UNIVERSITY OF GAZIANTEP
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EFFECT OF ULTRASOUND PRETREATMENT ON DRYING BEHAVIOR, ASCORBIC ACID, LYCOPENE, COLOR AND OTHER RELATED PROPERTIES OF TOMATO SLICES

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ABSTRACT

EFFECT OF ULTRASOUND PRE TREATMENT ON DRYING BEHAVIOR, ASCORBIC ACID, LYCOPENE, COLOR AND OTHER RELATED PROPERTIES OF TOMATO SLICES

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Drying of tomatoes is a process commonly used to preserve the product and to prolong its shelf-life. This study aims to investigate effect of ultrasonic pre-treatment on drying time and quality properties of tomato slices dried by microwave combined with hot air at 60°C with the intent to reduce drying time and to improve quality properties. The influence of ultrasound pre-treatment (20 and 40 min) and different microwave power levels (120, 150 and 180 Watt) on drying time, vitamin C, lycopene, total phenolics content, shrinkage, rehydration and color values of dried slices of tomato was studied. Results showed that as microwave power level increased, drying time to a final moisture content of 17.65 % decreased significantly. On the other hand, ultrasound pretreatment reduced drying time about 1.68-7.38 %. Depending on drying conditions, vitamin C and lycopene contents reduced from 433.94 to 81.89 mg AA/100 g dry solids and 3920.57 to 415.40 mg/100 g dry solids, respectively. The change in total phenolics content was not severe as much as vitamin C and lycopene contents. Rehydration capacity of ultrasound pretreated samples was larger than non-treated samples. The color values of dried tomato slices were in the acceptable range (TCD: 0.92 - 8.25 and a*/b* ratio: 1.30 - 1.59).

Key words: Drying, tomatoes, microwave, ultrasound pre-treatment, vitamin C, lycopene.

ÖZET

ULTRASON ÖNIŞLEMİNİN DOMATES DİLİMLERİNİN KURUMA DAVRANIŞI, ASKORBİK ASİT, LİKOPEN, RENK VE DİĞER İLGİLİ ÖZELLİKLERİ ÜZERİNE ETKİSİ

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Domatesin kurutulması, ürünün muhafaza edilmesi ve raf ömrünün uzatılması için yaygın olarak kullanılan bir işlemdir. Bu çalışma, ultrason ön işleminin kurutulan domates dilimlerinin kurutma süresi ve kalite özellikleri üzerine etkilerinin araştırılmasını amaçlamaktadır. Kurutma işlemi mikrodalgaile birlikte 60°C sıcak hava ile yapılarak kurutma süresinin kısaltılması ve kalite özelliklerinin iyileştirilmesi hedeflenmektedir. Ultrason önişlemi (20 ve 40 dakika) ve farklı mikrodalga güç seviyelerinin (120, 150 ve 180 Watt) domates dilimlerinin kurutma süresi, C vitamini, likopen ve toplam fenolik içerikleri, büzüşme, rehidrasyon ve renk değerleri üzerine etkileri çalışıldı. Sonuçlar, mikrodalga güç seviyesi arttığında domatesin % 17.65 nem miktarına kurutulması için gerekli zamanın azaldığını göstermektedir. Diğer yandan, ultrason önişlemi kurutma süresini sadece % 1.68-7.38 kadar azaltmıştır. Kurutma koşullarına bağlı olarak; C vitamini ve likopen içerikleri sırasıyla 433.94’ten 81.89 mg AA/100 g kuru madde ve 3920.57’den 415.40 mg/100 g kuru maddeye azalmıştır. Toplam fenolik içeriğindeki değişim, C vitamini ve likopen içeriklerindeki gibi şiddetli olmadı. Ultrason önişlemine tabi tutulan örneklerin rehidrasyon kapasiteleri önişlem görmeyen örneklerinkinden daha büyük oldu. Kurutulmuş domates dilimlerinin renk değerleri kabul edilebilir aralıktadır (TCD: 0.92 - 8.25 ve a*/b* oranı: 1.30 - 1.59).

Anahtar kelimeler: Kurutma, domates, mikrodalga, ultrason önişlemi, C vitamin, likopen.

To my many precious family . . .

Dear parents (Dr. Jawdat & Mrs. Galawezh)

And my lovely husband (Shano)

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CHAPTER ONE
INTRODUCTION

1.1 GENERAL PREVIEW

Tomato (*Lycopersicon esculentum*) belongs to the *solanaceae* family can be easily and widely cultivated and is adapted to a wide range of soils and climates. It is also recognized as the source of vitamins and minerals. For this reason, tomato is known as the most important fruit/vegetable in the world (Arslan and Ozcan, 2010). Tomato must be consumed immediately after harvest or preserved for later use because of spoiling easily in nature due to high moisture content (Chawla et al., 2008) Tomato is well-balanced diet, contribute to health, rich in minerals, vitamins, essential amino acids, sugars and dietary fibers. It contains more vitamin B and C, iron and phosphorus. Canned and dried tomatoes are economically important processed products. They are consumed freshly in salads or cooked in sauces, soup and meat or fish dishes. Tomato can also be processed into purees, juices and ketchup (Naika et al., 2005).

1.2 TOMATO PLANT

Tomato is a high, annual plant of over than two meters which can reach a height, however, the same plants can be harvested for several years in succession. The first harvest after sowing is possible 90-120 days later. The size or shape of the fruit differs per cultivar and the color ranges from yellow to red (Naika et al., 2005). The changes of quantitative and qualitative of the chemical composition are series take place during fruit ripening. Organic acids, soluble sugars, amino acids, pigments and over 400 aroma compounds contribute to the taste, flavor and aroma volatile profiles of the tomatoes. The ripening of tomatoes is characterized by the softening of the fruit, the degradation of chlorophylls and an increase in the respiration rate, ethylene production, as well as the synthesis of acids, sugars and lycopene. Tomatoes contain higher levels of fructose and glucose than sucrose (Suarez et al., 2008).Table 1.1 shows typical composition of tomato.

Table 1.1 Chemical composition of tomato per 100 gr.

	Ripe fresh	Ripe tinned natural
Water (g.)	93.76	93.65
Calories (Kcal.)	21	19
Fat (g.)	0.33	0.13
Protein (g.)	0.85	0.92
Carbohydrates (g.)	4.64	4.37
Fiber (g.)	1.1	1
Potassium (mg.)	223	221
Phosphorus (mg.)	24	18
Magnesium (mg.)	11	12
Calcium (mg.)	5	30
Vitamin C (mg.)	19	14.2
Vitamin A (UI)	623	595
Vitamin E (mg.)	0.38	0.32
Niacin (mg.)	0.628	0.73

1.3 PHENOLIC COMPOUNDS OF TOMATO

Phenolic compounds is a secondary metabolites as a develop group occur in most of fruits and vegetables. Hence, they are a component of the human diet although data for dietary intakes and metabolic fate are limited. Their role in oxidation processes, as either antioxidants or substrates in browning reactions, is examined. They are characterized by high chemical reactivity and this complicates their analysis, Phenolic compounds widely distributed in the medicinal plants, spices, vegetables, fruits, grains, pulses and other seeds are an important group of natural antioxidants with possible beneficial effects on human health. They can participate in protection against the harmful action of reactive oxygen species, mainly oxygen free radicals. Free radicals are produced in higher amounts in a lot of pathological conditions and are involved in the development of the most common chronic degenerative diseases, such as cardiovascular disease and cancer (Stratil et al., 2007).

Phenolic compounds have been extensively characterized in tomato varieties from different countries including genetically modified tomatoes, however, the chemical composition of tomatoes can vary among tissues of a single fruit and type of tomatoes, according to the cultivar, cultivation conditions, and handling and storage methods or conditions (Bahorun et al., 2004). Tomatoes are concentrated source of phenolic compounds, such as flavonoids and hydroxycinnamic acid derivatives (Trandafir and Ionica, 2005). Phenolic compounds in tomatoes are the main compounds that responsible for the most of functional properties in any of their forms a range of phenolics had been found in tomato. Galloylglucose, ellagic acid and gallic acid were main active compounds in tomato, there are the range of natural polyphenols can vary from simple molecules (phenolic acids, phenylpropanoids , flavonoids) to high polymerized compounds (lignins, melanins, tannins), and the subgroup that represents the most common and widely flavonoids, scientists define phenolic acids chemically that those substances can possess an aromatic ring bound to hydrogenated substituents, including their functional derivatives (Marin et al., 2001).

1.4 EVALUATION OF TOMATO

There are a many specific factors that require for maturity to improve quality standards of different products of tomato fruit, tomato maturity is an important factor associated the quality of processed tomato products. During ripening, tomato fruit go through some categories of highly ordered physiological and biochemical changes. Biochemical changes, such as increased respiration, chlorophyll degradation biosynthesis of carotenoids, starch degradation, and increased activity of cell wall-degrading enzymes, bring on changes in color, firmness, and development of aromas and flavors, Tomato maturity has been related to quantifiable parameters, which reflect the biochemical changes during ripening. Color is used as a major method in determining maturity of tomato. However, skin color of tomato varies from cultivar to cultivar even at the same maturity stage (Zhanga and Carthy, 2012) Studies show processed tomatoes are the leading source of lycopene in the American diet. Lycopene, the ingredient that makes tomatoes red, is an antioxidant that blocks cellular damage and is highly effective in preventing cancers. Tomatoes do not lose their health benefits as they are processed and cooked. In fact, lycopene in cooked and processed tomatoes (sauce, paste, salsa, canned tomatoes) is more easily absorbed than fresh tomatoes. This fact, along with their popularity, makes tomatoes a leading nutritional source in the American diet. The leading tomato producing countries are China, USA, India, Egypt, Turkey, Iran, Mexico, Brazil and Indonesia (Sahlina et al,. 2004).

1.5 PRE-TREATMENTS

There are many pre-treatments are used to reduction in drying time and consequently it's costliness of drying food products. This study contains the use of ultrasonic pre-treatments to induce structural changes in the fruit tissue as to improve the effective water diffusivity during microwave drying and consequently to reduce drying time. Use of ultrasound as an alternative has a growing interest to conventional processes. As well as the osmotic process is a technique used for the concentrate of solid in foods. Only a part of natural water content is removed through osmotic dehydration process of fruits and vegetables. Osmotic dehydration will not give a product of low moisture content considered for shelf stable. Consequently osmosed fruits or vegetables are further dried to desired moisture content. There is no phase change in osmotic dehydration process. The driving force for water removal is concentration gradient between the osmotic solution and intercellular fluid while natural cells act as semipermeable membrane. Thus, during this process the texture of the product is not disturbed and in the meantime the product gains solid in tissues from concentrated solution (Shukla and Singh, 2007).

Ultrasound pretreatment of food product before drying was examined as a method to increase the effective water diffusivity, reduce drying time, and improve quality of product, Ultrasound treatment has been promising effects in food processing and preservation for this recorded as an attractive means in food science and technology (Cao et al., 2010). It is one of the most important pre-treatment that can be used to reduction in drying time. Where this application applied it is responsible for producing chemical, mechanical or physical changes on the processes or products. At the application of the low frequency power ultrasound, ultrasonic waves travel through the solid medium causing a rapid series of alternative compressions and expansions, in a similar way to a sponge when it is squeezed and released repeatedly (sponge effect) (Fernandesa and Sueli, 2011). The sonication also causes cavitation in a liquid medium, which consists in the formation of bubbles in the liquid that can explosively collapse and generate localized pressure and temperature increase. The rate of cavitation or alternate compressions and expansions depend on the frequency of the ultrasonic waves. The use of this application in the food industry is new, in the last years only a few study talk about the use of ultrasound pre-treatment in drying technology, most of them dealing with ultrasound assisted osmotic dehydration and ultrasound-assisted spray-drying, not using ultrasound as a standalone treatment (Arez et al., 2007). The application of immersing fruit/vegetable pieces in water or in an osmotic solution and exposed to ultrasonic waves at the frequencies ranging from 18 to 40 kHz for a period of time that is usually less than 60 minutes is called ultrasound pre-treatment application, The ultrasonic waves produce a “sponge” effect which compresses and releases the fruit cells inducing in the appearance of microscopic channels within the tissue structure of the fruit. As these channels are responsible for the increasing in the effective of water diffusivity in the fruit/vegetable pieces during drying processes (Ercan and Soysal, 2011).

1.6 DRYING

According to the U.S. Department of Agriculture there are the difference between dehydration and drying of foods. Dehydrated foods as those with less than 2.5% water (dry basis), while dried foods are those food products with more than 2.5% water (dry basis). So the terms dried and dehydrated are not the same. Drying is one of the most known method for preservation of fruits and vegetables. Which removed water to at least to final concentration, this process confirms microbial stability of the product and decreases chemical and physical changes during storage. In most drying processes water is removed by convective evaporation, in which heat is supplied by hot air, in the industry of the food processing, drying is the most common method that used by humans. Also dehydration of food is one of the most important achievements in human history, making humans less dependent upon a daily food supply even under adverse environmental conditions, though in an earlier times drying was occurred by the sunshine, in the recent years many methods are used to dehydration of foods. During the present studies we can understand some of the chemical and biochemical changes that occur during dehydration, and developed methods for preventing undesirable quality losses. The reducing of water activity is drying, thus preservation of foods by protecting from microbial growth and deteriorative chemical reactions. In the drying processes, the microorganisms and the enzymes sensitivity to heat are also important. In the case of the preservation of foods by drying, it is an important to increase inactivation of microorganism and enzyme for preventing spoilage and enhancing safety, and reduce the components responsible for the deterioration of the dried foods (Erbersdobler, 1986).

1.6.1 Drying Curves

Drying curve usually contains of three major stages:

1. Transient period or Transient early stage, which the product's heating up stage.
2. First period is called constant rate period, in which moisture is easy to remove.
3. Second period is called falling rate, in which moisture is held within the solid matrix.

Typical drying rate curves are shown in Figure 1.1 when the moisture content change from the first to the second period it is known as the critical moisture content. Typically, two falling rate periods are observed for both hygroscopic and non-hygroscopic solids. The first falling rate period is postulated to depend on both internal and external mass transfer rates; while the second period, during which drying is much slower, is postulated to depend entirely on internal mass transfer resistance. The slower rate may be due to the solid–water interaction or glass–rubber transition. The drying behaviors of food materials depend on the porosity homogeneity, and hygroscopic properties. The immediate entrance into the falling rate is characteristic of hygroscopic food materials (Rahman, 2007).

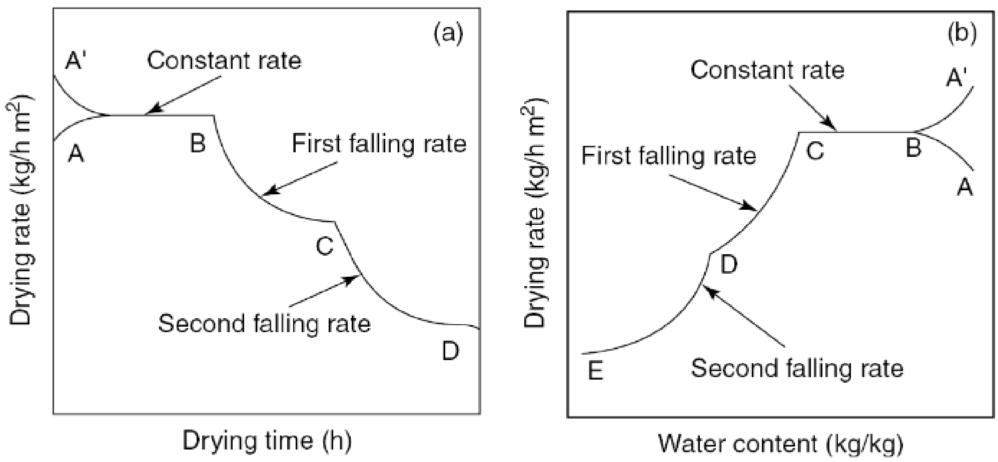

Figure 1.1 Typical drying curves (a): drying rate vs. drying time, (b) drying rate vs. water content.

1.6.2 Drying Methods for Fruits and Vegetables

1.6.2.1 Microwave Drying

Microwaves are the type of electromagnetic energy, which have a high frequency waves between 1mm and 1m with corresponding frequencies between 300GHz and 300MHz, when a dielectric material is placed in an electric or electromagnetic field, the material becomes polarized, and stores electric energy through polarization. The level and mechanism of polarization available to materials depend on the state and composition of the material, and the frequency of the applied electric field Microwaves are not forms of heat, but rather forms of energy that are manifested as heat through their interaction with materials. It is cause to heat materials themselves. There are many mechanisms for this energy conversion with the most important mechanism is dipole rotation (Al-Harahsheha et al., 2009). Recently, microwave drying has been proposed as a rapid and efficient drying alternative to conventional hot air drying. However, due to its high cost, microwave drying cannot compete with conventional air drying. Therefore, largely for economic reasons, it has been suggested that this technique should only be used during the final stages of air drying, The appropriate use of electromagnetic energy and its effect on the quality of dried foods has been extensively reviewed, Combined technologies that employ microwave also known as MW-assisted or MW-enhanced drying are also a rapid dehydration techniques that are allocated for specific foods, particularly fruits and vegetables. Increasing concerns regarding product quality and production costs have motivated the investigation and adoption of these combined drying technologies (Askari et al., 2009).

1.6.2.2 Advantages of Microwave Drying Technique

Shorter drying times, improved product quality, and flexibility in producing a wide variety of dried products are the main advantages of microwave combination drying techniques, However, current applications are limited to small categories of fruits and vegetables due to high startup, costs and relatively complicated technology compared to conventional drying. The traditional kinetic pattern observed during air drying dramatically changes when microwaves are applied. Several models of heat and mass transfer have been shown to be relevant to combined microwave–air drying processes. Compared with conventional hot air drying, when the microwave drying technique occurred the drying rate can be significantly increased; the nutritional value, color, and original flavor can be largely maintained; puffing, drying, and sterilization are accomplished simultaneously to enhance the overall product quality; heat loss is decreased because the drying time is shortened and the difference in temperature between the inside and outside of the equipment is small; energy absorption is proportional to the residual moisture content and can be easy controlled; and microwave drying can be suitable for processing a very heat-sensitive food products due to its performed at lower temperatures (Askari et al., 2009).

1.7 CHANGES OF PRODUCT QUALITY DURING DRYING

The primary objective of drying is the prevention of occurrence of undesirable changes due to activity of microorganisms. This objective is attained by reducing the water activity below the threshold of relevant microbial activity. The reduction of water content and water activity may also have the beneficial effect of reducing the probability of non-microbial changes in quality, in particular those due to enzyme action, to non-enzymatic browning, and to hydrolytic reactions. Secondary objectives of dehydration may include: the reduction of weight, potential reduction in volume, engineering of desirable textures, generation of a food structure useful as a preparation for subsequent processing, such as frying and impregnation with desirable ingredients, and encapsulation of desirable components (Karel and Lund., 2003). On the other hand, some physical and chemical changes take place during drying such as color degradation, aroma loss, nutritional values, texture, storage stability, vitamin retention, etc. Some of the significant features of food dehydration process, which affect both drying rate and final product characteristics, are considered below:

1.7.1 Browning Reactions

Browning reactions is the change in color, reduction in nutritional value and solubility, off-flavors creating and textural changes occur. It can be classified to two main parts; enzymatic or non-enzymatic. The non-enzymatic browning are caramelization and Millard browning. The rate of non-enzymatic browning is affected by moisture level, temperature, pH, and composition also are the other parameters. The rate of browning is most quick in the intermediate moisture range and reduces at very low and very high moisture contents. Browning tends are occur at the center of the drying periods primarily due to the migration of soluble constituents toward the center. Browning is also finished near to the end of the drying period, when the moisture level of the sample is low and less evaporative cooling is taking place that causes the product temperature to rise. There are many suggestions to help decrease browning reactions during drying. In all the cases, it was emphasized that the product should not exposed unnecessary to heat when in its critical moisture content range (Rahman, 2007; Okos, 1989).

1.7.2 Case Hardening

When the moisture concentration in the interior layers of foods is more than moisture concentration in the outer layer during drying process, this surface shrinkage causes checking, cracking, and warping due to the necessarily outer layers lose moisture before the interior layers. This type of shrinkage causes moisture gradient and resistance near the surface. On the other hand, shrinkage may combine to yield a skin practically impervious to moisture, which encloses the volume of the material so that the interior moisture cannot be removed. This is called case hardening. In food processing, case hardening is also known as crust formation commonly. The extent of crust formation can be reduced by maintaining flattening moisture gradients in the solid, which is a function of drying rate. The faster the drying rate, the thinner the crust (Achanta and Okos, 1996; Rahman, 2007) is reasons for case hardening are migration of soluble solids to the surface and high surface temperatures towards the end of drying.

In dried food products, crust formations are sometimes desirable .In microencapsulation of flavors, rapid crust formation is prevent flavor losses. Some of studies pointed that formation of crust may be inhibited by allowing the drying rate to be slow enough that moisture loss from the surface of product is renewed by moisture from the inside. Crust formation is also important in puffing explosion. In this case, the product with high-moisture content is exposed to rapid drying conditions such as high temperature and vacuum, which create a crust. The impermeable crust, coupled with the extreme drying conditions, results in rapid moisture vaporization and causes large internal pressures to build up, resulting in product expansion and puffing. During the expansion stage, stress buildup in the glassy surface may cause the surface to crack, allowing vapor to escape (Achanta and Okos, 1996).

1.7.3 Shrinkage

Shrinkage takes place during drying by all the drying methods with the exception of freeze drying. Shrinkage occurs in three stages:

1. During the early stages of drying (at high initial drying rates) the shrinkage in volume of fruits and vegetables pieces very nearly equals to the volume of water lost by evaporation. i.e., the more water evaporated, the more shrinkage is. Then, the outer layer becomes rigid and the final volume is fixed. But at low initial drying rates the pieces will shrink with little change in shape.
2. As drying proceeds, the tissues split and rupture internally forming an open structure.
3. Then, the volume shrinkage is less and no substantial further decrease in volume occurs in the later stages (Maskan, 2001).

Shrinkage is another important thing that impact the quality of dried food product by reducing the wetness of the final product, product texture changing, and reduction in product absorbency, crust and pore formation may be desirable or undesirable Depending on the final use. If a long bowl life is required for a cereal product, a crust product that prevents moisture reabsorption again may be preferred. If a dried product with good rehydration capacity is required, high porosity with no crust is required .To minimize shrinkage, low temperature drying should be employed so that moisture gradients throughout the product are minimized (Rahman, 2001).

1.7.4 Rehydration

The process of re hydrated or moistening of dry material is called rehydration. It is occur by applying a high amount of water. Recently, in most cases, dried foods are immersing in water before using, thus rehydration is one of the most important quality criteria. In practice, most of the changes during drying are irreversible and rehydration cannot be considered simply as a process reversible to dehydration (Rahman, 2001 and 2007). In general, the water absorption is fast at the beginning of the process and then slows down to the end of the process. This rapid moisture uptake is due to surface and capillary suction and called rehydration. Rahman and Perera, (1999) and Lewicki, (1998) showed the factors affecting the rehydration process in their studies. The factors are porosity, capillaries and cavities near to the surface, temperature, trapped air bubbles, amorphous–crystalline state, soluble solids, dryness, anions, and pH of the immersed water. Porosity, and capillaries and cavities near the surface enhance the rehydration process, whereas the presence of trapped air bubbles is a major obstacle to the invasion of the fluid. Until the void or air cavities are filled with water, water penetrates to the material through its solid phase. In general, increasing the early stages of water rehydration is strongly occurred by temperature. There is a resistance of crystalline structures to salvation, whereas amorphous regions hydrate fast. The presence of anions in water affects volume increase during water absorption.

1.7.5 Vitamin Retention

In general, dried food products are able to loss the vitamin content usually by less than 10% but Vitamin C is mostly able to destroy during drying process due to its sensitivity to heating. The loss of vitamin A and ascorbic acid in dried products could be avoided in the absence of oxygen. To optimize vitamin C (ascorbic acid) retention, the product should be dried at a low initial temperature when the moisture content is high since acid is the most heat sensitive at high moisture contents. The temperature, then, can be increased as drying continues and ascorbic acid is more stable due to a decrease in moisture content. There is general observation in ascorbic acid retention during drying processes due to its sensitivity to high temperatures (Erbersdobler, 1986; Rahman, 2007).

1.7.6 Color Retention or Development

Color in fruits and vegetables is composed of a complex mixture of pigments; water soluble anthocyanins carotenoids (lycopene and beta carotene) and chlorophylls (fat soluble pigments). Original color of products was degradate by high temperature and long drying time. We can preserve the food products color by using minimal heat exposure or applying high temperature and short time with pH adjustment. Water activity is one of the important factors degrading chlorophyll. Another cause of color degradation may be due to enzymatic browning reactions causing rapid darkening, mainly of the leafy portions. The formation of dark pigments via enzymatic browning is initiated by the enzyme polyphenol oxidase. Another reason for discoloration is photo oxidation of pigments, caused by light in combination with oxygen (Rahman, 2007). Heat treatment can change the color of products. Also, pigments are susceptible to oxidation. Sulfuring minimizes the pigment destruction.

CHAPTER TWO
LITERATURE REVIEW

2.1 INTRODUCTION

Drying of tomatoes is a process generally used to preserve the product and to prolong its shelf-life. However, dried tomatoes under natural conditions may be exposed to dust, rain and high temperatures. Under these conditions some problems can cause a worsening of the quality of the final products. These problems are: crack of the structure, bleaching, hard texture, loss of flavor and nutritional properties, low rehydration capacity, enzymatic and non-enzymatic browning and color. In spite of that, a rising attention to the production of dried tomatoes is clear owing to the several ways their use and cooking. Therefore, there is a rising demand by the consumer of finished products having their nutritional and sensorial characteristics preserved as much as possible.

Recently, growing interest in drying process of food products, especially microwave drying has suitable for processing a very heat-sensitive food products due to its performance at lower temperatures. Many studies report the results of using ultrasound pre-treatment for microwave drying of fruits and vegetables as a factor used to reduce drying time. The results led the researchers to conclude that ultrasound pre-treatment applications can be able to reduce drying time of some products but cannot reduce of some by more than 10%.

2.2 SUMMARIES OF THE RECENT STUDIES

Fernandes and Sueli (2011) applied ultrasound pre-treatment to several fruits: melons, strawberry, star apples and pine apples at the frequencies ranging from 18 to 40 kHz for a period of time not more than 60 min. They evaluated the influence of ultrasound pre-treatment on water loss and drying time. Overall, this application was able to reduce drying time by 20% and reduced drying costs up to 30%. Fabiano and Sueli (2007) studied effect of the ultrasonic pre-treatment on air drying of banana. Results showed that the water diffusivity increases after application of ultrasound and the overall drying time reduced by 11%. Another study of Fabiano and Sueli (2008) estimated the water diffusivity in the air-drying process for pineapples submitted to ultrasound. Results showed that the water diffusivity increased after application of ultrasound for 10, 20 and 30 min and the overall drying time was reduced by 8% (over 1 h of air-drying time). Jambrak and Timothy (2007) used ultrasound as a pre-treatment method prior drying of mushrooms, brussels sprouts and cauliflower in order to achieve reduction in drying time and to understand the effect of the ultrasound in mass transfer process. Pre-treatment with 20 kHz probe and 40 kHz bath for 3 and 10 min have been compared with blanched and untreated samples. The drying time after ultrasound treatment was shortened for all samples as compared to untreated. Nawocka et al. (2012) conducted a study to investigate the utilization of ultrasound as mass transfer enhancing method prior to drying of apple tissues. They used the ultrasound power at 35 kHz power for 10, 20 and 30 minutes at 70^{o}C. It has been observed that the reduction of the drying time was by 31% in comparison to untreated tissue. Also, they reported that use of ultrasound can facilitate water loss during drying. Ultrasonic treated material showed between 9% and 11% higher shrinkage than untreated samples. Considerable differences in the density and porosity of the dried apple with and without ultrasonic application were confirmed by analyzing the tissue images made with the scanning electron microscopy. Ultrasound treatment and drying induced changes of apples microstructure. Application of ultrasound before drying caused breakdown of cells and damage of the tissue. Moreover, the results showed the time of ultrasound treatment influence on apples microstructure. A longer ultrasound treatment time resulted in greater destruction of structure of dried apple. Furthermore, ultrasound application caused alteration of rehydration properties in comparison to untreated sample. Abano et al. (2013) showed in their study that the effect of four microwave powers and three vacuum pressures on drying time, lycopene content and ascorbic acid content of tomato slices. The drying time reduced from 84 to 14 min as the microwave power increased. It was shown that increase in microwave power enhanced the drying rate and significantly reduced the drying time of tomato slices. The effect of microwave power on the drying time was however higher than vacuum pressure. They observed that the lycopene levels of the tomato slices increased significantly after drying whereas the ascorbic acid content reduced. However, Marfil (2008) reported the reduction in the initial content of ascorbic acid in about 16.0%

during drying of tomato slices, the ascorbic acid degradation rates during drying were dependent on samples treatment before drying as well as on drying temperature. Although caustic peeling and osmotic pre-treatment caused a significant reduction in the initial ascorbic acid content of the product, during drying lower degradation rates were observed in osmotically pre-treated tomatoes. Higher drying temperatures increased vitamin C degradation rates. It must be considered, however, that the increase in ascorbic acid retention may not compensate the greater costs and longer processing times due to peeling and osmotic treatment. Lewicki and Michaluk (2004) studied the pretreatment of tomato slices by soaking in each solution before convective drying. They observed that the pretreatment caused shrinkage of tomato pieces by 15%. Their microscopic examination showed that pretreatment of tomato with calcium ion causes larger tissue structure alterations in comparison to those observed in non-treated tomato. Francenia et al. (2012) used rotating tray drier for drying of tomato slices at different temperatures (45, 50 and 60 °C) with and without tray rotation. They fit data to the Page mathematical model. Effective diffusivities for the different drying conditions correlated well with the chemical composition variables; lycopene, ascorbic acid and total polyphenols (TPP). The effect of drying conditions over quality of dried tomato slices was evaluated by quantifying their contents of lycopene, ascorbic acid and TPP, and measuring their color and rehydration ratio. The best drying conditions were at 60 °C drying temperature with the use of tray rotation. They observed that these conditions minimized the degradation of lycopene (2.9%), ascorbic acid (17.3%) and TPP (2.1%) during drying. Çelen and Kahveci (2013) dried tomatoes in a microwave oven. The microwave drying behavior of tomato slices was investigated experimentally to determine the effects of microwave power on the drying rate, energy consumption, and dried product quality in terms of color. A theoretical model was proposed to define the drying curves of tomato slices. The experiments performed with the microwave power of 90, 180, 360, and 600 W indicated that the drying time and the energy consumption decreased considerably with an increase in microwave power. Their experiments also revealed that the drying rate showed first an increase and then a decrease during drying. The color quality of the product deteriorated significantly with the increase of the microwave power. Fernandes and Oliveira (2008) evaluated the production of dehydrated papayas with low sugar content. The product was obtained by applying ultrasonic waves to enhance the loss of sugar from the fruit. To achieve this goal, their paper examined the influence of the ultrasonic pre-treatment before air-drying on dehydration of papaya. Ultrasonic pre-treatment for air-drying of fruits was studied and compared with osmotic dehydration. Their results showed that the water effective diffusivity increased after application of ultrasound causing a reduction of about 16% in the drying time.

2.3 AIM OF THIS STUDY

The recent investigation about positive effects of fruits and vegetables on human health increased the portion of fruits and vegetables in human diet. In order to contribute these demands different techniques were investigated to provide the consumption of some fruits and vegetables during the seasons of shortage. Tomato is one of the fruit which has a wide growth area in Turkey. The studies about the chemical composition of tomato show that it has high phenolic content and it contains a lot of minerals which are important for human body. However, in Turkey, the sufficient interest has not been shown to this valuable fruit, a lot of genotype which have an ability to give high quality fruits was obliterated to only use their board. Due to its high moisture content and sensitivity to storage, its consumption is limited. Many papers on single method dehydration have been published recently, but not so many evaluate effects of pretreatments combined with drying process, especially on tomatoes, and in particular using ultrasound pretreated microwave drying.

Therefore, the aim of this study was to investigate effect of ultrasonic pre-treatment before drying on drying time and quality properties of tomato slices dried by microwave energy combined with hot air at 60°C with the intent to reduce drying time and to improve quality properties. Vitamin C, lycopene, total phenolics content, moisture contents, color, rehydration capacity and shrinkage of dried tomato slices were measured as responses and compared among various process conditions.

CHAPTER THREE

MATERIALS AND METHODS

3.1 MATERIALS

For this study, fresh tomato was obtained from Gaziantep (Turkey). Tomatoes obtained from a local supplier were at harvest maturity and uniform size. All chemicals were obtained from Merck (Darmstadt, Germany).

3.2 METHODS

3.2.1 Preparation of Tomato Slices

The tomatoes were washed in cold tap water and drained, then, cut into the 8 slices the mean thickness (0.7 ± 0.1 mm), length (54 ± 2 mm) and width (19 ± 1 mm) of all tomato slices used in the experiments were shown in Figure 3.1.

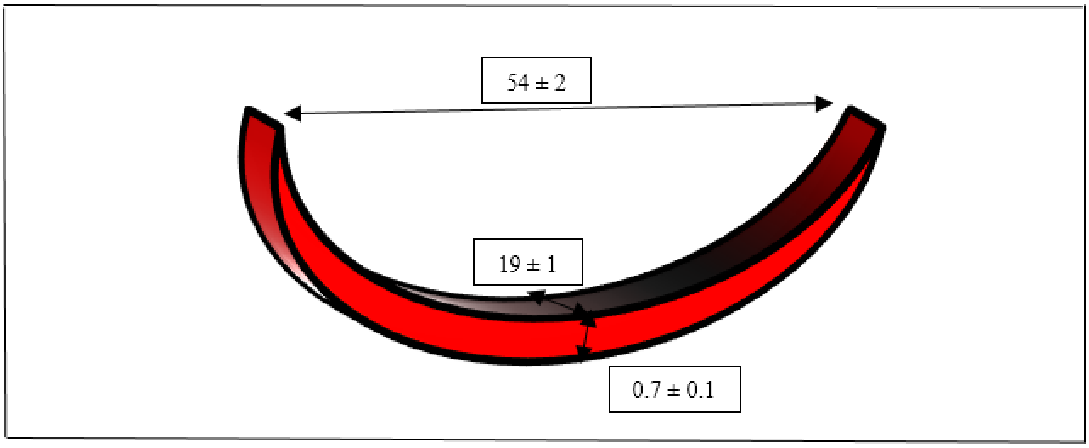

Figure 3.1 The mean thickness, length and width of tomato slices used in drying processes.

3.2.2 Ultrasound Pre-Treatment

The prepared tomato slices were pre-treated with ultrasound by immersing certain amount of slices into a 25 kHz ultrasound bath (INTERSONIC, MODEL: MIN 4 & 18, ISTANBUL/TURKEY) operating at 300 W effective power.

The bath contains tap water to a ratio of 1:4 tomato to water, Tomato slices were submitted to ultrasonic waves for different times (0, 20, 40 min), then transferred to an Air - Circulating Microwave Oven for drying.

3.2.3 Drying Processes

3.2.3.1 Microwave Drying

A programmable domestic microwave oven (Arçelik 9658, TURKEY) was used to drying tomato slices.

About 510 g of ultrasound pre-treated samples were put on a plate and replaced in the microwave dryer. The device operated at 120, 150 and 180 W power intensities. Moisture loss was recorded automatically by a digital balance connected to a computer at 30 minutes interval. The drying was continued until the moisture content reached around 17.65 % wet basis. This moisture content was selected as the final moisture content of dried tomato that is available in the markets.

Figure 3.2 Air - circulating microwave oven used in drying of tomato

Air velocity distribution in the oven chamber was measured by the PIV (Particle Image Velocimetry) method. The linear air velocity distribution on the surface of tray (m/s) was given in Figure 3.3. The air flow rate at the outlet of oven was 0.5 lt/s.

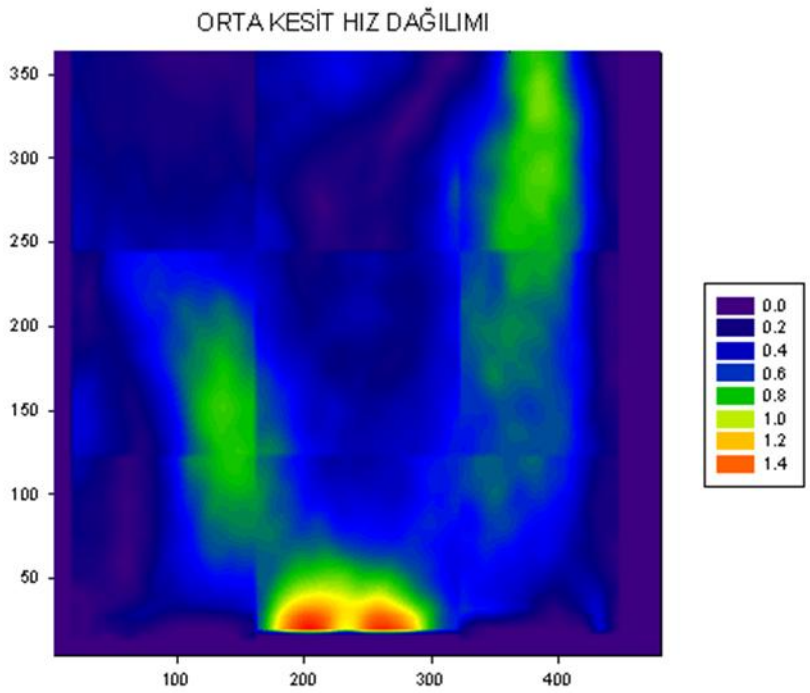

Figure 3.3 The velocity distribution of air (m/s) on the tray.

3.2.4 Measurement of Temperature Profiles

Air inside the oven, air outlet and sample centre temperatures were measured by fibre optic temperature sensor connected to a data acquisition and recording system (E-manager software). For monitoring the temperature profiles every second, three thermocouples were inserted at the centre of oven, output of oven and half-centre depth of sample.

3.2.5 Analyses

All the analyses were carried out in duplicate and results expressed as mean values ± standard deviation.

3.2.5.1 Determination of Moisture Content

The moisture content of tomato slices were determined by the oven method. A certain amount of minced/ground tomato was put in to a plate petri dish and replace in an oven at 105 ^{0}C for at least four hours. Then, it was cooled in–a desiccator then weighed. The moisture content (as wet basis) was determined by using the equation 3.1 (AOAC, 1995).

Moisture content % = $\frac{Wo-Wf}{Wo} x100$ 3.1

Where, w_0 is the initial weight of sample at time zero and w_f is the weight of dry sample.

3.2.5.2 Determination of Lycopene Content

A 0.50 g of tomato was ground in a mortar together with 1 mL of distilled water. Tomato pastes were transferred to light protected glass tubes with the addition of 5 mL of a 0.5 g/L Butylated Hydroxy Toluene (BHT) solution in acetone ; subsequently, 5 mL of 95%(v/v) aqueous ethanol and 10 mL of hexane were added. For lycopene extraction, the tubes were vortexes for 10 min. A supernatant aliquot (3.5 mL) was pipetted out and transferred to a quartz spectrophotometric cell. Absorbance was measured at 503 nm in a Perkin Elmer Lambda 25 UV/VIS spectrophotometer (Netherlands), Equation 3.2 was used to determine the amount of lycopene (mg/100 g dry solids) in tomato samples (Fish et al,. 2002).

$$\text{Lycopene content} = \frac{A_{503}}{\text{g sample}} * 312 \qquad 3.2$$

3.2.5.3 Determination of vitamin C

Vitamin C of fresh and dried samples were determined by standard AOAC method, where 5 g of fresh/dried tomato slices homogenized with 50 ml HPO_3-HOAc solution and filtered and stored at refrigerator. The filtrate was titrated with indophenol solution until light but distinct rose pink color persists about 5 sec. The amount of vitamin C was determined by using the Equation 3.3 (AOAC, 1995).

$$\text{mg ascorbic acid/ 100 g dry solid} = (X-B) \times (F/E) \times (V/Y) \qquad 3.3$$

where, X is average ml of sample titration, B is average ml of sample blank titration, F is mg ascorbic acid equivalent to 1.0 ml of indophenol standard solution, E is mass of sample assayed, V= volume of initial assay solution and Y= volume of sample aliquot titrated.

3.2.5.4 Determination of Total Phenolic Content

Total phenolic content was determined by Folin-Ciocalteu method. A 5 g of sample was homogenized and extracted in 50 ml of ethanol: acetone (70:30, v:v) for 1 h at 37 ^{0}C. the extract was filtered through a filter paper and rinsed with 50 ml of ethanol: acetone, this residue was re-extracted under the same conditions, the two filterates then combined and stored at -20 ^{0}C.

Then in a 10-ml Eppendorf tube, 7.9 ml distilled water, 0.1 ml of extract and 0.5 ml of Folin–Ciocalteu's Reagent (1:1 with water) were mixed. After 1 min, 1.5 ml of sodium carbonate (20 g per 100 ml) was added and mixed well, the reaction solution was then incubated at room temperature for 2 h in the dark before absorbance was read, then The absorbance were measured at 760 nm using Perkin Elmer lambda 25 UV/VIS spectrophotometer (Netherlands). Results were expressed as mg of Gallic acid equivalents per mass of dry tomato slices (Lako et al, 2007).

3.2.5.5 Color Determination

Color measurements of the dried tomato samples were carried out by using a Hunter Lab Color flex (A-60-1010-615 Model Colorimeter, Hunter Lab, and Reston, VA) according to CIELAB system. The color of fresh and dries tomato slices were measured. The color values were expressed as L*(whiteness or brightness/darkness), a*(redness/greenness) and b*(yellowness/blueness) at any time, respectively. The instrument was standardized each time with a black and a white tile. The total color difference (TCD) was calculated equation 3.4.

$$TCD = \sqrt{\left(L_o^* - L^*\right)^2 + \left(a_o^* - a^*\right)^2 + \left(b_o^* - b^*\right)^2} \qquad 3.4$$

Where, L_0^*, a_0^*, b_0^* were initial values of fresh tomato slices; L^*, a^*, b^* were dried sample values.

3.2.5.6 Rehydration Capacity Determination

Rehydration experiments were performed by soaking a weighed amount of dried samples into distilled water at 30 °C. At 5 min intervals the samples were withdrawn, drained over a mesh and placed onto two layers of paper towels, quickly blotted 4-5 times in order to eliminate the surface water by gently rolling the dried tomato pieces on the towel and then weighed to an accuracy of 0.0001 g. This procedure was established based on the preliminary test results and other reported studies (Maskan, 2001).

3.2.5.7 Measurement of Shrinkage

Volume changes due to sample shrinkage were measured by a water displacement method, certain amount of dried tomato slices whose initial volume is known was immersed in water and volume displayed was recorded immediately periodically. Measurements were made as quickly as possible to avoid water uptake by samples. The shrinkage/volume change of the samples was expressed as a percent shrinkage ratio of sample volume at any time to initial volume as given in Equation 3.5 (Maskan, 2001; Sjöholm and Gekas, 1995).

$$\%S = \frac{V}{V_0} * 100 \qquad 3.5$$

Where, S is shrinkage, V is volume of sample (ml) at any time during drying, V_0 is initial volume of sample (ml).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 GENERAL

In the present study, firstly, the initial properties of fresh tomato slices were determined. Moisture, vitamin C, lycopene and total phenolics contents were 94.77±0.13; 433.94±19.03; 3920.57±21.4 and 8.27±0.54, respectively. The Hunter color values L*, a* and b* were 27.72±0.1, 27.95±0.4 and 22.08±0.1, respectively. Since tomato contains high amount of moisture, vitamin C and lycopene, the study was continued with pre-treatment of samples by immersing samples in distilled water in an ultrasonic bath and exposed to ultrasonic waves for various times. Ultrasonic pretreatment of fresh tomato slices for 20 and 40 min reduced vitamin C content about 5.94 % and 21.71 %, and lycopene content about 31.61 % and 17.77 %, respectively. The last part of the study involves drying of pre-treated tomato slices by microwave drying process at 60°C hot air continuously circulated in the oven. The kinetics of drying data was studied. Also, the physical and chemical properties of dried tomato slices were investigated and compared with respect to drying methods.

4.2 DRYING BEHAVIOR OF TOMATO SLICES

4.2.1 Analysis of Drying Data

The microwave drying curves for tomato slices are shown in Figures 4.1, 4.2 and 4.3 for untreated tomatoes, ultrasound treated for 40 min and ultrasound treated for 20 min tomatoes, respectively. Experimental data are given in Appendix A (Tables 5.1, 5.4, and 5.7). The time required to reduce the moisture content to any given level in microwave drying was dependent on the power level, being the highest at 180 W (no ultrasound pre-treated) and lowest at 120 W (Ultrasound pre-treatment at 300 W for 20 min). The times necessary to reach 17.65% moisture content were 301, 334, and 330 min at microwave power level of 180 W (no ultrasound pre-treated), 180 W (Ultrasound pre-treatment at 300 W for 40 min) and 180 W

(Ultrasound pre-treatment at 300 W for 20 min). Thus, it is clearly seen that compared with microwave drying at 150 and 120 W in the same ultrasound pre-treatment conditions greatly reduced the drying time of tomato slices.

The results showed that the microwave power had an important effect on drying time. The decrease in drying times with increasing in microwave power and ultrasound pre-treatment time may be due to increase in water diffusivity within the tomato slices, which increased the migration of moisture. Similar observations were reported by Fernandes and Sueli (2004). The highest value of the drying constant (k) was noticed in sample treated with ultrasound for 40 min (Table 4.1). Therefore, at higher microwave power and higher ultrasound application power, due to quick removal of moisture the drying times were decrease by 3.22 %, 1.68 % and 5.66 % for 180, 150 and 120 W microwave powers as compared with no ultrasound pre-treated samples.

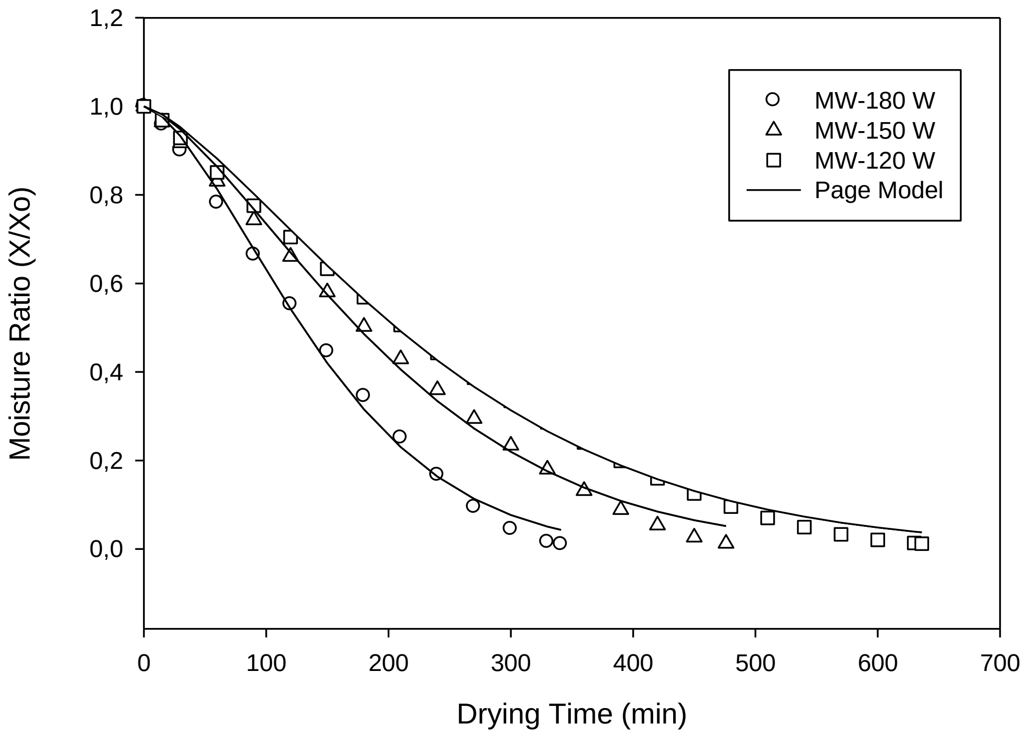

Figure 4.1 Effect of microwave power on drying behavior of tomato slices (No ultrasound pre-treatment).

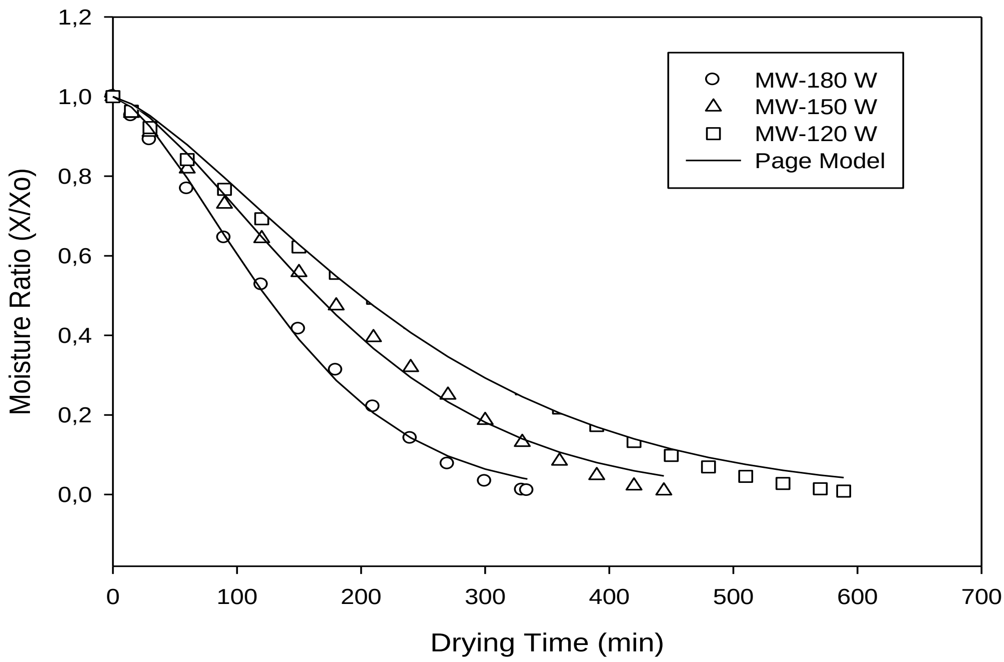

Figure 4.2 Effect of microwave power on drying behavior of tomato slices (Ultrasound pre-treatment at 300 W for 40 min).

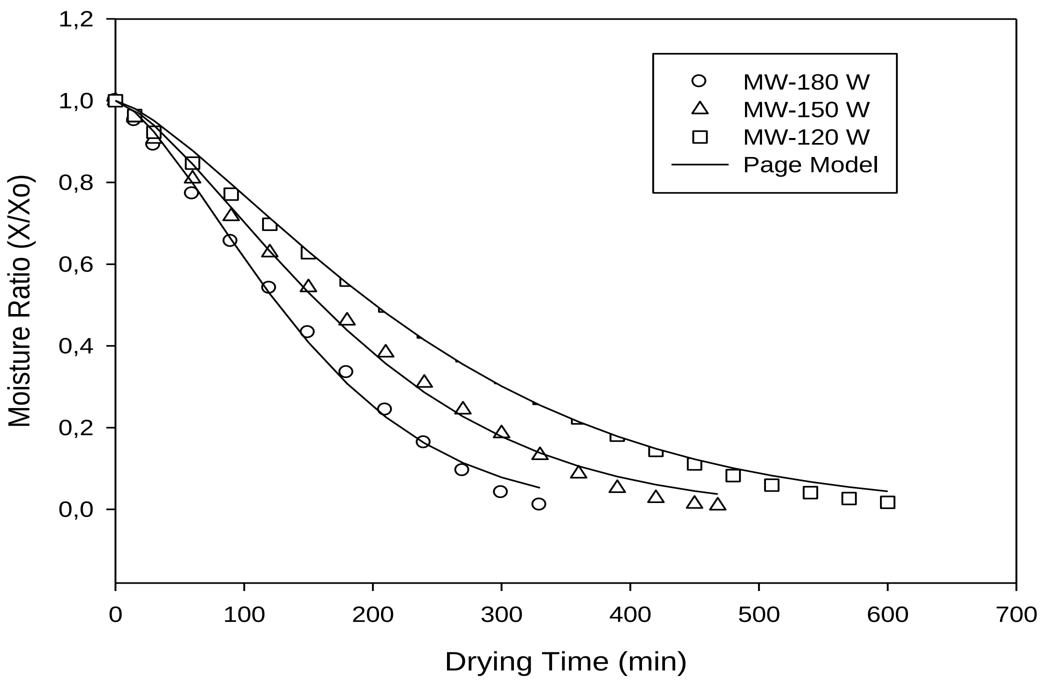

Figure 4.3 Effect of microwave power on drying behavior of tomato slices (Ultrasound pre-treatment at 300 W for 20 min).

4.2.2 Kinetic Modelling Of Drying Data

In this section, microwave drying curves of tomato slices were presented and compared. A well-known model, Page model, was used in order to numerically compare rate of moisture removal from dried samples by this drying method. Page's model (Eqn 4.1) has been widely used to describe drying behaviour of a variety of biological materials. The values of the equilibrium moisture content are relatively small compared to instantaneous moisture content and initial moisture content and the moisture ratio can be simplified to X/Xo (Doymaz, 2007).

$$MR = \frac{X - X_e}{X_o - X_e} = \frac{X}{Xo} = \exp(-kt^n) \qquad 4.1$$

where, X is moisture content (kg H_2O/kg dry solids) at any time, Xe equilibrium moisture content (kg H_2O/kg dry solids), Xo initial moisture content (kg H_2O/kg dry solids), n is empirical constant and k is drying constant (1/min).

In this work, equation 4.1 was employed as a physical model for description of the drying processes, rather than a mathematical model. Drying data were used to test the applicability of this model. The parameter k and n together with SE and R^2 values were evaluated using nonlinear regression. The results were tabulated in Table 4.1. The model gave good fit for all the experimental runs with R^2 values greater than 0.99.

Table 4.1 Nonlinear regression analysis results of Equation 4.1

Parameter	Drying method								
	MW (No US pre-treatment)			MW (US pre-treatment at 300 W for 40 min)			MW (US pre-treatment at 300 W for 20 min)		
	MW Power (W)			MW Power (W)			MW Power (W)		
	180	150	120	180	150	120	180	150	120
k	$4.5x10^{-4}$	$4.0x10^{-4}$	$3.0x10^{-4}$	$4.9x10^{-4}$	$4.2x10^{-4}$	$3.6x10^{-4}$	$4.6x10^{-4}$	$4.1x10^{-4}$	$3.4x10^{-4}$
SE(±)	$1.0x10^{-4}$	$1.0x10^{-4}$	0.00	$1.0x10^{-4}$	$1.0x10^{-4}$	$1.0x10^{-4}$	$2.0x10^{-4}$	$1.0x10^{-4}$	0.00
n	1.546	1.451	1.381	1.542	1.492	1.399	1.510	1.445	1.379
SE(±)	0.067	0.050	0.034	0.063	0.058	0.045	0.067	0.051	0.036
r^2	0.995	0.995	0.996	0.996	0.994	0.995	0.995	0.995	0.997

The parameters k and n have been correlated with different process variables such as air temperature and velocity, and sample conditions (e.g. existence of an external skin) (Methakhup et al., 2005) in the current study, both the parameters n and drying constant k increased as microwave power increased. Ultrasound pretreatment only slightly increased k parameter. However, the dependence of the drying constant n on microwave power has been reported in other studies (Chen et al., 2000; Queiroz et al., 2004) In addition, it has been observed an increase in the parameter n for the existence of an outer skin on the dried fruit, depending on the thickness and type of product (Karathanos and Belessiotis 1999). Increase in parameter n in current study may be due to skin formation on the tomato slices at high microwave power levels.

4.2.3 Analysis of Drying Rates

The drying rate of each study was calculated at different times and plotted against average moisture content (Data were shown in Appendix A, Tables 5.10, 5.11 and 5.12). Figures 4.4, 4.5 and 4.6 show drying rate against average moisture content of tomato slices for microwave drying processes and ultrasound pre-treatment application at zero, 20 and 40 minutes, respectively. From an examination of these figures it is obvious that the entire drying process for the samples occurred in falling rate period in this study. The entire drying process for the samples occurred in the range of falling rate period for microwave drying in this study. Although high moisture foods can be expected to have a period of constant rate drying, this was not observed in microwave drying process. The results indicated that mass transfer within the sample is rapid during microwave heating because heat is generated within the sample, creating a large vapour pressure differential between the centre and the surface of products. It accelerates removal of water from the tissues in the sample by microwave (Maskan, 2000, 2001).

Increasing both ultrasound treatment period and microwave power increased drying rates. Higher drying rates were obtained with higher ultrasound treatment period (40 min) and microwave power (180 W). Higher microwave power at both ultrasound pre-treated or not ultrasound pre-treated samples had the higher drying rates than lower microwave power at the same conditions. The results showed that the ultrasound pre-treatment application did not but microwave power significantly influenced the drying rate of tomato slices. The drying rate of ultrasound treated samples was slightly greater in comparison to untreated one. The highest drying rate, was noticed at the beginning of the drying for tomato slices after 40 min ultrasound application. Lowest drying rates were observed for samples ultrasound treated for 20 min, respectively. Untreated samples were characterized by the longest drying time and their drying rate was the smallest. The samples treated with ultrasound for 40 min were dried faster than tomatoes treated for 20 min. Moreover, the material after 20 min of ultrasonic treatment exhibited the longest drying time of all sonicated samples. The calculated values of the drying rate for each individual samples were presented in Appendix A (Table 5.10, 5.11 and 5.12).

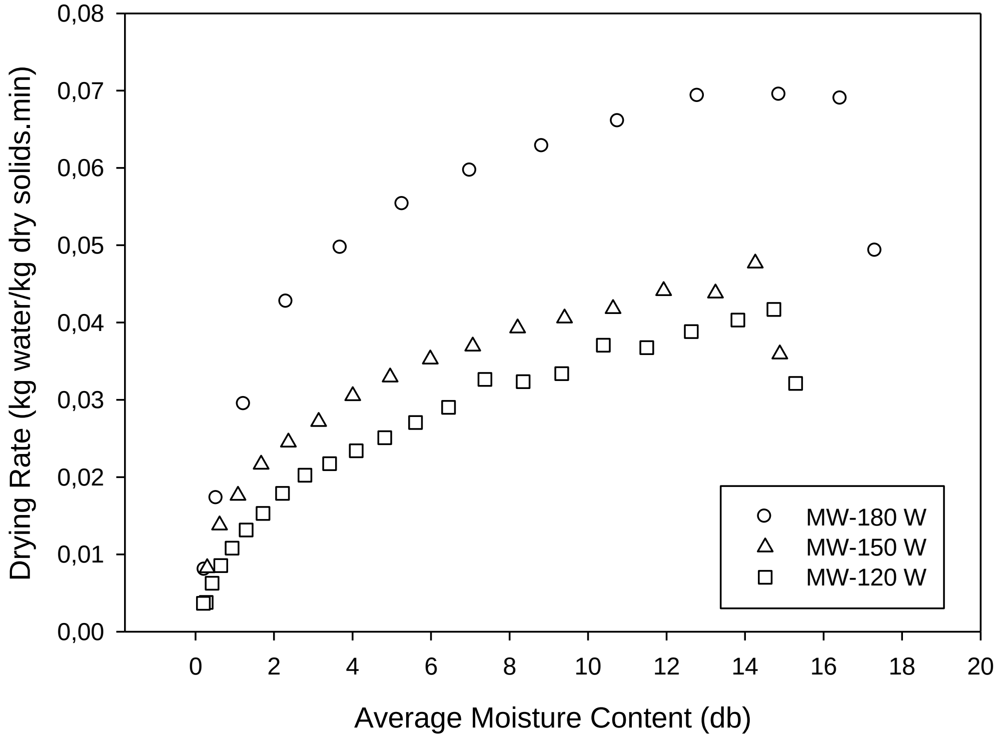

Figure 4.4 Effect of microwave power on drying rate of tomato slices (No ultrasound pre-treatment).

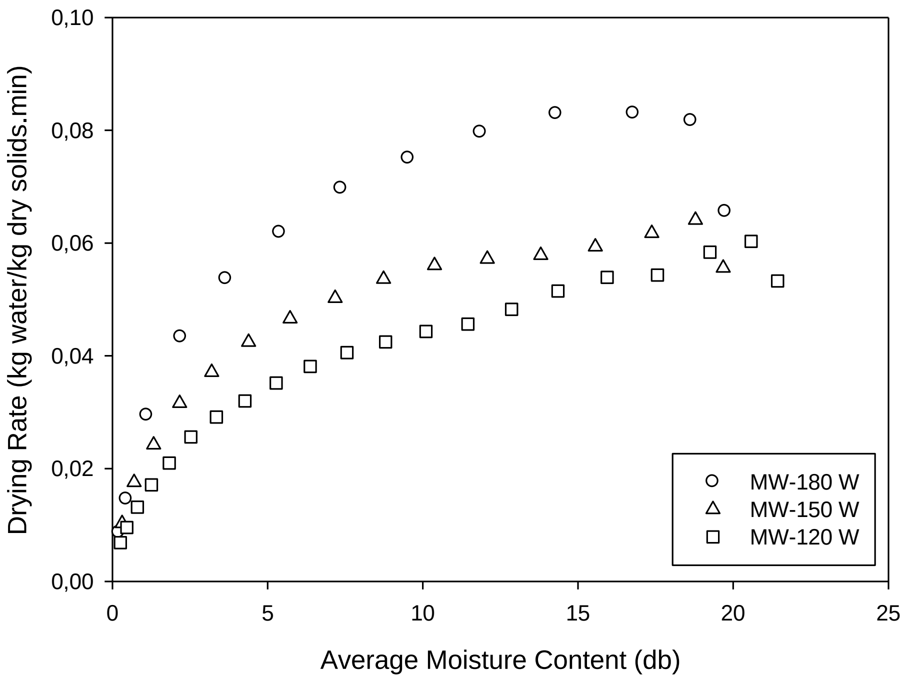

Figure 4.5 Effect of microwave power on drying rate of tomato slices (Ultrasound pre-treatment at 300 W for 40 min).

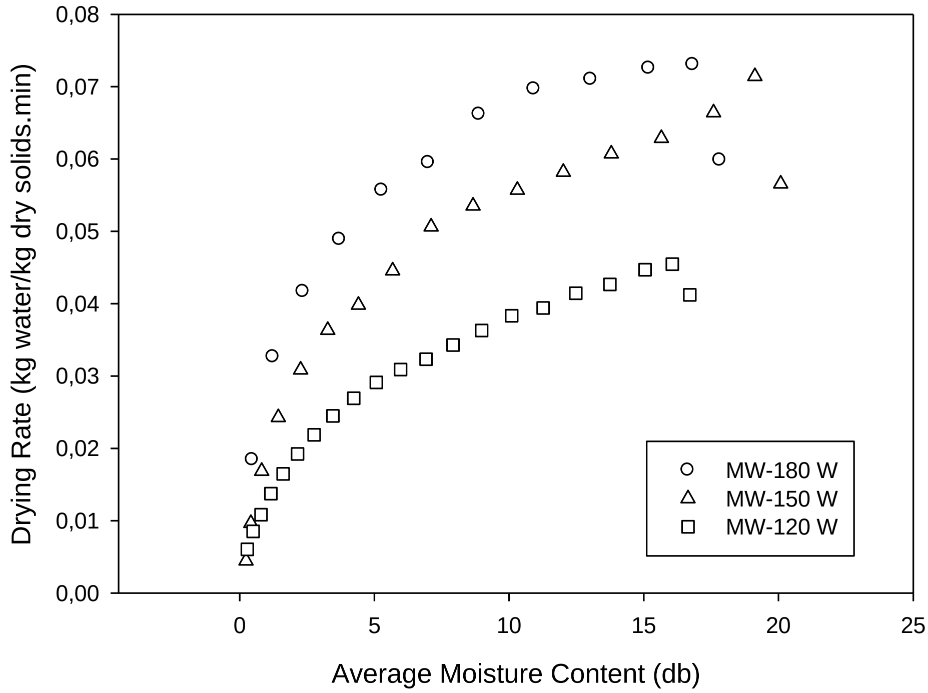

Figure 4.6 Effect of microwave power on drying rate of tomato slices (Ultrasound pre-treatment at 300 W for 20 min).

4.2.4 Temperature Development in the Samples

Monitoring the temperature distribution is important for understanding the reasons behind quality changes (e.g. change in color) that occur during drying. Therefore, the internal temperature in the tomato samples during drying was recorded as well as the oven air and output air temperatures using fiber optic temperature sensor thermocouples. Figures 4.7, 4.8 and 4.9 show typical graphs of the temperatures of–no ultrasound-pretreated drying of tomato slices. Temperature profile of ultrasound pretreated samples exhibited similar trend. Therefore, those data were not presented. It is clear from these figures that the higher the microwave power level, the faster the increase in temperature of oven inside, air output and center of the tomato.

Data are shown in Appendix A (Tables 5.13, 5.14 and 5.15). Figures showed that the internal tomato slices temperature change with levels of microwave power. The internal material air temperature rapidly increased during the first few minutes. The temperature curve during microwave drying categorized into three zones that different from each other, after reached the maximum value followed by steady state temperature period the material temperature decreased slowly as shown in drying rate curves (Figure 4.4, 4.5 and 4.6). The first and second zones corresponded to the region where the most moisture lost occurred, the similar effects shown in Workneh et al. (2011)'s study.

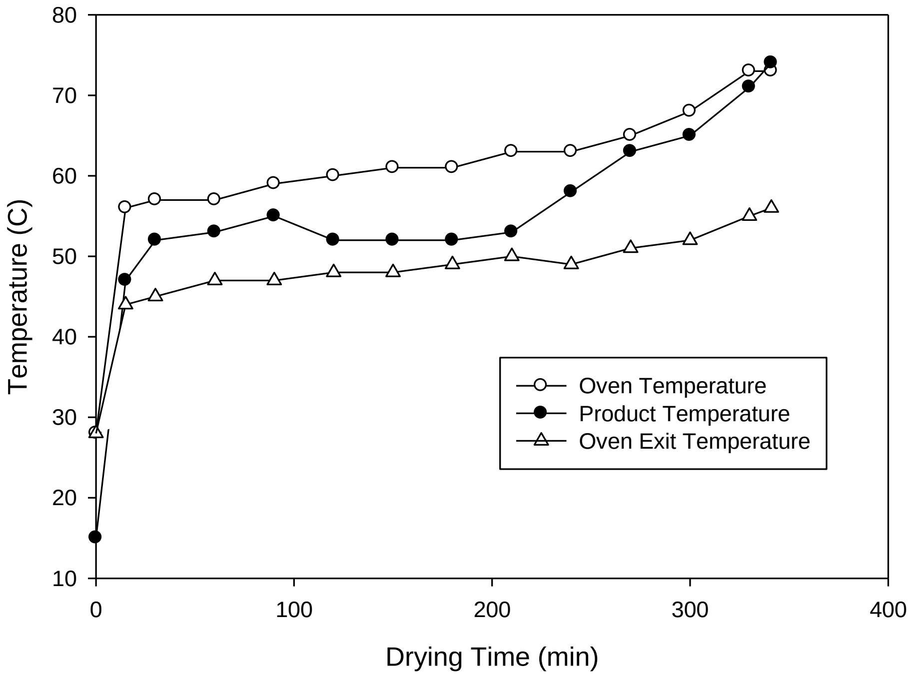

Figure 4.7 Temperature change in oven, product and oven exit during microwave drying of tomato slices at 180 W (No ultrasound pre-treatment).

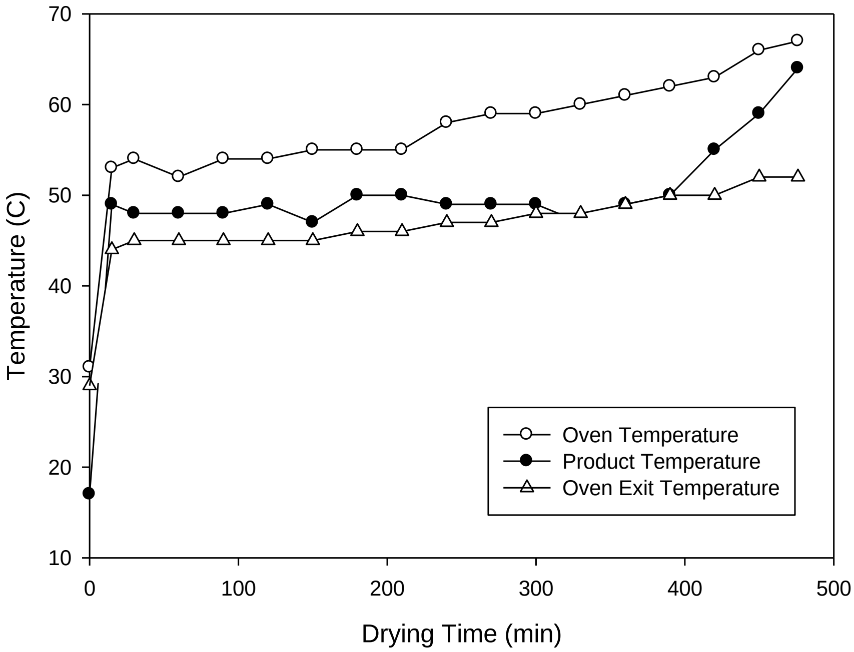

Figure 4.8 Temperature change in oven, product and oven exit during microwave drying of tomato slices at 150 W (No ultrasound pre-treatment).

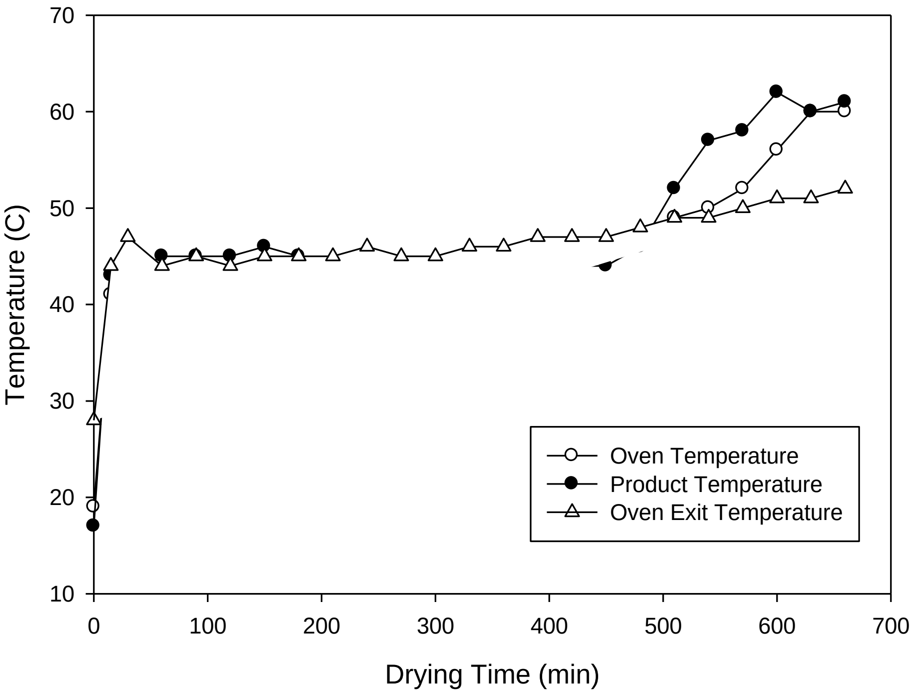

Figure 4.9 Temperature change in oven, product and oven exit during microwave drying of tomato slices at 120 W (No ultrasound pre-treatment).

4.3 EFFECT OF ULTRASOUND PRE- TREATMENT ON PROPERTIES OF DRIED TOMATO SLICES

In all experiments, tomato slices showed a noticeable tendency to small in size inside the drying chamber (Figure 4.10). Due to water lost during drying the results of moisture content, color, total phenolic content, lycopene content, vitamin c, shrinkage and rehydration capacity samples were presented in figures and tables.

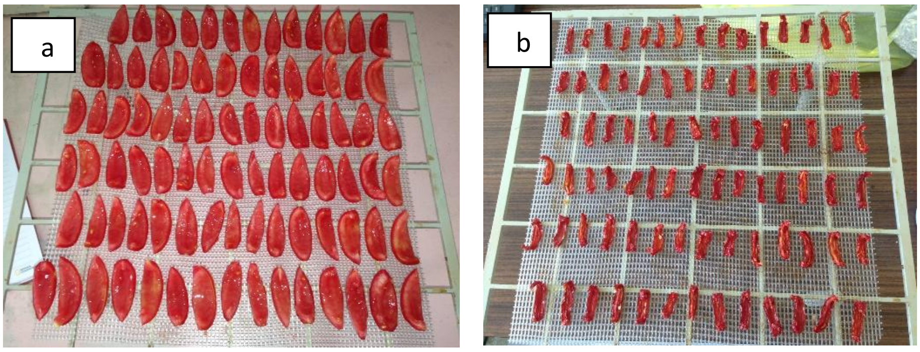

Figure 4.10 Tomato slices before drying (a), tomato slices after drying (b)

4.3.1 Color Change of Dried Tomato Slices

Change in total color difference (TCD) of dried tomato slices is shown in Table 4.2. It shows that as the ultrasound pre-treatment time and microwave power increase, change in total color difference decreases. This may be due to the sensitivity of colour pigments to heating. A TCD less than 5 represents an excellent colour, a TCD value equals to 10 is acceptable for dried products. According to these specifications the colour values of dried tomatoes falls into excellent to acceptable range.

Also, Hunter a^* value is an important parameter for many fruits because it is directly related to redness and it is investigated in many studies in order to measure the extent of red colour degradation. The results of the color changes in Hunter parameters obtained from the microwave drying of tomato slices at the various powers were displayed in Table 4.2. It is obvious that there was a significant decrease in the brightness (L*) for all the dried tomato slices at the various ultrasound pre-treated dried samples studied in comparison with the fresh ones. However, brightness increased significantly with microwave power, when microwave power increased from 120 W to 180 W. In comparison, the redness (a*) of the fresh tomatoes was significantly higher than the dried samples. The redness significantly increased with ultrasound pre-treatment of samples. This shows that, compared with the fresh tomatoes, there was red pigment degradation associated with drying within the microwave power in this study. The decrease in redness may be attributed to the occurrence of reaction between the amino acids and reducing sugars (Maillard reaction) in the tomato during drying. The yellowness of all dried tomato samples generally decreased significantly with microwave power and ultrasound pre-treatment for samples. The yellowness decreased from 22.8 in the fresh tomato to 21.10 for the samples dried at 180 W with 20 min ultrasound pre-treatment.

The higher L* values and a*/b* values are desirable in dried products. Nevertheless, higher L* values in the dried samples may be related to anthocyanin degradation caused by microwaves on the surfaces of the samples (Abano et al., 2014). The a*/b* ratio can be used as a quality specification for tomato paste. An a*/b* ratio ≥ 2 is excellent, a*/b* ratio < 1.8 is not acceptable.

Table 4.2 Effect of microwave drying at different power levels on shrinkage and color properties of dried tomato slices.

Ultrasound treatment time (min)	Micro wave drying power (W)	Drying time (min)	Shrinkage $(V/V_0)*100$	L*	a*	b*	a*/b*	TCD
0	120	636	6.25	24.85± 0.1	26.7 ± 0.7	16.97 ±0.9	1.57	5.99±0.8
0	150	476	8.82	22.81± 0.4	25.39± 0.0	15.96 ±0.0	1.59	8.25±0.2
0	180	341	6.66	24.56± 0.2	26.44 ±0.5	17.96 ±0.2	1.47	5.40±0.3
20	120	600	11.11	27.98± 0.99	28.24 ±0.4	21.10 ±0.9	1.34	1.04±0.8
20	150	468	5.26	23.32± 0.0	24.77 ±0.3	16.85 ±0.5	1.47	7.50±0.3
20	180	330	5.55	27.05 ± 0.4	28.57 ±0.2	21.90 ±0.2	1.30	0.92±0.3
40	120	589	6.66	26.31 ± 0.0	28.18 ±0.5	19.98± 0.11	1.41	5.53±0.4
40	150	444	6.25	24.55± 0.2	26.66 ±0.1	17.24 ±0.1	1.55	5.90±0.6
40	180	334	6.90	26.78± 0.6	28.65± 0.4	21.85± 0.12	1.31	5.93±0.1
Initial properties of fresh tomato			100	27.72± 0.1	27.95± 0.4	22.08± 0.1	1.26	0.00

4.3.2 Change in Shrinkage

Shrinkage occurred during drying was calculated by using Equation 3.5. The effects of ultrasound pre-treatment period and microwave power level on shrinkage of dried tomato slices are shown in Table 4.2. The shrinkage values of microwave dried tomato slices were 6.25, 8.82 and 6.66 for no ultrasound pre-treated dried tomato slices at 120, 150 and 180 W; 11.11, 5.26 and 5.55 for 20 minute ultrasound pre-treated at 120, 150 and 180 W and 6.66, 6.25 and 6.90 for 40 min ultrasound pre-treated at 120, 150 and 180 W, respectively. This shows that drying at 120 W with 20 min ultrasound pre-treatment promoted more shrinkage because of low drying rate. Göğüş (1994) explained that the larger differences in moisture content that may exist within a single piece of material create shrinkage effects that are dependent upon the rate of drying. If a piece of highly shrinkable material is dried so slowly, like microwave dried at 120 W, then, its centre is never very much wetter than the surface, the internal stresses are minimized and the material shrinks down fully onto a solid core. On the other hand, if it is dried rapidly, like microwave drying at high power intensity, the walls become more dry than the centre and are placed under sufficient tension to give them permanent set with similar dimensions to the original piece. Therefore, microwave dried samples at low power shrink less than those at high power. The study of Maskan (2001) found highest shrinkage value of microwave dried kiwifruits than hot air and hot air-microwave dried kiwifruits. This is not in agreement with our results.

4.3.3 Change in Total Phenolic Content

The changes in total phenolics content of microwave dried tomato slices, on a dry basis are shown in Figures 4.11, 4.12 and 4.13. As shown, ultrasound pre-treatment and microwave power affected total phenolics content proportionally. At less and more ultrasound pre-treatments, the decrease in microwave power resulted in an increase in total phenolics content of dried tomato slices. However, ultrasound pre-treatment had greater effect on total phenolics content than microwave power statistically. This may be due to encapsulation effect of ultrasound pre-treatment protecting phenolic compounds against external actions (Kha, 2010). Türkmen et al. (2005) investigated the total phenolics and antioxidant activities of some vegetables during heating process. They observed that total phenolic content of squash, peas and leek decreased, but of green pepper, green beans, broccoli and spinach increased. These are in agreement with our results.

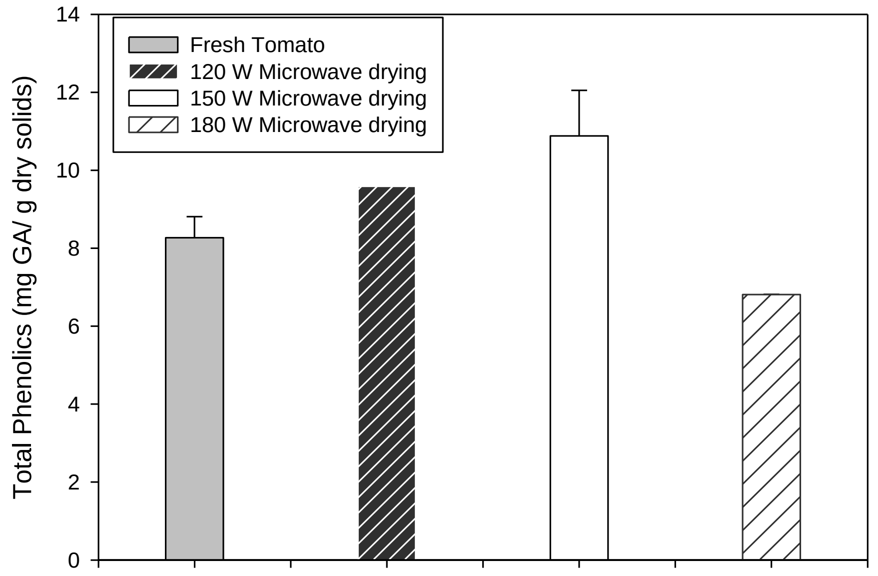

Figure 4.11 Effect of microwave drying on total phenolics content of tomato slices (No ultrasound pre-treatment).

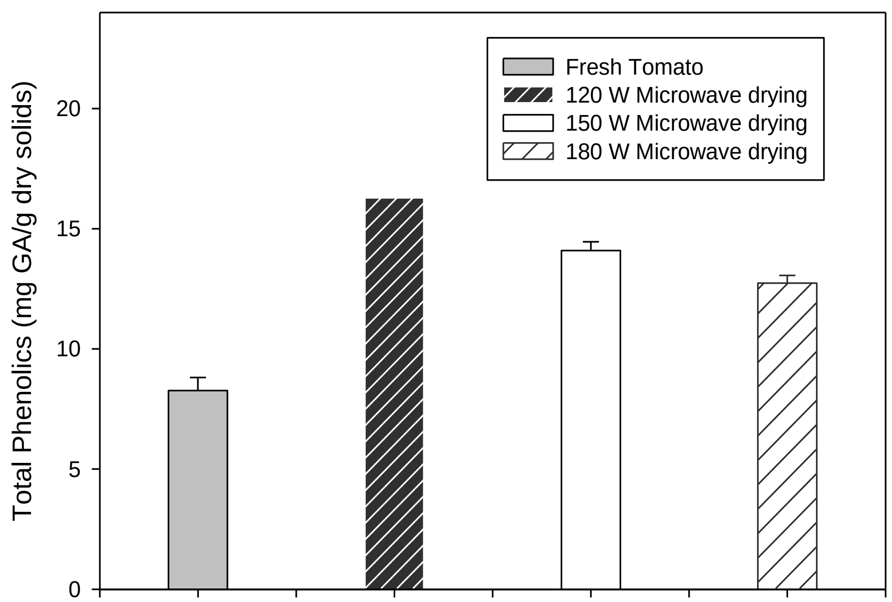

Figure 4.12 Effect of microwave drying on total phenolics content of tomato slices (Ultrasound pre-treatment at 300 W for 20 min).

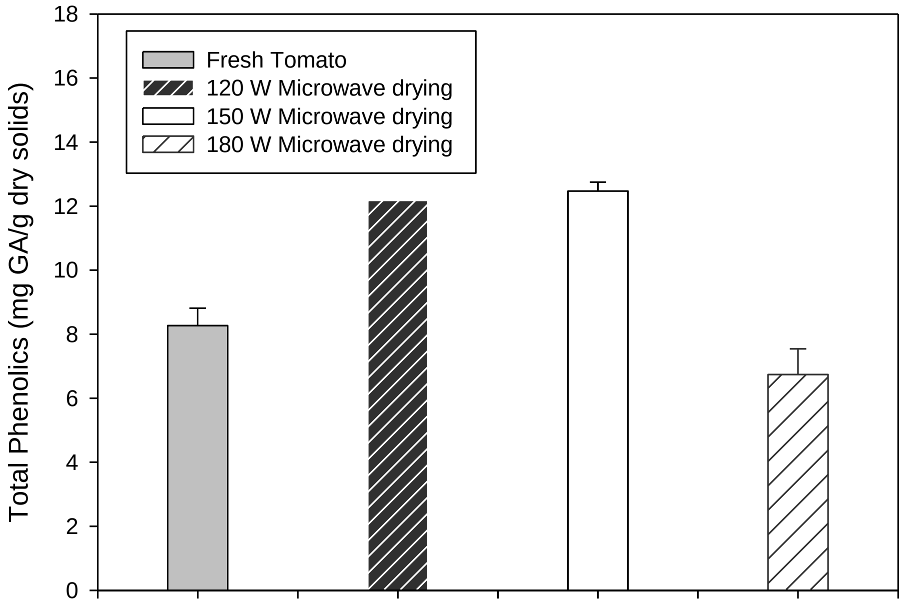

Figure 4.13 Effect of microwave drying on total phenolics content of tomato slices (Ultrasound pre-treatment at 300 W for 40 min).

4.3.4 Change in Lycopene Content

The change in total lycopene content of dried tomato slices, on a dry basis is shown in Figures 4.14, 4.15 and 4.16. As shown, ultrasound pre-treatment and microwave power affected lycopene content proportionally. Results showed that microwave drying significantly decreased lycopene content of tomato slices. Lycopene content of fresh tomatoes were higher than dried tomatoes. It has been reported that in tomatoes, lycopene content degradation depends on many factors including processing temperature, that is, the heat energy from the microwave power. Lycopene of the fresh tomato can isomerizes from its trans-form into the cis-lycopene as a result of thermal treatment or degrade into colourless form. (Abano et al., 2013).

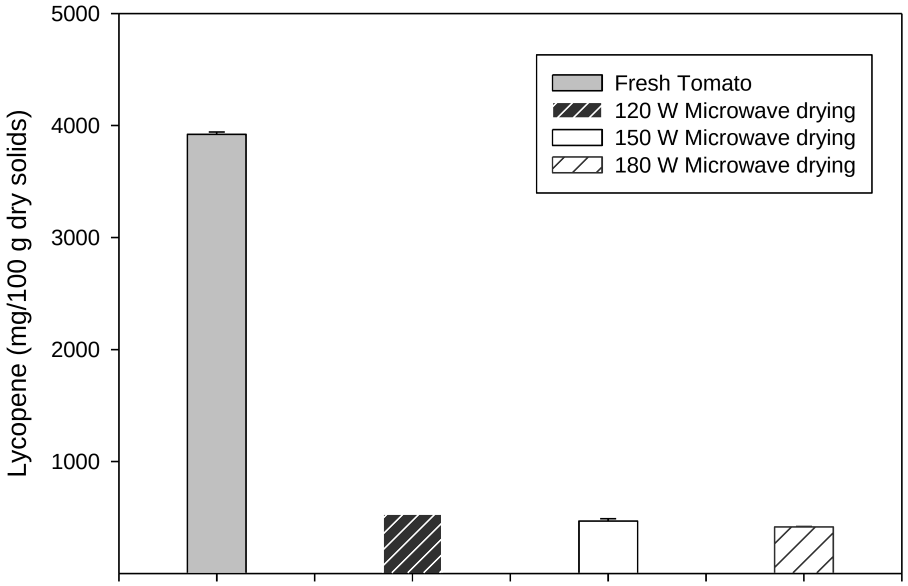

Figure 4.14 Effect of microwave drying on lycopene content of tomato slices (No ultrasound pre-treatment).

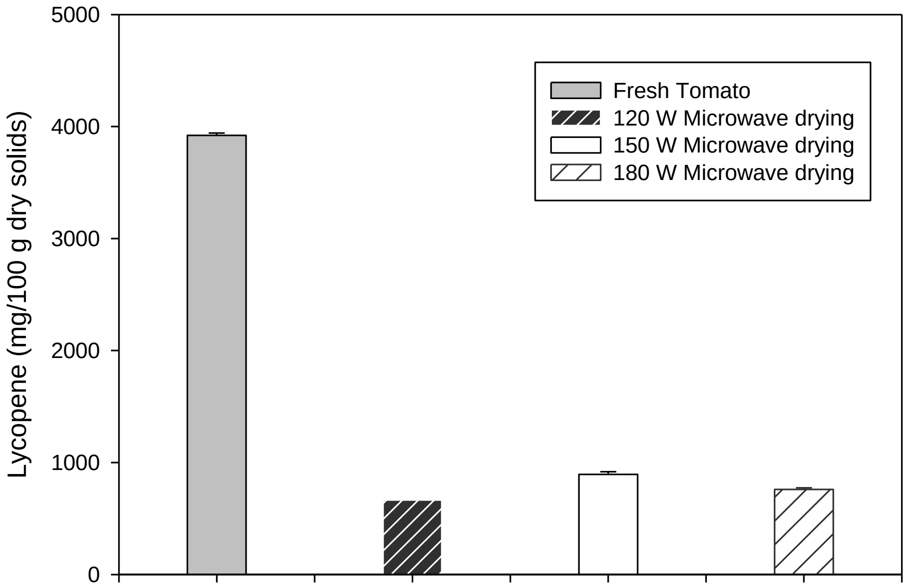

Figure 4.15 Effect of microwave drying on lycopene content of tomato slices (Ultrasound pre-treatment at 300 W for 20 min).

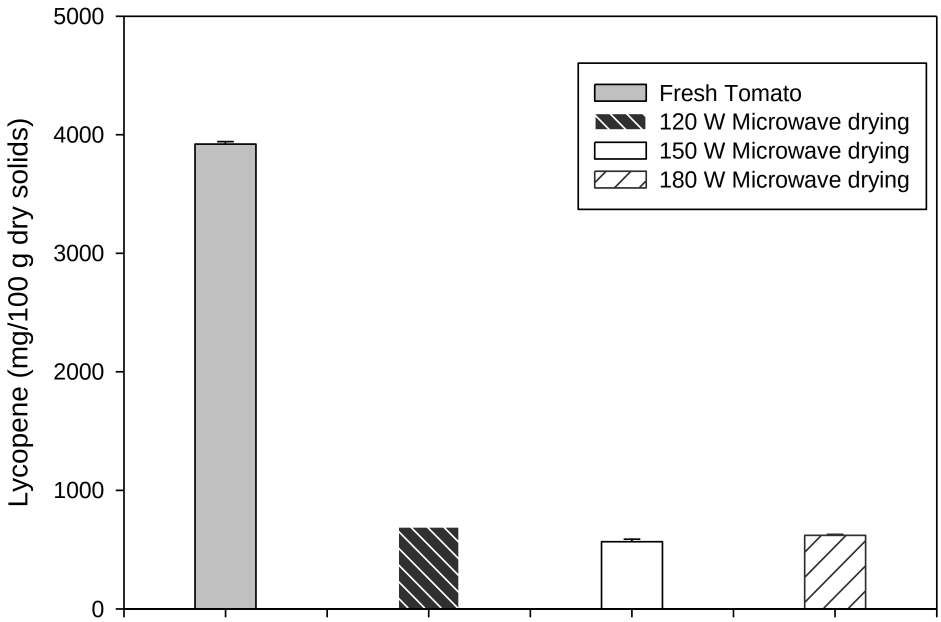

Figure 4.16 Effect of microwave drying on lycopene content of tomato slices (Ultrasound pre-treatment at 300 W for 40 min).

4.3.5 Change in Vitamin C Content

Drying of tomato slices by microwave at different powers can effect vitamin C content rapidly. Figure 4.17 shows the vitamin C content of no ultrasound pre-treated tomato slices. Ultrasound pre-treatment has effect on protecting vitamin C content of dries tomato slices as shown in Figures 4.18 and 4.19. Among them drying at lowest power of microwave had a higher content of vitamin C of both pre-treated or/and non-pre-treated dried tomato slices. The results showed that, however, as microwave power increases the amount of vitamin C decreases. The reduction of vitamin C content observed during microwave drying could be due to the destruction of vitamin C by the electromagnetic waves of the microwave power as the samples were dried. This is because of thermal damage and irreversible oxidative reactions. These are the two main causes of ascorbic acid degradation during drying as a result of long drying times. Therefore, the degradation in vitamin C content may be thermal damage resulting from the microwave energy as it impinges on the tomato surface (Abano et al., 2013). The similar study was found by Marfil (2008). He found that the vitamin C content decreased after osmotic pre-treatment of tomatoes.

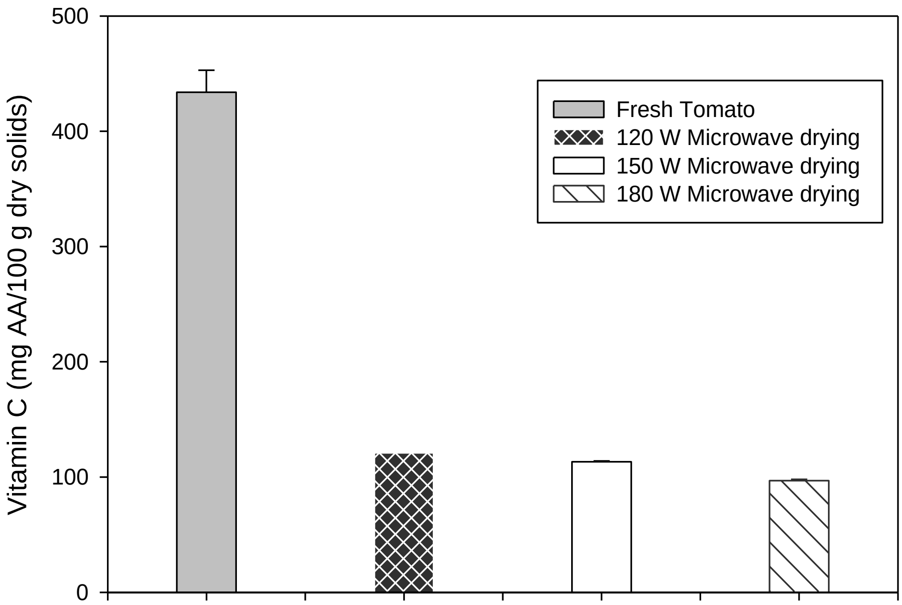

Figure 4.17 Effect of microwave drying on Vitamin-C content of tomato slices (No ultrasound pre-treatment).

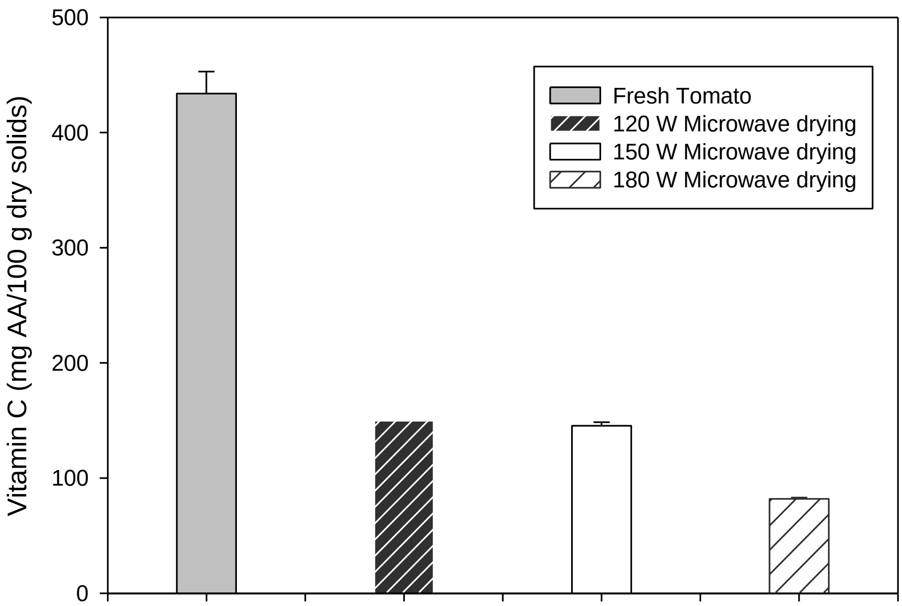

Figure 4.18 Effect of microwave drying on Vitamin-C content of tomato slices (Ultrasound pre-treatment at 300 W for 20 min).

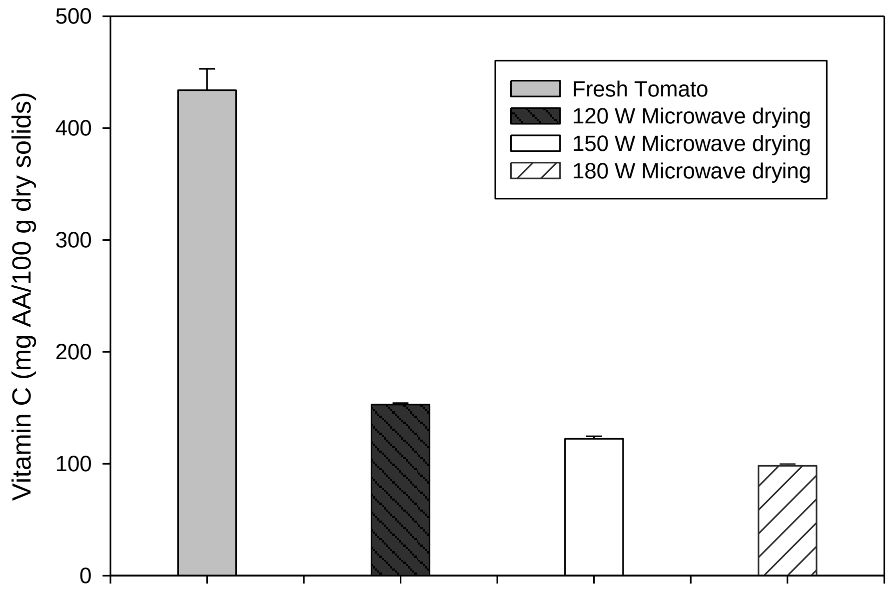

Figure 4.19 Effect of microwave drying on Vitamin-C content of tomato slices (Ultrasound pre-treatment at 300 W for 40 min).

4.3.6 Change in Rehydration Capacity

During reconstitution of dehydrated products the amount and rate of water absorption determines to a considerable extent the sensorial properties and preparation time. The rehydration characteristics of a dried product are used as a quality index and they indicate the physical and chemical changes during drying as influenced by processing conditions, sample pre-treatment and composition (Maskan, 2001). The rehydration capacities of tomato slices dried at different microwave powers and ultrasound pre-treatments were calculated and presented graphically. Experimental data are presented in Appendix A (Tables 5.16, 5.17 and 5.18). The rehydration curves of dried tomato slices are shown in Figures 4.20, 4.21 and 4.22 for no ultrasound pre-treated and ultrasound pre-treated microwave dried samples, respectively.

Figure 4.20 shows that the rehydration capacity (water holding capacity) of dried tomato slices with no ultrasound pre-treatment at 120 W microwave power was less than those dried at the other microwave powers. Also, Figure 4.21 shows the effect of microwave power on rehydration capacity of slices. The reduced hydrophilic properties gave lower values for the rehydration capacity, disallowing imbibition of water, and leaving unfilled pores (Jayarman et al., 1990; Krokida and Maroulis, 2001 and Vega-Galvez et al., 2008).

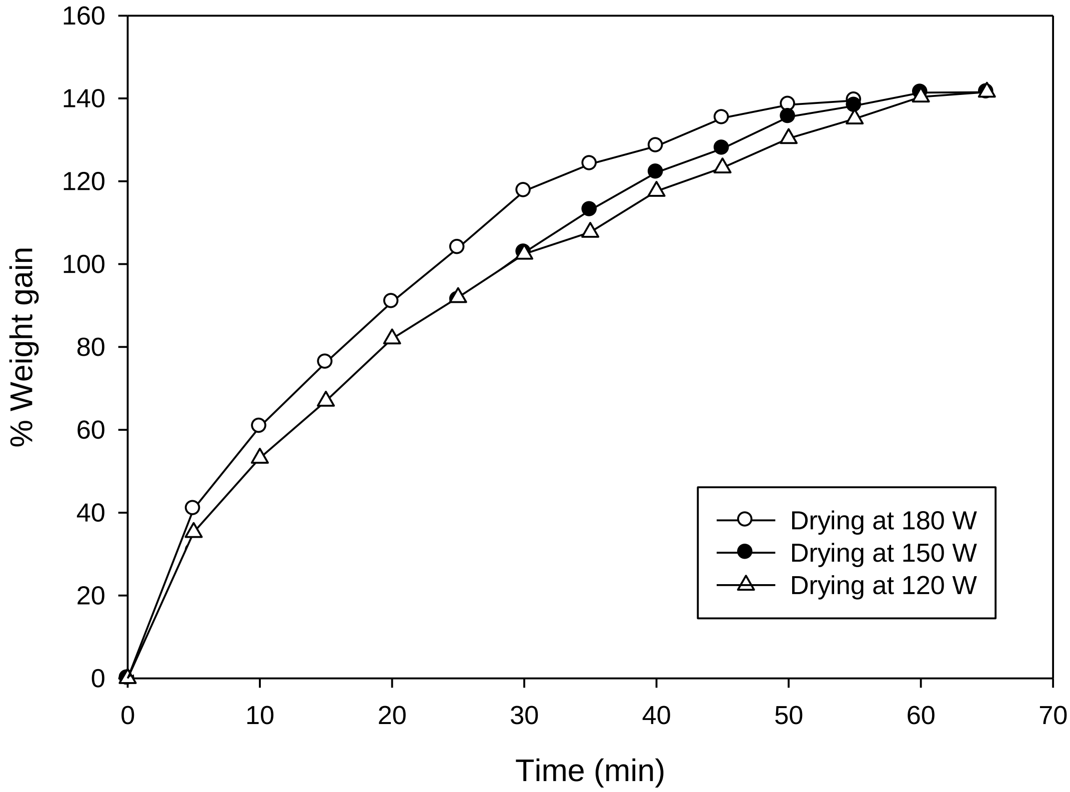

Figure 4.20 Effect of microwave drying at different power levels on rehydration capacity of dried tomato (No ultrasound pre-treatment).

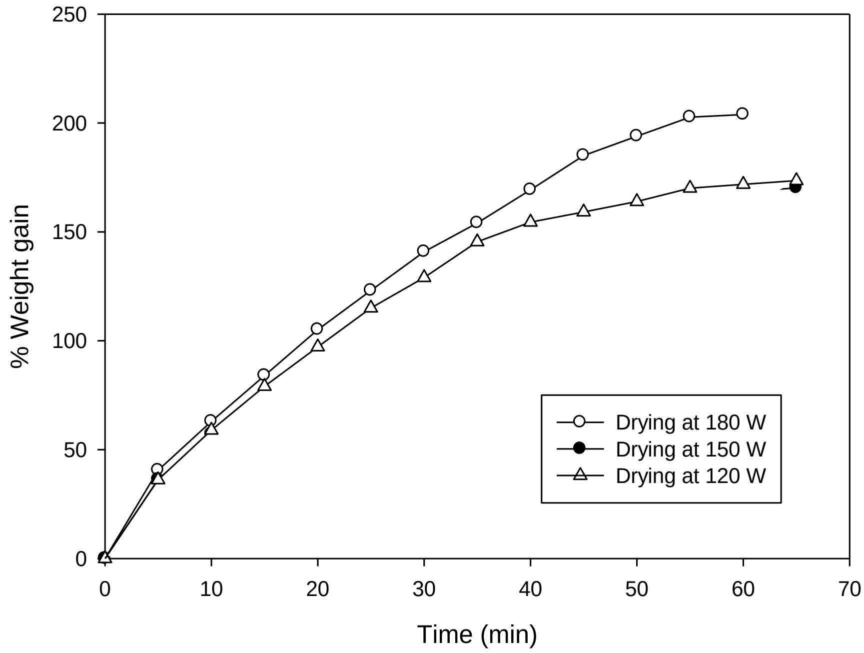

Figure 4.21 Effect of microwave drying at different power levels on rehydration capacity of dried tomato (Ultrasound pre-treatment at 300 W for 40 min).

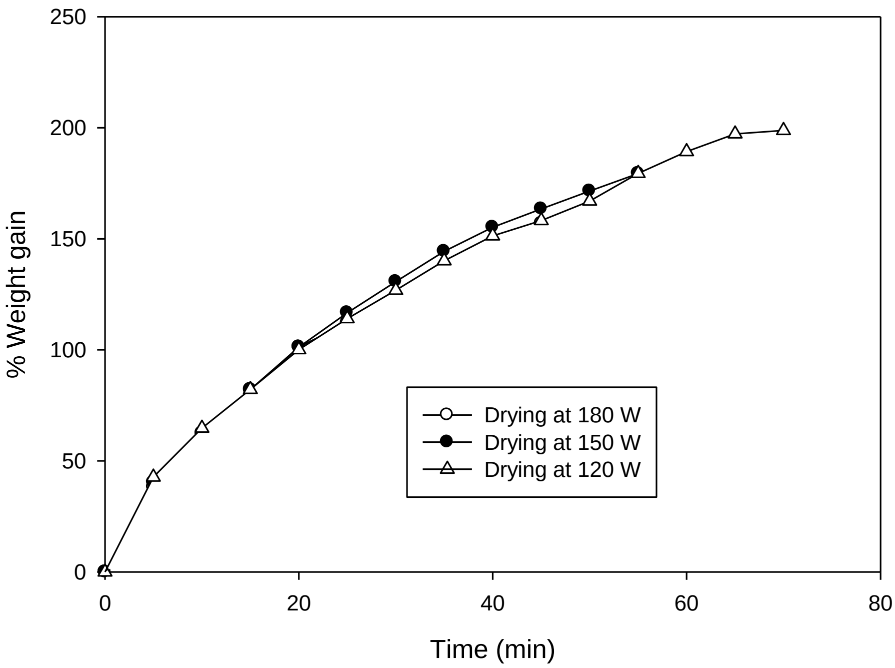

Figure 4.22 Effect of microwave drying at different power levels on rehydration capacity of dried tomato (Ultrasound pre-treatment at 300 W for 20 min).

CHAPTER FIVE

CONCLUSION

The study of effect of ultrasound pre-treatment on drying behavior of tomato slices has revealed some conclusions. Among them, color was significantly affected by ultrasound pre-treatment. Total color difference increased by increasing microwave power and ultrasound pre-treatment. High shrinkage values were obtained at 20 minute ultrasound pre-treated samples at 120 W drying process. Increasing of microwave power of both pre-treated or/and non-pre-treated samples increased drying rate of tomato slices. Rate of rehydration capacity of high power microwave dried samples with ultrasound pre-treatment was faster than low powers.

Among the drying parameters studied, 40 min ultrasound pre-treatment and 120 W microwave power could be recommended for drying tomato slices with respect to better colour, shrinkage, rehydration capacity and drying time.

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APPENDIX A

Table 5.1 Experimental and predicted drying data for microwave drying of tomato slices at 180 W power (No ultrasound pre-treatment).

Drying time (min)	Moisture content (g/g dry solids)	Moisture ratio (X/Xo)	Predicted
0	17.692	1.000	1.000
15	16.953	0.958	0.977
30	15.919	0.900	0.932
60	13.836	0.782	0.813
90	11.757	0.665	0.677
120	9.777	0.553	0.542
150	7.894	0.446	0.420
180	6.105	0.345	0.315
210	4.447	0.251	0.230
240	2.957	0.167	0.164
270	1.677	0.095	0.114
300	0.795	0.045	0.077
330	0.278	0.016	0.051
341	0.190	0.011	0.044

Table 5.2 Experimental and predicted drying data for microwave drying of tomato slices at 150 W power (No ultrasound pre-treatment).

Drying time (min)	Moisture content (g/g dry solids)	Moisture ratio (X/Xo)	Predicted
0	15.155	1.000	1.000
15	14.616	0.964	0.981
30	13.901	0.917	0.948
60	12.588	0.831	0.864
90	11.265	0.743	0.768
120	10.011	0.661	0.670
150	8.795	0.580	0.575
180	7.616	0.503	0.486
210	6.508	0.429	0.405
240	5.450	0.360	0.334
270	4.462	0.294	0.273
300	3.547	0.234	0.220
330	2.732	0.180	0.176
360	1.997	0.132	0.139
390	1.347	0.089	0.109
420	0.819	0.054	0.085
450	0.405	0.027	0.065
476	0.190	0.013	0.052

Table 5.3 Experimental and predicted drying data for microwave drying of tomato slices at 120 W power (No ultrasound pre-treatment).

Drying time (min)	Moisture content (g/g dry solids)	Moisture ratio (X/Xo)	Predicted
0	15.529	1.000	1.000
15	15.047	0.969	0.982
30	14.422	0.929	0.953
60	13.212	0.851	0.882
90	12.047	0.776	0.803
120	10.945	0.705	0.721
150	9.833	0.633	0.641
180	8.831	0.569	0.564
210	7.860	0.506	0.492
240	6.881	0.443	0.426
270	6.010	0.387	0.367
300	5.198	0.335	0.314
330	4.445	0.286	0.266
360	3.743	0.241	0.225
390	3.091	0.199	0.189
420	2.484	0.160	0.158
450	1.947	0.125	0.131
480	1.488	0.096	0.109
510	1.094	0.070	0.089
540	0.770	0.050	0.073
570	0.514	0.033	0.060
600	0.326	0.021	0.049
630	0.212	0.014	0.039
636	0.190	0.012	0.038

Table 5.4 Experimental and predicted drying data for microwave drying of tomato slices at 180 W power (Ultrasound pre-treatment at 300 W for 40 min).

Drying time (min)	Moisture content (g/g dry solids)	Moisture ratio (X/Xo)	Predicted
0	20.231	1.000	1.000
15	19.248	0.951	0.973
30	18.022	0.891	0.924
60	15.532	0.768	0.795
90	13.043	0.645	0.651
120	10.654	0.527	0.513
150	8.403	0.415	0.389
180	6.312	0.312	0.287
210	4.456	0.220	0.205
240	2.846	0.141	0.143
270	1.545	0.076	0.097
300	0.662	0.033	0.064
330	0.225	0.011	0.041
334	0.190	0.009	0.039

Table 5.5 Experimental and predicted drying data for microwave drying of tomato slices at 150 W power (Ultrasound pre-treatment at 300 W for 40 min).

Drying time (min)	Moisture content (g/g dry solids)	Moisture ratio (X/Xo)	Predicted
0	20.097	1.000	1.000
15	19.263	0.959	0.981
30	18.302	0.911	0.947
60	16.450	0.819	0.857
90	14.669	0.730	0.753
120	12.933	0.644	0.647
150	11.219	0.558	0.545
180	9.537	0.475	0.451
210	7.929	0.395	0.367
240	6.422	0.320	0.294
270	5.025	0.250	0.233
300	3.752	0.187	0.182
330	2.639	0.131	0.140
360	1.691	0.084	0.107
390	0.965	0.048	0.080
420	0.437	0.022	0.060
444	0.190	0.009	0.047

Table 5.6 Experimental and predicted drying data for microwave drying of tomato slices at 120 W power (Ultrasound pre-treatment at 300 W for 40 min).

Drying time (min)	Moisture content (g/g dry solids)	Moisture ratio (X/Xo)	Predicted
0	21.831	1.000	1.000
15	21.032	0.963	0.982
30	20.128	0.922	0.952
60	18.377	0.842	0.879
90	16.747	0.767	0.796
120	15.129	0.693	0.711
150	13.584	0.622	0.628
180	12.137	0.556	0.548
210	10.768	0.493	0.475
240	9.438	0.432	0.407
270	8.164	0.374	0.347
300	6.947	0.318	0.293
330	5.803	0.266	0.246
360	4.747	0.217	0.205
390	3.788	0.174	0.170
420	2.913	0.133	0.140
450	2.145	0.098	0.115
480	1.515	0.069	0.093
510	1.002	0.046	0.076
540	0.607	0.028	0.061
570	0.320	0.015	0.049
589	0.190	0.009	0.043

Table 5.7 Experimental and predicted drying data for microwave drying of tomato slices at 180 W power (Ultrasound pre-treatment at 300 W for 20 min).

Drying time (min)	Moisture content (g/g dry solids)	Moisture ratio (X/Xo)	Predicted
0	18.268	1.000	1.000
15	17.370	0.951	0.973
30	16.275	0.891	0.924
60	14.098	0.772	0.799
90	11.968	0.655	0.661
120	9.878	0.541	0.528
150	7.893	0.432	0.409
180	6.108	0.334	0.308
210	4.438	0.243	0.226
240	2.972	0.163	0.162
270	1.722	0.094	0.114
300	0.742	0.041	0.078
330	0.190	0.010	0.053

Table 5.8 Experimental and predicted drying data for microwave drying of tomato slices at 150 W power (Ultrasound pre-treatment at 300 W for 20 min).

Drying time (min)	Moisture content (g/g dry solids)	Moisture ratio (X/Xo)	Predicted
0	20.505	1.000	1.000
15	19.657	0.959	0.978
30	18.585	0.906	0.940
60	16.593	0.809	0.845
90	14.706	0.717	0.739
120	12.884	0.628	0.632
150	11.138	0.543	0.531
180	9.467	0.462	0.438
210	7.861	0.383	0.357
240	6.341	0.309	0.287
270	5.005	0.244	0.227
300	3.811	0.186	0.178
330	2.720	0.133	0.138
360	1.794	0.088	0.106
390	1.066	0.052	0.080
420	0.560	0.027	0.060
450	0.271	0.013	0.045
468	0.190	0.009	0.038

Table 5.9 Experimental and predicted drying data for microwave drying of tomato slices at 120 W power (Ultrasound pre-treatment at 300 W for 20 min).

Drying time (min)	Moisture content (g/g dry solids)	Moisture ratio (X/Xo)	Predicted
0	17.018	1.000	1.000
15	16.399	0.964	0.981
30	15.703	0.923	0.951
60	14.420	0.847	0.878
90	13.129	0.771	0.796
120	11.872	0.698	0.713
150	10.686	0.628	0.631
180	9.550	0.561	0.553
210	8.469	0.498	0.481
240	7.387	0.434	0.415
270	6.401	0.376	0.355
300	5.490	0.323	0.302
330	4.624	0.272	0.255
360	3.808	0.224	0.214
390	3.089	0.182	0.179
420	2.456	0.144	0.149
450	1.888	0.111	0.123
480	1.405	0.083	0.101
510	1.010	0.059	0.083
540	0.697	0.041	0.068
570	0.455	0.027	0.055
600	0.293	0.017	0.044

Table 5.10 Drying rate vs. average moisture content data for microwave drying of tomato slices at various microwave powers (No ultrasound pre-treatment).

180 W		150 W		120 W	
Average moisture content	Drying rate	Average moisture content	Drying rate	Average moisture content	Drying rate
17.322	0.049	14.886	0.036	15.288	0.032
16.436	0.069	14.259	0.048	14.734	0.042
14.877	0.069	13.245	0.044	13.817	0.040
12.796	0.069	11.926	0.044	12.630	0.039
10.767	0.066	10.638	0.042	11.496	0.037
8.835	0.063	9.403	0.041	10.389	0.037
6.999	0.060	8.205	0.039	9.332	0.033
5.276	0.055	7.062	0.037	8.346	0.032
3.702	0.050	5.979	0.035	7.371	0.033
2.317	0.043	4.956	0.033	6.446	0.029
1.236	0.029	4.005	0.031	5.604	0.027
0.536	0.017	3.139	0.027	4.822	0.025
0.234	0.008	2.364	0.025	4.094	0.023
		1.672	0.022	3.417	0.022
		1.083	0.018	2.787	0.020
		0.612	0.014	2.216	0.018
		0.298	0.008	1.718	0.015
				1.291	0.013
				0.932	0.011
				0.642	0.009
				0.420	0.006
				0.269	0.004
				0.201	0.004

Table 5.11 Drying rate vs. average moisture content data for microwave drying of tomato slices at various microwave powers (Ultrasound pre-treatment at 300 W for 40 min).

180 W		150 W		120 W	
Average moisture content	Drying rate	Average moisture content	Drying rate	Average moisture content	Drying rate
19.740	0.066	19.680	0.056	21.432	0.053
18.635	0.082	18.782	0.064	20.580	0.060
16.777	0.083	17.376	0.062	19.252	0.058
14.288	0.083	15.559	0.059	17.562	0.054
11.849	0.080	13.801	0.058	15.938	0.054
9.529	0.075	12.076	0.057	14.357	0.052
7.358	0.070	10.378	0.056	12.860	0.048
5.384	0.062	8.733	0.054	11.452	0.046
3.651	0.054	7.176	0.050	10.103	0.044
2.196	0.043	5.724	0.047	8.801	0.042
1.104	0.029	4.389	0.042	7.555	0.041
0.443	0.015	3.196	0.037	6.375	0.038
0.208	0.009	2.165	0.032	5.275	0.035
		1.328	0.024	4.268	0.032
		0.701	0.018	3.351	0.029
		0.314	0.010	2.529	0.026
				1.830	0.021
				1.258	0.017
				0.804	0.013
				0.464	0.010
				0.255	0.007

Table 5.12 Drying rate vs. average moisture content data for microwave drying of tomato slices at various microwave powers (Ultrasound pre-treatment at 300 W for 20 min).

180 W		150 W		120 W	
Average moisture content	Drying rate	Average moisture content	Drying rate	Average moisture content	Drying rate
17.819	0.060	20.081	0.057	16.709	0.041
16.822	0.073	19.121	0.071	16.059	0.045
15.186	0.073	17.589	0.066	15.047	0.045
13.033	0.071	15.650	0.063	13.737	0.043
10.923	0.070	13.795	0.061	12.475	0.041
8.885	0.066	12.011	0.058	11.262	0.039
7.000	0.059	10.302	0.056	10.096	0.038
5.273	0.056	8.664	0.054	8.976	0.036
3.705	0.049	7.101	0.051	7.917	0.034
2.347	0.042	5.673	0.045	6.918	0.032
1.232	0.033	4.408	0.040	5.970	0.031
0.466	0.018	3.265	0.036	5.070	0.029
		2.257	0.031	4.229	0.027
		1.430	0.024	3.458	0.024
		0.813	0.017	2.763	0.022
		0.415	0.010	2.146	0.019
		0.230	0.004	1.611	0.016
				1.158	0.014
				0.789	0.011
				0.499	0.009
				0.281	0.006

Table 5.13 Temperature change in oven, product and oven exit during microwave drying of tomato slices at 180 W (No ultrasound pre-treatment).

Drying Time (min)	% RH (Oven exit)	Oven exit temperature (ºC)	Product temperature (ºC)	Oven temperature (ºC)
0	55	28	15	28
15	79	44	47	56
30	82	45	52	57
60	80	47	53	57
90	79	47	55	59
120	75	48	52	60
150	71	48	52	61
180	67	49	52	61
210	62	50	53	63
240	61	49	58	63
270	57	51	63	65
300	39	52	65	68
330	28	55	71	73
341	25	56	74	73

Table 5.14 Temperature change in oven, product and oven exit during microwave drying of tomato slices at 150 W (No ultrasound pre-treatment).

Drying Time (min)	% RH (Oven exit)	Oven exit temperature (ºC)	Product temperature (ºC)	Oven temperature (ºC)
0	57	29	17	31
15	75	44	49	53
30	75	45	48	54
60	72	45	48	52
90	71	45	48	54
120	70	45	49	54
150	68	45	47	55
180	66	46	50	55
210	64	46	50	55
240	60	47	49	58
270	57	47	49	59
300	53	48	49	59
330	49	48	47	60
360	45	49	49	61
390	41	50	50	62
420	37	50	55	63
450	32	52	59	66
476	27	52	64	67

Table 5.15 Temperature change in oven, product and oven exit during microwave drying of tomato slices at 120 W (No ultrasound pre-treatment).

Drying Time (min)	% RH (Oven exit)	Oven exit temperature (ºC)	Product temperature (ºC)	Oven temperature (ºC)
0	62	28	17	19
15	71	44	43	41
30	69	47	43	44
60	70	44	45	43
90	69	45	45	42
120	66	44	45	41
150	65	45	46	42
180	63	45	45	42
210	62	45	44	43
240	60	46	45	43
270	58	45	42	41
300	55	45	43	41
330	54	46	45	42
360	51	46	43	43
390	49	47	43	43
420	45	47	44	44
450	43	47	44	45
480	41	48	46	47
510	38	49	52	49
540	35	49	57	50
570	32	50	58	52
600	30	51	62	56
630	28	51	60	60
660	28	52	61	60

Table 5.16 Effect of microwave drying at different power levels on rehydration capacity of dried tomato (No ultrasound pre-treatment).

Tomato dried at 180 W			Tomato dried at 150 W			Tomato dried at 120 W		
Rehydration time (min)	Weight (g) at any time	Weight gain (%)	Rehydration time (min)	Weight (g) at any time	Weight gain (%)	Rehydration time (min)	Weight (g) at any time	Weight gain (%)
0	0.749	0.000	0	0.839	0.000	0	0.751	0.000
5	1.055	40.908	5	1.097	30.656	5	1.015	35.225
10	1.204	60.748	10	1.245	48.350	10	1.150	53.171
15	1.320	76.235	15	1.373	63.577	15	1.253	66.960
20	1.430	90.868	20	1.485	76.897	20	1.366	81.988
25	1.527	103.925	25	1.606	91.314	25	1.441	91.966
30	1.630	117.650	30	1.702	102.824	30	1.520	102.438
35	1.679	124.166	35	1.788	113.035	35	1.559	107.740
40	1.712	128.518	40	1.865	122.149	40	1.633	117.613
45	1.762	135.287	45	1.913	127.904	45	1.676	123.248
50	1.786	138.491	50	1.977	135.530	50	1.729	130.336
55	1.794	139.533	55	2.000	138.246	55	1.765	135.079
			60	2.026	141.427	60	1.804	140.368
			65	2.027	141.511	65	1.813	141.540

Table 5.17 Effect of microwave drying at different power levels on rehydration capacity of dried tomato (Ultrasound pre-treatment at 300 W for 40 min).

Tomato dried at 180 W			Tomato dried at 150 W			Tomato dried at 120 W		
Rehydration time (min)	Weight (g) at any time	Weight gain (%)	Rehydration time (min)	Weight (g) at any time	Weight gain (%)	Rehydration time (min)	Weight (g) at any time	Weight gain (%)
0	0.637	0.000	0	0.824	0.000	0	0.813	0.000
5	0.895	40.512	5	1.123	36.315	5	1.107	36.147
10	1.038	62.941	10	1.295	57.216	10	1.292	58.981
15	1.172	83.974	15	1.428	73.358	15	1.455	79.060
20	1.307	105.117	20	1.562	89.598	20	1.603	97.219
25	1.421	123.105	25	1.682	104.139	25	1.748	115.022
30	1.535	140.888	30	1.783	116.434	30	1.862	129.023
35	1.619	154.073	35	1.868	126.666	35	1.995	145.436
40	1.716	169.298	40	1.972	139.386	40	2.069	154.528
45	1.816	185.042	45	2.036	147.057	45	2.106	159.154
50	1.873	193.910	50	2.112	156.390	50	2.145	163.939
55	1.928	202.668	55	2.193	166.209	55	2.195	170.054
60	1.936	203.861	60	2.213	168.637	60	2.210	171.875
			65	2.226	170.154	65	2.224	173.561

Table 5.18 Effect of microwave drying at different power levels on rehydration capacity of dried tomato (Ultrasound pre-treatment at 300 W for 20 min).

Tomato dried at 180 W			Tomato dried at 150 W			Tomato dried at 120 W		
Rehydration time (min)	Weight (g) at any time	Weight gain (%)	Rehydration time (min)	Weight (g) at any time	Weight gain (%)	Rehydration time (min)	Weight (g) at any time	Weight gain (%)
0	0.810	0.000	0	0.743	0.000	0	0.742	0.000
5	1.119	38.143	5	1.041	40.242	5	1.059	42.747
10	1.316	62.486	10	1.203	62.034	10	1.222	64.748
15	1.472	81.669	15	1.353	82.155	15	1.351	82.165
20	1.631	101.296	20	1.494	101.239	20	1.484	100.067
25	1.718	112.097	25	1.609	116.700	25	1.588	114.074
30	1.803	122.577	30	1.713	130.694	30	1.683	126.840
35	1.921	137.094	35	1.814	144.337	35	1.781	140.132
40	1.998	146.649	40	1.895	155.232	40	1.864	151.321
45	2.081	156.870	45	1.956	163.461	45	1.916	158.264
50	2.129	162.770	50	2.016	171.515	50	1.980	166.959
55	2.141	164.338	55	2.075	179.407	55	2.073	179.496
			60	2.094	182.020	60	2.146	189.269
						65	2.205	197.250
						70	2.216	198.773

APPENDIX B

Table 5.19 Quality properties of fresh and dried tomato slices.

Ultrasound treatment time (min)	Microwave drying power (W)	Drying time (min)	Vitamin-C (mgAA/100 g dry solids)	Lycopen (mg/100 g dry solids)	Total Phenolics (mg GA/g dry solids)	Shrinkage $(V/V_0)*100$	L*	a*	b*	a*/b*	TCD
0	120	636	120.97±2.95	530.34±19.32	9.59 ± 0.91	6.25	24.85± 0.1	26.7 ± 0.7	16.97 ±0.9	1.57	5.99±0.8
0	150	476	113.20± 0.72	467.75±22.09	10.88 ± 1.17	8.82	22.81 ± 0.4	25.39± 0.0	15.96 ±0.0	1.59	8.25±0.2
0	180	341	96.95±1.04	415.40±4.26	6.81± 0.01	6.66	24.56± 0.2	26.44 ±0.5	17.96 ±0.2	1.47	5.40±0.3
20	120	600	149.84± 1.13	666.09±12.20	16.29 ± 0.7	11.11	27.98±0.99	28.24 ±0.4	21.10 ±0.9	1.34	1.04±0.8
20	150	468	145.43±3.15	893.85±24.54	14.09 ± 0.37	5.26	23.32± 0.0	24.77 ±0.3	16.85 ±0.5	1.47	7.50±0.3
20	180	330	81.89± 1.10	760.02±13.36	12.74± 0.32	5.55	27.05 ± 0.4	28.57 ±0.2	21.90 ±0.2	1.30	0.92±0.3
40	120	589	152.94±1.23	692.03±4.11	12.18± 0.7	6.66	26.31 ± 0.0	28.18 ±0.5	19.98±0.11	1.41	5.53±0.4
40	150	444	122.31± 2.20	566.76±21.13	12.47 ± 0.28	6.25	24.55± 0.2	26.66 ±0.1	17.24 ±0.1	1.55	5.90±0.6
40	180	334	98.20± 1.54	619.74±9.22	6.74 ± 0.8	6.90	26.78±0.6	28.65±0.4	21.85±0.12	1.31	5.93±0.1
Initial properties of fresh tomato			433.94±19.03	3920.57±21.4	8.27±0.54	100	27.72±0.1	27.95±0.4	22.08±0.1	1.26	0.00