enzymatic browning reactions taking place in microwave-IR combination drying.

Both enzymatic and non-enzymatic reactions cause browning of foods. When polyphenolic substances are oxidized by the action of the enzyme polyphenol oxidase (PPO), enzymatic browning occurs. In the presence of oxygen, PPO catalyzes two different reactions which are the oxidation of monophenols to the corresponding orthodiphenol compounds and the oxidation of o-diphenol phenols to o-quinones, which condense to form the brown melanin pigment (Coultate, 2002). In eggplant, the PPO and phenolics are present in chloroplast and vacuoles, respectively (Mayer & Harel, 1979). Mishra et al. (2012) stated that by cutting eggplants, cellular structure is disrupted which leads to release of PPO enzyme and its phenolic substrate. In order to eliminate color changes of vegetables, controlling enzymatic browning is necessary. Enzymatic browning of fruits and vegetables can be prevented by heat inactivation of the enzyme, removal of substrates (O_2 or phenols), lowering the pH below the optimum, usage of reducing compounds such as ascorbate and bisulfites that inhibit PPO enzyme. With increasing temperature and inactivation time, enzyme activity is decreased due to the heat denaturation. In general, by applying temperature above 50°C, inactivation of PPO can be achieved (Madinez & Whitaker, 1995). However, the optimum temperature of PPO activity for eggplant is 30°C (Concellon et al., 2004). When eggplant was dried with hot air drying at 50°C, enzymatic browning of eggplants was inhibited by inactivating PPO enzyme. Similarly, when microwave-IR combination drying was used to dry eggplants, PPO enzyme was inactivated by heat treatment. Therefore, in both drying methods, enzymatic browning was not observed.

On the other hand, non-enzymatic browning or Maillard reactions occur between amino acids and reducing sugars which takes place in thermally processed foods. After Maillard reactions, brown nitrogeneous polymers which are known as melanoidin are formed (Carabasa-Giribet & Ibarz-Ribas, 2000). Many factors influence the Maillard reactions such as temperature, pH, moisture content, metal ions and sugar structure (Daniel et al., 2012). For drying, temperature is an important parameter. Martins et al. (2011) stated that increased temperature caused an increase of the reactivity between the sugar and the amino group. Thus, the rate of Maillard reaction increases with temperature. Rufián-Henares et al. (2013) showed that Maillard reaction was accelerated at temperature over 50°C. Garza et al. (1999) showed that the increase in temperature resulted browning of peach puree. In this study, eggplants dried using microwave-IR combination showed lower L* values and higher a* values than hot air dried eggplants since Maillard reaction was accelerated in microwave-IR combination oven due to higher temperature.

The effects of microwave and IR powers on the L* and a* values were represented in Figures 3.38-3.39. According to ANOVA results, there was no significant difference between the L* and a* values of eggplants dried at different microwave powers ($p>0.05$) (Tables A.1&A.5). In microwave heating, the temperature on the surface could not be reached to the required level for browning reactions. Cool ambient temperature in microwave oven caused low surface temperature that prevented browning reactions to occur so it provided higher L* values (Sumnu, 2001). Soysal (2004), Sarimeseli (2011) and Maskan (2000) pointed out that change in color values was not dependent on microwave power. However, according to Tables A.1&A.5, there was significant difference between L* and a* values of eggplants dried at different IR powers ($p \leq 0.05$). When IR heating was combined with microwave heating, IR power was found to be effective on color values. When IR powers were increased, surface temperature increased and it could reach the required values for browning (Sumnu et al., 2005b). Shi et al. (2008) and Tan et al. (2001) supported that IR heating caused greater color change than hot air drying. Therefore, higher IR power caused lower L* values and higher a* values (Figure 3.38 and 3.39).

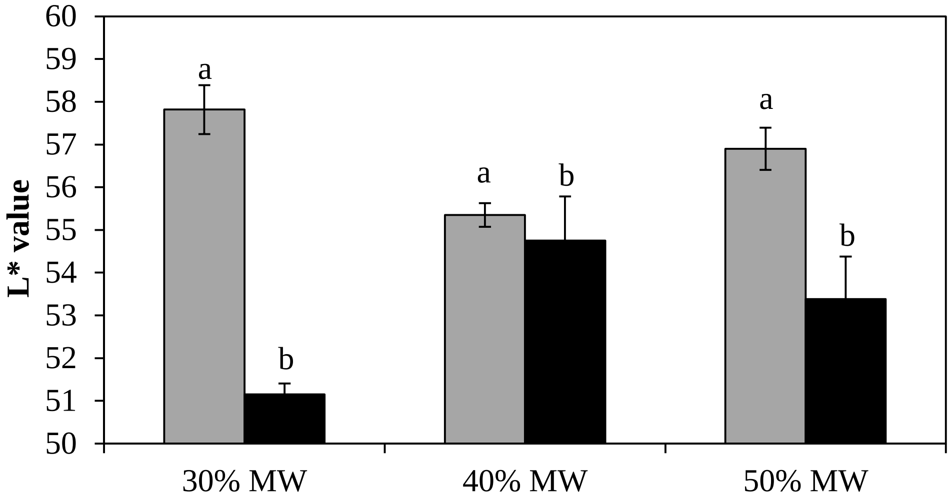

Figure 3.38 Effect of IR powers on L* values of eggplant dried in microwave-IR combination oven at; (■): 10% IR power, (■): 20% IR power.

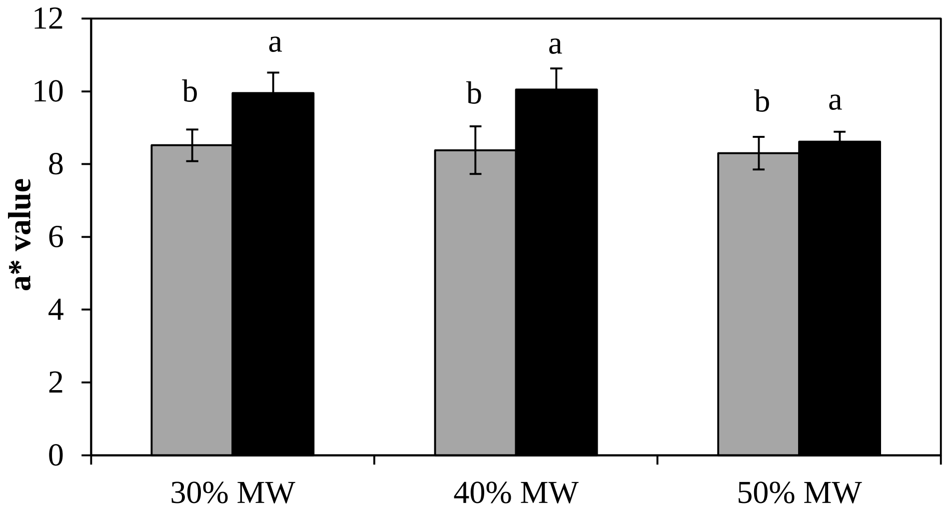

Figure 3.39 Effect of IR powers on a* values of eggplant dried in microwave-IR combination oven at; (■): 10% IR power, (■): 20% IR power.

Figure 3.40 - 3.41 shows the effect of osmotic dehydration on L* and a* values of eggplants dried in microwave-IR combination oven at 20% IR & 50% microwave power. Eggplants dried in microwave-IR combination oven after osmotic dehydration had higher L* values and lower a* values than untreated eggplants (Figure B.1). Osmotic dehydration was conducted at 50°C for 2 hours. During osmotic dehydration, PPO enzyme might be inactivated due to the heat treatment. Similarly, Mahayothee et al. (2009) founded that osmotic dehydration inhibited the PPO activity. Moreover, solute uptake results in lower O_2 which is transferred to the surface so browning due to the enzymatic browning is reduced with osmotic dehydration (Mandala et al., 2005). In addition, during osmotic dehydration, water activity of eggplants (a_w) is reduced. Water activity is an important factor that affects the Maillard reaction since at low water activity; the mobility of reactants is limited. Therefore, osmotic dehydration decreased non-enzymatic browning. In addition, during osmotic dehydration, reactants for Maillard reaction might be leached and which also decreased Maillard reaction. Tan et al. (2001) expressed that osmotic dehydration stabilized color of potato during drying due to a thick layer of fine salt crystals formed on the surface of samples. Krokida et al. (2000) reported that osmotic dehydration with sucrose solution prevented color deterioration during drying process. It was stated that the reason could be inactivation of enzymes for enzymatic browning and reduced non-enzymatic browning due to the lower water activity. Similar result was found in the research of Prothon et al. (2001) and it was stated that osmotically pre-treated apples had higher L* values and lower a* values after drying when compared to untreated ones.

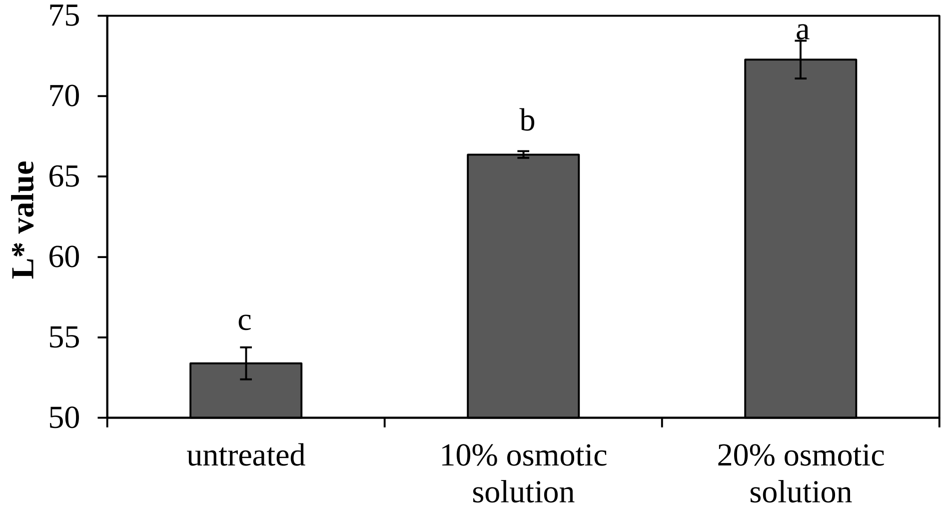

Figure 3.40 Effect of osmotic dehydration on L* values of eggplant dried in microwave-IR combination oven at 20% IR and 50% microwave powers.

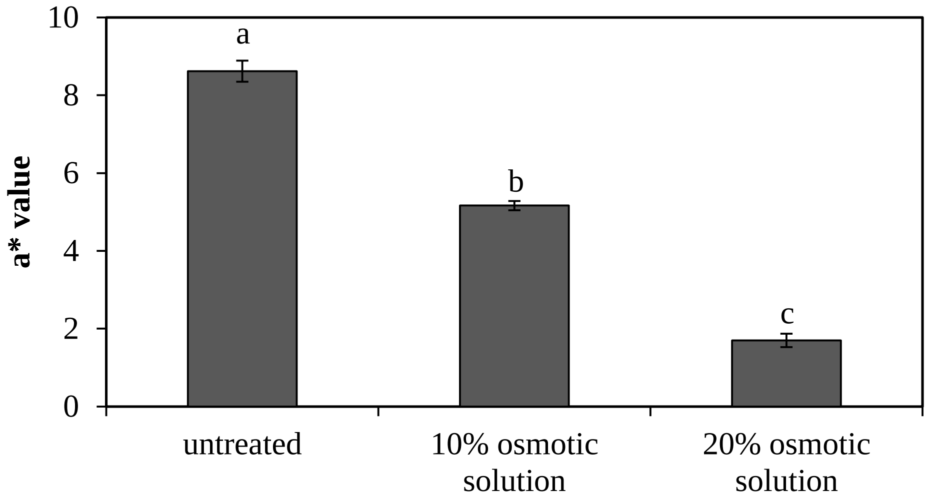

Figure 3.41 Effect of osmotic dehydration on a* values of eggplant dried in microwave-IR combination oven at 20% IR and 50% microwave powers.

Figures 3.42-3.45 shows the effect of microwave and IR powers on the L* and a* values of osmotically dehydrated eggplants with 10% and 20% (w/w) osmotic solution. According to ANOVA results, there was no significant difference between the L* and a* values of osmotically dehydrated eggplants dried at different microwave powers (p>0.05) (Tables A.2, A.3, A.6 and A.7). However, as the IR powers were increased, L* values decreased and a* values increased.

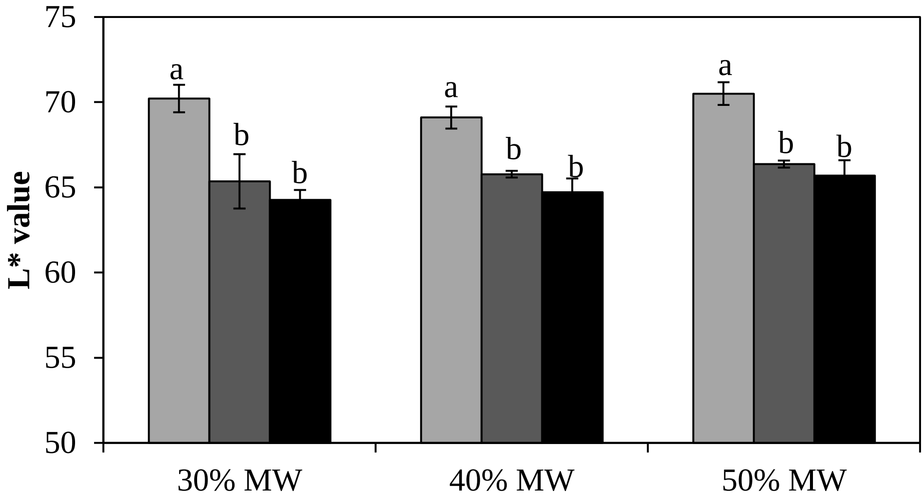

Figure 3.42 Effect of IR powers on L* values of 10% (w/w) osmotically dehydrated eggplant dried in microwave-IR combination oven at; (■): 10% IR power, (■): 20% IR power, (■): 30% IR power.

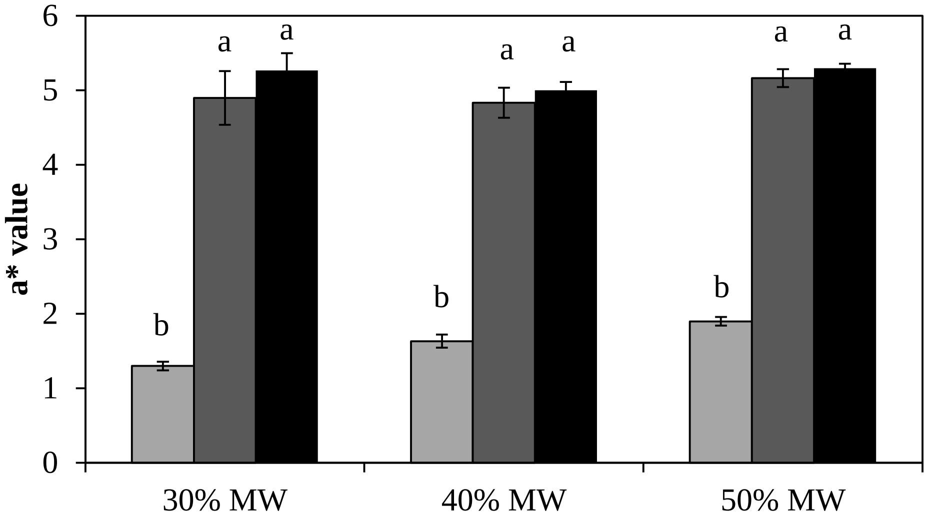

Figure 3.43 Effect of IR powers on a* values of 10% (w/w) osmotically dehydrated eggplant dried in microwave-IR combination oven at; (■): 10% IR power, (■): 20% IR power, (■): 30% IR power.

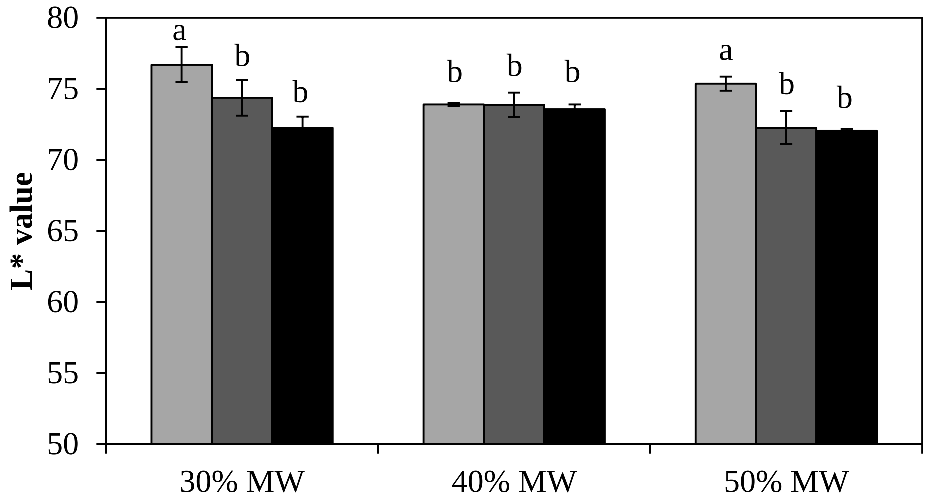

Figure 3.44 Effect of IR powers on L* values of 20% (w/w) osmotically dehydrated eggplant dried in microwave-IR combination oven at; (■): 10% IR power, (■): 20% IR power, (■): 30% IR power.

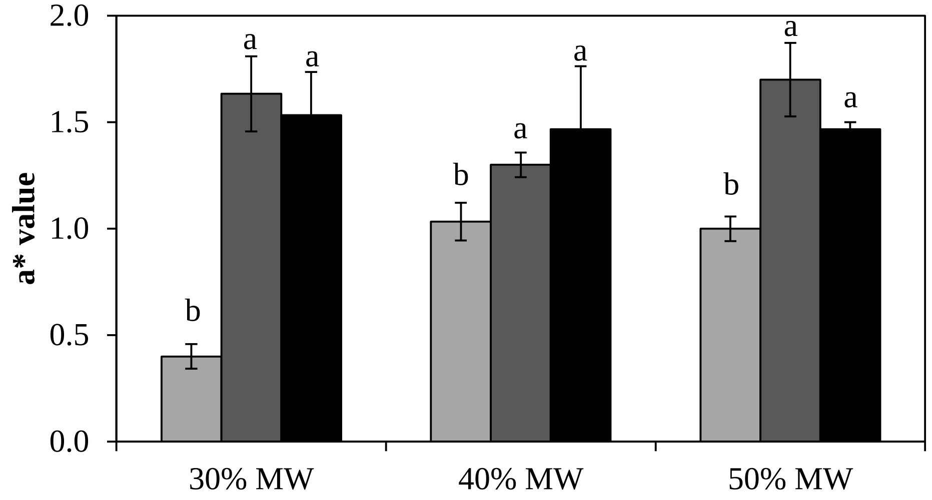

Figure 3.45 Effect of IR powers on a* values of 20% (w/w) osmotically dehydrated eggplant dried in microwave-IR combination oven at; (■): 10% IR power, (■): 20% IR power, (■): 30% IR power.

3.5 Shrinkage

During drying process, the loss of water causes a change in the mechanical and structural properties of food. Lower water content causes reduced structure mobility and increased in the solid fraction (Aversa et al., 2011). When water is removed from the material, a pressure unbalance is produced between the inner of the material and the external pressure which leads to changes in food shape and size. This phenomenon is known as shrinkage. Shrinkage is one of the most important quality problems of dried foods. It causes negative impression for consumers due to the loss of volume and irregular shape. Shrinkage depends on volume of removed water, mobility of the solid matrix and drying conditions that affect drying rate (Mayor & Sereno, 2004).

The shrinkage value of hot air dried samples was 0.91 while shrinkage values of microwave-IR combination dried samples at different microwave and IR powers were in the range of 0.59-0.67 (Figure 3.46). Hot air dried eggplants samples showed higher changes in volume, hence, higher shrinkage than eggplants dried with microwave-IR combination. Drying time of hot air drying was extremely long so it caused collapse of the cell walls and considerable shrinkage. Unlike hot air drying, high water vapor pressure inside food was generated in microwave drying. It caused cell expansion, which was known as puffing effect of microwave heating, so shrinkage of foods were reduced by using microwave heating (Argyropoulos et al., 2011). As can be seen in pore size distribution curve, microwave-IR combination dried eggplants had more porous structure compared to hot air dried ones so they had lower shrinkage values (Figure 3.29-3.33). Similar results were obtained in literature. It was stated that potato samples dried by microwave had lower shrinkage than hot air dried samples (Khraisheh et al., 1997). IR heating had also the same effect on shrinkage as microwave heating so IR drying method can be preferred to obtain dried food samples with lower shrinkage. Nathakaranakule et al. (2010) dried longan fruits with hot air at 65°C and obtained products with 86.5% shrinkage. However, when far IR radiation (450 W) was combined with hot air to dry samples, the shrinkage values of dried products decreased to 75.4%. IR heating supplied faster evaporation which resulted larger pores and lower shrinkage.

Microwave and IR power had significant influence on shrinkage values ($p \leq 0.05$) (Figure 3.46) (Table A.9). As the microwave power increased, shrinkage of dried eggplants was decreased due to the puffing effect of microwave heating. This phenomenon was in agreement with the study of Prabhanjan et al. (1995) who showed that minimum shrinkage was observed at the highest microwave power. Similarly, Khraisheh et al. (2004) mentioned that higher microwave power caused higher drying rates which resulted in lower shrinkage. Figiel (2007) dried apples with microwave-vacuum combination drying and stated that an increase in microwave power caused a reduction in shrinkage. Also, increasing IR power decreased shrinkage of dried eggplants (Figure 3.46). Higher IR power enhanced evaporation rates which resulted in more porous structure as shown in Figures 3.20-

3.23 so shrinkage was reduced. Mongpraneet et al. (2002) showed that onions had higher shrinkage at lower IR power.

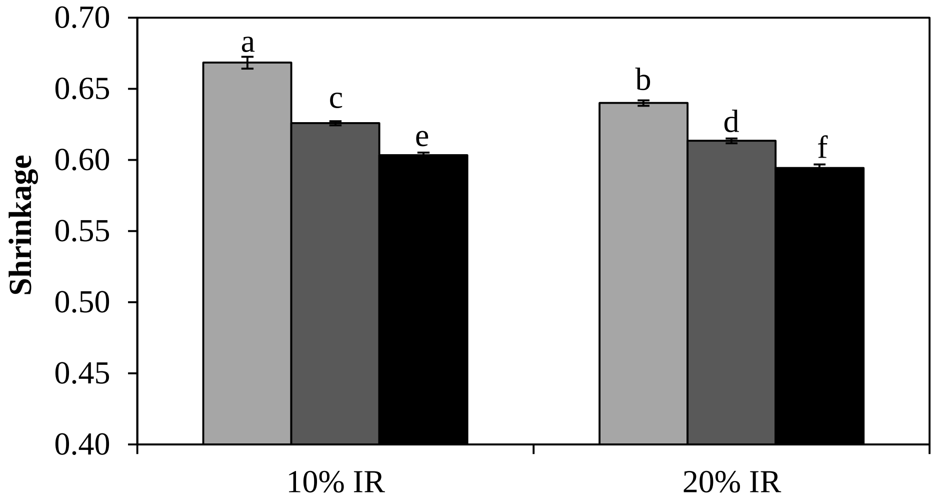

Figure 3.46 Effect of microwave and IR powers on shrinkage of eggplant dried in microwave-IR combination oven at; (■): 30% microwave power, (■): 40% microwave power, (■): 50% microwave power.

The effect of osmotic dehydration with different concentration on shrinkage of eggplants dried with microwave-IR combination at 20% IR power and 50% microwave power was shown in Figure 3.47. Osmotically dehydrated eggplants had higher shrinkage than untreated ones. As the concentration of osmotic dehydration increased, shrinkage increased, too. During osmotic dehydration, volume changes occurred because of compositional changes and mechanical stresses associated to mass fluxes. Due to the water loss, considerable shrinkage was reported after osmotic dehydration (Mayor et al., 2011). Prothon et al. (2001) reported that the decrease in sample size of pretreated apples after microwave-assisted air-drying can be explained by mainly cell size reduction due to the osmotic dehydration.

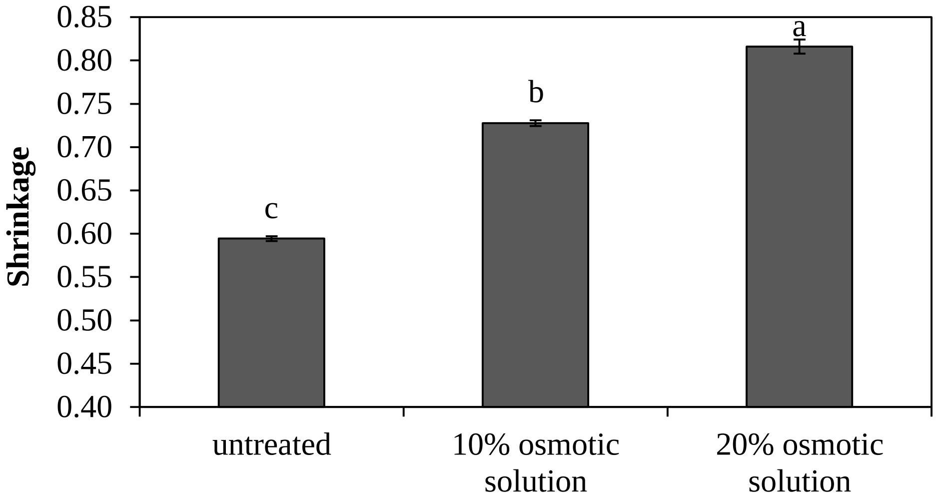

Figure 3.47 Effect of osmotic dehydration on shrinkage of eggplant dried in microwave-IR combination oven at 20% IR and 50% microwave powers.

Figures 3.48-3.49 shows that eggplants dehydrated with both 10% and 20% osmotic solution had lower shrinkage as the microwave and IR power increased. Higher microwave and IR power supplied higher drying rate and higher pore sizes thus the volume changes decreased.

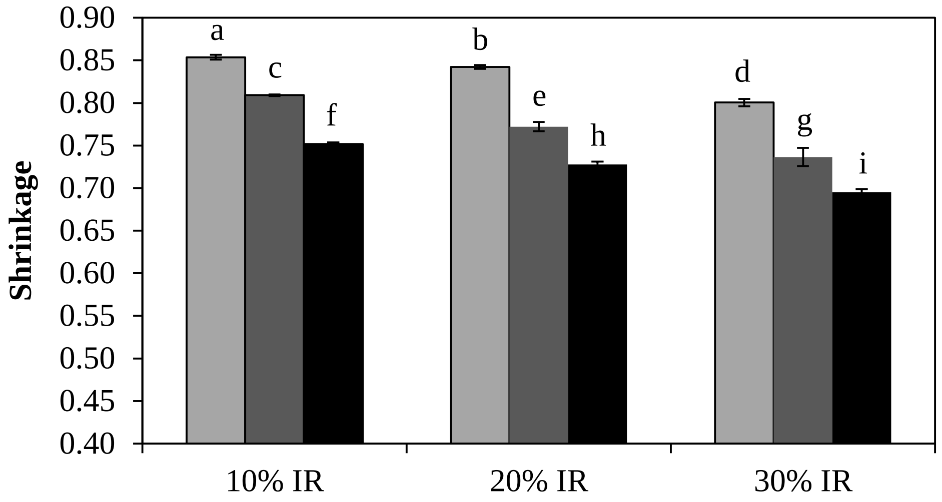

Figure 3.48 Effect of microwave and IR powers on shrinkage of 10% (w/w) osmotically dehydrated eggplant dried in microwave-IR combination oven at; (■): 30% microwave power, (■): 40% microwave power, (■): 50% microwave power.

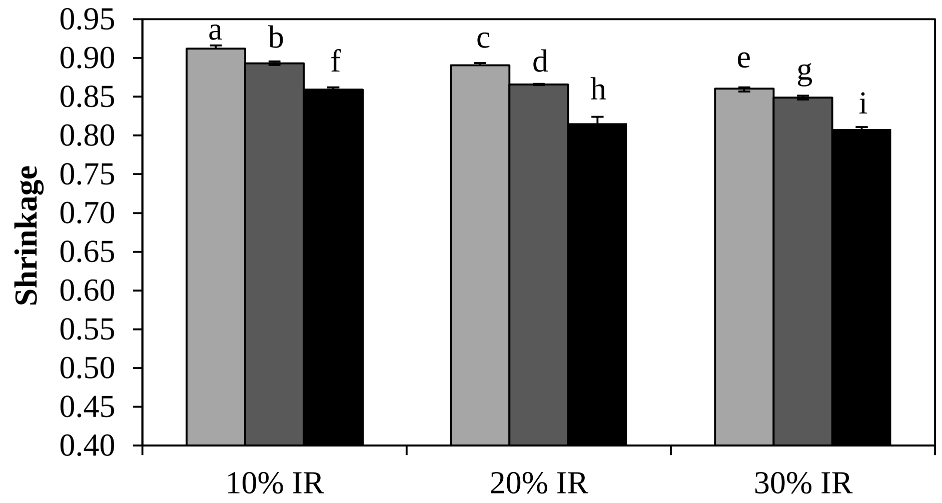

Figure 3.49 Effect of microwave and IR powers on shrinkage of 20% (w/w) osmotically dehydrated eggplant dried in microwave-IR combination oven at; (■):30% microwave power, (■): 40% microwave power, (■): 50% microwave power.

3.6 Rehydration Ratio

In dehydrated products, the amount and rate of water absorption affect the sensorial properties and preparation time. The rehydration properties of dried products are used widely as a quality index that indicates the physical and chemical changes caused by drying (Feng & Tang, 1998). Higher rehydration characteristic is an indication of high quality of dried products.

Eggplants dried in microwave-IR combination oven had rehydration ratios which were between 5.26- 6.47 (Figure 3.50), while rehydration ratio of eggplants dried with hot air was 4.74. This difference could be explained by lower porosity of hot air dried eggplants (Figure 3.33). Marabi & Saguy (2004) pointed out that rehydration ratio of dried foods increased with porosity. Argyropoulos et al. (2011) stated that hot air drying resulted significant shrinkage and due to the collapsed capillaries, a dense structure with reduced ability of water retention during rehydration was formed. In microwave-IR combination drying, high internal pressure produced might expand the cells of eggplants. Also, drying time of microwave-IR combination drying was significantly lower than hot air drying so cell destruction was minimized. Dev et al. (2011) investigated the effects of drying type on rehydration ratio and found that rehydration ratio of microwave-assisted hot air dried samples was significantly higher than convective hot air dried samples. Similarly, Funebo et al. (2000) stated that the rehydration capacity was increased by 25-50% for microwave-treated apples as compared to the air dehydrated ones.

The effects of microwave and IR powers on the rehydration ratio values of eggplants dried in microwave-IR combination oven were shown in Figure 3.50.

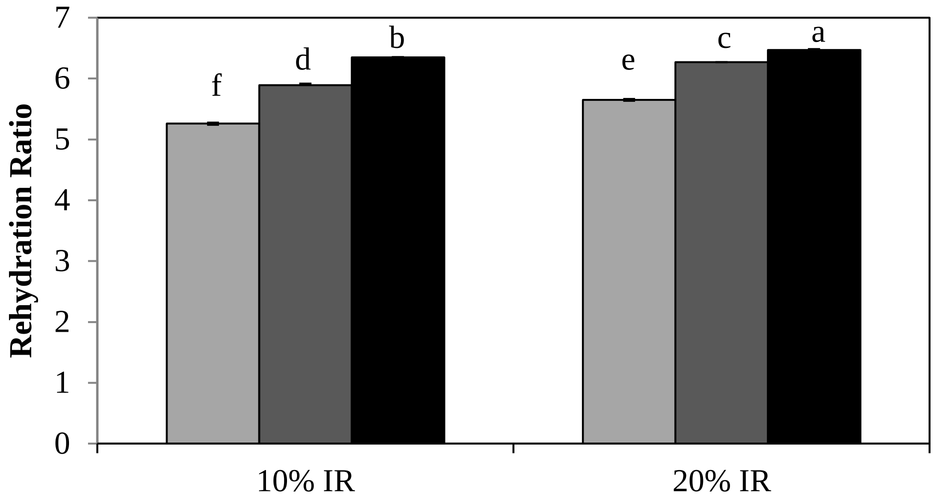

Figure 3.50 Effect of microwave and IR powers on rehydration ratio of eggplant dried in microwave-IR combination oven at; (■): 30% microwave power, (■): 40% microwave power, (■): 50% microwave power.

As can be seen in Figures 3.50, rehydration ratio was significantly affected from microwave and IR powers ($p \leq 0.05$) (Table A.13). The rapid microwave energy absorption resulted in rapid evaporation of water, creating a flux fast escaping vapor which reduced shrinkage so improved the rehydration characteristics (Kathirvel et al., 2006). Moreover, as the IR power increased, rehydration ratio increased, too. The higher rehydration ratios at higher IR power can be attributed to uniform and rapid heating by IR radiation and the absence of case hardening. The results were confirmed by Figure 3.46, which showed that as the microwave and IR powers increased, less shrinkage was observed so better rehydration characteristic was obtained. Higher porosity might lead to the increase in rehydration (Vishwanathan et al., 2010). As represented in Figures 3.29-3.32, higher porosity was obtained with higher IR and microwave powers due to rapid heating and faster diffusion of water vapor. Nasıroglu & Kocabıyık (2009) stated that higher IR power led to more porous structure that caused higher rehydration ratio.

The effects of osmotic dehydration on rehydration ratio of eggplants dried with microwave-IR combination at 20% IR & 50% microwave power was shown in Figure 3.51. It was shown that untreated eggplants showed significantly higher rehydration ratio compared to osmotically dehydrated ones at constant microwave and IR power. Moreover, as the concentration of osmotic solution increased, rehydration ratio decreased. Osmotic dehydration decreased the rehydration ability of samples because of salt crystals collected on the product surface. This can prevent the movement of water into the intercellular spaces of sample (Wang et al., 2010). Prothon et al. (2001) explained the lower rehydration ratio of osmotically dehydrated eggplants by lower porosity as a result of solute diffusion into the intercellular spaces and the cell walls. Hence, the cell walls were less permeable to water. As discussed before, osmotically dehydrated eggplants had higher shrinkage than untreated ones so they had lower rehydration ratios (Figure 3.47).

Rehydration ratios of osmotically dehydrated eggplants dried in microwave-IR combination oven at different microwave and IR powers were shown in Figures 3.52-3.53. Similar to the results obtained by untreated eggplants, eggplants pretreated with both 10% and 20% (w/w) osmotic solution showed higher rehydration ratio at higher microwave and IR power.

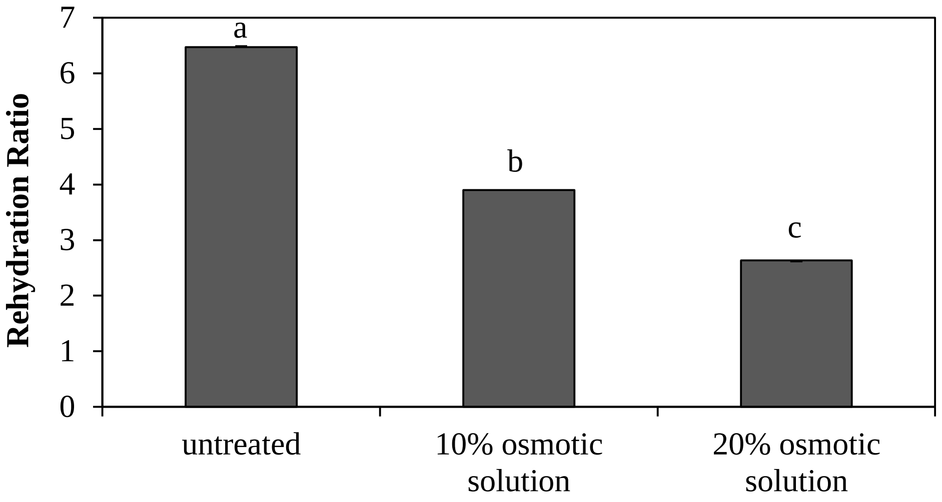

Figure 3.51 Effect of osmotic dehydration on rehydration ratio of eggplant dried in microwave-IR combination oven at 20% IR and 50% microwave powers.

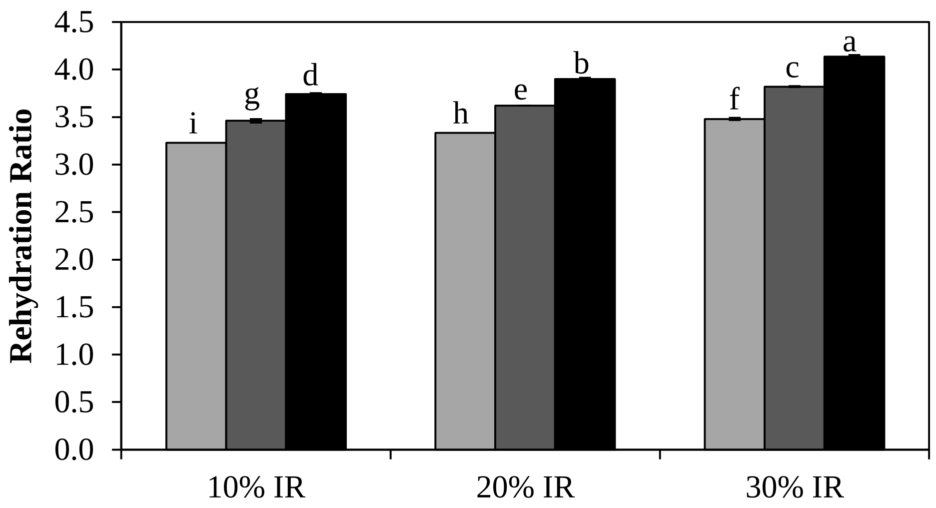

Figure 3.52 Effect of microwave and IR powers on rehydration ratio of 10% (w/w) osmotically dehydrated eggplant dried in microwave-IR combination oven at; (■): 30% microwave power, (■): 40% microwave power, (■): 50% microwave power.

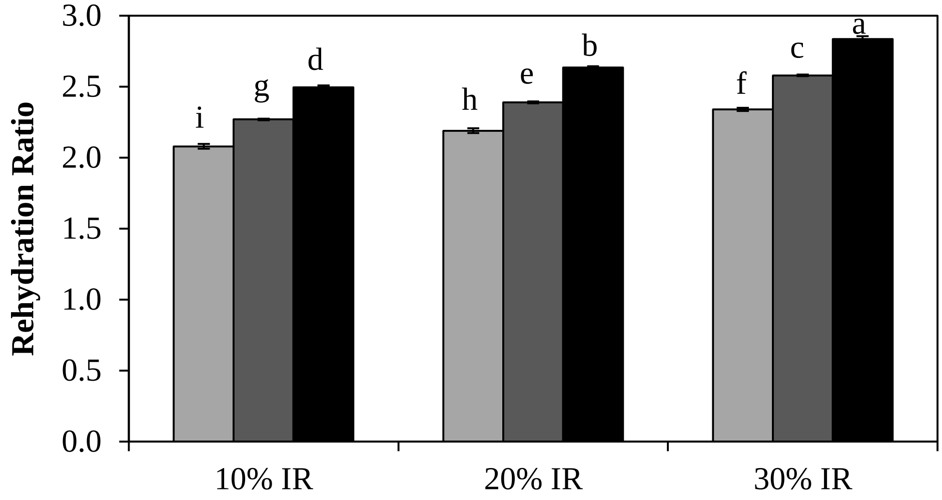

Figure 3.53 Effect of microwave and IR powers on rehydration ratio of 20% (w/w) osmotically dehydrated eggplant dried in microwave-IR combination oven at; (■): 30% microwave power, (■): 40% microwave power, (■): 50% microwave power.

3.7 Microstructural Analysis

Scanning Electron Microscopy (SEM) images of eggplants dried with microwave-IR combination and hot air were given in Figure 3.54. The SEM images of all eggplants were taken at 100× magnification.

When the images of the microwave-IR combination dried eggplants were considered, it was observed that the cell walls were intact and there was organized cellular compartment of the cells. The increase in microwave power resulted in larger pores. More microwave heating caused rapid evaporation of water so puffing effect led to larger pore size (Han et al., 2010). In addition, when the SEM images of dried eggplants at 20% IR power were compared to eggplants dried at 10% IR power, the number of pores was higher. IR heating resulted in porous structure due to the rapid heating and vapor diffusion within the sample (Vishwanathan et al., 2010). Similarly, Nathakaranakule et al. (2010) stated that with increasing IR power, more porous structure was obtained in dried longan fruit. Microstructural results can be related to porosity results which showed that microwave and IR power increase led to higher porosity (Figures 3.29-3.32). When the image for the conventionally dried eggplants was observed, some areas where the cells appeared to be collapsed could be seen. That is, the structure was non-uniform. This is confirmed with the pore size distribution curve of hot air dried eggplant in which both larger and smaller pores were observed (Figure 3.33). Moreover, in air dried eggplant sample, there was less porous structure as compared to microwave-IR combination dried samples. The pore development after microwave-IR combination drying was probably due to tissue expansion as a result of the internal water vapor pressure. Higher shrinkage and case hardening due to the long drying time in conventional drying might lead to lower porosity and tissue damages. In literature, similar results were pointed out. Reyes et al. (2008) stated that when IR radiation was used instead of hot air drying, microstructure with higher porosity was obtained. Giri & Prasad (2007b) indicated that air dried samples had less open structure and pores as compared to microwave-vacuum dried samples.

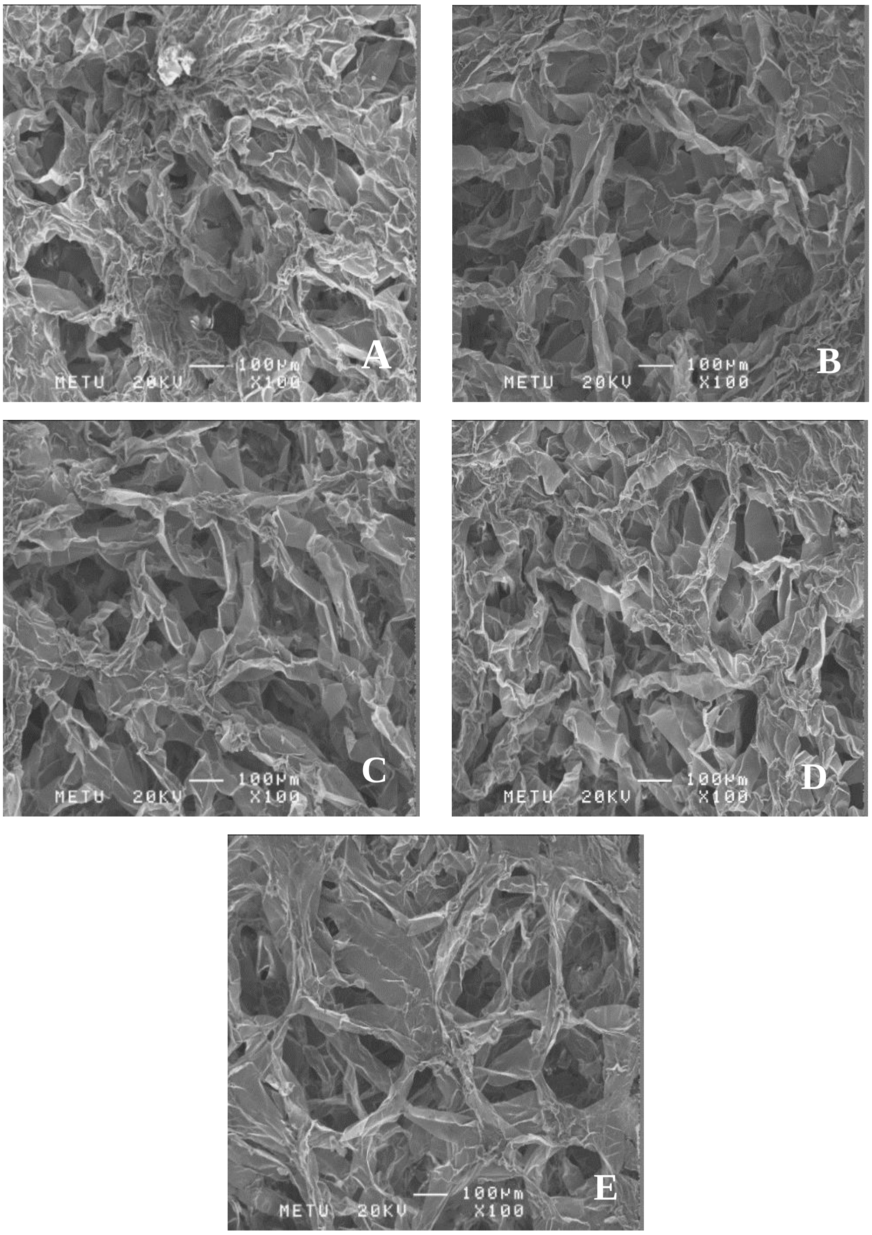

Figure 3.54 SEM images of eggplants dried with different microwave-IR combinations at; A: 10% IR & 30% microwave power; B: 20% IR & 30% microwave power; C: 10% IR & 50% microwave power; D: 20% IR & 50% microwave power) and E: hot air drying.

Scanning Electron Microscopy (SEM) images of osmotically dehydrated eggplants dried with microwave-IR combination were given in Figure 3.55. The SEM images of all eggplants were taken at 100× magnification.

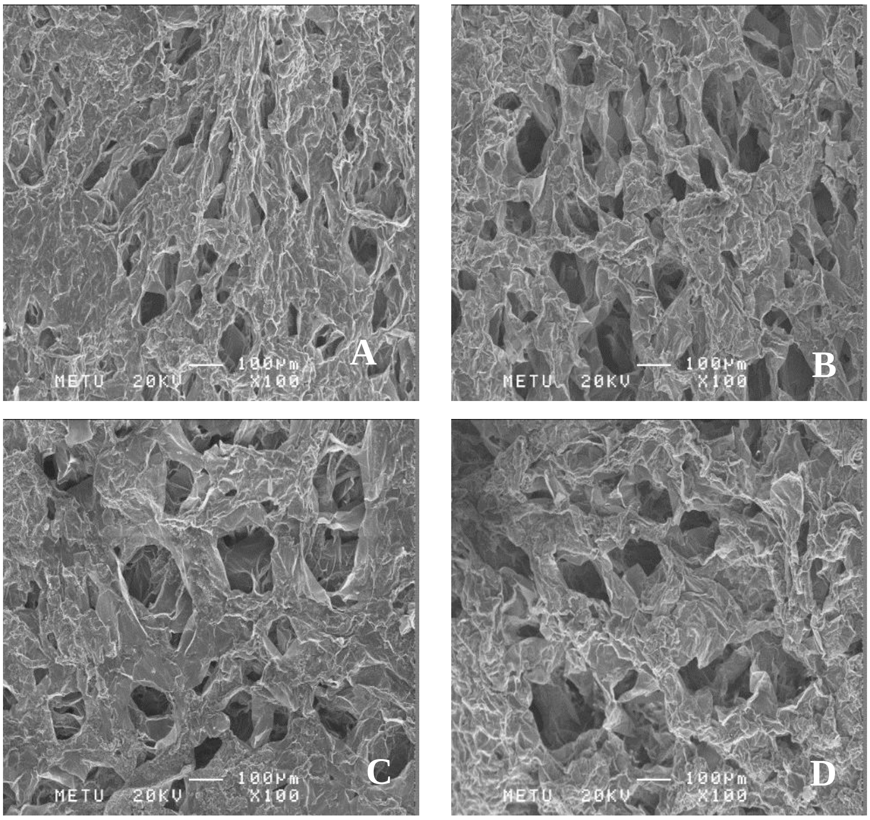

Figure 3.55 SEM images of osmotically dehydrated (10% w/w) eggplants dried with different microwave-IR combinations at; A: 10% IR & 30% microwave power; B: 20% IR & 30% microwave power; C: 10% IR & 50% microwave power; D: 20% IR & 50% microwave power.

When the SEM images of osmotically dehydrated eggplants were compared to untreated eggplants (Figures 3.54-3.55), the significant difference in terms of porosity was observed. Untreated eggplants showed more porous structure than osmotically dehydrated ones. The cells in osmotically dehydrated eggplants were filled with salt. Moreover, in osmotic dehydration there was also a decrease in cell size that caused lower porosity as compared to untreated ones (Prothon et al., 2001). The reason can be stated that during osmotic dehydration, shrinkage of cells, plasmolysis and folding of the cell walls were observed (Mayor et al., 2008). Similar to untreated eggplants, osmotically dehydrated ones showed higher porosity with increasing microwave and IR power due to the higher water vapor pressure. Similar results were obtained from cumulative intrusion and pore size distribution curves (Figures 3.25-3.29 and Figures 3.34-3.37).

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

In microwave-IR combination oven, as microwave and IR powers increased, drying time decreased which was significantly shorter than conventional drying. Instead of constant rate period, a rising and falling rate period was observed during drying of eggplant. When eggplants pretreated with osmotic solution, drying time in microwave-IR oven was significantly reduced. However, osmotically dehydrated eggplants had lower drying rates in microwave-IR combination oven than eggplants not dehydrated osmotically.

Effective diffusivity of eggplants dried in microwave-IR combination oven was significantly higher than that of eggplants dried using hot air. Osmotically dehydrated eggplants had lower effective diffusivity than not osmotically dehydrated ones. For both untreated and pretreated eggplants dried in microwave-IR combination oven, effective diffusivities increased with increasing microwave and IR powers.

According to cumulative intrusion curves, pore size distribution curves and microscopic analysis, hot air dried eggplants had less porous structure than the ones dried in microwave-IR combination oven. In addition, increasing microwave and IR power resulted in more porous structure for both untreated and osmotically dehydrated eggplants. Osmotically dehydrated eggplants showed lower porosity than untreated ones.

Eggplants dried with hot air had higher L* values and lower a* values than eggplants dried in microwave-IR combination oven. The effect of microwave power on L* and a* values was not significant. However, higher IR power caused lower L* values and higher a* values. Osmotically dehydrated eggplants had higher L* values and lower a* values than untreated eggplants.

Shrinkage of hot air dried eggplant samples was higher than that of the samples dried in microwave-IR combination oven. For eggplants dried in microwave-IR combination oven, as microwave and IR powers increased, lower shrinkage values were obtained. Osmotically dehydrated eggplants had higher shrinkage than untreated ones and as the concentration of osmotic solution increased, more shrinkage was observed.

Hot air dried eggplants had lower rehydration ratio than eggplants dried in microwave-IR combination oven. Rehydration ratios of eggplants dried in microwave-IR oven increased as microwave or IR power increased for both untreated and osmotically dehydrated samples. Untreated eggplants dried in microwave-IR combination oven had higher rehydration ratio than osmotically treated ones.

Eggplants with no pretreatment dried at 20% IR and 50% microwave power had higher rehydration ratio and lower shrinkage values than hot air dried eggplants. In addition, it reduced drying time significantly. Thus, microwave-IR combination drying can be recommended to be used for drying of eggplants.

For future studies, modelling of heat and mass transfer in microwave-IR drying can be studied. In addition, total phenolic contents of both fresh and dried eggplants can be analyzed and the effect of drying conditions on total phenolic contents of eggplants can be investigated. Moreover, glass transition temperature of dried eggplants can be determined.

REFERENCES

Ade-Omowaye, B., Rastogi, N., Angersbach, A., & Knorr, D. (2002). Osmotic dehydration behavior of red paprika (Capsium Annuum L.). *Food Engineering and Physical Properties*, 1790-1796.

Afzal, T. M., & Abe, T. (1998). Diffusion in potato during far infrared radiation drying. *Journal of Food Engineering*, 37:353-365.

Afzal, T. M., & Abe, T. (1999). Some fundamental attributes of far infrared radiation drying of potato. *Drying Technology*, 17:137-155.

Akanitapichat, P., Phraibung, K., Nuchklang, K., & Prompitakkul, S. (2010). Antioxidant and hepatoprotective activities of five eggplant varieties. *Food and Chemical Toxicology*, 48:3017-3021.

Al-Harahsheh, M., Al-Muhtaseb, A. H., & Magee, T. R. (2009). Microwave drying kinetics of tomato pomace: effect of osmotic dehydration. *Chemical Engineering and Processing: Process Intensification*, 48:524-531.

Alibas Ozkan, I., Akbudak , B., & Akbudak, N. (2007). Microwave drying characteristics of spinach. *Journal of Food Engineering*, 78:577-583.

Alibas, I. (2007). Microwave, air and combined microwave–air drying parameters of pumpkin slices. *LWT – Food Science and Technology*, 40:1445-1451.

Aligizaki, K. K. (2006). *Mercury intrusion porosimetry, Pore Structure of Cement-Based Materials: Testing Interpretation and Requirements.* New York: Taylor & Francis.

Andres, A., Bilbao, C., & Fito, P. (2004). Drying kinetics of apple cylinders under combined hot air-microwave dehydration. *Journal of Food Engineering*, 63:71-78.

Argyropoulos, D., Heindl, A., & Müller, J. (2011). Assessment of convection, hot-air combined with microwave-vacuum and freeze-drying methods for mushrooms with regard to product quality. *International Journal of Food Science & Technology*, 46:333-342.

Arslan, D., & Özcan, M. M. (2010). Study of the effect of sun, oven and microwave drying on quality of onion slices. *LWT-Food Science and Technology,* 43:1121-1127.

Askari, G. R., Emam-Djomeh, Z., & Mousavi, S. M. (2006). Effects of combined coating and microwave assisted hot-air drying on the texture, microstructure and rehydration characteristics of apple slices. *Food Science and Technology International*, 12(1): 39-46.

Aversa, M., Curcio, S., Calabrò, V., & Iorio, G. (2011). Measurement of the Water-Diffusion Coefficient, Apparent Density Changes and Shrinkage During the Drying of Eggplant (Solanum Melongena). *International Journal of Food Properties*, 14:523–537.

Azzouz, S., Guizani, A., Jomaa, W., & Belghith, A. (2002). Moisture diffusivity and drying kinetic equation of convective drying of grapes. *Journal of Food Engineering*, 55:323-330.

Bai, Y., Rahman, M. S., Perera, C. O., Smith , B., & Melton, L. D. (2002). Structural changes in apple rings during convection air-drying with controlled temperature and humidty. *Journal of Agricultural and Food Chemsitry,* 50 (11) : 3179-3185.

Bal, L. M., Kar, A., Satya, S., & Naik, S. N. (2010). Drying kinetics and effective moisture diffusivity of bamboo shoot slices undergoing microwave drying. *International Journal of Food Science and Technology,* 45:2321-2328.

Baysal, T., Icier, F., Ersus, S., & Yıldız, H. (2003). Effect of microwave and infrared drying on the quality of carrot and garlic. *European Food Research and Technology*, 218:68-73.

Beaudry, C., Raghavan, G., Ratti, C., & Rennie, T. (2004). Effect of four drying methods on the quality of osmotically dehydrated cranberries. *Drying Technology,* 22(4): 521-539.

Berk, Z. (2009). Dehydration. In Z. Berk, *Food Process Engineering and Technology* (pp. 459–510). Amsterdam: Academic Press.

Bouraout, M., Richard, P., & Durance, T. (1994). Microwave and convective drying of potato slices. *Journal of Food Process Engineering*, 17:353-363.

Buffler, C., (1993). *Microwave cooking and processing: Engineering fundamentals for the food scientist*. New York: Avi Book.

Caixeta, A. T., Moreira, R., & Castell-Perez, M. E. (2002). Impingement drying of potato chips. *Journal of Food Process Engineering*, 25 (1) : 63-90.

Cano-Chauca, M., Ramos, A. M., & Stringheta, P. C. (2002). Color and texture change during (*Musa spp. nanica*). *Allimentaria*, 337:153-158.

Cao, G., Sofic, E., & Prior, R. (1996). Antioxidant Capacity of Tea and Common Vegetables. *Journal of Agriculture and Food Chemistry*, 44: 3426–3431.

Carabasa-Giribet, M., & Ibarz-Ribas, A. (2000). Kinetics of colour development in aqueous glucose systems at high temperatures. *Journal of Food Engineering*, 44:181-189.

Chou, S. K., & Chua, K. J. (2001). New hybrid drying technologies for heat sensitive foodstuffs. *Trends in Food Science and Technology*, 12: 359-369.

Concellon, A., Anon, M.C., & Chaves, A.R. (2004). Characterization and changes in polyphenol oxidase from eggplant fruit (*Solanum melongena L.*) during storage at low temperature. *Food Chemistry*, 88: 17-24.

Coultate, T. P. (2002). *Food The Chemistry of Its Components.* Cambridge: The Royal Society of Chemistry.

Crank, J. (1975). *The mathematics of diffusion* . Oxford,UK: Clarendon Press.

Cruz, A. G., & Menegalli, F. C. (2004). Osmotic dehydration and drying of aubergine (Solanum Melongena). *Proceedings of the 14th International Drying Symposium*, (pp. 2149-2156). São Paulo.

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

Cui, Z., Xu, S., & Sun, D. (2004). Microwave-vacuum drying kinetics of carrot slices. *Journal of Food Engineering*, 65:157-164.

Dadali, G., Demirhan, E., & Özbek, B. (2007). Color change kinetics of spinach undergoing microwave drying. *Drying Technology*, 25:1713-1723.

Daniel, J. R., Yao, Y., & Weaver, C. (2012). Carbohydrates: Functional Properties. In Y. H. Hui, *Food Chemistyr: Principles and Applications* (pp. 5.1-5.26). West Sacramento,California: Science Technology System.

Das, I., & Das, S. K. (2011). Emitters and infrared heating system design. In Z. Pan, & G. G. Atungulu, *Infrared Heating for Food and Agricultural Processing* (pp. 57-89). Boca Raton: CRC Press.

Datta, A. K. (2001). Fundamentals of heat and moisture transport for microwaveable food product and process development. In A. Datta, & R. Anantheswaran, *Handbook of Microwave Technology for Food Applications* (pp. 115-172). New York: Marcel Dekker Inc.

Datta, A. K., & Ni, H. (2002). Infrared and hot air-assisted microwave heating of foods for control of surface moisture. *Journal of Food Engineering*, 51: 355-364.

Decareau, R. V. (1992). *Microwave Foods: New Product Development.* Trummbull, Connecticut: Food & Nutrition Press Inc.

Demiray, E., Tulek, Y., & Yilmaz, Y. (2013). Degredation kinetics of lycopene, B-carotene and ascorbic acid in tomatoes during hot air drying. *LWT- Food Science and Technology*, 50 : 172-176.

Dev, S. R., Geetha, P., Orsat, V., Gariepy, Y., & Raghavan, G. S. (2011). Effects of microwave-assisted hot air drying and conventional hot air drying on the drying kinetics, color, rehydration, and volatiles of Moringa oleifera. *Drying Technology*, 29:1452-1458.

Diamante, L. M., & Munro, P. A. (1993). Mathematical modelling of the thin layer solar drying of sweet potato slices. *Solar Energy*, 51:271-276.

Dibben, D. (2001). Electromagnetics: Fundamental Aspects and Numerical Modeling. In A. Datta, & R. Anantheswaran, *Handbook of Microwave Technology for Food Applications* (pp. 1-28). New York: Marcel Dekker Inc.

Doymaz, İ. (2011). Drying of eggplant slices in thin layers at different air temperatures. *Journal of Food Processing and Preservation*, 35:280-289.

Doymaz, İ., & Göl, E. (2011). Convective drying characteristics of eggplant slices. *Journal of Food Process Engineering*, 34:1234–1252.

Doymaz, İ., & Pala, M. (2002). Hot-air drying charcteristics of red pepper. *Journal of Food Engineering*, 55: 331-335.

Durance, T. D., & Wang, J. H. (2002). Energy consumption, density and rehydration rate of vacuum microwave and hot air convection dehydrated of tomatoes. *Journal of Food Science*, 67(6): 2212–2216.

Erle, U. (2005). Drying using microwave processing. In H. Schubert, & M. Regier, *The Microwave Processing of Foods* (pp. 142-152). Boca Raton: CRC Press.

Ertekin, C., & Yaldiz, O. (2004). Drying of eggplant and selection of a suitable thin layer drying model. *Journal of Food Engineering*, 63:349–359.

Falade, K., & Igbeka, J. (2007). Osmotic dehydration of tropical fruits and vegetables. *Food Reviews International* , 23:373-405.

Feng, H., & Tang, J. (1998). Microwave finish drying of diced apples in a spouted bed. *Journal of Food Science,* 63 (4): 679-683.

Figiel, A. (2007). Dehydration of apples by a combination of convective and vacuum-microwave drying. *Polish Journal of Food and Nutrition Sciences*, 57:131-135.

Funebo, T., & Ohlsson, T. (1998). Microwave-assisted air dehydration of apple and mushroom. *Journal of Food Engineering*, 38: 353-367.

Funebo, T., Ahrne, L., Kidman, S., Langton, M., & Skjöldebrand, C. (2000). Microwave hear treatment of apple before air dehydration-effects on physical properties and microstructure. *Journal of Food Engineering*, 46:173-182.

Garcia-Perez, J., Ozuna, C., Ortuno, C., Carcel, J., & Mulet, A. (2011). Modelling ultrasonically assisted convective drying of eggplant. *Drying Technology*, 29:1499-1509.

Garza, S., Ibarz, A., Pagan, J., & Giner, J. (1999). Non-enzymatic browning in peach puree during heating. *Food Research International*, 32:335-343.

Geankoplis, J. C. (2003). *Transport Processes and Separation Process Principles (Includes Unit Operations).* USA: 4th Edtion,Prentice Hall Inc.

Ghanem, N., Mihoubi, D., Kechaou, N., & Mihoubi, N. B. (2012). Microwave dehydration of three citrus peel cultivars: Effect on water and oil retention capacities, color, shrinkage and total phenols content. *Industrial Crops and Products*, 40:167-177.

Giri, S. K., & Prasad, S. (2007a). Optimization of microwave-vacuum drying of button mushrooms using response-surface methodology. *Drying Technology*, 25: 901-911.

Giri, S. K., & Prasad, S. (2007b). Drying kinetics and rehydration characteristics of microwave-vacuum and convective hot-air dried mushrooms. *Journal of Food Engineering*, 78:512-521.

Giri, S., & Prasad, S. (2009). Quality and moiture sorption characteristics of microwave-vacuum, air and freeze-dried button mushroom (Agaricus Bisporus). *Journal of Food Processing and Preservation*, 33: 237-251.

Han, Q.-H., Yin, L.-J., Li, S.-J., Yang, B.-N., & Ma, J.-W. (2010). Optimization of process parameters for microwave vacuum drying of apple slices using response surface method. *Drying Technology*, 28:523-532.

Han, S.-W., Tae, J., Kim, J.-A., Kim, D.-K., Seo, G.-S., Yun, K.-J., Choi, S-C., Kim, T-H., Nah, Y-H., & Lee, Y.-M. (2003). The aqueous extract of Solanum melongena inhibits PAR2 agonist-induced inflammation. *Clinica Chimica Acta*, 328:39-44.

Hasanati, M., Itaya, Y., & Miura, K. (1988). Hybrid drying of granular materials by combined radiative and convective heating. *Drying Tcehnology*, 6(1),43-68.

Hassini, L., Azzouz, S., Peczalski, R., & Belghith, A. (2007). Estimation of potato moisture diffusivity from convective drying kinetics with correction for shrinkage. *Journal of Food Engineering*, 79:47-56.

Hebbar, H. U., Vishwanatkan, K. H., & Ramesh, M. N. (2004). Development of combined infrared and hot air dryer for vegetables. *Journal of Food Engineering*, 65:557-563.

http://faostat3.fao.org/faostat-gateway/go/to/download/Q/QC/E. Last visited: October, 2013

http://nutritiondata.self.com/facts/vegetables-and-vegetable-products/2443/2. Last visited: October, 2013

Jain, D., & Pathare, P. B. (2004). Selection and evaluaiton of thin layer drying models for infrared radiative and convective drying of onion slices. *Biosystems Engineering*, 89:289-296.

Jangam, S. V. (2011). An overview of recent developments and some r&d challenges related to drying of foods. *Drying Technology*, 29: 1343-1357.

Jaturonglumlert, S., & Kiatsiriroat, T. (2010). Heat and mass transfer in combined convective and far-infrared drying of fruit leather. *Journal of Food Engineering*, 100:254-260.

Jayaraman, K. S., & das Gupta, D. K. (2007). Drying of fruits and vegetables. In A. Mujumdar, *Handbook of Industrial Drying* (pp. 606-633). Boca Raton: CRC Press.

Jun, S., Krishnamurthy, K., Irudayaraj, J., & Demirci, A. (2011). Fundamentals and Theory of Infrared Radiation. In Z. Pan, & G. G. Atungulu, *Infrared Heating for Food and Agricultural Processing* (pp. 1-18). Boca Raton: CRC Press.

Kahyaoglu, L. N. (2009). *Usage of spouted and microwave assisted spouted in bulgur prodcution.*

Kahyaoglu, L. N., Sahin, S., & Sumnu, G. (2012). Spouted bed and microwave-assisted spouted bed drying of parboiled wheat. *Food and Bioproducts Processing*, 90:301-308.

Karathanos, V. T., Kanellopoulos, N. K., & Belessiotis, V. G. (1996). Developmet of porous structure during air drying of agricultural plant products. *Journal of Food Engineering*, 29:167-183.

Kathirvel, K., Naik, K. R., Gariepy, Y., Orsat, V., & Raghavan, G. S. (2006). Microwave drying - a promising alternative for the herb processing industry. *CSBE/SCGAB Annual Conference.* Edmonton Alberta.

Kavak Akpinar, E., & Bicer, Y. (2005). Modelling of the drying of eggplants in thin-layers. *International Journal of Food Science and Technology*, 40:273-281.

Keey, R. B. (1972). *Drying: Principles and practice.* New York: Pergamon Press Inc.

Khraisheh, M. A., Cooper, T. J., & Magee, T. R. (1997). Shrinkage characteristics of potatoes dehydrated under combined microwave and convective air conditions. *Drying Technology*, 15(3&4): 1003-1022.

Khraisheh, M. A., Cooper, T. J., & Magee, T. R. (2004). Quality and structural changes in starchy foods during microwave and convective drying. *Food Research International*, 37: 497-503.

Kocabiyik, H., & Tezer, D. (2009). Drying of carrot slices using infrared radiation. *International Journal of Food Science and Technology*, 44: 953-959.

Kotwaliwale, N., Bakane , P., & Verma , A. (2007). Changes in textural and optical properties of oyster mushroom during hot air drying. *Journal of Food Engineering*, 78:1207-1211.

Krokida, M. K., & Maroulis, Z. B. (1997). Effect on drying method on shrinkage and porosity. *Drying Technology*, 15 (10): 2441-2458.

Krokida, M. K., & Maroulis, Z. B. (1999). Effect of microwave drying on some quality properties of dehydrated products. *Drying Technology*, 17(3):449-466.

Krokida, M. K., Karathanos, V. T., & Maroulis, Z. B. (2000). Effect of osmotic dehydration on color and sorption characteristics of apple and banana. *Drying Technology*, 18(4&5): 937-950.

Kumar, A., & Tiwari, G. N. (2007). Effect of mass on convective mass transfer coefficient during open sun and greenhouse drying of onion flakes. *Journal of Food Engineering*, 79: 1337-1350.

Lampinen, M. J., Ojala, K. T., & Koski, E. (1991). Modelling and measurements of infrared dryers for coated paper. *Drying Technology*, 9(4):973-1017.

Land, C. M. (2012). *Drying in the Process Industry.* New Jersey: John Wiley & Sons, Inc.

Lewicki, P. P., & Jakubczyk, E. (2004). Effect of hot air temperature on mechanical properties of dried apples. *Journal of Food Engineering*, 64 (1) : 307-314.

Lewicki, P. P., & Lenart, A. (2007). Osmotic dehydration of fruits and vegetables. In A. S. Mujumdar, *Handbook of Industrial Drying* (pp. 665-681)..

Li, T. S. (2008). *Vegetables and Fruits Nutritional and Therapeutic Values.* Boca Raton: CRC Press .

Lin, T. M., Durance, T. D., & Scaman, C. H. (1998). Characterization of vacuum microwave, air and freeze dried carrot slices. *Food Research International*, 31(2):111-117.

Lin, Y. P., Tsen, J. H., & King, V. A. (2005). Effects of far-infrared radiation on the freeze-drying of sweet potato. *Journal of Food Engineering*, 68:249-255.

Lowell, S., & Shields, J. E. (1984). *Powder surface area and porosity (2nd edition).* London: Chapman and Hall.

Madamba, P. S., & Jose, J. J. (2005). Optimization of the hot air drying of mango slices. *Food Australia*, 57 (6) : 237-243.

Madinez, M. V., & Whitaker, J. R. (1995). The biochemistry and control of enzymatic browning. *Trends in Food Science & Technology*, 6:195-200.

Mahayothee, B., Udomkun, P., Nagle, M., Haewsungcharoen, M., Janjai, S., & Mueller, J. (2009). Effects of pretreatments on colour alterations of litchi during drying and storage. *European Food Research and Technology*, 229:329–337.

Mandala, I. G., Anagnostaras, E. F., & Oikonomou, C. K. (2005). Influence of osmotic dehydration conditions on apple air-drying kinetics and their quality characteristics. *Journal of Food Engineering*, 69:307-316.

Marabi, A., & Saguy, I. S. (2004). Effect of porosity on rehydration of dry food particulates. *Jounal of the Science of Food and Agriculture*, 84:1105-1110.

Margaris, D. P., & Ghiaus, A.-G. (2008). Fruits and vegetables dehydration in tray dryers. In A. Urwaye, *New Food Engineering Research Trends* (pp. 45-101). New York: Nova Science Publishers Inc.

Martins, S. I., Jongen, W. M., & van Boekel, M. A. (2011). A review of maillard reaction in food and implications to kinetic modelling. *Trends in Food Science & Technology*, 11:364–373.

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

Maskan, M. (2001a). Drying, shrinkage and rehydration characteristics of kiwifruits during hot air and microwave drying. *Journal of Food Engineering*, 48: 177-182.

Maskan , M. (2001b). Kinetics of colour change of kiwifruits during hot air and microwave drying. *Journal of Food Engineering*, 48:169-175.

Matsubara, K., Kaneyuki, T., Miyake, T., & Mori, M. (2005). Antiangiogenic activity of nasunin, an antioxidant anthocyanin, in eggplant peels. *Journal of Agriculture and Food Chemistry*, 53:6272-6275.

Mayer, A. M., & Harel, E. (1979). Polyphenol oxidase in plants. *Phytochemistry*, 18:193-215.

Mayor , L., & Sereno, A. M. (2004). Modelling shrinkage during convective drying of food materials: a review. *Journal of Food Engineering*, 61:373-386.

Mayor, L., Moreira, R., & Sereno, A. M. (2011). Shrinkage, density, porosity and shape changes during dehydration of pumpkin (Cucurbita pepo L.) fruits. *Journal of Food Engineering*, 103:29-37.

Mayor, L., Pissarra, J., & Sereno, A. M. (2008). Microstructural changes during osmotic dehydration of parenchymatic pumpkin tissue. *Journal of Food Engineering*, 85:326-339.

McLaughlin, C. P., Magee, T., & Magee. (1998). The effect shrinkage during drying of potato spheres and the effect of drying temperature on Vitamin C retention. *Food and Bioproducts Processing*, 76:138-142.

Meda, V., Orsat, V., & Ragvahan, V. (2005). Microwave heating and the dielectric properties of foods. In H. Schubert, & M. Regier, *The microwave processing of foods* (pp. 61-73). Boca Raton: CRC Press.

Menges, H. O., & Ertekin, C. (2006). Mathematical modeling of thin layer drying of Golden apples. *Journal of Food Engineering*, 77 (1) : 119-125.

Mishra, B. B., Gautam, S., & Sharma, A. (2012). Browning of fresh-cut eggplant:Impact of cutting and storage. *Postharvest Biology and Technology*, 67:44-51.

Mongpraneet, S., Abe, T., & Tsurusaki, T. (2002). Far infrared-vacuum and -convection drying of welsh onion. *Transaction of the American Society of Agricultural Engineers*, 45:1529-1535.

Motevali, A., Minaei, S., Khoshtaghaza, M., & Amirnejat, H. (2011). Comparison of energy consumption and specific energy requirements of different methods for drying mushroom slices. *Energy*, 36:6433-6441.

Mousa, N., & Farid, M. (2002). Microwave vacuum drying of banana slices. *Drying Technology*, 20(10): 2055-2066.

Mui, W. W., Durance, T. D., & Scaman, C. H. (2002). Flavor and texture of banana chips dried by combinations of hot air, vacuum, and microwave processing. *Journal of Agricultural and Food Chemistry*, 50:1883-1889.

Mulet, A., Berna, A., Bon, J., & Garcia-Reverter , J. (2000). Effect of shape on potato and cauliflower shrinkage during drying. *Drying Technology*, 18: 1201-1219.

Murthy, T. P., & Manohar, B. (2012). Microwave drying of mango ginger (Curcuma amada Roxb):prediction of drying kinetics by mathematical modelling and artificial neural network. *International Journal of Food Science and Technology*, 47:1229–1236.

Namiki, H., Niinuma, K., Takemura, M., & Tou, R. (1996). Effects of far-infrared irradiation and lyophilization on the contents of carotenoids, tissue structure and bacterial counts of carrot. *Journal of the Food Hygienic Society of Japan*, 37(6): 395-400.

Nasıroglu, S., & Kocabıyık, H. (2009). Thin-layer infrared radiation drying of red pepper slices. *Journal of Food Process Engineering*, 32:1-16.

Nathakaranakule, A., Jaiboon, P., & Soponronnarit, S. (2010). Far-infrared radiation assisted drying of longan fruit. *Journal of Food Engineering*, 100:662-668.

Nelson, S. O., & Datta, A. K. (2001). Dielectric properties of food materials and electric field interactions. In A. Datta , & R. Anantheswaran, *Handbook of Microwave Technology for Food Applications* (pp. 69-114). New York: Marcel Decker Inc.

Nijhuis, H. H., Torringa, H. M., Muresan, S., Yuksel, D., Legujit, C., & Kloek, W. (1998). Approaches to improving the quality of dried fruits and vegetables. *Trends in Food Science Technology*, 9:13-20.

Nimmol, C., Devahastin, S., Swasdisevi, T., & Soponronnarit, S. (2007). Drying of banana slices using combined low-pressure superheated steam and far-infrared radiation. *Journal of Food Engineering*, 81:624-633.

Nindo, C., & Mwithiga, G. (2011). Infrared Drying. In Z. Pan, & G. G. Atungulu, *Infrared Heating for Food and Agricultural Processing* (pp. 89-101). Boca Raton: CRC Press.

Nowak, D., & Lewicki, P. P. (2004). Infrared drying of apple slices. *Innovative Food Science& Emerging Technologies*, 5:353-360.

Nowak, D., & Lewicki, P. P. (2005). Quality of infared dried apple slices. *Drying Technology*, 23:831-846.

Okos, M. R., Narsimhan, G., Singh, R. K., & Weitnauer, A. C. (1992). Food Dehydration. In D. R. Heldman, & D. B. Lund, *Handbook of Food Engineering* (pp. 437-562). New York: Marcel Dekker.

Orikasa, T., Wu, L., Shiina, T., & Tagawa, A. (2008). Drying characteristics of kiwifruit during hot air drying. *Journal of Food Engineering*, 85: 303-308.

Orsat, V., Raghavan, V., & Meda, V. (2005). Microwave technology for food processing : an overview. In H. Schubert, & M. Regier, *The Microwave Processing of Foods* (pp. 105-118). Boca Raton: CRC Press.

Owasu-Ansah, Y. J. (1991). Advances in microwave drying of foods and food ingredients. *J.Inst.Can. Sci.Technol.Aliment.*, 24 (3/4): 102-107.

Özbek, B., & Dadali, G. (2007). Thin-layer drying characteristics and modelling of mint leaves undergoing microwave treatment. *Journal of Food Engineering*, 83:541-549.

Pan, Y., Zhao, L., Zhang, Y., Chen, G., & Mujumdar, A. (2003). Osmotic dehydration pretreatment in drying of fruits and vegetables. *Drying Technology*, 21:1101-1114.

Pathare, P. B., & Sharma, G. P. (2006). Effective moisture diffusivity of onion slices undergoing infrared convective drying. *Biosystems Engineering*, 93(3):285-291.

Pereira, N. R., Marsaioli Jr., A., & Ahrne, L. M. (2007). Effect of microwave power, air velocity and temperature on the final drying of osmotically dehydrated bananas. *Journal of Food Engineering*, 81:79-87.

Piga, A., Pinna, I., Özer, K. B., Agabbio , M., & Aksoy, U. (2004). Hot air dehydration of figs (Ficus carica L.): drying kinetics and quality loss. *International Journal of Food Science and Technology,* 39: 793-799.

Piotrowski, D., Lenart, A., & Wardzynski, A. (2004). Influence of osmotic dehydration on microwave-convective drying of frozen strawberries. *Journal of Food Engineering*, 65:519-525.

Prabhanjan, D. G., Ramoswamy, H. S., & Raghavan, G. S. (1995). Microwave assisted convective air drying of thin layer carrots. *Journal of Food Engineering*, 25(2):283-293.

Praveen Kumar, D. G., Umesh Hebbar, H., Sukumar, D., & Ramesh, M. N. (2005). Infrared and hot-air drying of onions. *Journal of Food Processing and Preservation*, 29:132-150.

Prothon, F., Ahrne, L. M., Funebo, T., Kidman, S., Langton, M., & Sjöholm, I. (2001). Effects of combined osmotic and microwave dehydration of apple on texture, microstructure and rehydration characteristics. *LWT - Food Science and Technology*, 34:95-101.

Rahman, M. S., Al-Amri, O. S., & Al-Bulushi, I. M. (2002). Pores and physico-chemical characteristics of dried tuna produced by different methods of drying. *Journal of Food Engineering*, 53:301-313.

Rahman, M. S., Al-Zakwani, I., & Guizani, N. (2005). Pore formation in apple during air-drying as a function of temperature: porosity and pore-size distribution. *Journal of the Science of Food and Agriculture*, 85:979-989.

Rahman, S., & Lamb, J. (1991). Air drying behavior of fresh and osmotically dehydrated pineapple. *Journal of Food Process Engineering* , 14:163-171.

Ramaswamy, H. S., & Marcohe, M. (2005). *Food Processing Principles and Applications.* Boca Raton: CRC Press.

Ratti, C. (2001). Hot air and freeze drying of high-value foods : a review. *Journal of Food Engineering*, 49 : 311-319.

Ratti, C., & Mujumdar, A. S. (2007). Infrared Drying. In A. S. Mujumdar, *Handbook of Industrial Drying* (pp. 423-438). Boca Raton: CRC Press.

Regier, M., & Schubert, H. (2005). Introducing microwave processing of food : principles and technologies. In H. Schubert, & M. Regier, *The microwave processing of foods* (pp. 3-20). Boca Raton: CRC Press.

Reyes, A., Ceron, S., Zuniga, R., & Mayano, P. (1998). A comparative study of microwave-assisted air drying of potato slice. *Biosystems Engineering*, 310-318.

Reyes, A., Vega , R., Bustos, R., & Araneda, C. (2008). Effect of processing conditions on drying kinetics and particle micro-structure of carrot. *Drying Technology*, 26: 1272-1285.

Rivzi, S. S. (1986). Thermodynamic properties of food in dehydration. In M. Rao, & S. Rivzi, *Engineering Properties of Foods* (pp. 133–214). New York: Marcel Dekker Inc.

Rufián-Henares, J. Á., Guerra-Hernández, E., & García-Villanova, B. (2013). Effect of red sweet pepper dehydration conditions on Maillard reaction,ascorbic acid and antioxidant activity. *Journal of Food Engineering*, 118:150-156.

Russo, P., Adiletta, G., & Matteo, M. D. (2013). The influence of drying air temperature on the physical properties of dried and rehydrated eggplant. *Food and Bioproducts Processing*, 91:249-256.

Sablani, S. S., Marcotte, M., & Baik, O. D. (1998). Modelling of simultaneous heat and water transport in the baking process. *LWT-Food Science and Technology*, 31:201-209.

Sahin, S., & Sumnu, S. G. (2006). *Physical Properties of Foods.* New York: Springer.

Sakiyan, O., Sumnu , G., Sahin, S., & Meda, V. (2007). Investigation of dielectric properties of different cake formulations during microwave and infrared–microwave combination baking. *Journal of Food Science*, 72(4) :205-213.

Sankat, C. K., Castaigne, F., & Maharaj, R. (1996). The air drying behaviour of fresh and osmotically dehydrated banana slices. *International Journal of Food Science and Technology*, 31:123–135.

Sarimeseli, A. (2011). Microwave drying characteristics of coriander(Coriandrum sativum L.) leaves. *Energy Conversion and Management* , 52:1449-1453.

Schiffmann, R. F. (1986). Food product development for microwave processing. *Food Technology*, 94-98.

Schiffmann, R. F. (2001). Microwave processes for the food industry. In A. Datta, & R. Anantheswaran, *Handbook of Microwave Technology for Food Applications* (pp. 299-337). New York: Marcel Dekker Inc.

Schiffmann, R. F. (2007). Microwave and dielectric drying. In A. Mujumdar, *Handbook of Industrial Drying* (pp. 285-305). Boca Raton: CRC Press.

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

Sharma, G. P., Verma, R. C., & Pathare, P. B. (2005a). Mathematical modelling of infrared radiation thin layer drying of onion slices. *Journal of Food Engineering*, 71:282-286.

Sharma, G. P., Verma, R. C., & Pathare, P. B. (2005b). Thin-layer infrared radiation drying of onion slices. *Journal of Food Engineering*, 67:361-366.

Shi, J., Pan, Z., McHugh, T. H., Wood, D., Hirschberg, E., & Olson, D. (2008). Drying and quality characteristics of fresh and sugar-infused blueberries dried with infrared radiation heating. *LWT-Food Science and Technology*, 41:1962-1972.

Shukla, B., & Singh, S. (2007). Osmo-convective drying of cauliflower, mushroom and greenpea. *Journal of Food Engineering*, 80: 741-747.

Singh, B., & Gupta, A. (2007). Mass transfer kinetics and determination of effective diffusivity during convective dehydration of pre-osmosed carrot tubes. *Journal of Food Engineering*, 79:459-470.

Sobukola, O. P., Dairo, O. U., Sanni, L. O., Odunewu, A. V., & Fafiolu, B. O. (2007). Thin layer drying process of some leafy vegetables under open sun. *Food Science and Technology Inernational*, 13(1) : 35-40.

Sokhansanj, S., & Jayas, D. S. (2007). Drying of foodstuffs. In A. S. Mujumdar, *Handbook of Industrial Drying* (pp. 522-537). Boca Raton: CRC Press.

Soysal, Y. (2004). Microwave Drying Characteristics of Parsley. *Biosystems Engineering*, 89(2): 167–173.

Soysal, Y., & Oztekin, S. (2001). Technical and economic performance of a tray dryer for medicinal. *Journal of Agricultural Engineering Research*, 79(1): 73-79.

Soysal, Y., Ayhan, Z., Eştürk, O., & Arıkan, M. F. (2009). Intermittent microwave-convective drying of red pepper:Drying kinetics, physical (colour and texture) and sensory quality. *Biosystems Engineering*, 455-463.

Srikiatden, J., & Roberts, J. S. (2005). Moisture loss kinetics of apple during convective hot air and isothermal drying. *International Journal of Food Properties*, 8 (3) : 493-512.

St.George, S. D., & Cenkowski, S. (2009). Dehydration processes for nutraceuticals and functional foods. In C. Ratti, *Advances in Food Dehydration* (pp. 285-313). Boca Raton: CRC Press.

Sturm, B., Hofacker, W. C., & Hensel, O. (2012). Optimizing the drying parameters for hot-air-dried apples. *Drying Technology*, 30:1570-1582.

Sumnu, G. (2001). A review on microwave baking of foods. *International Journal of Food Science and Technology*, 36:117-127.

Sumnu, G., & Sahin, S. (2005). Recent developments in microwave processing. In D.-W. Sun, *Emerging technologies for food processing* (pp. 419-444). San Diago: Elsevier Academic Press.

Sumnu, G., Sahin, S., & Sevimli, M. (2005b). Microwave, infrared and infrared-microwave combination baking of cakes. *Journal of Food Engineering*, 71:150–155.

Sumnu, G., Turabi, E., & Oztop, M. (2005a). Drying of carrots in microwave and halogen lamp–microwave combination ovens. *LWT-Food Science and Technology*, 38:549-553.

Sumnu, S. G., & Ozkoc, S. O. (2011). Infrared Baking and Roasting. In Z. Pan, & G. G. Atungulu, *Infrared Heating for Food and Agricultural Processing* (pp. 203-224). Boca Raton: CRC Press.

Sunjka, P., Rennie, T., Beaudry, C., & Raghavan , G. (2004). Microwave-convective and microwave-vacuum drying of cranberries: a comparative study. *Drying Technology*, 22(5): 1217-1231.

Supmoon, N., & Noomhorm, A. (2013). Influence of combined hot air impingement and infrared drying on drying kinetics and physical properties of potato chips. *Drying Technology*, 31:24-31.

Tan, M., Chua, K. J., Mujumdar, A. S., & Chou, S. K. (2001). Effect of osmotic pre-treatment and infrared radiation on drying rate and color changes during drying of potato and pineapple. *Drying Technology*, 19(9):2193-2207.

Tang, J. (2005). Dielectric properties of foods. In H. Schubert, & M. Regier, *The microwave processing of foods* (pp. 22-38). Boca Raton: CRC Press.

Telis, V., & Sobral, P. (2002). Glass transitions for freeze-dried and air-dried tomato. *Food Research International*, 35: 435-443.

Tireki, S. (2005).Infrared-assisted microwave drying in the production of bread crumbs.

Tireki, S., Şumnu, G., & Esin, A. (2006). Production of bread crumbs by infrared-assisted microwave drying. *European Food Research and Technology*, 222:8-14.

Togrul, I. T. (2003). Determination of convective heat transfer coefficient of various crops under open sun drying conditions. *Int. Comm. Heat Mass Transfer*, 30,2:285-294.

Togrul, I. T., & Pehlivan, D. (2004). Modelling of thin layer drying kinetics of some fruits under open-air sun drying process. *Journal of Food Engineering*, 65:413-425.

Toğrul, H. (2005). Simple modeling of infrared drying of fresh apple slices. *Journal of Food Engineering*, 71:311-323.

Toğrul, H. (2006). Suitable drying modell for infrared drying of carrot. *Journal of Food Engineering*, 77:610-619.

Torringa, E., Esveld, E., Scheewe, I., Berg, R. v., & Bartels, P. (2001). Osmotic dehydration as a pretreatment before combined microwave-hot-air drying of mushrooms. *Journal of Food Engineering*, 49: 185-191.

Tulasidas, T., Raghavan, G., & Norris, E. (1993). Microwave and convective drying of grapes. *Transactions of the ASAE*, 36:1861-1865.

Tutuncu, M. A., & Labuza, T. P. (1996). Effect of geometry on the effective moisture transfer diffusion coefficient. *Journal of Food Engineering*, 30:433-447.

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

Varith, J., Dijkanarukkul, P., Achariyaviriya, A., & Achariyaviriya, S. (2007). Combined microwave-hot air drying of peeled longan. *Journal of Food Engineering*, 81:459-468.

Velic, D., Planinic, M., Tomas, S., & Bilic, M. (2004). Influence of airflow velocity on kinetics of convection apple drying. *Journal of Food Engineering*, 64 (1) : 97-102.

Venkatachalapathy, K., & Raghavan, G. (1998). Microwave drying of osmotically dehydrated blueberries. *Journal of Microwave Power and Electromagnetic Energy*, 33(2): 95-102.

Vishwanathan, K. H., Hebbar, H. U., & Raghavarao, K. S. (2010). Hot air assisted infrared drying of vegetables and its quality. *Food Sci. Technol. Res.*, 16(5):381-388.

Walde, S. G., Velu, V., Jyothirmayi, T., & Math, R. G. (2006). Effects of pretreatments and drying methods on dehydration of mushroom. *Journal of Food Engineering*, 74:108-115.

Wang, J., & Sheng, K. (2006). Far-infrared and microwave drying of peach. *LWT-Food Science and Technology*, 39:247-255.

Wang, J., Xiong, Y.-S., & Yu, Y. (2004). Microwave drying characteristics of potato and the effect of different microwave powers on the dried quality of potato. *Eur Food Res Technol*, 219:500–506.

Wang, R., Zhang, M., & Mujumdar, A. S. (2010). Effect of osmotic dehydration on microwave freeze-drying characteristics and quality of potato chips. *Drying Technology*, 28:798-806.

Wang, Z., Sun, J., Chen, F., Liao, X., & Hu, X. (2007). Mathematical modelling on thin layer microwave drying of apple pomace with and without hot air pre-drying. *Journal of Food Engineering*, 80:536-544.

Wu, L., Orikasa, T., Ogawa, Y., & Tagawa, A. (2007). Vacuum drying characteristics of eggplants. *Journal of Food Engineering*, 83: 422-429.

Yanyang, X., Min, Z., Mujumdar, A. S., Le-qun, Z., & Jin-cai, S. (2004). Studies on hot air and microwave vacuum drying of wild cabbage. *Drying Technology*, 22:2201-2209.

APPENDIX A

STATISTICAL ANALYSES

Table A.1 Two way ANOVA and Duncan's Multiple Range Test for L* values of untreated eggplants dried in microwave-IR combination oven.

X1 IR power (10%, 20%)

X2 Microwave Powers (30%, 40%, and 50%)

Class Level Information

Class	Levels	Values
X1	2	1 2
X2	3	1 2 3

Number of Observations Read 18

Number of Observations Used 18

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	59.4616667	19.8205556	6.24	0.0065
Error	14	44.4877778	3.1776984		
Corrected Total	17	103.9494444			

R-Square	Coeff Var	Root MSE	Y Mean
0.572025	3.246684	1.782610	54.90556

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	1	57.96055556	57.96055556	18.24	0.0008
X2	2	1.50111111	0.75055556	0.24	0.7927

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	1	57.96055556	57.96055556	18.24	0.0008
X2	2	1.50111111	0.75055556	0.24	0.7927

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	3.177698

Number of Means	2
Critical Range	1.802

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	56.7000	9	1
B	53.1111	9	2

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	3.177698

Number of Means	2	3
Critical Range	2.207	2.313

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	55.150	6	3
A	55.067	6	2
A	54.500	6	1

Table A.2 Two way ANOVA and Duncan's Multiple Range Test for L* values of 10% (w/w) osmotically dehydrated eggplants dried in microwave-IR combination oven.

X1 IR power (10%, 20%, 30%)

X2 Microwave Powers (30%, 40%, 50%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 27

Number of Observations Used 27

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	134.7614815	33.6903704	19.38	<.0001
Error	22	38.2370370	1.7380471		
Corrected Total	26	172.9985185			

R-Square	Coeff Var	Root MSE	Y Mean
0.778975	1.970410	1.318350	66.90741

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	129.4451852	64.7225926	37.24	<.0001
X2	2	5.3162963	2.6581481	1.53	0.2388

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	129.4451852	64.7225926	37.24	<.0001
X2	2	5.3162963	2.6581481	1.53	0.2388

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	1.738047

Number of Means	2	3
Critical Range	1.289	1.353

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	69.9556	9	1
B	65.8556	9	2
B	64.9111	9	3

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	1.738047

Number of Means	2	3
Critical Range	1.289	1.353

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	67.5333	9	3
A	66.6333	9	1
A	66.5556	9	2

Table A.3 Two way ANOVA and Duncan's Multiple Range Test for L* values of 20% (w/w) osmotically dehydrated eggplants dried in microwave-IR combination oven.

X1 IR power (10%, 20%, 30%)

X2 Microwave Powers (30%, 40%, 50%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 27

Number of Observations Used 27

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	40.94814815	10.23703704	4.18	0.0114
Error	22	53.86814815	2.44855219		
Corrected Total	26	94.81629630			

R-Square	Coeff Var	Root MSE	Y Mean
0.431868	2.119454	1.564785	73.82963

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	34.08074074	17.04037037	6.96	0.0046
X2	2	6.86740741	3.43370370	1.40	0.2672

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	4.08074074	17.04037037	6.96	0.0046
X2	2	6.86740741	3.43370370	1.40	0.2672

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	2.448552

Number of Means	2	3
Critical Range	1.530	1.606

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	75.3333	9	1
B	73.5222	9	2
B	72.6333	9	3

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	2.448552

Number of Means	2	3
Critical Range	1.530	1.606

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	74.4667	9	1
A	73.7889	9	2
A	73.2333	9	3

Table A.4 One way ANOVA and Duncan's Multiple Range Test for L* values of untreated and osmotically dehydrated eggplants dried in microwave-IR combination oven at 20% IR and 50% microwave powers.

X1 Pretreatment (untreated, 10% osmotic dehydration, 20% osmotic dehydration)

Class Level Information

Class	Levels	Values
X1	3	1 2 3

Number of Observations Read 9

Number of Observations Used 9

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	559.3688889	279.6844444	116.32	<.0001
Error	6	14.4266667	2.4044444		
Corrected Total	8	573.7955556			

R-Square	Coeff Var	Root MSE	Y Mean
0.974857	2.422014	1.550627	64.02222

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	559.3688889	279.6844444	116.32	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	559.3688889	279.6844444	116.32	<.0001

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	6
Error Mean Square	2.404444

Number of Means	2	3
Critical Range	3.098	3.211

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	72.267	3	3
B	66.400	3	2
C	53.400	3	1

Table A.5 Two way ANOVA and Duncan's Multiple Range Test for a* values of untreated eggplants dried in microwave-IR combination oven.

X1 IR power (10%, 20%)

X2 Microwave Powers (30%, 40%, and 50%)

Class Level Information

Class	Levels	Values
X1	2	1 2
X2	3	1 2 3

Number of Observations Read 18

Number of Observations Used 18

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	8.09500000	2.69833333	3.47	0.0450
Error	14	10.87444444	0.77674603		
Corrected Total	17	18.96944444			

R-Square	Coeff Var	Root MSE	Y Mean
0.426739	9.798626	0.881332	8.994444

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	1	5.89388889	5.89388889	7.59	0.0155
X2	2	2.20111111	1.10055556	1.42	0.2752

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	1	5.89388889	5.89388889	7.59	0.0155
X2	2	2.20111111	1.10055556	1.42	0.2752

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	0.776746

Number of Means	2
Critical Range	.8911

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	9.5667	9	2
B	8.4222	9	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	0.776746

Number of Means	2	3
Critical Range	1.091	1.144

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	9.2500	6	1
A	9.2333	6	2
A	8.5000	6	3

Table A.6 Two way ANOVA and Duncan's Multiple Range Test for a* values of 10% (w/w) osmotically dehydrated eggplants dried in microwave-IR combination oven.

X1 IR power (10%, 20%, 30%)

X2 Microwave Powers (30%, 40%, 50%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 27

Number of Observations Used 27

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	72.86888889	18.21722222	202.64	<.0001
Error	22	1.97777778	0.08989899		
Corrected Total	26	74.84666667			

R-Square	Coeff Var	Root MSE	Y Mean
0.973576	7.644432	0.299832	3.922222

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	72.32888889	36.16444444	402.28	<.0001
X2	2	0.54000000	0.27000000	3.00	0.0703

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	72.32888889	36.16444444	402.28	<.0001
X2	2	0.54000000	0.27000000	3.00	0.0703

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.089899

Number of Means	2	3
Critical Range	.2931	.3078

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	5.1889	9	3
A	4.9667	9	2
B	1.6111	9	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.089899

Number of Means	2	3
Critical Range	.2931	.3078

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	4.1222	9	3
A	3.8222	9	2
A	3.8222	9	1

Table A.7 Two way ANOVA and Duncan's Multiple Range Test for a* values of 20% (w/w) osmotically dehydrated eggplants dried in microwave-IR combination oven.

X1 IR power (10%, 20%, 30%)

X2 Microwave Powers (30%, 40%, 50%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 27

Number of Observations Used 27

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	3.18370370	0.79592593	8.27	0.0003
Error	22	2.11703704	0.09622896		
Corrected Total	26	5.30074074			

R-Square	Coeff Var	Root MSE	Y Mean
0.600615	24.20698	0.310208	1.281481

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	3.00074074	1.50037037	15.59	<.0001
X2	2	0.18296296	0.09148148	0.95	0.4018

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	3.00074074	1.50037037	15.59	<.0001
X2	2	0.18296296	0.09148148	0.95	0.4018

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.096229

Number of Means	2	3
Critical Range	.3033	.3184

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	1.5444	9	2
A	1.4889	9	3
B	0.8111	9	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.096229

Number of Means	2	3
Critical Range	.3033	.3184

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	1.3889	9	3
A	1.2667	9	2
A	1.1889	9	1

Table A.8 One way ANOVA and Duncan's Multiple Range Test for a* values of eggplant dried in microwave-IR combination oven at 20% IR and 50% microwave powers.

X1 Pretreatment (untreated, 10% osmotic dehydration, 20% osmotic dehydration)

Class Level Information

Class	Levels	Values
X1	3	1 2 3

Number of Observations Read 9

Number of Observations Used 9

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	72.80222222	36.40111111	306.18	<.0001
Error	6	0.71333333	0.11888889		
Corrected Total	8	73.51555556			

R-Square	Coeff Var	Root MSE	Y Mean
0.990297	6.659279	0.344803	5.177778

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	72.80222222	36.40111111	306.18	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	72.80222222	36.40111111	306.18	<.0001

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	6
Error Mean Square	0.118889

Number of Means	2	3
Critical Range	.6889	.7140

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	8.6667	3	1
B	5.1667	3	2
C	1.7000	3	3

Table A.9 Two way ANOVA and Duncan's Multiple Range Test for shrinkage of untreated eggplants dried in microwave-IR combination oven.

X1 IR power (10%, 20%)

X2 Microwave Powers (30%, 40%, and 50%)

Class Level Information

Class	Levels	Values
X1	2	1 2
X2	3	1 2 3

Number of Observations Read	18
Number of Observations Used	18

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.01069883	0.00356628	92.33	<.0001
Error	14	0.00054078	0.00003863		
Corrected Total	17	0.01123961			

R-Square	Coeff Var	Root MSE	Y Mean
0.951886	0.995560	0.006215	0.624278

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	1	0.00126672	0.00126672	32.79	<.0001
X2	2	0.00943211	0.00471606	122.09	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	1	0.00126672	0.00126672	32.79	<.0001
X2	2	0.00943211	0.00471606	122.09	<.0001

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	0.000039

Number of Means	2
Critical Range	.006284

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	0.632667	9	1
B	0.615889	9	2

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	0.000039

Number of Means	2	3
Critical Range	.007696	.008064

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	0.654333	6	1
B	0.619667	6	2
C	0.598833	6	3

Table A.10 Two way ANOVA and Duncan's Multiple Range Test for shrinkage of 10% (w/w) osmotically dehydrated eggplants dried in microwave-IR combination oven.

X1 IR power (10%, 20%, 30%)

X2 Microwave Powers (30%, 40%, 50%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 27

Number of Observations Used 27

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.06900444	0.01725111	207.59	<.0001
Error	22	0.00182822	0.00008310		
Corrected Total	26	0.07083267			

R-Square	Coeff Var	Root MSE	Y Mean
0.974190	1.174067	0.009116	0.776444

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	0.01685089	0.00842544	101.39	<.0001
X2	2	0.05215356	0.02607678	313.80	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	0.01685089	0.00842544	101.39	<.0001
X2	2	0.05215356	0.02607678	313.80	<.0001

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.000083

Number of Means	2	3
Critical Range	.008912	.009358

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	0.804778	9	1
B	0.780556	9	2
C	0.744000	9	3

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.000083

Number of Means	2	3
Critical Range	.008912	.009358

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	0.832111	9	1
B	0.772556	9	2
C	0.724667	9	3

Table A.11 Two way ANOVA and Duncan's Multiple Range Test for shrinkage of 20% (w/w) osmotically dehydrated eggplants dried in microwave-IR combination oven.

X1 IR power (10%, 20%, 30%)

X2 Microwave Powers (30%, 40%, 50%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read	27
Number of Observations Used	27

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.02796622	0.00699156	118.64	<.0001
Error	22	0.00129644	0.00005893		
Corrected Total	26	0.02926267			

R-Square	Coeff Var	Root MSE	Y Mean
0.955696	0.891009	0.007677	0.861556

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	0.01103267	0.00551633	93.61	<.0001
X2	2	0.01693356	0.00846678	143.68	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	0.01103267	0.00551633	93.61	<.0001
X2	2	0.01693356	0.00846678	143.68	<.0001

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 22

Error Mean Square 0.000059

Number of Means	2	3
Critical Range	.007505	.007880

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	0.888111	9	1
B	0.857444	9	2
C	0.839111	9	3

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.000059

Number of Means	2	3
Critical Range	.007505	.007880

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	0.887667	9	1
B	0.869222	9	2
C	0.827778	9	3

Table A.12 One way ANOVA and Duncan's Multiple Range Test for shrinkage of eggplant dried in microwave-IR combination oven at 20% IR and 50% microwave powers.

X1 Pretreatment (untreated, 10% osmotic dehydration, 20% osmotic dehydration)

Class Level Information

Class	Levels	Values
X1	3	1 2 3

Number of Observations Read 9

Number of Observations Used 9

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.07451022	0.03725511	420.17	<.0001
Error	6	0.00053200	0.00008867		
Corrected Total	8	0.07504222			

R-Square	Coeff Var	Root MSE	Y Mean
0.992911	1.321483	0.009416	0.712556

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	0.07451022	0.03725511	420.17	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	0.07451022	0.03725511	420.17	<.0001

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	6
Error Mean Square	0.000089

Number of Means	2	3
Critical Range	.01881	.01950

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	0.815667	3	3
B	0.727667	3	2
C	0.594333	3	1

Table A.13 Two way ANOVA and Duncan's Multiple Range Test for rehydration ratio of untreated eggplants dried in microwave-IR combination oven.

X1 IR power (10%, 20%)

X2 Microwave Powers (30%, 40%, and 50%)

Class Level Information

Class	Levels	Values
X1	2	1 2
X2	3	1 2 3

Number of Observations Read 18

Number of Observations Used 18

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	3.21915000	1.07305000	185.69	<.0001
Error	14	0.08090000	0.00577857		
Corrected Total	17	3.30005000			

R-Square	Coeff Var	Root MSE	Y Mean
0.975485	1.270832	0.076017	5.981667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	1	0.39605000	0.39605000	68.54	<.0001
X2	2	2.82310000	1.41155000	244.27	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	1	0.39605000	0.39605000	68.54	<.0001
X2	2	2.82310000	1.41155000	244.27	<.0001

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	0.005779

Number of Means	2
Critical Range	.07686

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	6.13000	9	2
B	5.83333	9	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 14

Error Mean Square 0.005779

Number of Means	2	3
Critical Range	.09413	.09863

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	6.41000	6	3
B	6.08000	6	2
C	5.45500	6	1

Table A.14 Two way ANOVA and Duncan's Multiple Range Test for rehydration ratio of 10% (w/w) osmotically dehydrated eggplants dried in microwave-IR combination oven.

X1 IR power (10%, 20%, 30%)

X2 Microwave Powers (30%, 40%, 50%)

Class Level Information

Class	Levels	Values
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 27

Number of Observations Used 27

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	2.00755556	0.50188889	426.13	<.0001
Error	22	0.02591111	0.00117778		
Corrected Total	26	2.03346667			

R-Square	Coeff Var	Root MSE	Y Mean
0.987258	0.943976	0.034319	3.635556

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	0.51095556	0.25547778	216.92	<.0001
X2	2	1.49660000	0.74830000	635.35	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	0.51095556	0.25547778	216.92	<.0001
X2	2	1.49660000	0.74830000	635.35	<.0001

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 22

Error Mean Square 0.001178

Number of Means	2	3
Critical Range	.03355	.03523

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	3.81222	9	3
B	3.61778	9	2
C	3.47667	9	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	22
Error Mean Square	0.001178

Number of Means	2	3
Critical Range	.03355	.03523

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	3.92556	9	3
B	3.63222	9	2
C	3.34889	9	1

Table A.15 Two way ANOVA and Duncan's Multiple Range Test for rehydration ratio of 20% (w/w) osmotically dehydrated eggplants dried in microwave-IR combination oven.

X1 IR power (10%, 20%, 30%)

X2 Microwave Powers (30%, 40%, 50%)

Class Level Information

Class	Levels	Value
X1	3	1 2 3
X2	3	1 2 3

Number of Observations Read 27

Number of Observations Used 27

Dependent Variable: Y

Source	DF	Sum ofSquares	Mean Square	F Value	Pr > F
Model	4	1.17643704	0.29410926	95.77	<.0001
Error	22	0.06756481	0.00307113		
Corrected Total	26	1.24400185			

R-Square	Coeff Var	Root MSE	Y Mean
0.945688	2.272082	0.055418	2.439074

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	0.41717963	0.20858981	67.92	<.0001
X2	2	0.75925741	0.37962870	123.61	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	0.41717963	0.20858981	67.92	<.0001
X2	2	0.75925741	0.37962870	123.61	<.0001

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 22

Error Mean Square 0.003071

Number of Means	2	3
Critical Range	.05418	.05689

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	2.58556	9	3
B	2.45000	9	2
C	2.28167	9	1

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha 0.05

Error Degrees of Freedom 22

Error Mean Square 0.003071

Number of Means	2	3
Critical Range	.05418	.05689

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X2
A	2.65611	9	3
B	2.41333	9	2
C	2.24778	9	1

Table A.16 One way ANOVA and Duncan's Multiple Range Test for rehydration ratio of eggplant dried in microwave-IR combination oven at 20% IR and 50% microwave powers.

X1 Pretreatment (untreated, 10% osmotic dehydration, 20% osmotic dehydration)

Class Level Information

Class	Levels	Values
X1	3	1 2 3

Number of Observations Read 9

Number of Observations Used 9

Dependent Variable: Y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	22.91235000	11.45617500	22536.7	<.0001
Error	6	0.00305000	0.00050833		
Corrected Total	8	22.91540000			

R-Square	Coeff Var	Root MSE	Y Mean
0.999867	0.520098	0.022546	4.335000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
X1	2	22.91235000	11.45617500	22536.7	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
X1	2	22.91235000	11.45617500	22536.7	<.0001

Duncan's Multiple Range Test for Y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	6
Error Mean Square	0.000508

Number of Means	2	3
Critical Range	.04505	.04669

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	X1
A	6.47000	3	1
B	3.90000	3	2
C	2.63500	3	3

APPENDIX B

PICTURES OF DRIED EGGPLANTS

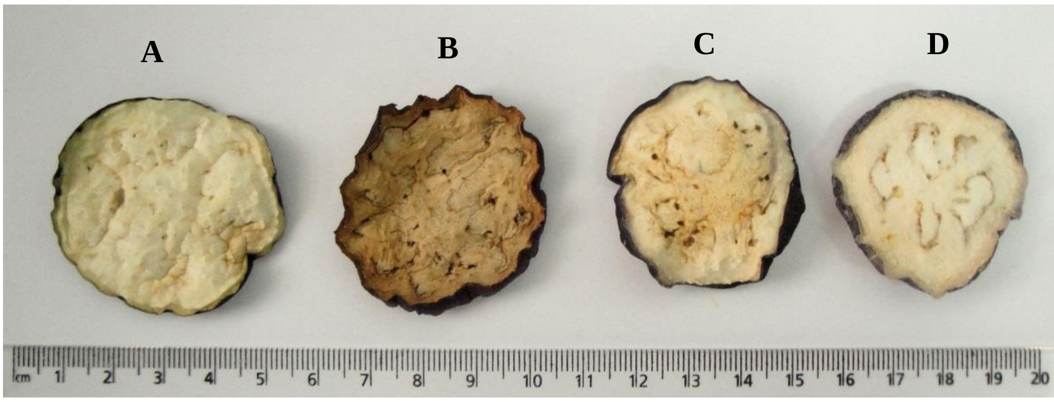

Figure B.1 Picture of eggplants dried with; A: hot air drying, B: no pretreatment and microwave-IR drying at 20% IR & 50% microwave power, C: 10% (w/w) osmotically dehydration and microwave-IR drying at 20% IR & 50% microwave power, D: 20% (w/w) osmotically dehydration and microwave-IR drying at 20% IR & 50% microwave