JUNE 2019 M.Sc. in Food Engineering İBRAHİM HALİL SÖNMEZ

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DRYING OF ZUCCHINI BY USING TRAY DRYING AND MICROWAVE PRETREATMENT

M.Sc. THESIS

IN

FOOD ENGINEERING

BY

İBRAHİM HALİL SÖNMEZ

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Supervisor

Assoc. Prof. Dr. Çiğdem SOYSAL

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İbrahim Halil SÖNMEZ

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İbrahim Halil SÖNMEZ

ABSTRACT

DRYING OF ZUCCHINI BY USING TRAY DRYING AND MICROWAVE PRETREATMENT

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In this thesis, zucchini (*Cucurbita pepo L. var cylindrica*) slices were dried with and without microwave pretreatment in the tray dryer. Microwave pretreatment was applied for 7 minutes at three different microwave power levels (350, 490 and 700 W). Hot air drying was carried out at three different temperatures (40, 50 and 60°C) and two different air flow rates (1.0 and 1.2 m/s). Drying behaviors, bulk density and color changes of the dried zucchinis were examined. Increasing the temperature, microwave power and air flow rate reduced the drying time. The microwave pretreatment was led to a significant reduction in the drying time compared to the non-pretreated samples. The shortest drying time was observed in the zucchini at 60°C with an air flow rate of 1.2 m/s and 700 W. Effective moisture diffusivity values (D_{eff}) were found as between $1.54*10^{-10}$ and $2.75*10^{-9}$ m^2/s. The minimum activation energy was found as 20.51 kJ/mol for hot air drying at 1.2 m/s air flow rate, and maximum activation energy was found as 65.50 kJ/mol for microwave pretreatment at 700 W air flow rate of 1.2 m/s. For color values of L*, a*, b* and ΔE there were significant change ($p<0.05$) between air flow rates and hot air temperatures. Minimum total color difference (ΔE) was found 10.60±2.30 during hot air temperature at 60^oC and 1.0 m/s air flow rate and 700 W microwave pretreatment. Shrinkage values varied in between 0.75 and 0.80. Bulk density values were found between 0.21±0.02 and 0.41±0.01 g/mL.

Keywords: Zucchini, Microwave, Drying, Diffusion, Color

ÖZET

MİKRODALGA ÖN İŞLEM VE TEPSİLİ KURUTUCU KULLANARAK KABAK KURUTULMASI

SÖNMEZ, İbrahim Halil
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Bu tezde kabak (*Cucurbita pepo L. var cylindrica*) dilimleri mikrodalga ön işlemi ile ve ön işlem olmadan tepsili kurutucuda kurutulmuştur. Üç farklı mikrodalga güç seviyesinde (350, 490 ve 700 W) 7 dakika süreyle mikrodalga ön işlemi uygulanmıştır. Sıcak hava ile kurutma işlemi üç farklı sıcaklıkta (40, 50 ve 60^oC) ve iki farklı hava akış hızında (1.0 ve 1.2 m/s) uygulanmıştır. Kurutma işlemi uygulanan kabakların kuruma davranışı, yığın yoğunluğu ve renk değişimleri incelenmiştir. Sıcaklığın, mikrodalga gücünün ve hava akış hızının arttırılmasının kurutma süresini azalttığı gözlemlenmiştir. Mikrodalga ön işleminin, ön işlem uygulanmayan örneklere göre kurutma süresinde önemli bir azalmaya yol açtığı gözlenmiştir. En kısa kurutma süresi 60^oC sıcaklık 1.2 m/s hava akış hızı ve 700 W gücünde mikrodalga ön işlemi uygulanmış kabakta gözlenmiştir. Efektif nem difüzyon değerleri (D_{eff}) $1.54*10^{-10}$ ve $2.75*10^{-9}$ m^2/s arasında bulunmuştur. Minimum aktivasyon enerjisi 1.2 m/s hava akış hızında sıcak hava kurutma işleminde 20.51 kJ/mol, maksimum aktivasyon enerjisi ise 700 W mikrodalga ön işleminde 1.2 m/s hava akışı hızında 65.50 kJ/mol olduğu belirlenmiştir. Hava akış hızı ve sıcaklık değişiminin L*, a*, b* ve ΔE renk değerleri üzerinde anlamlı bir etkiye sahip olduğu gözlemlenmiştir ($p<0.05$). Minimum toplam renk farkı (ΔE), 60^oC sıcaklık 1.0 m/s hava akış hızı ve 700 W mikrodalga ön işleminde 10.60±2.30 olarak hesaplamıştır. Büzülme değerleri 0.75 ile 0.80 arasında değişmiştir. Yığın yoğunluğu değerleri 0.21±0.02 ile 0.41±0.01 g/mL arasında olduğu tespit edilmiştir.

Anahtar kelimeler: Kabak, Mikrodalga, Kurutma, Difüzyon, Renk

''To my family''

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LIST OF SYMBOLS

ΔE	Total color change
A	Exposed surface area for drying in m^2
a*	Redness / greenness
b*	Yellowness / blueness
D	Effective moisture diffusivity in m^2/s
E_a	Activation energy
L	Half thickness of the slice (m)
L*	Whiteness or brihtness / darkness
L_S	kg of dry solid used
m_f	Dried sample mass
MR	Moisture ratio
P_W	The partial pressure of water vapor
P_W^0	The saturated vapor pressure
R	Ideal gas constant
R^2	Coefficient of determination
V_0	Volume of fresh slices
V_s	Volume of dried sample
W	Weight of the wet solid in kg total water plus dry solid
W_s	Weight of the dry solid in kg
X	Moisture content
X_0	Moisture content at time t=0
X_e	Equilibrium moisture content
X_t	Moisture content at time t=t

LIST OF ABBREVIATIONS

AD	Anno Domini
ANOVA	Analysis of variance
a_w	Water activity
BC	Before Christ
DFE	Dietary Folate Equivalent
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
ITIS	Integrated Taxonomic Information System
IU	International Unit is a measure of biological activity
RAE	Retinol Activity Equivalent
S	Shrinkage
SPSS	Statistical package for the social sciences
TurkStat	Turkish Statistical Institute
USDA	U.S. Department of Agriculture
WHO	World Health Organization

CHAPTER 1
INTRODUCTION

Drying is widely used technique for preservation of food and agricultural products for centuries. Main aim of drying is reducing of the water activity by dehydration in order to minimize microbial and enzymatic activities which deteriorate the food products. Traditionally drying carried under sun can be affected by weather conditions and during drying products are susceptible to microbial contamination due to long drying times (Doymaz, 2007; Mirzaee et al., 2009). Hot air drying, freeze drying, spray drying, vacuum drying and osmotic drying are most widely used for drying of foodstuffs (Gaukel et al., 2017).

Fruits and vegetables are important part of our diet and in order to maintain a healthy life we have to consume them, because they are rich source of fibres, vitamins and minerals. Moisture content of fruits and vegetables are high which is more than 80%. So, they are prone to microbial activity. Drying is widely used for increasing shelf life of fruit and vegetables due to most of them are seasonal products and some of them are grown on specific regions of the world. And also dried products occupies less volume than fresh, thus transportation, packaging and storage are more easier (Eissa et al., 2013; Lüle and Koyuncu, 2015; Orsat et al., 2005).

Consumer demands for healthy food and agricultural products increasing year by year. This leads to developing novel drying systems and combined use of drying methods in order to eliminate disadvantages of using one type of drying systems to produce high quality fresh-like products (Chizoba Ekezie et al., 2017; Figiel, 2010; Motevali et al., 2012).

Zucchini is a rich source of micronutrients and macronutrients particularly antioxidants such as Vitamin C, phenols and beta-carotene in between other fruits and vegetables. Its consumption is very popular and production amount is increasing year by year. Moisture content of zucchini is high and it can be deteoriated easily.

For this reason drying of zucchini is important in order to prevent spoilage and economical losses (Eissa et al., 2013).

Fruits and vegetables are generally dried with hot-air that provide control of drying temperature and air flow rate. But, this method has some drawbacks of on the product quality such as loss of nutrients, color retention and shrinkage due to the long drying times and high temperatures. This problem can be eliminated by using hot air drying with taking advantages of other drying methods in combination or pretreatments. Use of microwave alone for drying of food products has some disadvantages due to the overheating such as undesirable color and off-flavors. However combinational or pretreatment usage of microwave with hot-air drying helps to obtaining high quality end products and decreasing drying time considerably (Chizoba Ekezie et al., 2017; Figiel, 2010; Orsat et al., 2005).

1.1 Aim of the Thesis

Fruits and vegetables are important part of our diet. Zucchini is highly perishable and not suited for storage longer than two weeks. According to TurkStat (2018) data production of zucchini is increasing every year and in Turkey production is made more than needed. The most widely preservation method of zucchini is drying. Traditional drying method is sun drying. This method is dependent on weather conditions and long drying times become susceptible to microbial contamination and this effect final quality of product.

In this study; zucchini dried by hot air and microwave pretreated hot air drying systems to determine the drying kinetics, activation energy and effects on some physical and chemical parameters. Aim of this thesis is to obtain dried zucchini slices and also increase the consumer appreciation by production of healty snacks.

CHAPTER 2
LITERATURE REVIEW

2.1 Zucchini

Cucurbita pepo L. (Cucurbitaceae) fruits are formed in numerous colors, shapes and sizes and a wide variety of these fruits are cultivated (Paris, 1989). Warm season annuals of *Cucurbitaceae* family are Zucchini or Summer squashes *(Cucurbita pepo).* Gourds, cucumbers, melons and winter squash are also including in this family. *C. pepo* have often named arbitrarily in English language which are pumpkin, gourd, marrow and squash. The origin of the word squash has been translated into English from the Native Americans of North America which is, asq and the plural form of asquash. The meaning of this word is something that is eaten when it is immature or raw.

The pumpkin word means larger size and roundness which was derived The Greek pepon and Latin pepo. Therefore, the widespread usage of the word pumpkin for round and large forms of mature Cucurbita fruits and for the unripe fruits of *C. pepo* the word summer squash was adapts to the ancient usages (Paris, 1989). The Italian plural form of summer squash is named zucchini. From the port of Marseilles, France Naudin (1856) was first mentioned the zucchini as zouquette or zouquetti (Paris, 1989).

Origin of zucchini is derived from an Italian word for little pumpkin “zucca” plus a diminutive suffix which is known that based on American language. Economically important and most common agriculture group of *C. pepo* is zucchini. It describes a fairly smooth, cylindrical fruit, the length to broadest width ratio which is usually between 3.5 and 4.5. It can be eaten only after cooking, being harvested immature, and skin color is generally green (Verdone et al., 2018).

In many countries ease of cultivation, suitability to mild temperature and subtropical regions, short crop cycle appropriateness to low-calories diet routines and thanks to the ability to cook in various ways cultivation of zucchini has increased recently. In western societies, summer squash, mainly zucchini spread more widely more than many other vegetables (Verdone et al., 2018). Table 2.1 shows botanical classification of zucchini. The zucchini will likely keep on being the most financially important group of *C. pepo* around the worldwide (Paris, 1989).

Table 2.1 Botanical classification of zucchini used in thesis (ITIS)

Order	*Cucurbitales*
Family	*Cucurbitiacea*
Genus	*Cucurbita*
Species	*Cucurbita pepo L.*
Name	*Cucurbita pepo L. var cylindrica*

2.2 Zucchini Growth, Production and Chemical Compositon

It is not suitable for storage of mature summer squash longer than two weeks due to summer squash are highly perishable. Temperature, atmospheric composition and relative humidity must be considered carefully that defined as storage conditions to ensure for keeping of the fruits fresh and increase the shelf life of the fruits after harvest. Enzymatic activity, respiration rate, transpiration, and microbial growth and contamination are significant factors for the quality of fresh products and that can be achieved by adequate temperature management. Freedom from defects as that of decay, water loss, physiological disorders, mechanical injury as well blemishes refers to quality. The most important parameter of quality appearance of fruits in the fresh produce market worldwide is that appeals to consumers. Depending on cultivar ideal conditions for storage of the mature zucchini have been studied by various researchers (Brew et al., 2006).

Zucchini cultivars are mostly hybrids. During the last half century, the improvement of *C. pepo* cultivars achieved by American breeders. For zucchini hybrids a strong trend toward to produce very intensely colored, pure and more productive fruits during the last 25 years. The type grown summer squash is almost always the zucchini where the regions summer squash is produced large quantities as a commercial product (Paris, 1989).

In order to produce high quality fruits, zucchini should be picked up more than once in a week for subsequent fruits at times of limited availability. Mechanical harvesting has not been possible, due to summer squash fruits are tender (Paris, 1989).

Zucchini consumption is very popular, because zucchini being source of nutrients and natural antioxidants such as folic acid, beta-carotene and vitamins C and E. But, shelf life of zucchini is limited to 1–2 days because zucchini is highly perishable and it deteriorates rapidly after slicing due to browning, decay and firmness loss (Lucera et al., 2010).

Attention of consumers to low calorific value, appropriate biological and taste properties vegetables, diet of a greater part of society changes. In comparison to other cucurbitales zucchini contains higher vitamin C and protein content. Low content of fats and carbohydrates is recommended in low-calorie diets (Stępień et al., 2016).

In the diet of a conscious consumer fruits and vegetables play more significant role. They are obtained seasonally so their shelf life is short. Considerable quantity and quality losses are occur during in cool storage of these raw materials. Nutritional values and consumption values are reduced at high costs of raw material storage (Stępień et al., 2016).

According to Turkish Statistical Institute data, 474527 tons of zucchini were produced in Turkey in 2018. Table 2.2 shows that production amount increases year by year.

Table 2.2 Production amount of zucchini in Turkey (TurkStat, 2018).

Years	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Tonnes	317705	302374	293709	299858	312923	351550	449561	474527

Fruit and vegetable production has increased significantly globally. Production growth in the world was mainly due to the expansion of area in Asia. China is emerging country which world’s largest vegetable and fruit producer. Table 2.3 shows that production amount of pumpkins, squash and gourds worldwide and China is the first country. Turkey is also takes its place among the first 10 countries producer.

In addition to the monetary value, consumption of fruits and vegetables plays a very important role in order to ensure a balanced and high quality diet. According to World Health Organisation (WHO), depending on the consumption of low fruits and vegetables, 1.7 million people die each year on the world and many people experience various health problems. It is recommended to consume 400g of vegetables and fruits per day by WHO and Food and Agriculture Organisation (FAO) to minimize micro-nutrient deficiencies, particularly in underdeveloped countries and to alleviate chronic diseases (FAOSTAT, 2013).

Table 2.3 Worldwide production amount of pumpkins, squash and gourds at 2017 (FAOSTAT).

Country	Tonnes
China, mainland	7996362
India	5142812
Russian Federation	1165834
Ukraine	1164660
United States of America	1091121
Mexico	710632
Spain	702278
Italy	590541
Turkey	580624
Indonesia	566857

Approximately 40% of the total vegetable production in the world constitutes Cucurbitaceae and ratio in all of the cucurbit vegetables in Turkey is around 31%. Zucchini production in this group is around 1.3% of the total vegetable production in our country and the production amount corresponding to this rate is 300-400 thousand tons. Zucchini is rich in nutrient content (Özçelik, 2015).

Zucchini consumption also provides many benefits. 100 grams of the zucchini gives only 21 calories and is one of the very low calorie vegetables. It is also a good source of fiber for use in diets, and the dietary fiber improves the digestive properties of the fat and provides a good bond with bile acid. Thus, the production of more fatty acids in the liver is prevented and cholesterol levels are decreased, and blood vessel obstructions caused by high cholesterol are prevented (Özçelik, 2015).

Chemical compositon of zucchini is given Table 2.4. Due to its high vitamin A and vitamin C, it prevents the onset of atherosclerosis. Also, the high amount of fiber in the structure of a further benefit of providing healthy and regular bowel movements help to prevent the settling of carcinogenic toxins in column (Özçelik, 2015).

Table 2.4 Chemical Compositon of Zucchini (USDA).

Nutrient	Unit	Value per 100g
Water	g	92.73
Energy	kcal	21
Protein	g	2.71
Total lipid (fat)	g	0.40
Carbohydrate, by difference	g	3.11
Fiber, total dietary	g	1.1
Minerals		
Calcium, Ca	mg	21
Iron, Fe	mg	0.79
Magnesium, Mg	mg	33
Phosphorus, P	mg	93
Potassium, K	mg	459
Sodium, Na	mg	3
Zinc, Zn	mg	0.83
Vitamins		
Vitamin C, total ascorbic acid	mg	34.1
Thiamin	mg	0.042
Riboflavin	mg	0.036
Niacin	mg	0.705
Vitamin B-6	mg	0.142
Folate, DFE	µg	20
Vitamin A, RAE	µg	25
Vitamin A, IU	IU	490

2.3 Drying

One of the important unit operation in food production is drying. Drying is aim that to reduce moisture levels in foodstuffs to certain levels for prevention by inhibition of enzymatic and microbial activity and related product quality degradation (Sabarez, 2015).

Since the first recorded human civilization to preserve the food product drying is applied. Drying foods history goes date back to 20 000 BC. Under the hot sun, by the oriental societies, evidence shows that foodstuffs dried actively around 12 000 BC. In southern France, Solvieux drying was used to store fish for a long time by people during the mesolithic age (around 10 000 BC) was known. Around 2800 BC, fruits such as figs, grapes, apples, apricots were dried under the sun in Egypt. The

Mongolian army was produced sun dried powdered milk along the middle ages (AD 630 to AD 1630), as in Mexico and Peru fruits and cocoa leaves were sun dried (Sabarez, 2016).

A successful dehydration unit was developed by French in the late 1700s for dehydration at a controlled temperatures vegetables and fruits was used. Sliced vegetables and fruits dried at hot air (40^{o}C) by the French team and then covered with tinfoil and stored. But, mechanical drying did not a substitute for drying in the natural sun, until the end of the twentieth century. Drying with the mechanical methods have great step since taken off when World War II ended. Tray drying and drum drying were improved shortly after as the early methods of drying. New methods of drying systems developed at this time which includes freeze, fluidized bed, vacuum and spray drying. Today, to improve these methods of drying significant effort continues. Likewise, as new drying necessities show up for new products, new difficulties are always rising. Developing modern, innovative, and novel drying techniques will continue by drive further efforts (Sabarez, 2016).

Preservation of numerous food products routinely by drying, that include meat products, dairy products, marine products, grains, also fruits and vegetables. Drying food materials made in many different ways and these methods have advantages and disadvantages. Because of the distinctions in the physical properties of the product various dryer structures detailed in the literature which are operating temperatures and pressures, modes of heat input quality characterizations of the dried product (Sabarez, 2016).

2.3.1 Effect of Drying

The quality paramaters for drying of foods has been paid much attention in recent years. Quality of the product during drying affected by both the method of drying and physicochemical changes that occur in tissues. Colour, density, texture, porosity and sorption characteristics of materials affected by drying methods. In the literature, various methods for drying fruits and vegetables have been proposed, whereby efficiently produced high quality and suitable products at a affordable prices (Krokida et al., 2001).

The appearance, processing and acceptability of foodstuffs color also play a key role. The visual acknowledgment and evaluation of the surface and subsurface properties of the product, color is seen as a feature of the all out appearance. Consumers first quality decision on a sustenance at shopping is about the its color, size and shape. The maintenance of quality throughout and at the final of the process preparing appearance examinations of sustenances such as determination of color and texture and sensory analysis methods are used. The most important appearance attribute is color and foodstuff to be refused by the buyer, because it is considered as deterioration of product and not suitable for consumption (Lüle and Koyuncu, 2015).

At the very beginning of the drying process shrinkage starts which occur due to changes in plant tissue structure. Shrinkage throughout drying rely on the tissue structure of the foodstuff directly linked with moisture content of fruits and vegetables. The porosity of dried material affected by extent of shrinkage, so it is a considerable parameter as much as the textural, mechanical and mass transfer properties of the foodstuff. Applied method and parameters of the drying process is important for degree of shrinkage due to damage on the internal structure of plant tissue is dependent on drying temperature and air velocity (Lewicki and Jakubczyk, 2004).

For food dehydration one of the most frequently used operations is convection drying. Temperature and air flow rate should be high during drying for this method and long drying times are required and also at the end of drying products are qualified as high apparent density and low porosity. After drying, changes in the physical properties of the plant tissue (including mechanical strength) occur evaporation of water and other volatile compounds during drying (Lewicki and Jakubczyk, 2004).

2.3.2 Drying Systems

Drying generally consumes a large amount of energy and makes important changes in quality characteristics of the product because of the high drying temperatures or prolonged drying times. Rivalry is increasing because of today's globalization keep going to create novel technologies in the dehydration operations as well as increased consumer demand for better quality products, and further efforts to improve the performance of existing drying technologies and the maintanence of forthcoming industry continuity. There is a great difficulty in dehydration process while drying of the food, best effective way is achieved with better control of the product quality, minimum effect on the surroundings and the lowest operating and investment costs. A wide variety of physical or chemical properties must be considered according to product quality specifications and the production scales of food materials different requirements may be needed for drying operations (Sabarez, 2015).

Operating conditions and selected drying methods has significant action that influence the quality and cost of the dried food product. Amount of moisture, kind of feed, drying kinetics, physical structure, sensitivity of the heat, requirements for quality and many others which are various factors it affect the choose of drying methods (Sabarez, 2015). There are different drying methods used in food industry such as sun drying, tray drying, conveyor drying, vacuum drying and microwave drying.

2.3.2.1 Sun Drying

In tropical and subtropical countries, drying in the sun has long been used in drying fruits and vegetables. It is a simple, inexpensive and popular method. Although there are disadvantages in sun drying such as drying times are long and the suitable weather conditions are required (Doymaz, 2008).

Homogeneity and quality of the final product affected depending on weather conditions and also another issue that should not be ignored is that the products are prone to microbial and other contamination. Method of drying thanks to the sun ought to be take the place of with the mechanical drying to reduce drying time, to decrease product losses, to produce high quality products steadily (Doymaz, 2008, 2012).

2.3.2.2 Tray Drying

Drying is usually carried out by evaporation of water in the product. Therefore, the latent heat of evaporation must be ensured. To take away the vapor out of the product airflow is also required. The better drying rate depends on the low humidity of the hot air provided to the drying chamber, so that more moisture can be transported through the surface of the product more easily thanks to the fact that the hot air sent for the drying contains less humidity. Drying time usually decreasing depending on increase in the hot air temperature and air flow rate. However, quality of foodstuffs and other products may reduce due to the high temperature due to those are susceptible to heat. Color of the dried product preserved as fresh can be achieved to keep drying temperature and humidity low by using the desiccant system (Misha et al., 2013).

Tray dryer is the very commonly utilized dryer in food industry due to its uncomplicated and economical design. Foodstuffs can be dried uniformly by spreading the product with a suitable thickness out on trays. The heating of the products in the tray dryer by means of radiation and convection takes place with the help of applied hot air. By arranging the trays at different levels, it is able to dry more products in tray dryer. Uniform airflow distribution over the trays is the main factor for the accomplished process. Whichever of the conventional dryer that utilize electrical energy, solar energy or other energy sources, tray dryer can be applicable. The uniformity of the final moisture content of the dried products on the trays is ensured with good airflow distribution. Determination of the moisture content of the product is generally by using electronic balance to get the difference between initial and final mass (Misha et al., 2013).

2.3.2.3 Conveyor Drying

conveyor (or belt) drying systems are preferred frequently for large industrial drying applications. In this system, various foodstuffs can be dried and this dryer works continuous basis. Heating unit, ventilation fan, drying chamber and conveyor belt are main parts of this dryers. The products placed on a carrier continuously move from the feed inlet at the carrier speed along the drying chamber to the product outlet of the dryer. Duration of dehydration can be controlled by adjusting the speed of the conveyor. Multi-stage conveyor dryer be formed as vertical or horizontal group of conveyors which is used for if longer drying time is required (Sabarez, 2016).

The height of the dryer rises of the dryer due to extra conveyors are attached into the system vertically, as a result of this size of the dryer to be smaller. The materials to be dried are moving in the dryer, in multistage (vertical) conveyor dehydration. In a conveyor dehydrator the movement of drying air may also be in a cocurrent, countercurrent, or mixed-flow configuration. Product mixing and reorientation to evolve the homogenity of drying is achieved by the conveying of the product among the stages. Maximize drying rate and optimize energy efficiency, dryer can take place of various sections for each stage, that can be achieved by management of the air flow direction and rate, speed of the conveyor and temperature for each stage.

Conveyor dryers need more initial capital investment cost as per tunnel dryers, usually ensure increase in yields and quality of the product more steadily (Sabarez, 2016).

2.3.2.4 Vacuum Drying

Moisture within the foodstuff removed under the low pressure in vacuum drying. Quality of the products to be higher than classical air conventional process at atmospheric pressure due to reducing the drying temperature with by lowering the pressure. In the food products, air and water vapor exist inside expands under vacuum that forms a foamed or inflated structure. Temperature sensitive and oxidizable biotechnology products are suitable for vacuum drying process. In order to produce better quality and change the structure of the foodstuff some of researcher have proposed that mass transfer coefficients can be evolved by the application of the physical pretreatments for solid foodstuffs in drying (Arévalo-Pinedo and Xidieh Murr, 2007).

2.3.2.5 Microwave Drying

Over a period of several decades microwave heating are one of the widely used applications in the food processing field. Pasteurization, sterilization, drying, tempering, thawing, baking of food materials are some of the applications of microwave heating in processing of foodstuffs. Due to the its capability to get high heating rates, microwave heating has gained popularity in food processing and also more uniform heating, considerable decrease in time of cooking, ease of operation, low maintenance and safe usage. In addition, compared to heating with conventional methods during reheating or cooking process nutritional values and flavor of food might be affected a lesser. The frequency of the microwave which is an electromagnetic wave varies between 300 MHz and 300 GHz. Microwave systems operate at frequencies of 915 MHz and 2.45 GHz for industrial devices, while operate usually at a frequency of 2.45 GHz for domestic microwave devices (Chandrasekaran et al., 2013).

The capability of the materials absorption of microwave energy and conversion into the heat is caused due to microwave heating. Because of the dipolar and ionic mechanisms of food materials microwave heating mainly occurs. Dielectric heating occurs when the moisture or water are present due to the dipolar nature of water.

The permanently polarized dipolar molecules, when on the water molecules an oscillating electric field is occur, make an effort to realign in the direction of the electric field. The volumetric heating of the material occurs due to the internal friction of the molecules, which is realignment of the molecules in the presence of a high-frequency electric field million times per second. The existence of a high frequency oscillating electric field in the food microwave heating may also take place because of the oscillatory migration of ions and that generates heat. Although there are many factors, penetration depth and dielectric properties are the most important factors that have effect on distribution of heat and microwave heating (Chandrasekaran et al., 2013).

Advantages of drying with microwave are improving the quality of some food products and achieving fast drying rates. Moisture in the inner side of the sample can be removed by selective heating without an undesirable effect on the outer side of the product, that is achieved by wet products used for control of the energy absorption level. During a falling rate period microwave drying is considerably useful. The diffusion is rate-limiting which results reduced surface moisture content and the shrinkage of the structure during the falling rate period. Nevertheless, a pressure gradient is formed inside of the material due to the steam released by volumetric heating in the microwave drying process, which forces the water from inside to outside. So, in microwave drying shrinkage of food materials is prevented (Chandrasekaran et al., 2013).

Drying with microwave alone has some important disadvantages which are potential damage on texture, uneven heating and restricted penetration of the microwave into the product. To overcome these drawbacks combined use of other drying methods can preferable (Zhang et al., 2006). Combined use of microwave energy with other drying methods the quality of food products and efficiency of the drying are better, compared to the use of microwave drying alone or use of other conventional methods alone (Chandrasekaran et al., 2013).

Fruits and vegetables with high initial moisture contents, success of microwave heating depends on uniformity of heating. While there are energy level limits that can be applied to product, this issue may be partly compensated by using waveguides and a rotating tray. According to some researchers irreversible changes on the product while drying may occur because of the overheating resulting in development of off-flavors and possible scorching along the corners and edges of products (Zhang et al., 2006).

2.3.2.6 Combined Drying Systems

One of the combined drying method is microwave assisted air drying which microwave heating is combined with hot air drying to enhance the drying rate. There are three different stages of the drying process hot air can be combined with microwave heating. At the beginning of the dehydration process microwave heating is applied in order to heat the interior rapidly to reach the evaporation temperature. Drying rate improved and vapor is forced outside so by help of the hot air water is removed easily from the surface of the material. Porous structure is formed on the food material due to improved drying rate which can further facilitate the vapor is forced outside (Chandrasekaran et al., 2013; Zhang et al., 2006).

When the drying rate begins to fall application of microwave is second way. In this case moisture is intensed at the center and the material surface is dry. At this moment vapor pressures enforce the moisture to the surface due to the generation of internal heat when applying microwave, moisture removed easily by ambient environment. To ease of finish drying microwave energy applied at low moisture content or in the falling rate period(s). Diffusion restricted when hot air drying due to shrinkage affects the structure of the foodstuffs that causes a sharp decrease in drying rates. Shrinkage of tissue structure can be prevented by during microwave assisted drying when the vapor pressure and flux of vapor outward. Removing bound water from the product by implementing microwave in the last stage of the drying process may be very efficient in some cases (Zhang et al., 2006).

2.3.3 Drying Kinetics

Drying of foodstuffs containing transient mechanisms of momentum, mass and heat transfer processes combined with chemical, physical and phase change transformations is an extremely complex process. Two distinct transport mechanisms occur at the same time as drying the foodstuffs, which include transport of water from the interior of the solid product to its surface and transfer of heat from the heat source to foodstuffs. For molecular movement activation and generation of a phase change of water, energy is required. To provide both heat and removal of moisture hot air is used as a carrier gas. By conduction or radiation heat can be also supplied and also, for the wet material it can be supplied volumetrically in a microwave or radio frequency applications. Because of the latent heat of vaporisation of water is high and using of hot air which has inefficiency inherently as the drying medium, drying is high energy consuming unit operation (Sabarez, 2015).

Energy is transferred in three modes which are conduction, convection and radiation which can be used alone or in combination for supplying heat to the food materials from the heat source. Heat must spread out into the solid mainly through conduction due to heat supply at the boundaries of the drying material for all heat transfer modes, other than those using microwave and radio frequency. Depending on the application to improve energy efficiency, simultaneous or sequential various modes of heat transfer may be implemented (Sabarez, 2015).

There are two control mechanisms of mass transfer which are internal transfer is that inside of the food matrix the moisture diffusion rate (liquid or vapour) and external transfer is the evaporation rate of moisture from the product surface to the drying medium. Temperature is the main effect on the drying process controlled internally and that have strong influence on the product replenishment rate of moisture. Rate of mass transfer which is from the inner side to the surface, is slower than the external. Different mechanisms of moisture movement generally involves for the internal mass transfer process. Food materials which are comprising of porous medium having void spaces at solid matrices that are filled with gas or liquid. During the drying process of the food material movement of the water inside causes deformation of this porous medium which is shrinkage (Sabarez, 2015).

Chemical reactions and microbial growth are related with water activity (a_w) which is an index of the availability of water. By the following (Equation 2.1) it can be defined.

$$a_W = \frac{P_W}{P_W^0} \tag{2.1}$$

$P_{W:}$ the partial pressure of water vapor

P_W^0: the saturated vapor pressure

According to its availability in the food matrix moisture content can be classified in two terms. First one is bound moisture which is the amount of water tightly bound to the food matrix on active sites of hydrophilic macromolecular materials by physical adsorption such as proteins and polysaccharides. Second one the amount of water mechanically entrapped in the void spaces of the system which is free moisture content. Energy is required to overcome the capillary forces so free water is not in the same thermodynamic state as liquid water. Free water may alter the drying characteristics and also it may contain chemicals, especially dissolved acids, salts and sugars (Ratti, 2009).

Experimental determination of the rate of drying for a given material is generally carried out by placing a sample on the tray. The drying air stream have an impact only the top surface of the material if the tray fill with solid material. A balance can be placed by hanging in a cabinet or duct in which air flows of the tray, without interrupting the process the weight loss can be determined during drying at different time intervals. In order to obtain data that can be used under conditions that are very similar to those to be used in large scale operations, by performing batch drying experiments. The same and constant drying conditions have to be considered to simulate drying conditions such as humidity, temperature, weight, tray size, velocity and direction of the air (Geankoplis, 2003).

Total weight (W) of the wet solid including dry solid plus moisture is obtained from batch drying experiment at different intervals during the drying period. Calculation of moisture content is performed by using Equation 2.2. W is the total weight of the water plus dry solid in kg and Ws is the weight of the dry solid in kg.

$$X_t = \frac{W - W_s}{W_s}\left(\frac{kg\ water}{kg\ dry\ solid}\right) \tag{2.2}$$

The equilibrium moisture content is an important value which is defined as the moisture content of a product in equilibrium with the surrounding air at given temperature and humidity conditions. A material may be dried under these conditions theoretically which it is the minimum moisture content. Sorption isotherm is found at constant temperature by plotting of the equilibrium moisture content versus the relative humidity or water activity. And also sorption isotherm is used for describe the degree of water interactions with foods. The equilibrium moisture content X_e kg equilibrium moisture/kg dry solid determined at constant drying conditions. After that for each value of X_t the free moisture content X in kg free water/kg dry solid is calculated by using Equation 2.3. Experiments are required to determine the correct values the equilibrium moisture due to temperature is not only the affect water binding only and also it can be affected by composition and structure (Geankoplis, 2003; Ratti, 2009).

$$X = X_t - X_e \tag{2.3}$$

The average material moisture content and temperature changes with time is refer to the drying kinetics. Calculation of drying kinetics is important due to the determination of the drying time, amount of evaporated moisture, energy consumption and product quality (Ratti, 2009). The rate of drying data can be obtained by using moisture content in the following ways, determination of the equilibrium moisture content firstly, and then free moisture content calculated for each value of X_t. After that plot of free moisture versus time graph, rate of drying curve can be found by drawing slope of tangent, which can be calculated also the derivative of time of moisture content by using Equation 2.4 (Geankoplis, 2003).

$$Rate = -\frac{L_S}{A}\frac{dX}{dt} \tag{2.4}$$

Drying rate curve for constant drying conditions shown in Figure 2.1. In Figure 2.1.b for constant drying conditions the rate of drying curve is shown. Three main stages of drying may be observed in the drying curve. Point A shows that the initial free moisture content at zero time and the surface temperature rises to its equilibrium value at point B. The line is straight from point B to C, and therefore the slope and rate are constant during this period which is the constant rate of drying period. The drying rate starts to decrease in the falling-rate period at point C until it reaches point D. This the first falling rate period and at point D the second falling-rate period begins. Point E, where the equilibrium moisture content. Drying rate (kg H_2O/h.m^2) versus free moisture (kg H_2O/kg dry solid) graphs plotted to observe constant rate period and falling rate period(s). And also Figure 2.2 shows diffusion controlled and capillary controlled falling-rate period(s) (Geankoplis, 2003).

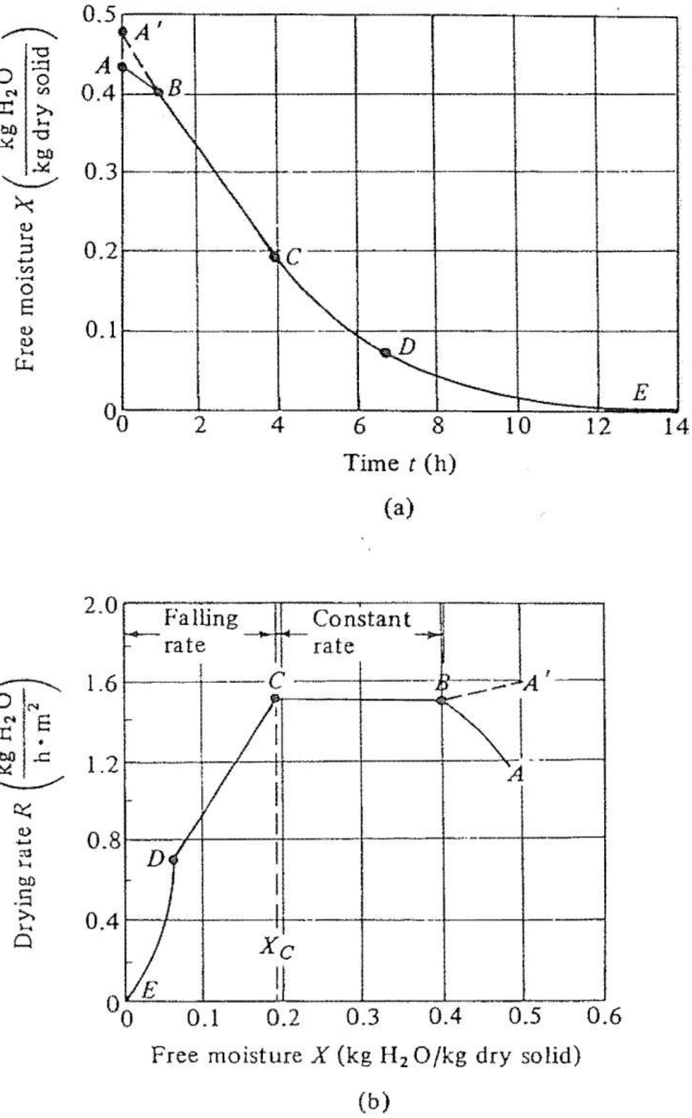

Figure 2.1 Drying rate curve for constant drying conditions: (a) plot of data as free moisture versus time, (b) rate of drying curve as rate versus free moisture content (Geankoplis, 2003).

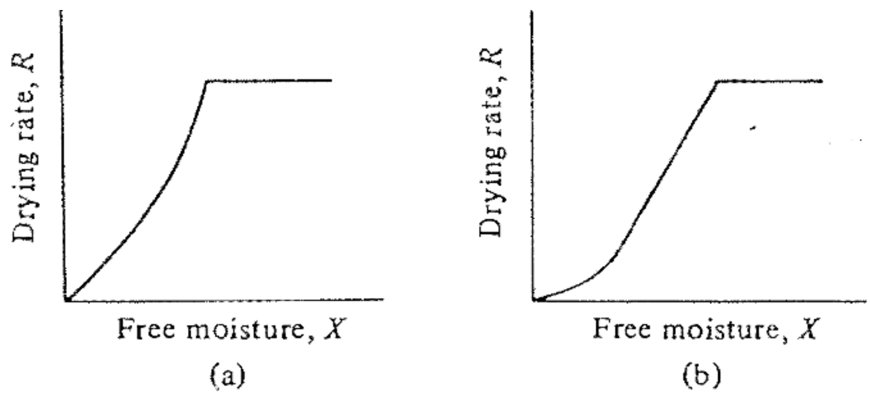

Figure 2.2 Typical drying rate curves: (a) diffusion controlled failing-rate period, (b) capillary controlled falling-rate period in a fine porous solid (Geankoplis, 2003).

2.3.4 Moisture Diffusivity

The moisture within the food product according to some authors can migrate by a number of different of mechanisms with several ways (liquid or vapour phase). Capillary flow, liquid diffusion and surface diffusion which are include the liquid transport mechanisms although Knudsen diffusion, Stefan diffusion, mutual diffusion, Poiseuille flow and condensation evaporation are the vapour transport mechanisms. Depending on the nature of the foodstuff, water concentration difference and temperature the rate at which moisture migrates affected in liquid diffusion. The driving force for moisture transfer in some situations can occur vaporisation of inside of the product and so the difference in vapour pressure to the water diffuses in the form of vapour through the food matrix. The internal mobility of moisture may also influenced by the differences in between the interior of the product and the surface (thermal flow) and also internal food structure and the drying medium pressure differences (pressure flow). Due to the combination of mass transfer mechanisms such as pressure differences, liquid diffusion and vapour diffusion, moisture transport inside of the solid can also takes place (Sabarez, 2015).

Moisture have to reach limits of the dried material and thereafter carried away by gas for non-convective dryers. Properties of the drying air controls the moisture transfer between drying medium and the solid surface. The properties of the material itself, the air velocity field and both concentration of water and temperature differences are usually control the heat and mass transfer.

Sabarez (2015) described the combined transfer of momentum, mass and heat in convective drying for food matrix during drying that occur both externally and internally. First one is conductive and convective heat transfer in the air, second one is convective and diffusive water transfer in the air, third one is within the solid interior heat transfer by conduction, fourth one is in the solid interior mass transfer by diffusion, fifth one is evaporation of moisture at the food air interface and the last one is turbulent or laminar airflow around the food material.

The air velocity field (fluid dynamics), temperature and relative humidity which are drying air properties affect both the heat and mass external transfer rates. Physical changes can also affect internal heat and mass transfer processes such includes puffing, glass transitions crystallization and shrinkage (Sabarez, 2015).

Moisture Ratios (MR) can be determined by Equation 2.5;

$$MR = \frac{X - X_e}{X_0 - X_e} \quad (2.5)$$

X is the instantaneous, X_0 is the initial and X_e is the equilibrium dry basis moisture contents (kg water/kg dry solids). Compared to X or X_0 equilibrium moisture content (X_e) of samples is relatively small, so MR equation can be simplified to Equation 2.6 (Contreras et al., 2008; Doymaz, 2004; Mirzaee et al., 2009).

$$MR = \frac{X}{X_0} \quad (2.6)$$

Moisture Diffusity for an infinite slab can be calculated from Ficks second law (Equation 2.7);

$$MR = \frac{X}{Xo} = \frac{8}{n^2} \sum_{n=1}^{\infty} \frac{1}{(2n-1)^2} \exp\left(-\frac{(2n-1)^2 \pi^2 Dt}{4L^2}\right) \quad (2.7)$$

where:

MR: moisture ratio

X: moisture content at any time (kg water/kg dry mater)

X_0: initial moisture content (kg water/kg dry mater)

n: 1, 2, 3, . . . the number of terms taken into consideration

t: time of drying in seconds

D: effective moisture diffusivity in m^2/s

L: half thickness of the slice (m)

Only the first term of (Equation 2.7) is used for a long drying time drying (Mirzaee et al., 2009). Hence:

$$MR = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 Dt}{4L^2}\right) \quad (2.8)$$

From Equation 2.8 a plot of natural logarithm of moisture ratio versus time gives a straight line with a negative slope of k_0 (Equation 2.9) in which D_{eff} value can be estimated.

$$k_0 = -\frac{\pi^2 D}{4L^2} \quad (2.9)$$

The activation energy is defined as the energy which allows water molecules to overcome the energy barrier that moves within the sample. The effective moisture diffusivity (D_{eff}) reliance on drying temperature has been appeared to pursue an Arrhenius relationship introduced as follows (Equation 2.10):

$$D_{eff} = D_0 exp\left[-\frac{Ea}{R(T+273.15)}\right] \quad (2.10)$$

Where D_0 is the constant diffusivity basis (m^2/ s); Ea is the activation energy (kJ/ mol); R is the universal gas constant with 8.31 kJ/ mol K as its value; T is temperature of the drying air (^oC). the natural logarithm of both sides in the equation is taken, the Equation 2.10 can be transformed into a linear-logarithmic form, as shown in Equation 2.11. As a result of this the activation energy (Ea) can be calculated from the slope of ln (D_{eff}) versus the reciprocal of the temperature (1/(T+273.15)) (Doymaz, 2007; Mirzaee et al., 2009; Xiao et al., 2010).

$$\ln(D_{eff}) = \ln(D_0) - \frac{E_a}{R}\frac{1}{T+273.15} \quad (2.11)$$

CHAPTER 3
MATERIALS AND METHODS

3.1 Materials

Fresh zucchinis (species given in Table 2.1) were bought from local market at Gaziantep, Turkey and stored at +4^{o}C.

3.2 Methods

3.2.1 Preparation of Samples

Zucchinis were cut into 0.6±0.03 cm thick slices by using mandoline slicer.

3.2.2 Hot Air Drying

Drying experiments was performed in laboratory type tray dryer (UOP 8 tray dryer, Armfield, UK) at University of Gaziantep, Turkey. Hot-air drying was performed at three different temperatures (40, 50 and 60°C) and two different air flow rates (1.0 and 1.2 m/s). Tray dryer was started 30 minutes before experiments, due to achieve steady state. Moisture loss was recorded at 15 minute time intervals until reaching the constant weight.

3.2.3 Microwave Pretreated Hot Air Drying

Microwave pretreatment was performed at programmable domestic microwave oven (Arçelik ARMD 580, TURKEY), with maximum output of 700 W at 2450 MHz. Microwave pretreatment was performed at three different power levels (350, 490 and 700 W) for 7 minutes. During pretreatment microwave power was applied 1 minute interval for 15 second pausing.

3.2.4 Analyses

3.2.4.1 Determination of Moisture Content

Initial moisture content of zucchinis was detemined at oven drying at 105^{o}C for 5 hours.

3.2.4.2 Determination of Color

Color measurement of the samples were performed by HunterLab color measurement device according to CIELAB system. L* (whiteness or brihtness/darkness), a* (redness/greenness) and b* (yellowness/blueness) values were measured from surface of samples. The equipment was calibrated with a black and white ceramic plate standards. For each sample, three measurements were taken. The results were expressed as total color difference (ΔE) between the initial sample and dried ones to the (Equation 3.1):

$$\Delta E = \sqrt{(L^*_{initial} - L^*_{dried})^2 + (a^*_{initial} - a^*_{dried})^2 + (b^*_{initial} - b^*_{dried})^2} \quad (3.1)$$

3.2.4.3 Determination of Bulk Density and Measurement of Shrinkage

Determination of drying shrinkage and bulk density were carried out by using a measuring cylinder. The zucchini samples were placed in the cylinder, which was gently shaken. When the samples involve the minimum volume measurements were determined. By using the following formula drying shrinkage was calculated (Equation 3.2):

$$S = \frac{V_0 - V_s}{V_0} \quad (3.2)$$

where V_0 is volume of fresh slices (mL), and Vs is volume of dried slices (mL). Bulk density was determined by the quotient of dried sample mass and its volume in the measuring cylinder. Bulk density was calculated in terms of the following formula (Equation 3.3) (Nawirska et al., 2009).

$$Bulk\ density = \frac{m_f}{V_s} \quad (3.3)$$

where, m_f is dried sample mass (g), V_s is volume of dried sample (ml).

3.3 Statistical Analyses

Zucchini drying experiments datas were analyzed by one-way analysis of variance (one-way ANOVA) to test for significant differences. Means of the groups were compared using Duncan's multiple range test by using IBM SPSS Statistics 16. Differences among sample means were reported to be significant when $p<0.05$.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Drying of Zucchini

4.1.1 Drying Kinetics

The initial moisture content of zucchini was about as average 93.5 % (wet basis). Drying of samples were continued until the constant weight reached. Moisture content change of zucchini samples with drying time were shown in figures 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6. Hot-air drying was performed at three different temperatures (40, 50 and 60°C with relative humidity ranges between 7 % and 29 %) and two different air flow rates (1.0 and 1.2 m/s). Tray dryer was started 30 minutes before experiments, due to achieve steady state. Moisture loss was recorded at 15 minute time intervals. Microwave pretreatment was performed at three different power levels (350, 490 and 700 W) for 7 minutes. During pretreatment microwave power was applied 1 minute interval for 15 second pausing. The length of the microwave pretreatment is 7 minutes and it is decided to ensure that the samples do not burn at maximum output power. Same time of microwave with different power level was chosen due to show effect of microwave power on pretreatment of all samples.

Hot air temperature and microwave power had an important effect on drying. Increase in both temperature of hot air, air flow rate and microwave power level shows decrease in drying time. Longest drying time was 870 minutes at 40^{o}C with 1.0 m/s air flow rate without microwave pretreatment and shortest drying time was 157 minutes at 60^{o}C and 1.2 m/s air flow rate with 700 W microwave pretreatment. For minimum hot air temperature (40^{o}C) and minimum air flow rate (1.0m/s) drying times were reduced to 547, 487 and 382 minutes by microwave pretreatment at 350, 490 and 700 W respectively. For maximum hot air temperature (60^{o}C) and maximum air flow rate (1.2 m/s) drying times were reduced to 295, 292 and 157 minutes by microwave pretreatment at 350, 490 and 700 W respectively. Microwave pretreatments at 350 and 490 W have very close trends and nearly the same effect on reducing drying time when 1.2 m/s air flow rate was used in drying. Compared with hot air drying, microwave pretreatment decreased the drying time of zucchinis considerably. Also, at higher temperature and higher microwave power, due to quick removal of moisture, the drying times were less than hot air drying. Generally increasing microwave power decreased drying time. But, for microwave treatment at 350 and 490 W powers, this difference is nonsignificant.

Increase in air flow rate for all temperatures has significant effect on decreasing drying time of microwave pretreated and hot air dried samples. At hot air temperature of 40^oC, increasing air flow rate reduced drying times to 630 minutes for hot air drying and 517, 487 and 322 minutes by microwave pretreatment at 350, 490 and 700 W respectively. For maximum hot air temperature of 60^oC, increasing air flow rate reduced drying time from 487 minutes for hot air drying and 382, 307 and 217 minutes for microwave pretreated samples to 465 minutes for hot air drying and at 295, 292 and 157 minutes for microwave pretreated samples at 350, 490 and 700 W respectively.

Kutlu and Isci (2017) was reported drying times for zucchini at 5 mm slice thickness as 300, 270 and 240 minutes for convective hot air temperatures at 60, 70 and 80^oC, respectively, with air flow rate of 2.0 m/s. In our experiment slice thickness was 6 mm and maximum air flow rate was 1.2 m/s and maximum hot air temperature was 60^oC. 465 minutes was found drying at hot air temperature 60^oC and air flow rate was 1.2 m/s. At this drying conditions , we found 465 minutes for drying time of zucchini. This value is higher than Kutlu and Isci (2017) works. There are several reasons to explain this difference which are slice thickness, air flow rate and relative humidity of air. Sacilik and Elicin (2006) was found drying time of apple samples 400, 300 and 240 minutes at the drying air temperatures of 40, 50 and 60^oC, respectively for the apple thickness of 5 mm.

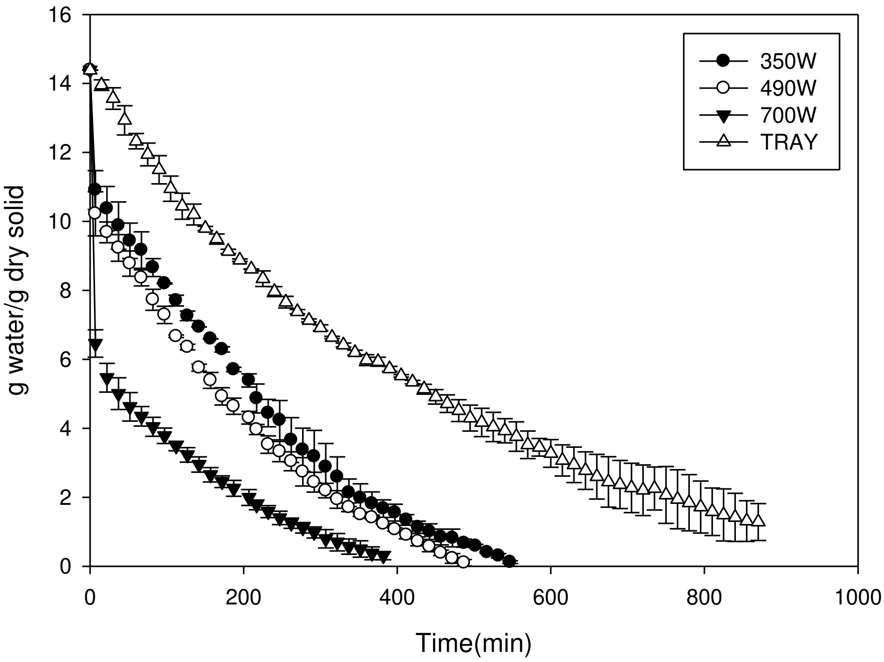

Figure 4.1 Change of moisture content of zucchini with drying time at 40°C and 1.0 m/s air flow rate

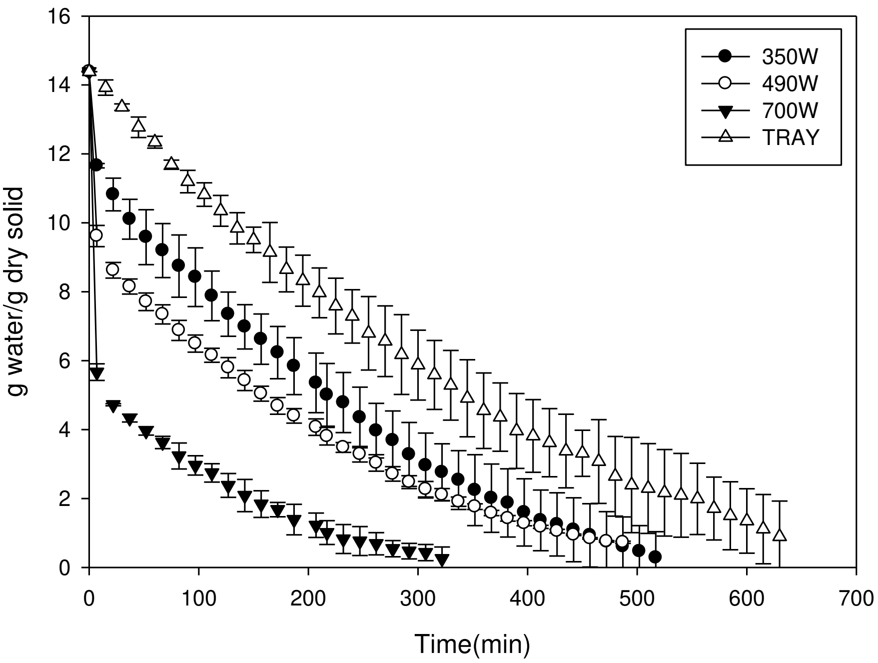

Figure 4.2 Change of moisture content of zucchini with drying time at 40°C and 1.2 m/s air flow rate

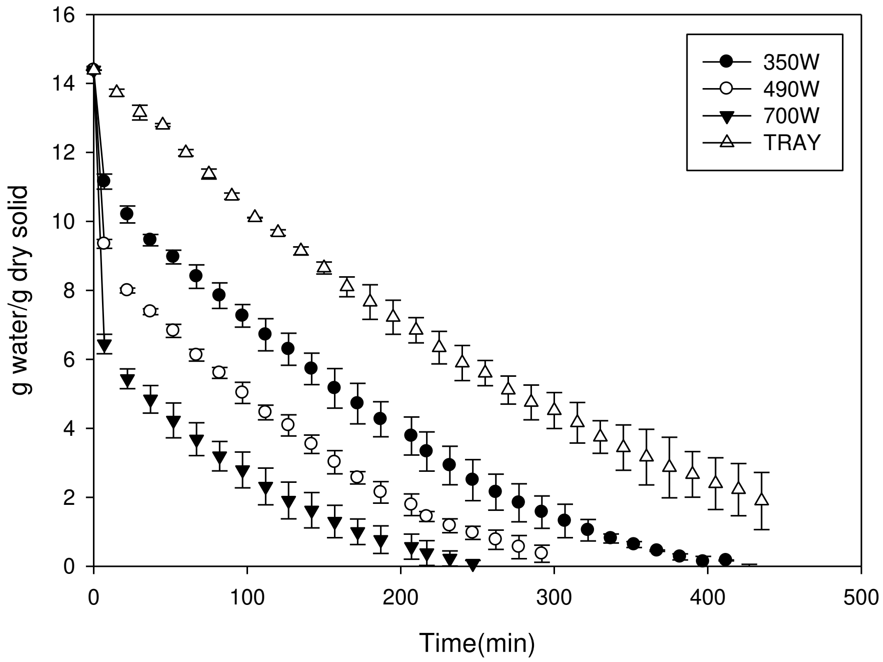

Figure 4.3 Change of moisture content of zucchini with drying time at 50°C and 1.0 m/s air flow rate

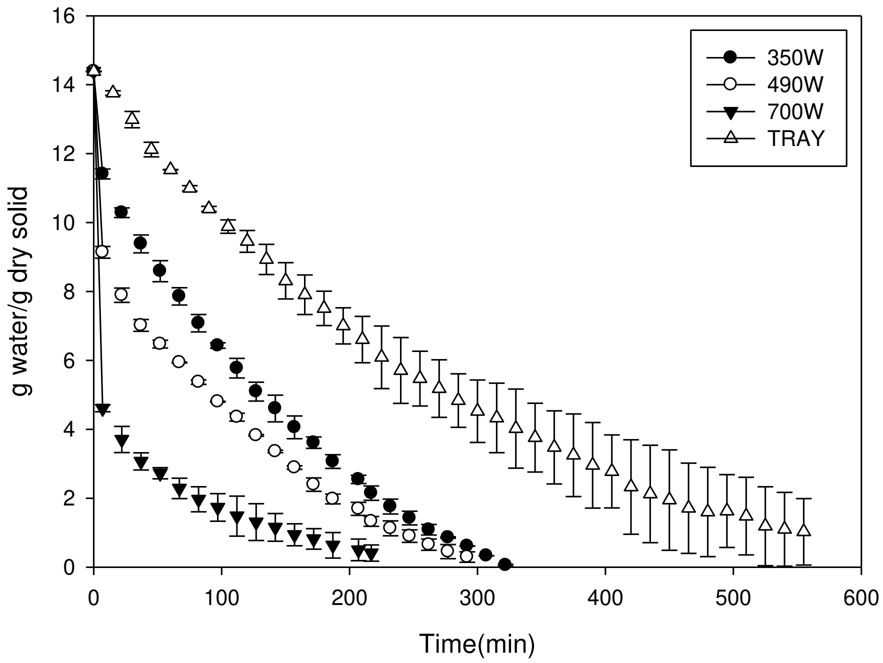

Figure 4.4 Change of moisture content of zucchini with drying time at 50°C and 1.2 m/s air flow rate

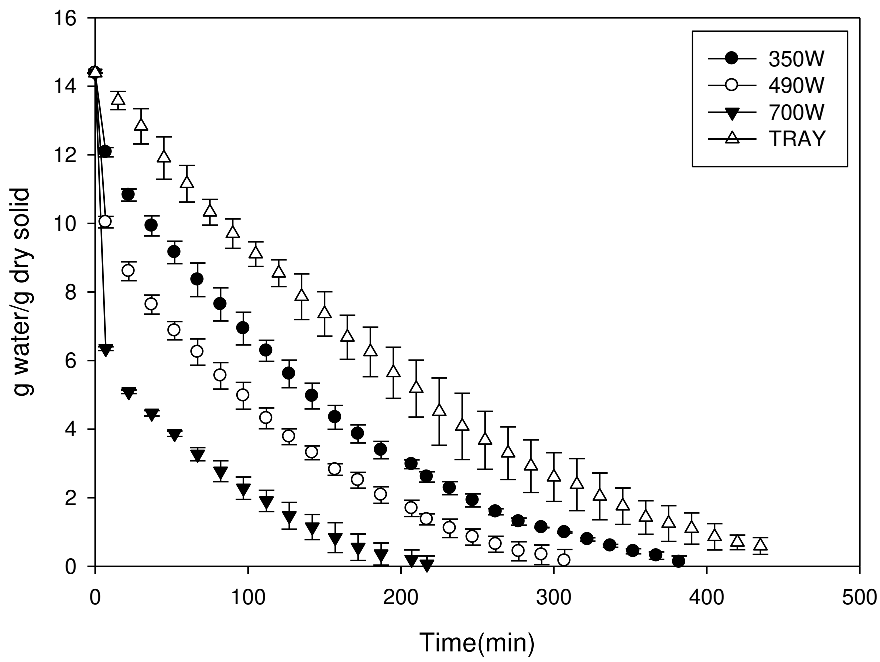

Figure 4.5 Change of moisture content of zucchini with drying time at 60^oC and 1.0 m/s air flow rate

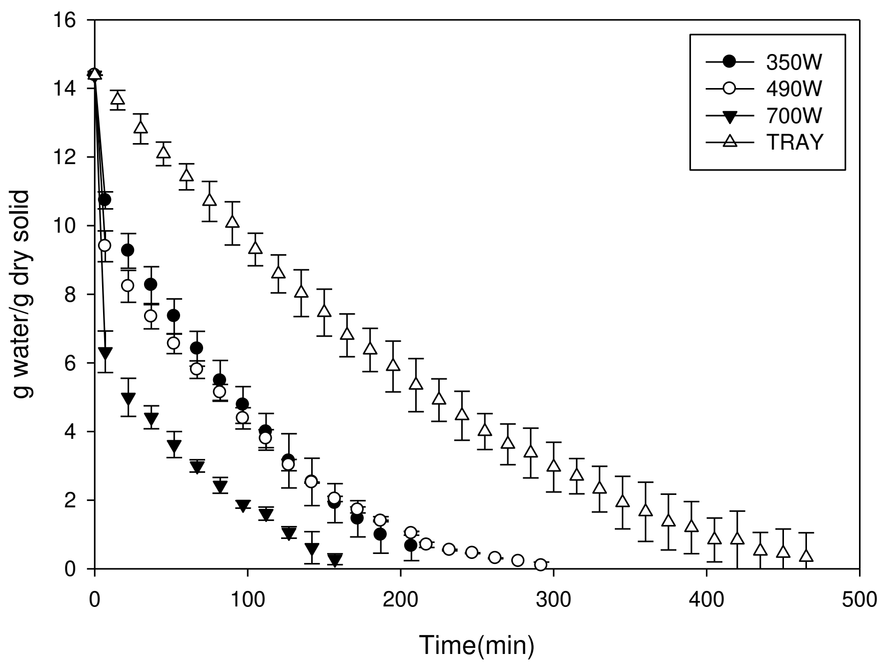

Figure 4.6 Change of moisture content of zucchini with drying time at 60^oC and 1.2 m/s air flow rate

4.1.2 Drying Rate

Change of drying rate of zucchini samples with drying time were shown in Figures 4.7, 4.8, 4.9, 4.10, 4.11 and 4.12. Drying rate versus free moisture content graphs were plotted to understand where drying occurs in these experiments. Figures 4.13, 4.14, 4.15, 4.16, 4.17 and 4.18 shows drying rate versus free moisture contents of zucchini dried at different temperatures and air flow rate with and without microwave pretreatment. All figures showed that drying were occured in falling rate period and controlled by diffusion. Geankoplis mentioned that for drying most of food products movement of water controlled by diffusion at falling rate period (Geankoplis, 2003). Constant rate period not examined. Doymaz (2007) also found same results. Kutlu and Isci (2017) has found falling rate period for convective hot-air drying of zucchini samples, but drying with microwave they observed that both constant rate and falling rate period. Also they mentioned that slice thickness has significance on drying rates. Drying rates decreased by increasing of hot air temperature, air flow rate and microwave pretreatment power levels. Increase in drying time indicates that decrease in drying rates. Mirzaee et al. (2009) has found similar results as in this study which that drying rates higher at the beginning of the drying process and decreasing with drying time. Microwave pretreatment has important effect on drying rate of samples than hot air drying. Andrés et al. (2004) mentioned that application of microwave pretreatment at the beginning of drying process evaporation is higher due to initially sample is cold and heating of sample by microwave pretreatment helps to hot air drying. For microwave pretreatment power level at 350 and 490 W change in drying rates were nonsignificant.

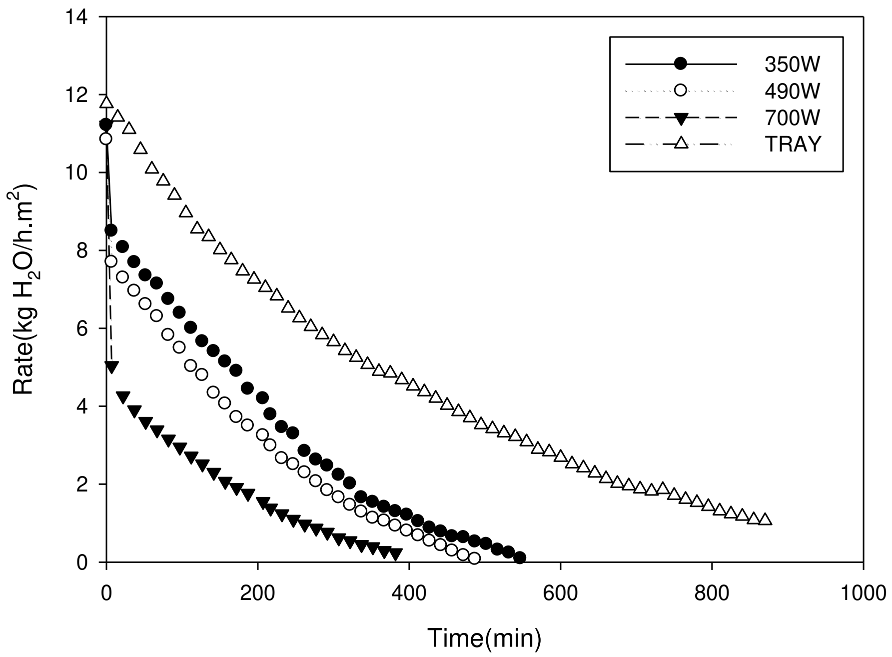

Figure 4.7 Change of drying rate of zucchini with drying time at 40°C and 1.0 m/s air flow rate

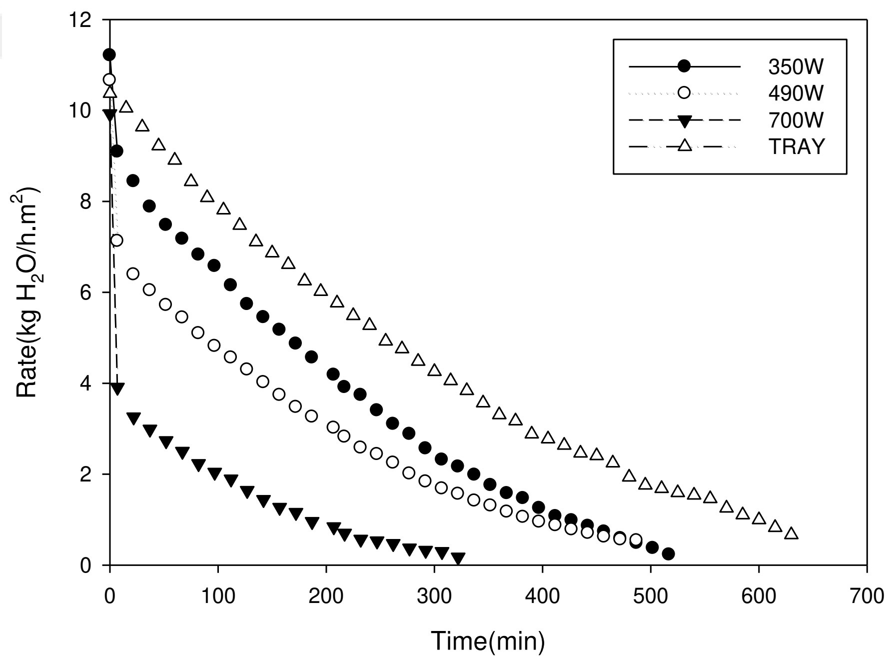

Figure 4.8 Change of drying rate of zucchini with drying time at 40°C and 1.2 m/s air flow rate

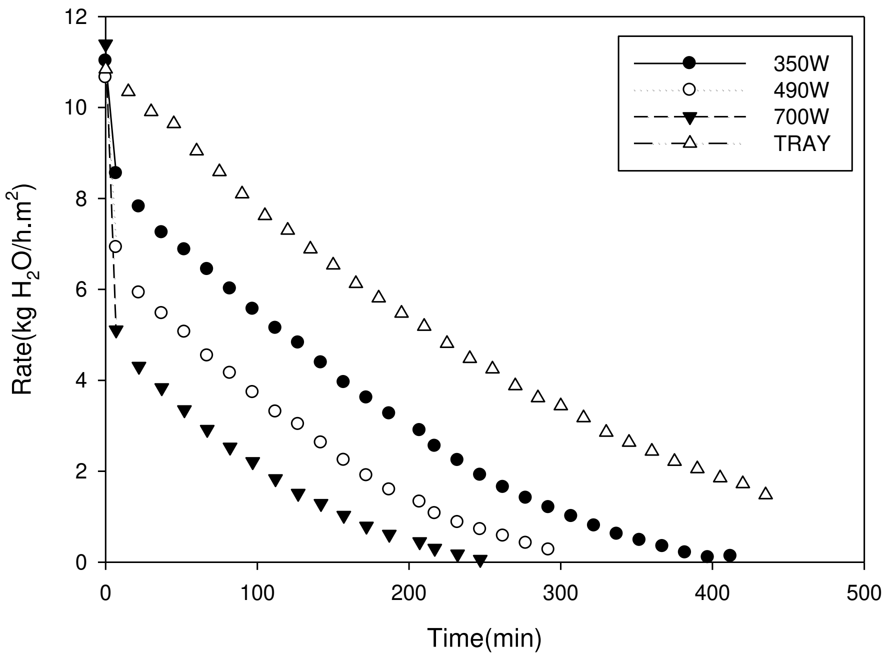

Figure 4.9 Change of drying rate of zucchini with drying time at 50°C and 1.0 m/s air flow rate

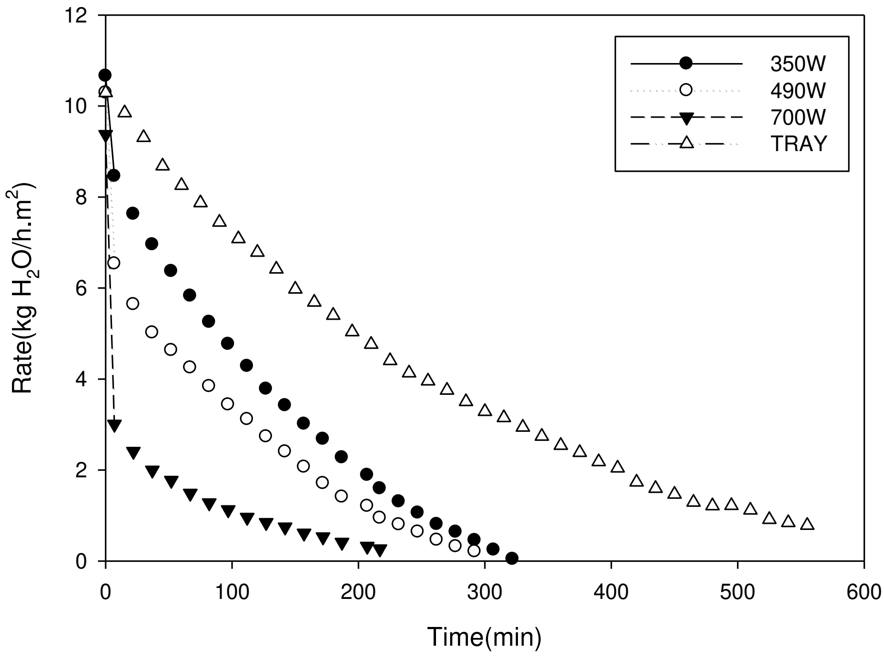

Figure 4.10 Change of drying rate of zucchini with drying time at 50°C and 1.2 m/s air flow rate

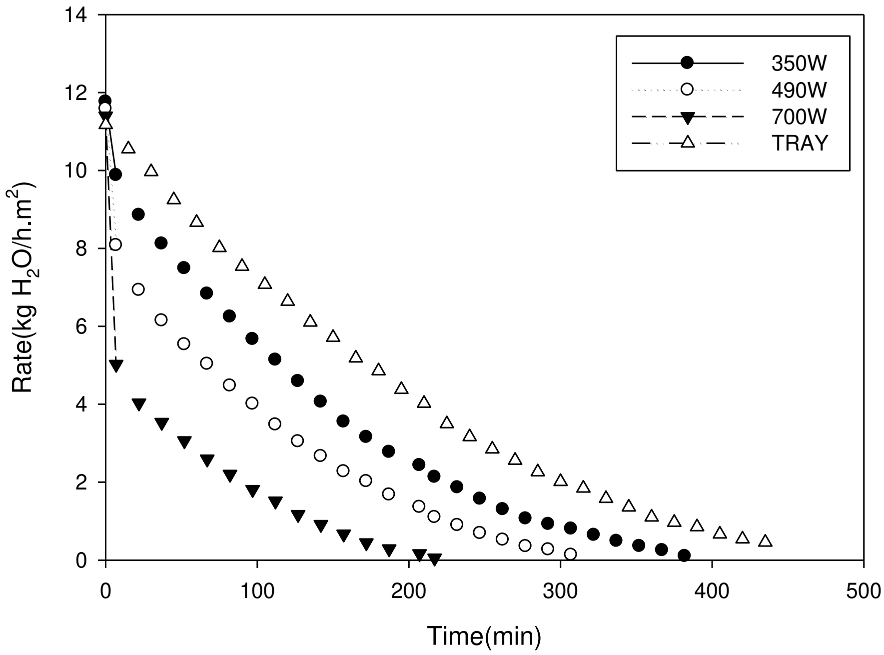

Figure 4.11 Change of drying rate of zucchini with drying time at 60°C and 1.0 m/s air flow rate

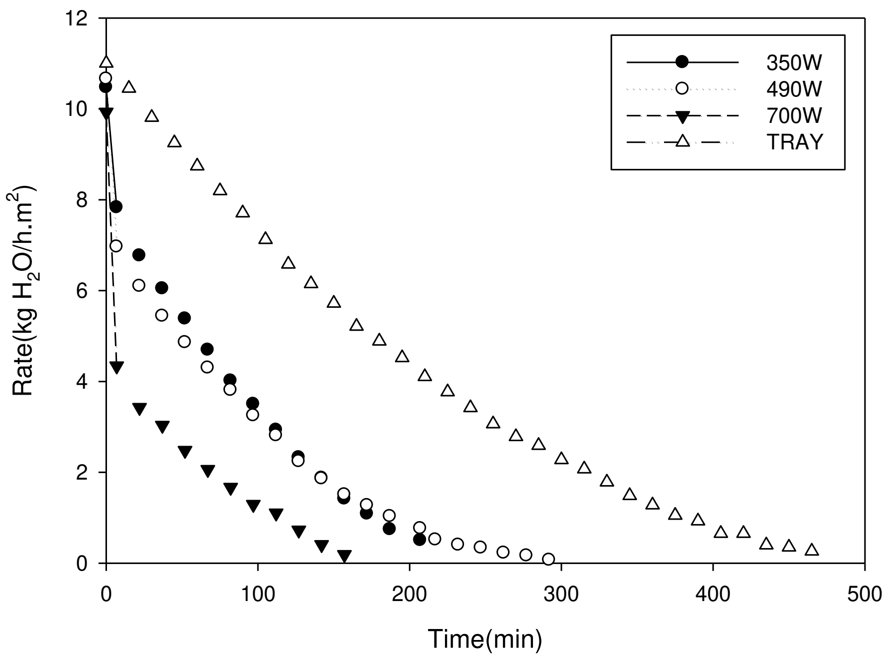

Figure 4.12 Change of drying rate of zucchini with drying time at 60°C and 1.2 m/s air flow rate

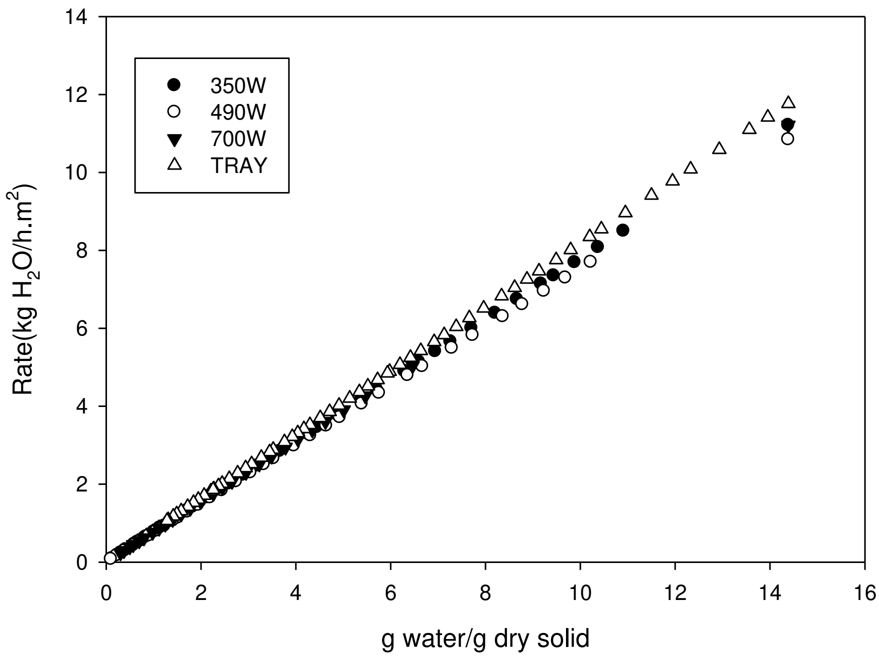

Figure 4.13 Change of drying rate with free moisture content at 40^{o}C and 1.0 m/s air flow rate

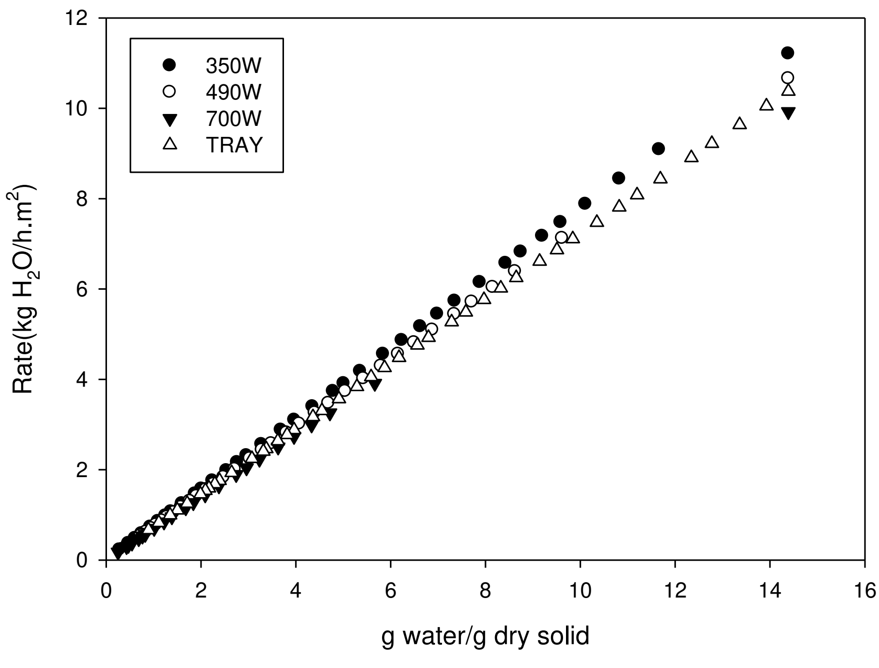

Figure 4.14 Change of drying rate with free moisture content at 40^{o}C and 1.2 m/s air flow rate

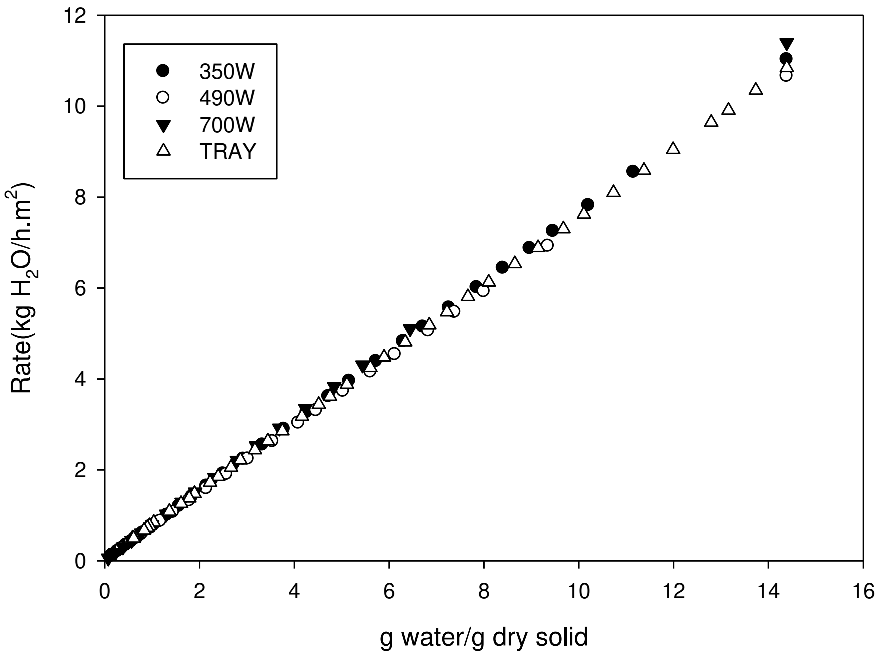

Figure 4.15 Change of drying rate with free moisture content at 50^{o}C and 1.0 m/s air flow rate

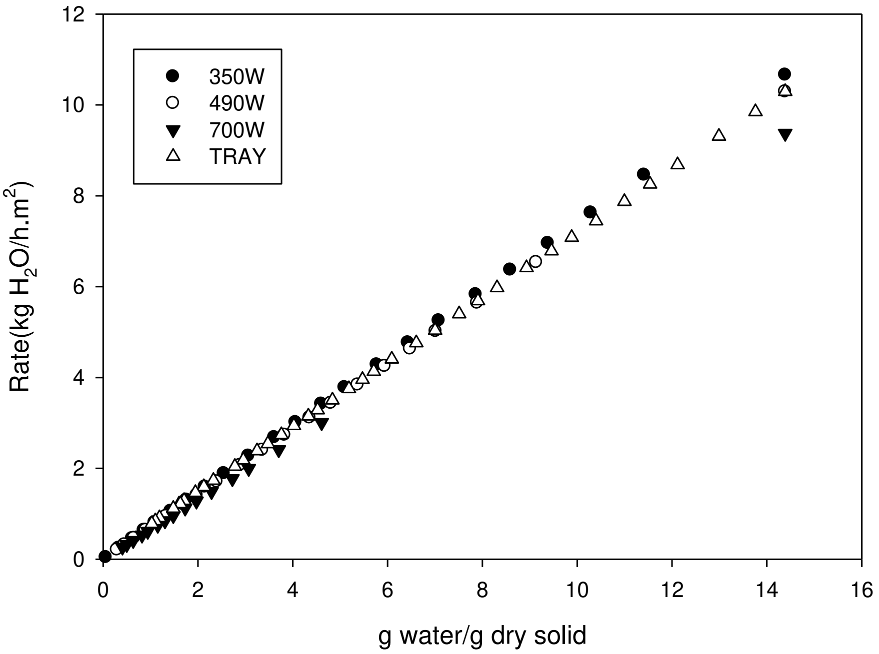

Figure 4.16 Change of drying rate with free moisture content at 50^{o}C and 1.2 m/s air flow rate

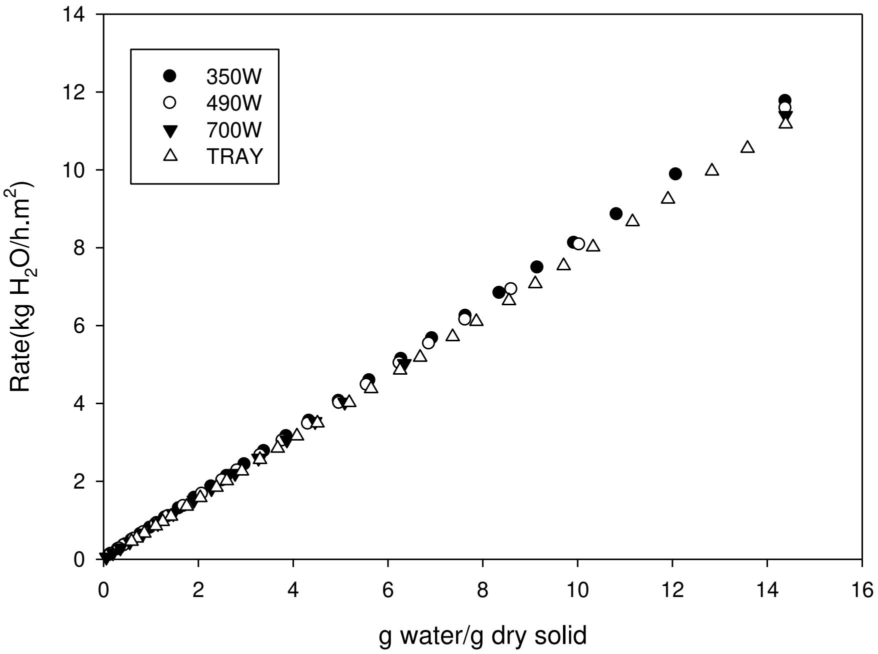

Figure 4.17 Change of drying rate with free moisture content at 60^{o}C and 1.0m/s air flow rate

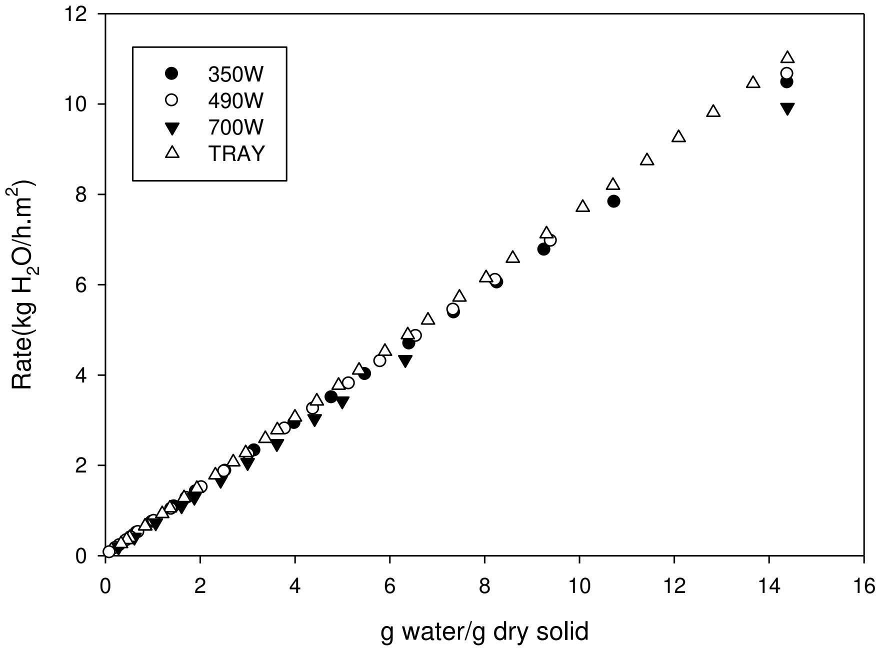

Figure 4.18 Change of drying rate with free moisture content at 60^{o}C and 1.2 m/s air flow rate

4.1.3 Effective Moisture Diffusivity (D_{eff})

Moisture ratio was defined by Equation 2.5. Equilibrium mosture content (X_e) was relatively small number with comperad to X and X_0 and moisture ratio graphs was plotted by using Equation 2.5. Doymaz (2004) and Contreras et al. (2008) were used simplified form of moisture ratio equation (Equation 2.6). Change of moisture ratio of zucchini samples with drying time were shown in Figures 4.19, 4.20, 4.21, 4.22, 4.23 and 4.24. Moisture ratio decreased with increasing temperature, air flow rate and increase in microwave power level. Increase in microwave power level shows that significant reduction in moisture ratio more than hot air dried samples.

Natural logarithm of moisture ratio versus time was plotted in order to find D_{eff} values. Equation 2.9 was used to find a plot of a straight line with a negative slope of k_0. From Equation 2.10 which D_{eff} value can be estimated. Effective moisture diffusivity is an important parameter for food and agricultural products in order to modeling the mass transfer properties as surface absorption and moisture desorption (Motevali et al., 2012). Change of natural logarithm of moisture ratio of zucchini samples with drying time were shown in Figures 4.25, 4.26, 4.27, 4.28, 4.29 and 4.30. D_{eff} values were found by using two linear slope of natural logarithm of moisture ratio graps of each sample, because of two falling rate was observed. Determined D_{eff} values were shown in Tables 4.1 and 4.2. D_{eff} values were ranges between $1.54*10^{-10}$ and $2.75*10^{-9}$ m^2/s and confidence intervals were ranges between 0.9815 and 0.9986. Minimum D_{eff} values was found at $1.54*10^{-10}$ m^2/s at 40°C at 1.0 m/s air flow rate and maximum D_{eff} values was found at $2.75*10^{-9}$ m^2/s at 60°C at 1.2 m/s air flow rate. D_{eff} values were increased with increase in hot air temperature, air flow rate and microwave power level. And also it is observed that D_{eff2} values were higher than D_{eff1} values. Change in D_{eff} values at microwave power level at 350 and 490 W were close to each other, but at microwave power level at 700 W D_{eff} values are higher than others, especially difference between other microwave power levels at D_{eff2} values this difference is greater than D_{eff1} values. Generally it is expected that D_{eff} values ranges in between 10^{-11} to 10^{-9} m^2/s (Doymaz, 2007). In this study experimental values were in this range.

Doymaz (2007) was reported D_{eff} values of $3.8*10^{-10}$ m^2/s at 50°C and $9.38*10^{-10}$ m^2/s at 60°C and 1.0 m/s air flow rate at hot air drying for zucchini. In our experiment for hot air drying at 50^{o}C and 1.0 m/s air flow rate 2.32*10^{-10} and 4.17*10^{-10} m^2/s and hot air drying at 60^{o}C at 1.0 m/s air flow rate 2.97*10^{-10} and 5.87*10^{-10} m^2/s for D_{eff1} and D_{eff2} values were found. Effective moisture diffusivity values at 50^{o}C for D_{eff1} value is less than and D_{eff2} values higher than Doymaz (2007) results. Effective moisture diffusivity values at 60^{o}C D_{eff1} and D_{eff2} values were less than Doymaz (2007) results.

The effective moisture diffusivity values was found for apple (*cv. Starking*) in range of 2.27*10^{-10} to 4.97*10^{-10} m^2/s at drying experiments 40, 50 and 60^{o}C and air flow rate at 0.8 m/s (Sacilik and Elicin, 2006). Compared to this study in our experiment D_{eff1} values were found close to this range, but D_{eff2} values were higher than this study.

Guiné et al. (2011) was found effective moisture diffusivity values for convective drying of pumpkin (*Cucurbita maxima*) varies between 4.08*10^{-8} m^2/s at 30^{o}C and 2.35*10^{-7} m^2/s at 70 ^{o}C and air flow rate 300 m^3/h. Compared to this study in our experiment D_{eff1} values and D_{eff2} values were found less than this range.

Tavakolipour et al. (2014) was found that effective moisture diffusivity values for zucchini hot air drying temperature of 60^{o}C 1.85*10^{-8}, 4.18*10^{-8} and 5.41*10^{-8} m^2/s for slice thicknesses of 3, 5 and 7 mm, respectively. D_{eff1} values and D_{eff2} values were found in our study were less than compared to this study.

Kutlu and Isci (2017) determined effective moisture diffusivity values for zucchini convective hot air temperatures at 60, 70 and 80°C air flow rate at 2.0 m/s 0.58*10^{-9}, 0.84*10^{-9} and 1.12*10^{-8} m^2/s, respectively for slice thickness 5mm. Compared to this study in our experiment for hot air drying at 60^{o}C air flow rate at 1.0m/s D_{eff1} value was 2.97*10^{-10} m^2/s is less than 0.58*10^{-9} m^2/s, but D_{eff2} value was found as 5.87*10^{-10} m^2/s which was nearly same result. And also for hot air drying at 60^{o}C air flow rate at 1.2 m/s D_{eff1} value was 3.13*10^{-10} m^2/s is less than 0.58*10^{-9} m^2/s, but D_{eff2} value was found as 6.34*10^{-10} m^2/s which higher than this study.

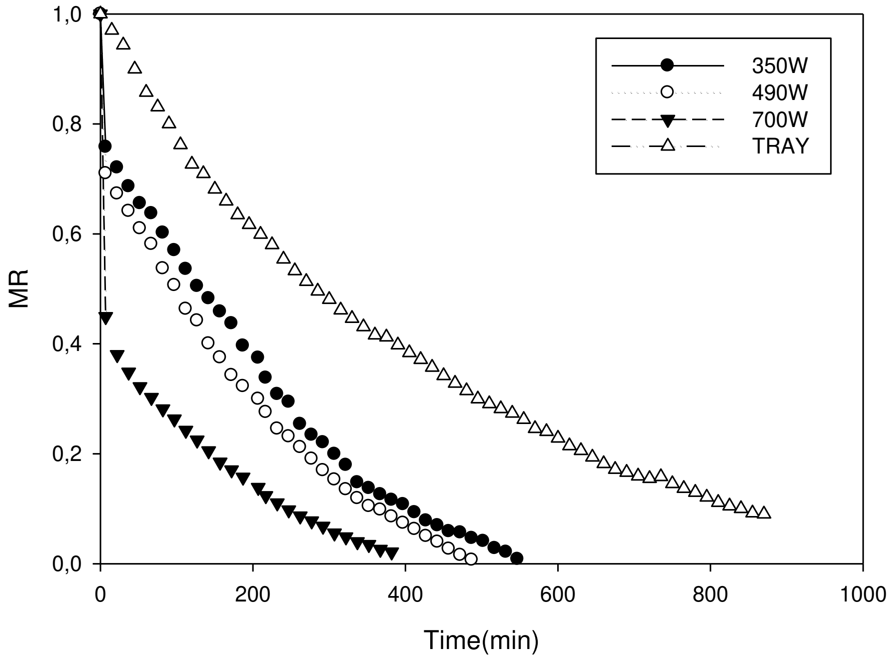

Figure 4.19 Change of moisture ratio of zucchini with drying time at 40^{o}C and 1.0 m/s air flow rate

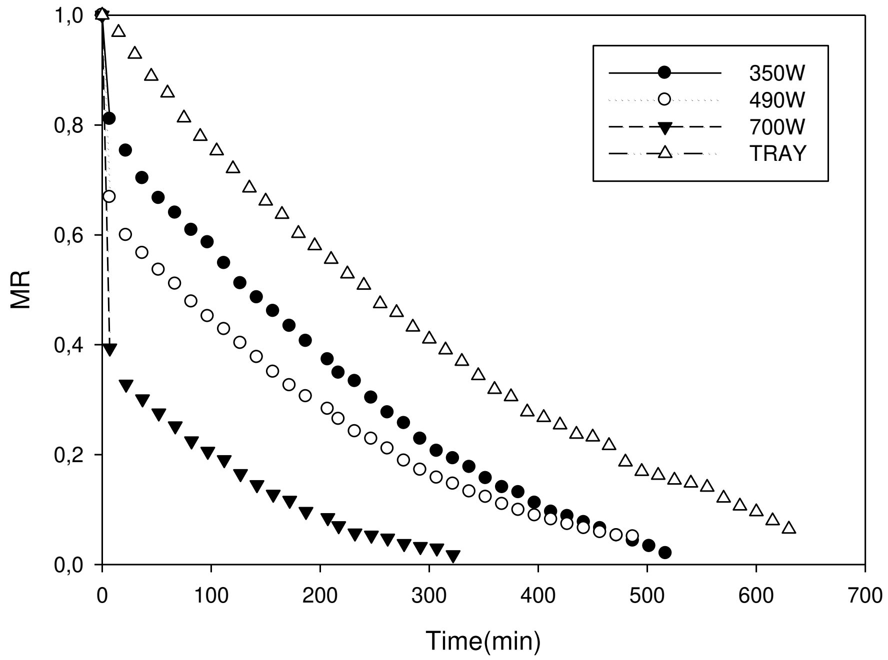

Figure 4.20 Change of moisture ratio of zucchini with drying time at 40^{o}C and 1.2 m/s air flow rate

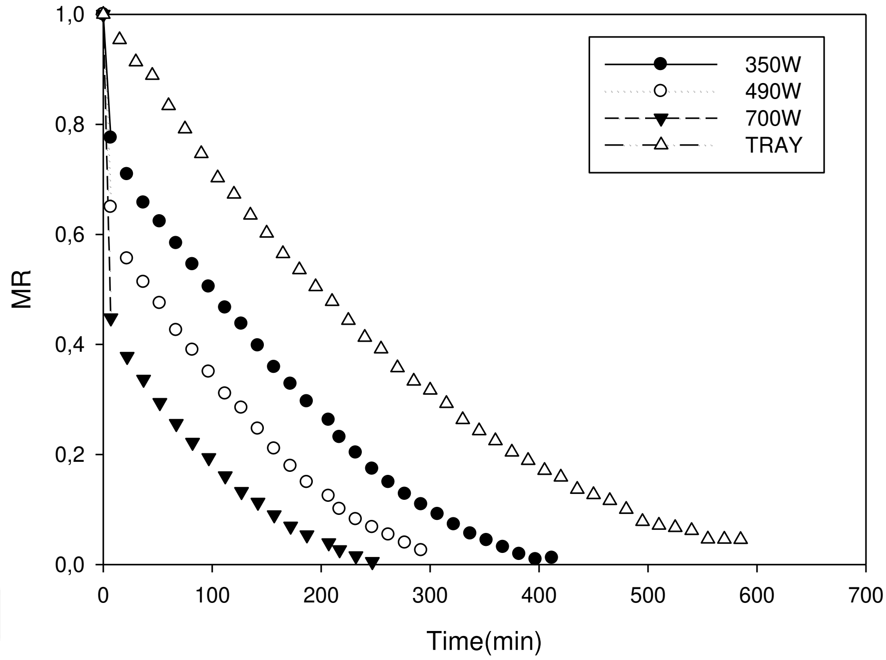

Figure 4.21 Change of moisture ratio of zucchini with drying time at 50^{o}C and 1.0 m/s air flow rate

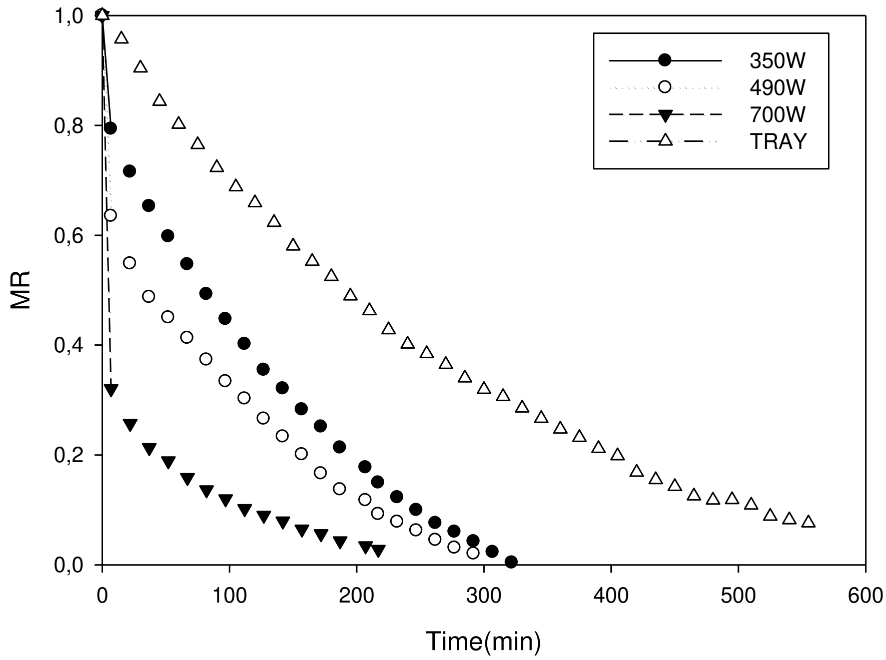

Figure 4.22 Change of moisture ratio of zucchini with drying time at 50^{o}C and 1.2 m/s air flow rate

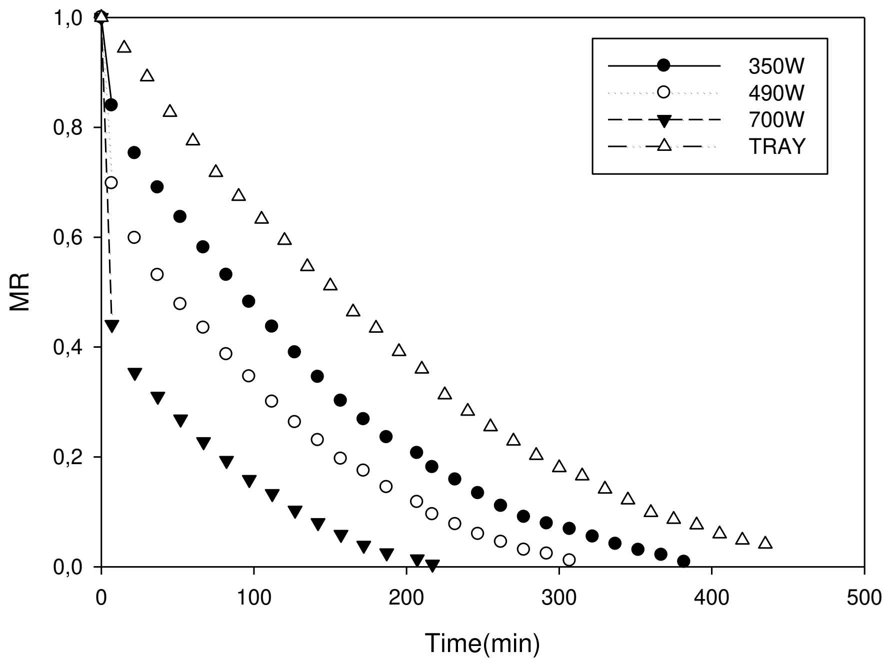

Figure 4.23 Change of moisture ratio of zucchini with drying time at 60°C and 1.0 m/s air flow rate

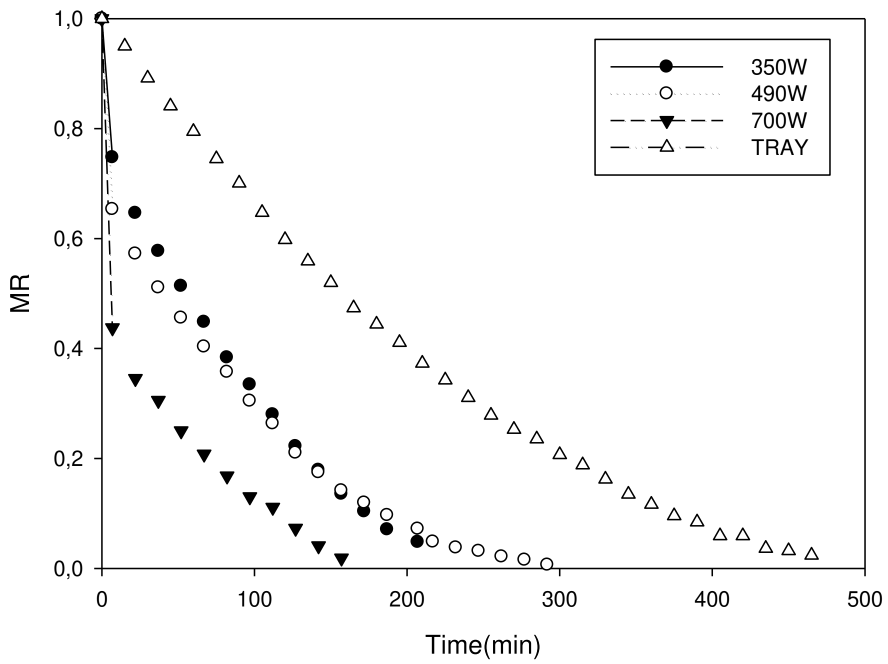

Figure 4.24 Change of moisture ratio of zucchini with drying time at 60°C and 1.2 m/s air flow rate

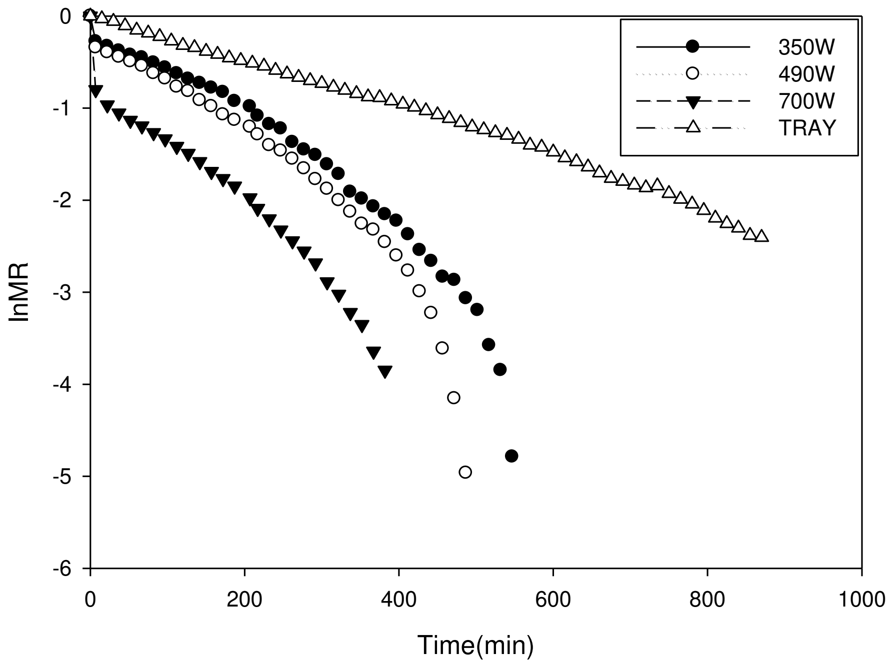

Figure 4.25 Natural logarithm of moisture ratio versus time graph at 40°C and 1.0 m/s air flow rate

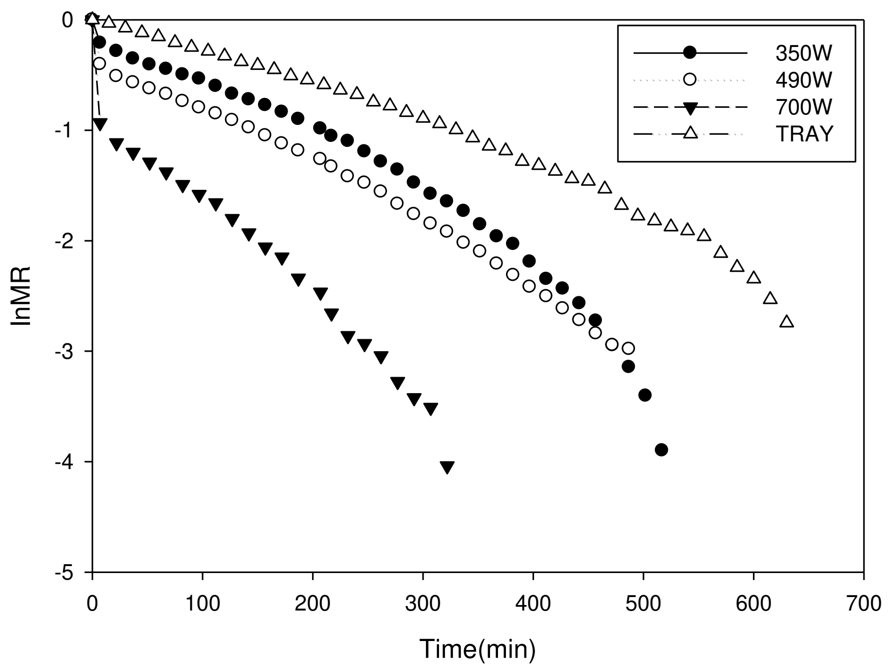

Figure 4.26 Natural logarithm of moisture ratio versus time graph at 40°C and 1.2 m/s air flow rate

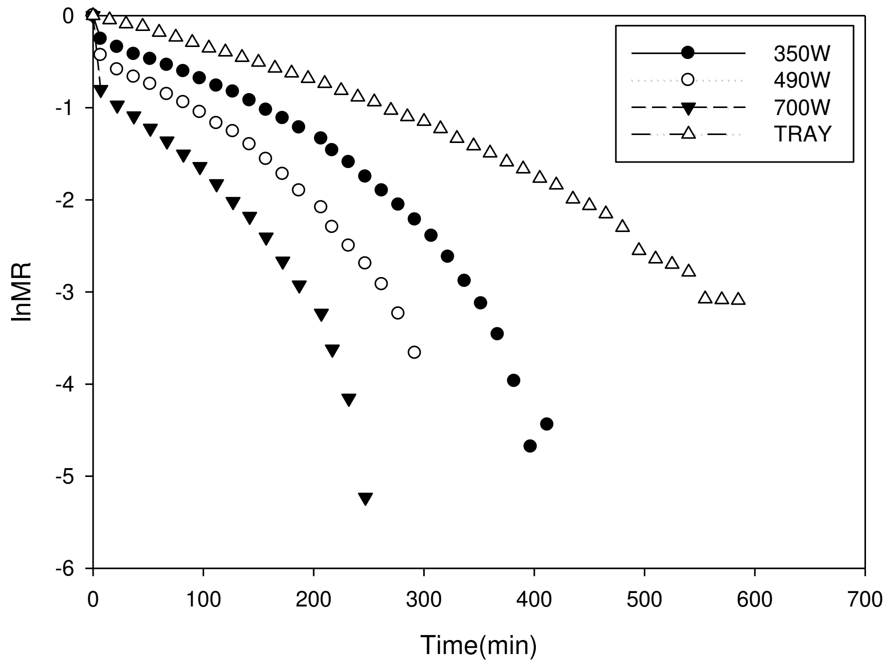

Figure 4.27 Natural logarithm of moisture ratio versus time graph at 50^{o}C and 1.0 m/s air flow rate

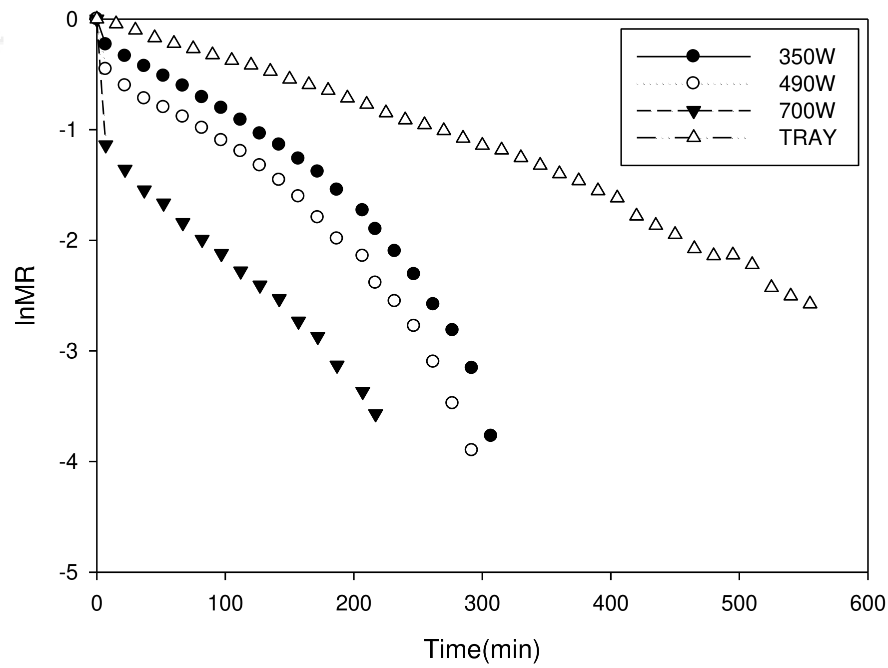

Figure 4.28 Natural logarithm of moisture ratio versus time graph at 50^{o}C and 1.2 m/s air flow rate

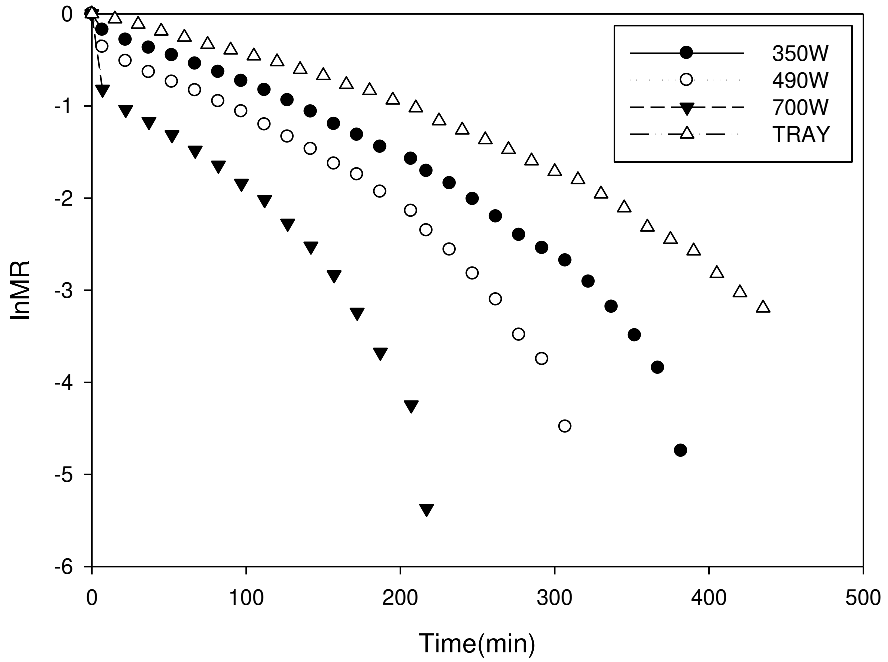

Figure 4.29 Natural logarithm of moisture ratio versus time graph at 60^{o}C and 1.0 m/s air flow rate

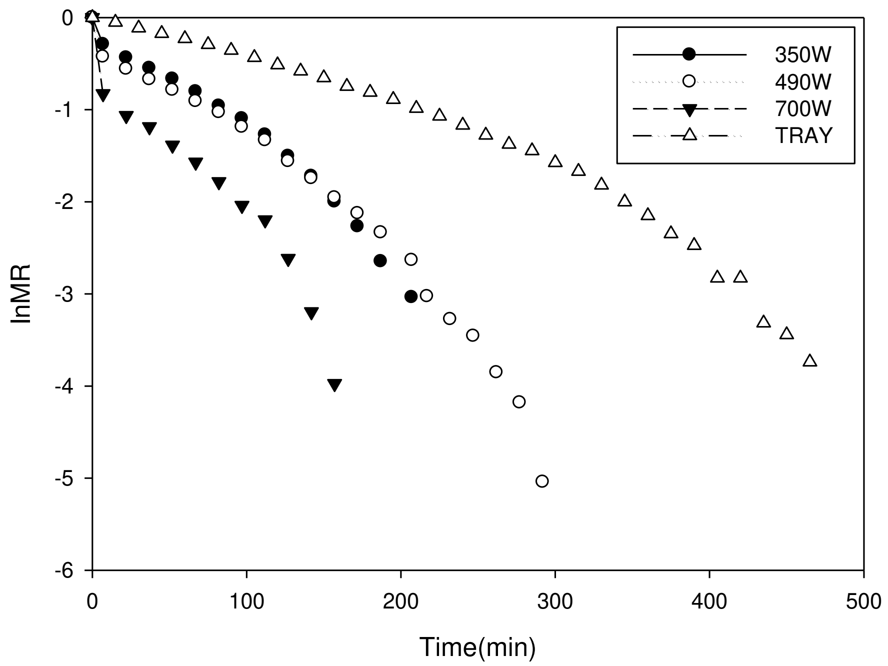

Figure 4.30 Natural logarithm of moisture ratio versus time graph at 60^{o}C and 1.2 m/s air flow rate

Table 4.1 Effective moisture diffusivity values of zucchini drying at 1.0 m/s air flow rate

Drying Temperature		D_{eff1} *10^{-10} (m^2/s)	R^2	D_{eff2} *10^{-10} (m^2/s)	R^2
40°C	Tray	1.54	0.9960	2.53	0.9939
	350 W	2.38	0.9866	4.65	0.9924
	490 W	2.79	0.9942	5.07	0.9816
	700 W	3.33	0.9940	6.19	0.9828
50°C	Tray	2.32	0.9963	4.17	0.9869
	350 W	3.25	0.9914	7.36	0.9862
	490 W	4.31	0.9933	8.55	0.9937
	700 W	6.09	0.9954	12.15	0.9918
60°C	Tray	2.97	0.9965	5.87	0.9849
	350 W	4.58	0.9919	8.17	0.9824
	490 W	5.13	0.9956	11.05	0.9903
	700 W	7.04	0.9941	17.38	0.9880

Table 4.2 Effective moisture diffusivity values of zucchini drying at 1.2 m/s air flow rate

Drying Temperature		D_{eff1} *10^{-10} (m^2/s)	R^2	D_{eff2} *10^{-10} (m^2/s)	R^2
40°C	Tray	1.95	0.9934	2.89	0.9817
	350 W	2.49	0.9931	5.04	0.9816
	490 W	2.66	0.9969	3.98	0.9977
	700 W	4.32	0.9950	6.06	0.9918
50°C	Tray	2.37	0.9986	3.71	0.9832
	350 W	4.32	0.9949	9.53	0.9890
	490 W	4.42	0.9945	8.54	0.9900
	700 W	6.15	0.9949	9.46	0.9968
60°C	Tray	3.13	0.9934	6.34	0.9955
	350 W	5.57	0.9962	12.41	0.9879
	490 W	6.44	0.9864	12.03	0.9897
	700 W	7.94	0.9958	27.5	0.9928

4.1.4 Activation Energy (E_a)

Activation energy is calculated by using Arrhenius Equation (Equation 2.10). To determine activation energy, natural logarithm of effective moisture diffusivity versus 1/Temperature in Kelvin graph was plotted for each effective moisture diffusivity values. Plotted graphs were shown for drying at 1.0 and 1.2 m/s at Figure 4.31 and Figure 4.32, respectively. Negative slope of each line at plotted graps gives us ($-E_a/R$) Ea is the activation energy (kJ/mol); R is the universal gas constant with

8.31 kJ/mol K. Calculated activation energy values was shown at Table 4.3. Two activation energy was found for first and second period of falling rate due to activation energy was calculated for each effective moisture diffusivity values. Chayjan et al. (2017) mentioned that activation energy of food products varies in between 12 and 110 kJ/mol. In this study it is observed that activation energy values were in this range. The minimum activation energy was 20.51 kJ/mol at hot air drying at 1.2 m/s, and maximum activation energy was 65.50 kJ/mol at microwave pretreatment at 700 W at 1.2 m/s drying. For hot air drying E_{a1} and E_{a2} values decreased with increasing air velocity from 1.0 to 1.2 m/s. For microwave pretreatment at 350 and 490 W increasing air velocity increased E_{a1} and E_{a2} values. For microwave pretreatment at 700 W increasing air velocity decreased E_{a1} value, but Ea_2 value was increased.

Activation energy is calculated due to activation energy indicates the amount of energy that needed to remove water from zucchinis. Doymaz (2007) found activation enegy of 78.93 kJ/mol at 50, 55 and 60°C at constant air velocity of 1.0 m/s drying for zucchinis. Kutlu and Isci (2017) was found activation energies as 32.58 kj/mol for 5 mm and 36.55 kj/mol for 10 mm samples at drying at 60, 70 and 80°C at constant air velocity of 2.0 m/s for zucchinis. Tunde-Akintunde and Ogunlakin (2011) was found activation energies for pumpkin (*Cucurbita mixta*) as 25.93 kJ/mol at 40, 60 and 80°C at constant air velocity of 1.5 m/s. Kaya et al. (2009) was found activation energy for carrot (*Daucus carota L.*) as 23.00 kJ/mol at 35, 45 and 55°C at velocities of 0.2, 0.4 and 0.6 m/s. Aghbashlo et al. (2008) was found activation energies for berberis fruit (*Berberis vulgaris*) as 110.84, 118.91, 130.61 and 124.36 kJ/mol for air velocities at 0.5, 0.7, 1.0 and 2.0 m/s respectively for hot air drying at 50, 60 and 70°C. Guiné et al. (2011) was found activation energy for convective drying of pumpkin (*Cucurbita maxima*) as 33.74 kJ/mol drying experiment at 30, 40, 50, 60 and 70°C at air flow rate 300m^3/h. Mirzaee et al. (2009) was found activation energies for apricot (*cv. Rajabali*) as 33.78, 30.14 and 29.35 kJ/mol air flow rate at 1.0, 1.5 and 2.0 m/s, respectively at drying air temperatures of 40, 50, 60, 70, and 80°C.

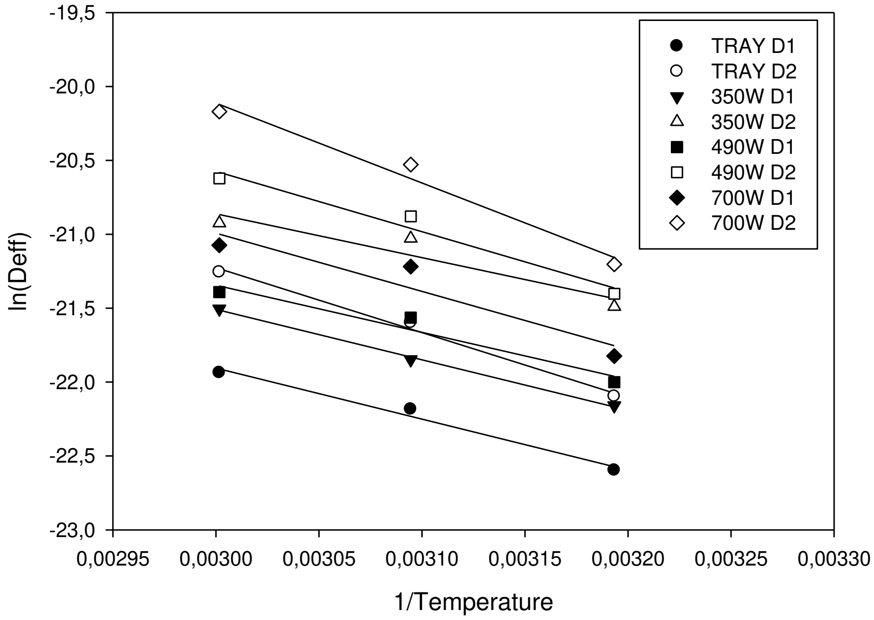

Figure 4.31 Plot of natural logarithm of effective moisture diffusivity versus 1/T at 1.0 m/s air flow rate

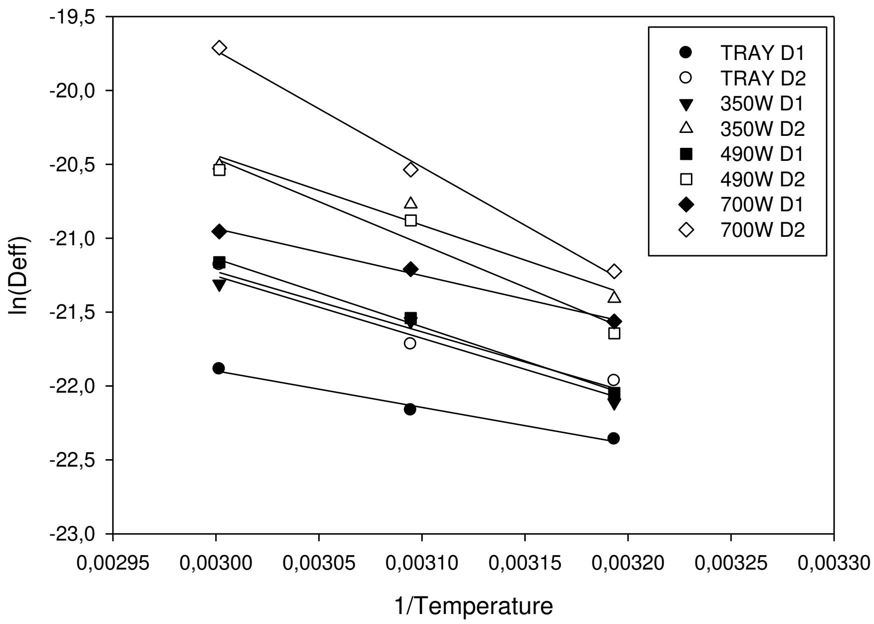

Figure 4.32 Plot of natural logarithm of effective moisture diffusivity versus 1/T at 1.2 m/s air flow rate

Table 4.3 Activation energy values of zucchini drying at 1.0 and 1.2 m/s air flow rate

Air flow rate		E_{a1} (kJ/mol)	R^2	E_{a2} (kJ/mol)	R^2
1.0 m/s	Tray	28.70	0.9841	36.52	0.9921
	350 W	28.34	0.9978	24.64	0.8937
	490 W	26.54	0.9495	33.93	0.9689
	700 W	32.72	0.8992	44.92	0.9754
1.2 m/s	Tray	20.51	0.9868	33.94	0.9495
	350 W	34.96	0.9637	39.24	0.9534
	490 W	38.36	0.9955	48.12	0.9610
	700 W	26.44	0.9945	65.50	0.9951

4.2 Effect of Drying on Physical Properties of Zucchini

4.2.1 Color

Color values of all samples before and after drying process given in Table 4.4 and Table 4.5 for air flow rate of 1.0 and 1.2 m/s, respectively. For each sample, three measurements were taken. L* (whiteness or brightness darkness), a* (redness/greenness) and b* (yellowness/blueness) values were measured from surface of samples. The total color difference (ΔE) between the initial sample and dried ones were calculated by using to the (Equation 3.1). Stastistical analysis were applied to determine effect of application of hot air temperature, microwave pretreatment and air flow rate. Stastistical analysis were calculated for each constant air flow rate and hot air temperature due to there are no noticable change observed by calculation of constant microwave power level and constant air flow rate.

For L* value there were significant ($p<0.05$) difference in drying with air flow rate of 1.0 m/s at 40 and 60°C with air flow rate of 1.2 m/s the significant ($p<0.05$) change was observed only at 60°C. From the Table 4.4 and Table 4.5 it is observed that the lightness value decreased with compared to control value for all experiments. And also this decrease was less than compared to hot air drying and microwave pretreatment where hot air temperature is 60°C and air flow rate is 1.0 m/s for microwave pretreatment at 700 W. Same trend was also observed at air flow rate at 1.2 m/s for microwave pretreatment at 350 W at hot air temperature of 50 and 60°C.

For the redness/greenness value (a*), there were significant change observed ($p<0.05$) for both air flow rates and nearly all hot air temperatures, except air flow rate at 1.0 m/s and hot air temperaure at 60^{o}C. The redness/greenness values were increased with increase in hot air temperature, air flow rate and microwave pretreatment power level. This increase is less than other samples for air flow rate of 1.0 m/s and microwave pretreatment of 490 W and hot air temperature of 40 and 50^{o}C. Similar change was observed for hot air temperature at 50^{o}C and air flow rate of 1.2 m/s for microwave pretreatment at 490 W.

For the yellowness/blueness value (b*), there were significant change observed ($p<0.05$) for both air flow rates and almost all hot air temperatures, except air flow rate at 1.2 m/s and hot air temperaure of 50^{o}C. From the Table 4.4 and Table 4.5 it is observed that the yellowness/blueness values were increased for most of the samples. There was only one sample at hot air temperaure of 50^{o}C and air flow rate of 1.0 m/s that the yellowness/blueness value was decreased.

For total color difference (ΔE), there were significant ($p<0.05$) change observed for samples dried with both air flow rates and nearly all hot air temperatures, except air flow rate at 1.0 m/s and hot air temperature of 50^{o}C. The total color difference (ΔE) at air flow rate of 1.0 m/s for hot air drying temperature at 40 and 50^{o}C close to each other, but temperature at 60^{o}C greater than them. The total color difference (ΔE) at air flow rate of 1.2 m/s increased with increasing temperatures. For microwave pretreatment at 350 W total color difference (ΔE) was decrease with increasing hot air temperatures and increasing air flow rate except, drying temperature of 60^{o}C and air flow rate of 1.2 m/s.

For microwave pretreatment at 490 W total color difference (ΔE) was increased with increasing hot air temperatures and increasing air flow rate. For microwave pretreatment at 700 W total color difference (ΔE) was decreased with increasing hot air temperatures and increasing air flow rate except, drying temperature at 50^{o}C and air flow rate of 1.2 m/s. Alibas (2007) found color values near to fresh product after drying of pumpkin (*Cucurbita maxima*) by application of microwave pretreatment at 350 W, hot air temperature at 75^{o}C and air flow rate of 1.0 m/s. Nawirska et al. (2009) reported the lightness (L*) values varied from 56.91 to 86.11, and the redness/greenness value (a*) varied from 3 to 17 and the yellowness/blueness value (b*) varied from 32 to 48 for convection drying of pumpkin species (*Cucurbita maxima* and *Cucurbita pepo*) at hot air temperature of 60^{o}C and air flow rate of 1.0 m/s.

Table 4.4 Changes of color values of zucchini dried at 1.0 m/s air flow rate

Drying Temperature		L*	a*	b*	ΔE
	Control	82.53	-0.51	30.01	-
40^{o}C	Tray	70.80±0.99^{a}	1.15±0.15^{a}	33.30±1.72^{a}	15.62±0.87^{a}
	350 W	60.15±0.23^{b}	2.57±0.21^{b}	39.99±0.56^{c}	21.90±0.03^{b}
	490 W	69.86±0.88^{a}	-0.16±0.27^{c}	31.63±0.92^{a}	14.68±0.48^{a}
	700 W	61.06±0.07^{b}	1.68±0.26^{a}	36.77±0.62^{b}	23.89±0.15^{c}
50^{o}C	Tray	69.08±2.00^{a}	2.07±0.34^{a}	28.14±0.62^{a}	14.95±2.01^{a}
	350 W	63.37±3.46^{a}	3.18±1.37^{a}	34.65±1.10^{c}	18.43±3.03^{a}
	490 W	65.97±2.83^{a}	-1.01±0.19^{b}	31.70±0.23^{b}	20.80±2.79^{a}
	700 W	66.72±2.81^{a}	3.45±0.17^{a}	37.78±3.87^{d}	16.64±3.03^{a}
60^{o}C	Tray	64.78±2.02^{a}	1.45±0.25^{a}	30.76±1.33^{a}	18.10±2.30^{a}
	350 W	67.37±0.64^{a,c}	1.91±1.14^{a}	38.65±1.42^{c}	14.81±1.15^{a,c}
	490 W	58.88±2.69^{b}	1.42±0.39^{a}	35.88±0.37^{b,c}	24.30±2.64^{b}
	700 W	72.56±2.10^{c}	2.02±1.24^{a}	33.65±0.47^{b}	10.60±2.30^{c}

Table 4.5 Changes of color values of zucchini dried at 1.2 m/s air flow rate

Drying Temperature		L*	a*	b*	ΔE
	Control	82.53	-0.51	30.01	-
40^{o}C	Tray	74.22±0.85^{a}	2.17±0.10^{a}	34.02±0.06^{a}	8.14±0.84^{a}
	350 W	70.84±1.13^{a}	0.19±0.54^{b}	33.52±0.69^{a}	16.01±0.56^{b,c}
	490 W	71.85±3.95^{a}	0.73±0.35^{b}	38.67±1.07^{b}	11.51±3.93^{a,b}
	700 W	67.43±2.70^{a}	0.17±0.67^{b}	37.71±2.46^{b}	19.89±2.68^{c}
50^{o}C	Tray	70.43±1.78^{a}	1.97±0.37^{a}	32.65±0.01^{a}	13.52±1.82^{a}
	350 W	70.75±1.14^{a}	-0.66±0.11^{c}	33.81±1.77^{a,b}	13.34±0.59^{a}
	490 W	65.34±0.15^{a}	0.82±0.09^{b}	36.22±0.90^{b}	18.92±0.15^{b}
	700 W	65.32±3.65^{a}	0.84±0.48^{b}	34.73±0.82^{a,b}	21.31±3.12^{b}
60^{o}C	Tray	64.01±0.30^{a}	3.63±0.28^{a}	31.90±0.25^{a}	18.81±0.41^{a}
	350 W	70.84±2.11^{b}	1.28±0.29^{b}	38.31±0.81^{b}	17.57±2.02^{a}
	490 W	60.93±0.59^{a}	1.36±0.66^{b}	38.01±2.18^{b}	24.82±0.60^{b}
	700 W	63.98±3.20^{a}	2.74±0.48^{a}	37.72±1.12^{b}	18.25±2.66^{a}

4.2.2 Shrinkage and Bulk Density

Shrinkage and bulk density were determined using a graduated cylinder of 500 mL. The zucchini samples were placed in the graduated cylinder, which was gently shaken. Measurements were conducted when the samples occupied the smallest possible volume. Drying shrinkage was calculated by using Equation 3.2 and bulk density was calculated by using Equation 3.3. The mass of the fresh and dried sample and volume of fresh slices and dried slices were recorded in order to calculate bulk density and shrinkage. For each sample, two measurements were taken. Shrinkage and bulk density values of all samples given in Table 4.6 for air flow rate at 1.0 m/s and for air flow rate at 1.2 m/s in Table 4.7. Statistical analysis were done for each constant air flow rate and constant hot air temperature seperately.

For shrinkage values there were significant ($p<0.05$) change observed for samples dried at hot air temperature of 50^{o}C and air flow rate of 1.0 m/s and hot air temperature of 60^{o}C at air flow rate of 1.2 m/s. Shrinkage values varies in between 0.75 and 0.80. It is observed from table that shrinkage values are very close to each other.

Nawirska et al. (2009) was found shrinkage values for convective drying of pumpkin (*Cucurbita maxima* and *Cucurbita pepo*) slices at 60^{o}C and air flow rate of 1.0 m/s ranges between 0.60 and 0.82. Lewicki and Jakubczyk (2004) reported shrinkage values for convective drying of apple slices 0.58±0.01, 0.56±0.01, 0.54±0.02 and 0.49±0.01 at 1.7 m/s air flow rate for 50, 60, 70 and 80^{o}C respectively. For shrinkage values, we found nearly same results with Nawirska et al. (2009) which studied drying of variety of pumpkin types. But our results were higher than the results found for drying of apples (Lewicki and Jakubczyk, 2004).

For bulk density values there were significant ($p<0.05$) change observed for only one sample which was hot air temperature at 40^{o}C and air flow rate of 1.2 m/s. From the Table 4.6 and Table 4.7 it is observed that increase in microwave pretreatment power level cause decrease in bulk density values for most of samples. Nawirska et al. (2009) was found bulk density values for convective drying of pumpkin (*C. maxima* and *C. pepo*) slices at 60^{o}C and air flow rate at 1.0 m/s ranges in between 60 and 190 kg/m^{3} (which were 0.06 and 0.19 g/mL). In this experiments the minimum bulk density was found 0.21±0.02 g/mL at hot air temperature at 50^{o}C at air flow rate at 1.2 m/s at microwave pretreatment power level at 700 W. The maximum bulk density was found 0.41±0.01 g/mL at hot air temperature of 40^{o}C and air flow rate of 1.2 m/s. Our result for hot air temperature at 60^{o}C and air flow rate at 1.0 m/s was 0.23±0.07 g/mL and this value is very close to Nawirska et al. (2009) experiment results.

Table 4.6 Shrinkage and bulk density values of zucchini dried at 1.0 m/s air flow rate

Drying Temperature		Shrinkage	Bulk Density (g/mL)
40^{o}C	Tray	0.76±0.01[a]	0.34±0.08[a]
	350 W	0.77±0.02[a]	0.30±0.00[a]
	490 W	0.76±0.00[a]	0.22±0.00[a]
	700 W	0.76±0.00[a]	0.28±0.00[a]
50^{o}C	Tray	0.75±0.02[a]	0.22±0.10[a]
	350 W	0.80±0.02[c]	0.28±0.02[a]
	490 W	0.79±0.00[b,c]	0.30±0.05[a]
	700 W	0.77±0.02[a,b]	0.26±0.02[a]
60^{o}C	Tray	0.79±0.00[a]	0.23±0.07[a]
	350 W	0.76±0.00[c]	0.25±0.01[a]
	490 W	0.79±0.00[b]	0.28±0.01[a]
	700 W	0.78±0.02[c]	0.25±0.01[a]

Table 4.7 Shrinkage and bulk density values of zucchini dried at 1.2 m/s air flow rate

Drying Temperature		Shrinkage	Bulk Density (g/mL)
40^{o}C	Tray	0.78±0.02[a]	0.41±0.01[a]
	350 W	0.79±0.01[a]	0.32±0.06[a,b]
	490 W	0.78±0.00[a]	0.31±0.04[a,b]
	700 W	0.78±0.01[a]	0.25±0.01[b]
50^{o}C	Tray	0.80±0.01[a]	0.32±0.07[a]
	350 W	0.79±0.01[a,b]	0.27±0.01[a,b]
	490 W	0.77±0.01[a,b]	0.31±0.01[a.b]
	700 W	0.76±0.02[b]	0.21±0.02[b]
60^{o}C	Tray	0.77±0.00[a]	0.26±0.06[a]
	350 W	0.79±0.02[a]	0.33±0.05[a]
	490 W	0.78±0.00[a]	0.25±0.02[a]
	700 W	0.78±0.02[a]	0.27±0.08[a]

CONCLUSION

In this study, zucchini was dried with hot air at three different temperatures (40, 50 and 60°C) and two different air flow rates (1.0 and 1.2 m/s). Microwave pretreatments were performed at three different power levels (350, 490 and 700 W) for 7 minutes.

We can conclude that:

- Increase in hot air temperature and increase in air flow rate reduced drying times.
- Microwave pretreatment affected drying times with combination of hot air and drying times were shortened. Increase in microwave pretreatment power level was also affected drying times. The shortest drying time was found 157 minutes for hot air drying at 60°C and 1.2 m/s air flow rate and 700W microwave pretreatment.
- Drying rate graphs showed that drying were occured in falling rate period and controlled by diffusion. Constant rate period was not observed for all samples. Drying rates decreased by increasing hot air temperature, air flow rate and microwave pretreatment power levels.
- Two effective moisture diffusivity values were found in this study due to there were two falling rate period observed. D_{eff} values were ranges between $1.54*10^{-10}$ and $2.75*10^{-9}$ m^2/s.
- The minimum activation energy was 20.51 kJ/mol for hot air drying at 1.2 m/s, and maximum activation energy was 65.50 kJ/mol for microwave pretreatment at 700 W at 1.2 m/s drying. Two activation energy was found due to activation energy was calculated for each effective moisture diffusivity values.
- Hot air temperature, air flow rate and microwave pretratment affected color values. L* values were decreased, a* values and b* values were increased during drying. The minimum total color difference (ΔE) was found at hot air temperature of 40°C and 1.2 m/s air flow rate.

- Shrinkage values varied in between 0.75 and 0.80. It is observed that shrinkage values are very close to each other.
- Bulk density values were found in between 0.21±0.02 and 0.41±0.01 g/mL. The minimum bulk density was found at hot air temperature at 50^{o}C at air flow rate at 1.2 m/s at microwave pretreatment power level at 700 W. The maximum bulk density was found at hot air temperature of 40^{o}C and air flow rate of 1.2 m/s.
- According to these results, hot air drying at 60^{o}C and 1.0 m/s air flow rate and 700 W microwave pretreatment, drying time was 217 minutes and total color difference (ΔE) was found 10.60±2.30 is better choice for drying of zucchini to preserve color and to shorten drying time.

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APPENDICES

APPENDIX A

Table A.1 Anova results of dried zucchini L* values at 40^{o}C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	190,882	3	63,627	299,246	,000
Within Groups	,851	4	,213		
Total	191,732	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05	
		1	2
350W	2	60,1450	
700W	2	61,0600	
490W	2		69,8550
TRAY	2		70,8000
Sig.		,118	,110

Table A.2 Anova results of dried zucchini a* values at 40^{o}C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7,818	3	2,606	50,187	,001
Within Groups	,208	4	,052		
Total	8,026	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05		
		1	2	3
490W	2	-,1600		
TRAY	2		1,1450	
700W	2		1,6750	
350W	2			2,5700
Sig.		1,000	,081	1,000

Table A.3 Anova results of dried zucchini b* values at 40^{o}C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	83,083	3	27,694	24,635	,005
Within Groups	4,497	4	1,124		
Total	87,580	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05		
		1	2	3
490W	2	31,6300		
700W	2	33,2950		
TRAY	2		36,7700	
350W	2			39,9850
Sig.		,191	1,000	1,000

Table A.4 Anova results of dried zucchini ΔE values at 40^{o}C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	124,832	3	41,611	162,546	,000
Within Groups	1,024	4	,256		
Total	125,856	7			

Duncans's Multiple Range Test Table

		Subset for alpha = 0.05		
Sample	N	1	2	3
490W	2	14,6773		
TRAY	2	15,6171		
350W	2		21,9016	
700W	2			23,8855
Sig.		,137	1,000	1,000

Table A.5 Anova results of dried zucchini L* values at 40^{o}C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	47,665	3	15,888	2,556	,193
Within Groups	24,864	4	6,216		
Total	72,529	7			

Duncans's Multiple Range Test Table

		Subset for alpha = 0.05
Sample	N	1
700W	2	67,4300
350W	2	70,8400
490W	2	71,8500
TRAY	2	74,2200
Sig.		,057

Table A.6 Anova results of dried zucchini a* values at 40^{o}C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6,332	3	2,111	9,651	,026
Within Groups	,875	4	,219		
Total	7,207	7			

Duncans's Multiple Range Test Table

		Subset for alpha = 0.05	
Sample	N	1	2
700W	2	-,1650	
350W	2	,1900	
490W	2	,7300	
TRAY	2		2,1700
Sig.		,133	1,000

Table A.7 Anova results of dried zucchini b* values at 40^{o}C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	40,284	3	13,428	24,166	,005
Within Groups	2,223	4	,556		
Total	42,506	7			

Duncans's Multiple Range Test Table

		Subset for alpha = 0.05	
Sample	N	1	2
350W	2	33,5200	
TRAY	2	34,0150	
700W	2		37,7100
490W	2		38,6700
Sig.		,543	,267

Table A.8 Anova results of dried zucchini ΔE values at 40°C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	158,347	3	52,782	8,933	,030
Within Groups	23,635	4	5,909		
Total	181,982	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05		
		1	2	3
TRAY	2	8,1387		
490W	2	11,5130	11,5130	
350W	2		16,0106	16,0106
700W	2			19,8857
Sig.		,237	,138	,186

Table A.9 Anova results of dried zucchini L* values at 50°C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	33,140	3	11,047	1,384	,369
Within Groups	31,930	4	7,982		
Total	65,069	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05
		1
350W	2	63,3700
490W	2	65,9700
700W	2	66,7200
TRAY	2	69,0750
Sig.		,119

Table A.10 Anova results of dried zucchini a* values at 50°C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	25,013	3	8,338	16,172	,011
Within Groups	2,062	4	,516		
Total	27,075	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05	
		1	2
490W	2	-1,0050	
TRAY	2		2,0700
350W	2		3,1800
700W	2		3,4500
Sig.		1,000	,132

Table A.11 Anova results of dried zucchini b* values at 50°C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	101,599	3	33,866	43,674	,002
Within Groups	3,102	4	,775		
Total	104,700	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05			
		1	2	3	4
TRAY	2	28,1400			
490W	2		31,7000		
350W	2			34,6450	
700W	2				37,7750
Sig.		1,000	1,000	1,000	1,000

Table A.12 Anova results of dried zucchini ΔE values at 50°C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	37,740	3	12,580	1,667	,310
Within Groups	30,189	4	7,547		
Total	67,929	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05
		1
TRAY	2	14,9460
700W	2	16,6359
350W	2	18,4290
490W	2	20,8019
Sig.		,105

Table A.13 Anova results of dried zucchini L* values at 50°C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	55,435	3	18,478	4,151	,101
Within Groups	17,806	4	4,452		
Total	73,241	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05
		1
700W	2	65,3200
490W	2	65,3350
TRAY	2	70,4300
350W	2	70,7450
Sig.		,066

Table A.14 Anova results of dried zucchini a* values at 50°C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6,952	3	2,317	23,594	,005
Within Groups	,393	4	,098		
Total	7,345	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05		
		1	2	3
350W	2	-,6600		
490W	2		,8150	
700W	2		,8400	
TRAY	2			1,9650
Sig.		1,000	,940	1,000

Table A.15 Anova results of dried zucchini b* values at 50°C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	13,619	3	4,540	3,922	,110
Within Groups	4,630	4	1,157		
Total	18,249	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05	
		1	2
TRAY	2	32,6500	
350W	2	33,8050	33,8050
700W	2	34,7300	34,7300
490W	2		36,2150
Sig.		,130	,093

Table A.16 Anova results of dried zucchini ΔE values at 50°C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	95,140	3	31,713	9,457	,027
Within Groups	13,413	4	3,353		
Total	108,554	7			

Duncans's Multiple Range Test Table

		Subset for alpha = 0.05	
Sample	N	1	2
350W	2	13,3419	
TRAY	2	13,5171	
490W	2		18,9205
700W	2		21,3101
Sig.		,928	,262

Table A.17 Anova results of dried zucchini L* values at 60°C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	193,969	3	64,656	16,039	,011
Within Groups	16,125	4	4,031		
Total	210,095	7			

Duncans's Multiple Range Test Table

		Subset for alpha = 0.05		
Sample	N	1	2	3
490W	2	58,8800		
TRAY	2		64,7800	
350W	2		67,3700	67,3700
700W	2			72,5550
Sig.		1,000	,267	,061

Table A.18 Anova results of dried zucchini a* values at 60°C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,576	3	,192	,251	,857
Within Groups	3,061	4	,765		
Total	3,637	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05
		1
490W	2	1,4150
TRAY	2	1,4500
350W	2	1,9050
700W	2	2,0200
Sig.		,529

Table A.19 Anova results of dried zucchini b* values at 60°C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	67,153	3	22,384	21,564	,006
Within Groups	4,152	4	1,038		
Total	71,305	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05		
		1	2	3
TRAY	2	30,7600		
700W	2		33,6450	
490W	2		35,8750	35,8750
350W	2			38,6450
Sig.		1,000	,094	,053

Table A.20 Anova results of dried zucchini ΔE values at 60°C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	200,445	3	66,815	14,187	,013
Within Groups	18,838	4	4,710		
Total	219,283	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05		
		1	2	3
700W	2	10,6049		
350W	2	14,8106	14,8106	
TRAY	2		18,0995	
490W	2			24,3028
Sig.		,125	,204	1,000

Table A.21 Anova results of dried zucchini L* values at 60°C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	105,254	3	35,085	9,275	,028
Within Groups	15,130	4	3,783		
Total	120,384	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05	
		1	2
490W	2	60,9300	
700W	2	63,9800	
TRAY	2	64,0050	
350W	2		70,8350
Sig.		,195	1,000

Table A.22 Anova results of dried zucchini a* values at 60^{o}C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7,747	3	2,582	12,399	,017
Within Groups	,833	4	,208		
Total	8,580	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05	
		1	2
350W	2	1,2750	
490W	2	1,3600	
700W	2		2,7400
TRAY	2		3,6250
Sig.		,861	,124

Table A.23 Anova results of dried zucchini b* values at 60^{o}C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	56,352	3	18,784	11,127	,021
Within Groups	6,753	4	1,688		
Total	63,105	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05	
		1	2
TRAY	2	31,9000	
700W	2		37,7150
490W	2		38,0050
350W	2		38,3100
Sig.		1,000	,674

Table A.24 Anova results of dried zucchini ΔE values at 60°C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	67,236	3	22,412	7,662	,039
Within Groups	11,700	4	2,925		
Total	78,937	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05	
		1	2
350W	2	17,5678	
700W	2	18,2460	
TRAY	2	18,8073	
490W	2		24,8249
Sig.		,514	1,000

APPENDIX B

Table B.1 Anova results of dried zucchini shrinkage values at 40°C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,000	3	,000	,622	,637
Within Groups	,001	4	,000		
Total	,001	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05
		1
TRAY	2	,7604
490W	2	,7619
700W	2	,7619
350W	2	,7738
Sig.		,302

Table B.2 Anova results of dried zucchini shrinkage values at 40°C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,000	3	,000	1,147	,432
Within Groups	,000	4	,000		
Total	,001	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05
		1
700W	2	,7750
TRAY	2	,7788
490W	2	,7857
350W	2	,7929
Sig.		,167

Table B.3 Anova results of dried zucchini shrinkage values at 50°C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,003	3	,001	6,843	,047
Within Groups	,001	4	,000		
Total	,003	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05		
		1	2	3
TRAY	2	,7505		
700W	2	,7619	,7619	
490W	2		,7857	,7857
350W	2			,7976
Sig.		,384	,110	,365

Table B.4 Anova results of dried zucchini shrinkage values at 50°C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,002	3	,001	4,898	,079
Within Groups	,001	4	,000		
Total	,003	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05	
		1	2
700W	2	,7625	
490W	2	,7685	,7685
350W	2	,7929	,7929
TRAY	2		,8025
Sig.		,072	,053

Table B.5 Anova results of dried zucchini shrinkage values at 60^oC and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,002	3	,001	297,327	,000
Within Groups	,000	4	,000		
Total	,002	7			

Duncans's Multiple Range Test Table

		Subset for alpha = 0.05		
Sample	N	1	2	3
350W	2	,7619		
700W	2	,7619		
490W	2		,7857	
TRAY	2			,7936
Sig.		1,000	1,000	1,000

Table B.6 Anova results of dried zucchini shrinkage values at 60^oC and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,000	3	,000	,614	,641
Within Groups	,001	4	,000		
Total	,001	7			

Duncans's Multiple Range Test Table

		Subset for alpha = 0.05
Sample	N	1
TRAY	2	,7727
700W	2	,7757
490W	2	,7831
350W	2	,7923
Sig.		,287

APPENDIX C

Table C.1 Anova results of dried zucchini bulk density values at 40^{o}C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,015	3	,005	2,844	,169
Within Groups	,007	4	,002		
Total	,022	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05
		1
490W	2	,2196
700W	2	,2847
350W	2	,3039
TRAY	2	,3389
Sig.		,051

Table C.2 Anova results of dried zucchini bulk density values at 40^{o}C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,028	3	,009	7,565	,040
Within Groups	,005	4	,001		
Total	,033	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05	
		1	2
700W	2	,2466	
490W	2	,3139	,3139
350W	2	,3174	,3174
TRAY	2		,4124
Sig.		,118	,051

Table C.3 Anova results of dried zucchini bulk density values at 50°C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,007	3	,002	,705	,597
Within Groups	,014	4	,003		
Total	,021	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05
		1
TRAY	2	,2185
700W	2	,2586
350W	2	,2771
490W	2	,3010
Sig.		,237

Table C.4 Anova results of dried zucchini bulk density values at 50°C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,016	3	,005	3,565	,126
Within Groups	,006	4	,002		
Total	,022	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05	
		1	2
700W	2	,2038	
350W	2	,2659	,2659
490W	2	,3055	,3055
TRAY	2		,3202
Sig.		,063	,242

Table C.5 Anova results of dried zucchini bulk density values at 60^{o}C and 1.0 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,002	3	,001	,481	,713
Within Groups	,006	4	,002		
Total	,008	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05
		1
TRAY	2	,2306
700W	2	,2470
350W	2	,2487
490W	2	,2770
Sig.		,307

Table C.6 Anova results of dried zucchini bulk density values at 60^{o}C and 1.2 m/s air flow rate

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,007	3	,002	,752	,576
Within Groups	,013	4	,003		
Total	,020	7			

Duncans's Multiple Range Test Table

Sample	N	Subset for alpha = 0.05
		1
490W	2	,2466
TRAY	2	,2629
700W	2	,2654
350W	2	,3255
Sig.		,240