ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

THE EFFECT OF ULTRASOUND PRETREATMENT ON DRYING CHARACTERISTICS OF APPLE SLICES

M.Sc. THESIS

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To my family and friends,

FOREWORD

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December 2015 Gizem Muazzez YILMAZ
(Food Engineer)

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ABBREVIATIONS

d.b.	**:** Dry basis
FAO	**:** Food and Agriculture Organization
MR	**:** Moisture ratio
RMSE	**:** Root mean square error
US	**:** Ultrasound
RH	**:** Relative humidity
w.b.	**:** Wet basis

SYMBOLS

$\mathbf{a_w}$	: Water activity
$\mathbf{a^*}$	: Redness
$\mathbf{b^*}$	: Greenness
$\mathbf{E^*}$	: Total colour change
$\mathbf{L^*}$	: Lightness
$\mathbf{M_{eq}}$	: Equilibrium moisture content
P	: Partial pressure
$\mathbf{P_w}$	: Equilibrium vapor pressure
$\mathbf{R^2}$	: Coefficient of determination
$\mathbf{X^2}$	: Reduced chi-square

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THE EFFECT OF ULTRASOUND PRETREATMENT ON DRYING CHARACTERISTICS OF APPLE SLICES

SUMMARY

Drying is one of the oldest and most famous methods for the preservation of fruits and vegetables. Convectional drying is one of the most common method in food industry. Shelf life extension, resulting product diversity and enabling easier packaging and transportation through weigth reduction are the main reasons for being important of food dehydration.

Apple fruit(Malus domestica) is one of the most popular and favorite fruits among the world. These ‘nutrition value’ fruits are obtained from medium-sized tree belonging to the Rosaceae family and nowadays, this fruit is being cultivated and consumed in many parts of the world. Apples are often eaten as raw but it can also be found in prepared foods like desserts.

In drying process, moisture is removed by the application of heat. This is a mass transfer phenomenon, heat transfers from the surface to interior of product and the product temperature starts to rise. This vaporizes moisture.

With Dehydration of fruits and vegetables, moisture content is reduced to minimum levels so that microbiological and other spoiling reactions are prevented. Also, with the reduction of moisture content, protection of quality properties like flavour, aroma and nutritional value is aimed.

During drying process, drying and drying rate curves should be plotted to determine the drying kinetics of fruits and vegetables. Necessary data to draw the curves is gained from weigth measurements during the dehydration process. Measurements are proceeded in certain time intervals until contstant weigth is reached. In the constant point, food can be said as dried teoritically.

In this study, apples slices, which have 8 mm thickness value, were dried using convectional method in three different temperatures (50ºC, 60ºC and 70ºC). The temperature was controlled to stay stable. To determine the effect on drying of apple, ultrasound was applied as pretreatment in different durations. Ultrasound power provided at a frequency of 35 kHz for 10, 20 and 30 min in ultrasound bath at a constant temperature, 60ºC. The effects of ultrasound upon drying were investigated. During drying processes, weigth loss was measured in certain time intervals and recorded. The measured data was used to draw drying and drying rate curves.

It is known that with the increasing temperature, drying time shortens, in this study, it is seen that drying temperature has positive effect on rehdyration process duration. However the effect on colour was measured and it has been showed that with the increase in temperature, darkness and redness of samples also increase and greenness decreases.

Selected quality parameters of fresh and dried apples resulting from different duration of ultrasonic pre-treatment and convectional-drying were used to compare the effect of ultrasound as pretreatment. Results showed that ultrasound as pretreatment reduces the required time for drying. This pretreatment process also has a positive effect on colour properties of apple slices.

ULTRASON ÖNİŞLEMİNİN ELMA DİLİMLERİNİN KURUMA KARAKTERİSTİĞİ ÜZERİNE ETKİLERİ

ÖZET

Endüstriyel bir proses olan kurutma islemi başta gıda sanayii olmak üzere farklı sektörlerde de yaygın olarak kullanılan bir işlemdir. Özellikle meyve ve sebzeler için kullanılmakla birlikte, tüm gıda sanayii açısından önemli yer tutar. Kurutma meyve ve sebzelerin yapısındaki % 80-95 oranlarındaki suyun % 10-20 oranlarına düşürülmesi ve böylece uzun süre dayanmasını sağlama işlemidir. Bu süre boyunca dikkat edilmesi gereken nokta tat profili, görünüş, renk, besin değeri gibi kalite özelliklerinin mümkün olduğunca az değişime uğraması, ayrıca pişirme işlemi sırasında su ilave edildiğinde meyve ve sebzelerin taze iken içerdikleri miktara yakın su alıyor olmalarıdır. Kurutma işleminin etkin bir şekilde devam ettirilebilmesi açısından uygun modelleme gerekir. Ancak meyve ve sebzelerin su içeriği çok yüksek olduğu için, bu modelleme oldukça karışıktır.
Kurutma, meyve ve sebzelerin saklanmasında kullanılan en eski ve en popular yöntemlerden biridir. Aynı zamanda, besin değeri ve kalite özelliklerinin korunması sebebiyle de gıdaları korumak için kullanılabilecek en iyi yöntemlerden biri olduğu kanıtlanmıştır. Bununla birlikte gıda endüstrisindeki en yüksek maliyetli, en çok enerji gerektiren ve en fazla zaman gerektiren proseslerden bir tanesidir. Bu soruna çözüm olarak, kurutma işlemi öncesinde ön ısıtma, ultrason, ozmotik kurutma gibi çeşitli önişlem metotları kullanılmaya başlanmıştır. Kurutma işlemi ile gıdaların korunması çok eski çağlara dayanmakla birlikte, gıda sanayiinde kullanılmaya başlanması 18.yy'ı bulmaktadır. Gıda sanayinde en sık kullanılan kurutma yöntemi de konveksiyonel(geleneksel) kurutmadır. Bu yöntemin diğer metotlara oranla daha çok kullanılmasının sebebi, işlem pratikliği, enerji ihtiyacının az olması ile ilk yatırım maliyetinin düşük olmasıdır. Gıdaların kurutulmasının bir çok amacı vardır. Depolama sırasında ürünün bozulmasını önleyerek raf ömrünü uzatması, ürün çeşitliliğini sağlaması, ve ürünün hacmini azaltarak taşıma ve depolama da verimliliği arttırması, kurutmanın önemli bir proses olmasının başlıca nedenleridir. Meyve ve sebzelerin kurutulması ile ürün su aktivite değeri düşer, böylece ürünün bozulmasına sebep olabilecek mikrobiyel ve kimyasal reaksiyonlar önlenmiş olur. Bu da depolama süresini uzatır ve depolama süresince oluşabilecek kalite kayıplarını engeller. Aynı zamanda raf ömrü süresince, tüketici kabulunü arttrır.

Meyveler genellikle güneş enerjisinden yararlanmak amacıyla açıkta kurutulur. Bu işlem sırasında toz, toprak, yağmur ve açıkta kurutulduğu için çeşitli böcek zararlarına uğrayabilir ve bu da ürün kalitesi olumsuz yönde etkileyebilir. Bu gibi zararları en aza indirmek için; meyve olabildiğince olgunken hasat edilmeli, temizliğe önem verilmeli, kükürtleme gibi koruyucu işlemler uygulanmalıdır. Ayrıca kurutma işlemine tabi tutulacak meyve ve sebzeler olgun, sağlam, beresiz olmalı, böcek yeniği bulundurmamalıdır. Güneşte kurutma çok eski zamanlardan beri kullanılan bir tekniktir ancak geniş çaplı üretimler için uygun değildir. Kontaminasyon riskinin yanı

sıra kurutma işlemi hava koşullarına bağı olduğundan zaman ve ürün kalitesi açısındanverimli sonuçlar alınamayabilir.

Elma(Malus domestica), hem dünya genelinde hem de ülkemizde çok geniş yetiştirme alanları olan ve sıklıkla tüketilen bir meyvedir ve Rosaceae familyasına ait olan orta boylu ağaçlarda yetişmektedir. Çeşitli ve dengeli bir besin içerği olan elma enerji vermesinin yanısıra şeker ve asit içeriği ile tüketici zevkine uyumlu lezzete sahip bir meyvedir. Taze tüketimi yaygın olmakla beraber, özellikle tatlılar gibi çeşitli besinlerde pişmiş olarak, reçel, marmelat, meyvu suyu şeklinde de tüketilmektedir. Elma üretimi ve tüketimi dünya genelinde sürekli artmaktadır. Çok sık tüketilmesi sebebiyle elmanın saklama koşulları ve kalitesi üzerine çeşitli çalışmalar yapılmaktadır. Kurutma işlemi, bu meyve için uygulanabilecek en uygun metotlardan bir tanesidir. Depolama süresini uzatmanın yanı sıra kurutma prosesi ile yeni ürün eldesi sağlanır ve kurutulmuş meyve pazarında elma yüksek oranda ilgi görmektedir.

Kurutma işleminde, gıdanın içindeki nem, ısı uygulaması ile uzaklaştırılır. Bu işlem, gıdanın yüzeyinden içine doğru gerçekleşen ısı transferi etkisiyle ürün sıcaklığının artması ile sonuçlanan eş zamanlı bir ısı kütle transferi olayıdır. Isı enerjisi ile gıdanın nemi buharlaşır. Uçucu bileşenlerin uzaklaşması için ısı enerjisi uygulanır we böylece su, gıdanın iç boşluklarından yüzeye doğru hareket eder. Bu göç işlemi ile gıda yapısında bulunan su uzaklaşmış olur.

Gıdaların kurutulmasında temel amaç üründeki serbest suyu uzaklaştırarak, ürünlerde meydana gelebilecek biyokimyasal reaksiyonları ve mikroorganizmaların gelişmesini sınırlandırmak, olabiliyorsa durdurmak, ve nem miktarını mikroorganizma gelişimi olamayacak bir seviyeye düşürerek gıda maddelerinin uzun bir raf ömrüne sahip olmalarını, kalite kayıplarını önlemeyi sağlamaktır. Bununla beraber kurutulmuş ürünün kalite özelliklerini olumsuz yönde etkilememesi için, kurutuma koşullarına da dikkat edilmelidir. Kurutma sıcaklığı, ortam havasının hızı ve bağıl nemi gibi kurutma koşulları, son ürünün duyusal, besinsel ve yeniden su alma gibi özelliklerini önemli ölçüde etkiler. Bu nedenle gıdaların kurutulması sırasında, sıcaklğın kurumuş ürün üzerindeki olumsuz etkilerini azaltmak amacıyla ön işlem uygulamaları gerçekleştirilmektedir. Özellikle tüketicilerin ürün kalitesi üzerine ve üreticilerin de ürün miktarı üzerinde artan eğilimleri, çeşitli ön işlemler ile kombine edilmiş kurutma teknolojilerini kullanılması yönündeki trendi arttırmıştır. Son yıllarda ön işlem destekli kurutma metotlarının son ürün kalitesi üzerine etkileri karşılaştırmalı çalışmalar ile araştırılmaktadır.

Kurutma işleminde anahtar terim su aktivitesidir. Su aktivitesi ifadesi, ürün yapısında bulunan suyun, gıdaya kimyasal ve/veya yapısal olarak ne kadar kuvvetli bağlı olduğunu ifade eder. Kurutma prosesinde su aktivitesi değerinin kimyasal ve mikrobiyal reaksiyonların gerçekleşemeyeceği kadar düşük seviyelere düşürülmesi hedeflenir.

Kurutma sırasında ürün içeriğindeki su hareket eder ve dokularda büzüşme ile boyutlarda değişimler meydana gelir. Bu da kurutma prosesinin modellemesini karmaşık hale getiren temel sebeptir. Dehidrasyon koşullarının incelenmesi ile kurutma kinetiğinin belirlenmesi kurutma işlemi sırasında kullanılan işlem koşullarının optimize edilmesini sağlar. Bunun sonucunda da son ürün kalitesi iyileşir, tüketici kabulü artar.

Ultrason işlemi, kurutma işleminin etkinliğini arrtımak ve ısının ürün üzerinde oluşturabileceği olumsuz etkileri ortadan kaldırmak amacıyla uygulanan bir ön işlemdir. Bu ön işlem ile ürünün yapısında kasılma ve gevşemeler meydana gelir. Bu etki, sünger etkisi olarak adlandırılır. Kasılıp gevşemelerin etkisiyle ürün dokularında mikrokanalları oluşur ve bu mikrokanallar yapıda bulunan suyun uzaklaştırılmasına yardımcı olur. Böylece ürünün kuruması kolaylaşır, kuruma için gereken enerji miktarı azalır ve kuruma süresi kısalır. Özetle, işlem daha etkin bir hale gelir, ürün fiziksel ve besinsel kalitesi bozulmaz ve tüketici kabulü artar.

Kurutma işlemi sırasında, meyve ve sebzelerin kurutma kinetiğinin belirlenebilmesi için, kuruma ve kuruma oranı eğrileri çizilmelidir. Eğrilerin çizimi için gereken veri, sabit sıcaklıkta gerçekleşen kuruma sırasında belli aralıklarla alınan ağırlık tartımlarından elde edilir. Ölçümlere, sabit tartıma ulaşıncaya kadar devam edilir. Ürünün sabit tartıma gelmesi, içindeki tüm serbest suyun uzaklaştığını gösterir. Sabit tartıma ulaşılan nokta, teorik olarak gıdanın içinde bulunan nemin tamamen uzaklaştığı, tam kurumanın gerçekleştiği noktadır. Bu değere ulaşılana kadar belli zaman aralıklarında ağırlık tartımları yapılır. Bu sayede kuruma hızı ve oranı belirlenmiş olur.

Bu çalışmada, 8 mm kalınlığındaki elma dilimleri konveksiyonel(Etüv kurutma) metot kullanılarak 3 farklı sıcaklıkta (50ºC, 60ºC ve 70ºC) 3 paralel ile olacak şekilde laboratuvar ortamında kurutuldu. Kurutma işlemi süresince, koşulların sabit kalması için sıcaklık kontrolü sağlandı. Ayrıca, ön işlem olarak 60ºC sabit sıcaklıkta ve 35 kHz frekansta, 10, 20 ve 30 dk sürelerle olmak üzere ultrasound ön işlem uygulaması gerçekleştirildi. Ön işlem uygulaması da 3 paralel ile olacak şekilde gerçekleştirildi. Ultrasound uygulamasının kurutma işlemine olan etkisinin belirlenmesi amacıyla ön işlem uygulanmış ve 60ºC de kurutulmuş elma dilimleri ile ön işlem uygulanmaksızın 60ºC sıcaklıkta kurutulmuş elma dilimlerinin kuruma süreleri ve kurutma işlemi sonrasındaki renk profilleri karşılaştırıldı. Ön işlem sonrasında ve ön işlem uygulanmadan gerçekleştirilen kurutma işlemlerinde belli zaman aralıklarında alınan tartımlarla ağırlık kayıpları belirlendi ve kaydedildi. Ölçümler sonucunda elde edilen veriler kuruma ve kuruma oranı eğrilerinin çizimlerinde kullanıldı. Bu şekilde elma dilimlerinin kurutma kinetiği belirlendi, kurutma işlemi için en uygun olan modelleme yapıldı. Kuruma süresi ve renk, kurutulmuş elmanın kalitesinin belirlenmesinde kullanılan parametrelerdir.

Sıcaklığın artmasıyla birlikte kuruma süresinin kısaldığı bilinen bir gerçektir ancak, sıcaklıktaki bu artış aynı zamanda duyusal özellikleri ve besin değerini de olumsuz yönde etkileyebilir. Bu da hem kalite kayıplarına yol açar hem de tüketici kabulünü olumsuz yönde etkiler. Yapılan çalışmada, elmanın kuruma kinetiğinin modellemesi ve kurutma sıcaklığının elma dilimlerinin rengi üzerindeki etkisinin belirlenmesi için 50ºC , 60ºC ve 70ºC olmak üzere 3 farklı işlem sıcaklığı kullanıldı. Sıcaklığın artışı ile birlikte örneklerin kuruma süresi kısaldı ancak sıcaklık artışı aynı zamanda rengi de olumsuz yönde etkiledi. Artan sıcaklıkla birlikte daha koyu renkli örnekler elde edildi.

60ºC, elmaların kurutulması için hem süre hem de kurutma sonrası etkiler açısından optimum sıcaklık olarak tespit edildi. Bu sıcaklığın altındaki değerlerde, işlem süreleri çok uzadı ve koşullarda dalgalanmalar meydana geldi. Ultrasound ön işleminin kurutma işlem süresine etkisinin incelenmesi için, optimum sıcaklık olarak belirlenen 60ºC, işlem sıcaklığı belirlendi. Örneklere 35 kHz frekansta, 10, 20 ve 30 dk sürelerde olmak üzere ultrasound ön işlemi uygulandı. Her bir işlem 3 tekrarlı olacak şekilde tamamlandı. Ön işlemler sonrasında örneklere 60ºC sıcaklıkta kurutma işlemi uygulandı. Sonuç olarak ön işlem uygulanmış elma dilimlerinin, ön işlem olmadan kurutulan örneklere göre daha kısa sürede kuruduğu yani önişlemin kuruma süresini kısalttığı görüldü. Bunun yanında, en kısa kuruma süresi 20 dk ön işlem uygulanan örneklerde görülürken, 10 ve 30 dk ön işleme maruz bırakılmış örnekler yaklaşık olarak eşit sürede kurudu. Ultrason ön işleminin renk üzerine etkisi incelendiğinde ise, aynı sıcaklık değerinde kurutulmuş elma dilimlerinden ön işlem uygulanmış olanların renk kalitesi açısından daha iyi oldukları tespit edildi.

1. INTRODUCTION

Drying is a crucial postharvest process which is used for preservation of many agricultural crops for thousands of years(University of Missouri, 2015).

Dried food industry is very significant among general foods indursty. Suitable modelling is necessary to control industrial dehydration. However, mathematical modelling of fruits and vegetables are difficult as they have very high initial moisture content (80-95%) (Agnieszka et.al., 2010). Thus, simulation and theoretical practices are important during removal of water.

In recent years, dehydration has been verified to be great method to preserve fruits by protecting nutrition value and quality (Jinfeng et. Al., 2014). It is one of the oldest method for food preservation. However, this process is one of the most time consuming and energy needed processes in food industry. As a solution for this problem, a number of different pretreatment methods are applied to reduce the drying time and increase the energy efficiency during drying process. These pretreatment operations are also solutions for the main problems of drying of fruits such as darkening of skin and damage of nutrition values.

Consumers prefer is increasing for foods protecting their sensoric and nutritional properties. Because of this reason, optimization of drying conditions is very important to protect sensoric and physical characteristics such as color, texture and water content(Hastürk et. al., 2011). High drying temperatures may cause quality deterioration in sensoric and nutritional properties. Using pretreatment methods can be necessary such situations.

In this study, effect of different temperatures and ultrasound application as pretreatment upon drying process was determined. Color and shrinkage attributes were analysed as quality indicators. Oven drying was selected as drying method, because it is the most practical method for drying analysis. Food can be protected from dust and insects, process does not depend on weather and not too much initial investment is necessary (University of Missouri, 2015).

2. APPLE

Apple is one of the most important raw material in food industry and is cultivated almost all over the world(Jinfeng et.al., 2014). In general it is consumed as fresh, juice or jam. Apple fruits have been traditionally consumed in relation to their health benefits, and for that reason a popular aphorism refers to this fruit as “An apple a day keeps the doctor away”(Raul et.al., 2014).

As seen in table 2.1, apple’s global production in the last decade has increased by 38% from 55 million tons in 2002 up to 76 million tons in 2012(Paweł et.,al., 2015). However, just as every fruit, unsuitable preservation and storage methods can cause loss of fresh furits. In the last years, it has been proven that drying is a suitable method to preserve fruits and vegetables. This process maintains nutrients and also avoids quality deterioration(Jinfeng et.,al., 2014). Thus, dehdyration is one of the most important preservation methods for apple. Also dried apple is a new kind of product to be consumed as it is seen in Fig. 2.1 for consumers.

Figure 2.1 : Fresh and dried apple appearance.

Table 2.1 : The most important countries for apple production in the World and their production amounts [Oğuz et.al., 2009].

Country	Production Area (Hectare)	Production Amount (Tone)	Yield (Tone/Hectare)
China	2.000.650	27.507.000	13.7
USA	156.000	4.237.730	27.2
Iran	150.000	2.660.000	13.1
Turkey	110.000	2.266.437	20.6
Russia	370.000	2.211.000	5.9
Italy	61.188	2.072.500	33.9
India	261.600	2.001.400	7.6
France	46.000	1.800.000	39.1
Chile	38.000	1.390.000	36.6
Belgium	8.100	1.093.853	40.7
Polland	175.400	1.039.100	5.9
Germany	31.700	911.900	28.8

2.1 Apple Varieties

Apples are fruits that adapted to different areas to be cultivated. In general, for red ones, weather without humidity is necessary for their colour and a cool winter weather is necessary for a lot of kinds [Vossen et., al., 2000]. Apple fruit has a lot of different kinds, basic varieties are listed below [Vossen et., al., 2000];

- *Fuji:* Apple skin colour is red, having with a very sweet yellow-orange flesh. Storing stregnth is much.
- *Gala:* Can be stored long period without defects. Size is generallu small or medium. For early seasons, this kind is the best one.
- *Golden Delicious:* Skin of apple if green and flesh is yellow and taste is sweet and juicy.
- *Granny Smith:* Apple which is very firm, having yellowish green skin colour. If the fruit is harvested late, colour becomes yellow and taste is sweet.
- *Gravenstein:* This kind has greenish yellow color with red stripes. Also has aromatic taste. Can not be stored long periods.
- *Jonathan:* Apple having white flesh and red skinç. It is a very good choice to eat fresh, use as sauce and juice.
- *Red Delicious:* Variety having different skin colors. Can be stored long periods.
- *Rome Beauty:* Having round shap with a deep cavity. It can be used as baked.

3. DRYING OF FRUITS AND VEGETABLES

For Fruits and vegetables, dehdyration is one of the oldest methods used for the preservation of them, and generally is utilized as unit operation in food engineering(Famurewa et., al., 2014). Drying of fruits and vegetables extends the storage life, reduces product losses during storage, and provides the effectiveness in transportation costs with the reduction of volume(Doymaz, 2005). According to Famurewa and Akinmuyisitan (2014), if drying process is applied properly, dried product will have almost the same the nutritional sensoric quality as the fresh product. Otherwise, remarkable spoilages occur(Famurewa et., al., 2014).

3.1 Aim of Dehydration Process

The main purpose of dehydration is the separation of moisture to the level at which microbial spoilage and deterioration reactions are mostly minimized(Nahia et., al., 2009). The minimazing of water content inhibits microbial and enzymatic activity so that prevents food damage(Lüle&Koyuncu, 2015). Drying also simplifies food product handling trough the volumetric shrinkage and weight losses(Ochoa et., al., 2002).

3.2 Drying Process

Previously, sun drying was being used for dehydration of frutis and vegetables especially in hot climates. Comparing to other methods, natural open air drying is very cost effective because heat energy is free and renewable. However, usage of this technique is very difficult because of weather dependence, contamination risk and long drying times(Lüle&Koyuncu, 2015). Of late years, dried food quality is being important for both producers and consumers. Drying method affects sensoric and physical properties such as colour, texture, density, porosity, and sorption characteristics of material (Krokida et., al., 2001). Especially color is very important for consumer acceptance. Since it is the first judgement for food, appearance analyses of foods (color, taste, odor, and texture) are used for determining the quality in the end of drying(Lüle&Koyuncu, 2015). In order to protect the quality, open air sun drying is not used in large scale. Instead, convectional drying is being popular as controlling of drying temperature is easy and contamination risk is minimum. In present study, convecational drying is applied because of these reasons.

Drying is a process based on moisture removal resulting simultaneous heat and mass transfer(Yücel, 2006). In dehydration of fruits and vegetables, heat energy is applied for vaporization of volatile components after removing them from solid particles(Dikbasan, 2007). This process is a heat and mass transfer phenomenon where water migrates from the interior of the drying product on to the surface from which it evaporates. Heat is transferred from the air that surraounds the food to the surface of it and then to the interior of the product. This transfer provides a increase in temperature and water vapor occurs. Jangam et. al.(2010) Explained the basic drying terms as seen in table 3.1.

Table 3.1 : Basic terminologies in drying (Jangam et., al., 2010).

Terms / Symbol	Meaning
Adiabatic saturation temperature (T_{ad})	Equilibrium gas temperature reached by unsaturated gas and vaporizing liquid under adiabatic conditions. Only for air/water system, it is equal to wet bulb temperature.
Bound moisture	Liquid physically and/or chemically bound to solid matrix so as to exert a vapor pressure lower than that of pure liquid at the same temperature.
Constant rate drying period (N_c)	Under constant drying conditions, drying period when evaporation rate per unit drying area is constant (when surface moisture is removed).
Dew point (T_d)	Temperature at which a given unsaturated air-vapor mixture becomes saturated.
Equilibrium moisture content (X_e)	At a given temperature and pressure, the moisture content of moist solid in equilibrium with the gas-vapor mixture (zero for non-hygroscopic materials).

3.2.1 Water activity

During dehydration of material, water availability is crucial because of microorganism growth and different chemical reactions formation, especially in foods(Jangam et., al., 2010). Different foods have different water activity values.

This affects the reaction rate(Table 3.2., Figure 3.1, Figure 3.2). Energy amount or going out leaning of product water is represented as water activity(Court, 1980). This expression describes the strength of attachment the water to the product structurally or chemically(Court, 1980).

Table 3.2 : Water acitivity values for selected furits and vegetables (Shelly et., al., n.d.).

Fruits and vegetable products	a_W Range
Apples	0.988-0.975
Apricots	0.985-0.977
Bananas	0.987-0.964
Bilberries	0.989
Cherries	0.986-0.959
Currants	0.990
Figs	0.974
Lemon	0.989-0.982

According to Jangam et.al., water activity, aw, is defined as the ratio of the partial pressure, *P*, of water over the wet solid system to the equilibrium vapor pressure, pw, of water at the same temperature, thus, aw, which is also equal to the equilibrium relative humidity of the surrounding humid air, is defined as equation 3.1(Jangam et., al., 2010):

$$aw = \frac{P}{Pw} = \frac{RHeq}{100} \tag{3.1}$$

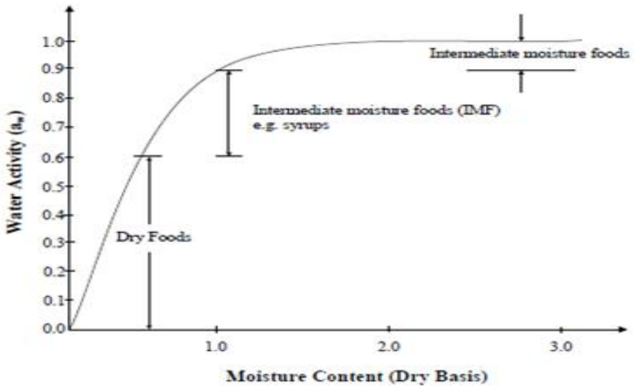

Figure 3.1 : Water acitivty versus moisture content plot for different types of foods(Jangam et., al., 2010).

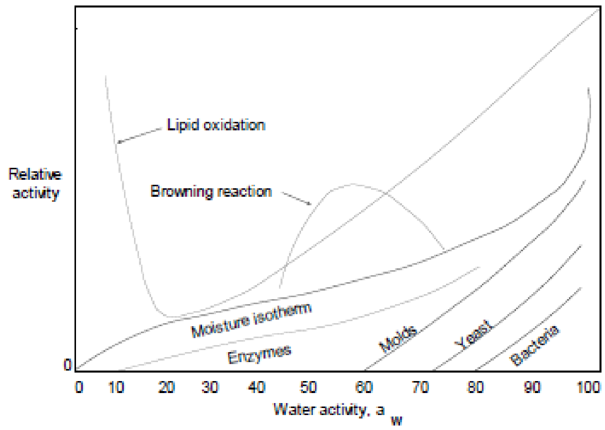

Figure 3.2 : Deterioration rates as a function of water activity for food systems (Jangam et., al., 2010).

3.2.2 Drying methods

Basic drying methods can be listed as below(Flores, 2007);

- Sun Drying: This method is generally used for fruits because they have high sugar and acid content which protect them from deterioration. It is not offered to be used for vegetables and meats because of spoilage risk. For the best result, temperature should be min 85ºF and relative humidity should not be above 60%. The method is maintained on a open air plate as seen as figure 3.3.

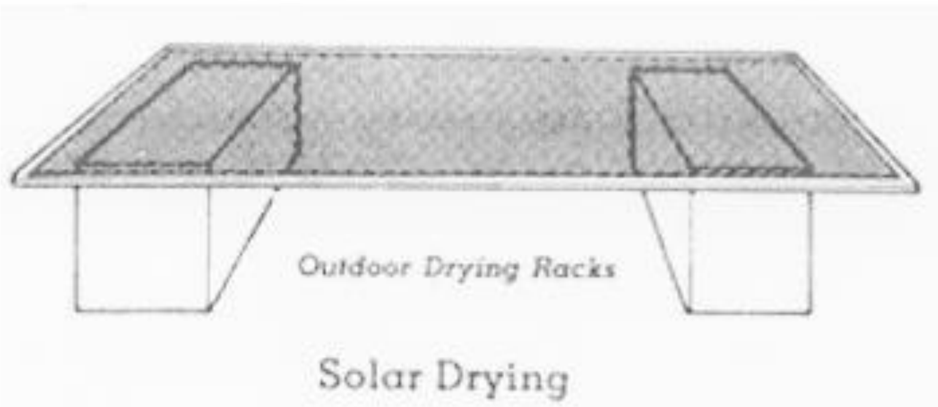

Figure 3.3 : Solar drying system (Flores, 2007).

- Oven drying: This method is applied through trays. Drying temperature should be above 60–65°C. Dehydrated food moisture must be taken out of the oven. For allowing the moisture, a kind of gas can be used.

- Dehydrator: Two kinds of dryer is used; solar and electric. While using a solar dehydrator, direct sunligth should be prevented and while using an electric dehydrator, a thermostat should be used for regulating the temperature and circulation of air.

3.3 Effects of Pretreatment Methods on Drying Process

In general, different teqniques such as tunnel dryer, heatpump dryer, vacuum dryer, freeze dryer, solar dryer and natural sun dryer are used to preserve fruits, vegetables or other agricultural products(Ching&Jeremiah, 2014). Among them, convectional drying is one of the most common methods using in food industry. However, in dehydration of fruits process, energy requirement is very high and this causes high cost too(Shahram et., al., n.d.). In order to provide an energy and cost effective process and also protect the nutritional value and sensoric quality, pretreatment methods is used before main drying(Ching&Jeremiah, 2014).

According to Bingöl (2008), there are two main pretreatment methods; chemical (inorganic and organic) and physical (heating, blanching, freezing, etc.). Author mentioned that the most important benefits of these methods are accelerating drying process, denaturation and inactivation of surface enzymes and texture softening. Especially in recent years, suitable production for both consumers and producers demand is being very important. Applying pretreatment methods prevents damages because of temperature and reduces the energy consumption and product loss during dehydration process.

3.3.1 Ultrasonic bath application as pretreatment

In food industry, ultrasound usage as a pretreatment method is new and there are not too many studies related with this pretreatment method (Fabiano et., al., 2008). Ultrasonic pretreatment can be used for water content reduction or changing the tissue microstructure of fruits to accelerate the drying process (Ching&Jeremiah, 2014). It has been proven that this pretreatment method is effective to preserve functional components, because of usage at nearly ambient conditions and this avoids thermal degradation of thermolabile components (Carlos et., al., 2015).

According to Nowacka et. Al, Ultrasounds can be considered as the air vibrations of a frequency from 20 kHz to 100 MHz, and also caused by the mechanical waves propagated in solids, liquids and gases other than air(Nowacka et., al., 2012).

A stream of fast alternative compressions and expansions occur resulting of ultrasonic waves. This is like a sponge; squeezing and releasing repeatedly of sponge (sponge effect). Besides, ultrasound produces cavitation, this helps for removing strongly attached moisture and it can be said that sponge effect of ultrasound application is responsible for the creation of microscopic channels in porous materials, such as fruits (Fernandes et., al., 2009).

3.4 Drying of Biological Materials

Drying of food process does not mean only choosing of dryer equipment. Physicochemical facts related with food drying should be understood well for an appropriate analyzing of drying phenomena(Mercado et., al., 2001). Besides, in order to make a better design and optimization of many industrial unit operations, heat and mass transfer phenomena should be understood well. Drying, evaporation, and distillation are general unit operations including heat and mass transfer actions(Bingol, 2008).

Energy requirement for food dehydration changes according many factors such as initial mositure content, moisture content of dried food, relative humidity, drying temperature and drying velocity. Different mathematical modellings are determined and used for different food materials in the design of dryers and standardization of drying process(Cesur, 2013).

3.4.1 Characteristics of drying curves

The process of drying can be divided into a "constant-rate" period and one or two "falling-rate" periods (Bingol, 2008) as seen in Figure 3.4.

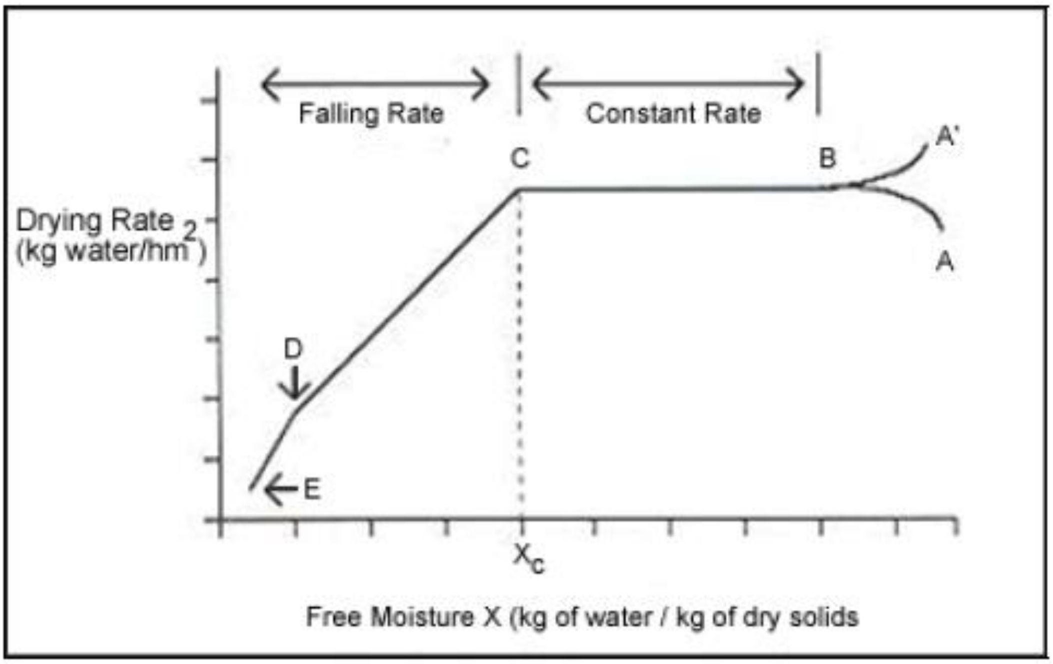

Figure 3.4 : Constant rate period and falling rate period in drying process (Bingol, 2008).

- Constant-rate drying period (B-C): Liquid flow may occur under hydraulic gradient, if the material is wet at the beginning of drying. Moisture is free and exerts its full vapor pressure and wait in the surface and the largest capillaries. The surface temperature is nearly the same with the wet-bulb temperature.
- First drying period (C-D): The moisture continues exerting its full vapor pressure and through capillarity, it is carried. The temperature increases and exceeds the wet-buld temperatue. Water goes with diffusion.
- Second drying period (D-E): A sharp decrease occurs in drying rate and partial pressure of water vapor
- Third drying period: It is the equilibrium period. In this stage, amount of water that vaporizes equals to amount of water that condenses(Bingol, 2008).

3.4.2 Mathematical modelling of drying curves

Significant changes occur in volume and exchange area of foods containing high initial moisture content such as fruits and vegetables during dehydration process. In drying, water migrates and exchange area of foods decrease because of tissue shrinkage.

Internal and external dimension changes occur and as a result of these changes, simulation of a complete model for drying food is very complex(Jannot et., al., 2004).

Drying kinetics determination through dehydration conditions provides approximation of drying so that convenient drying circumstances can be seen(Rayaguru & Routray, 2012). In different studies, various modellings are being used for description of drying process. In this study, page, modified page, logarithmic, Henderson&Pabis and Newton modelling have been used to describe the drying process.

4. LITERATURE RESEARCH

Drying process, dynamics and kinetics is one of the widely experimented topics. Since fruits and vegetables have high moisture content, it is important to optimize the drying of these food products. So large amount of researchments exist in literature.

Pennstate University (2013) mentioned about drying of fruits vegetables, drying and pretreatment methods. According to the university, pretreatment application before drying process has a positive effect on color and nutritional values of fruits.

Revaskar et.al. (2014) also used 50 ºC, 60 ºC, 70ºC temperature values in their experiments for dehydration of onion slices. They observed that the similar drying times with current study. Temperature values for dehydration has a great effect on duration. With an increase in temperature, moisture moves quickly from inside to outside of the material. They used osmotic pretreatment for onion slices but this resulted similar with our study, pretreated samples showed shorter drying durations.

In research done by Keroehnke et.al. (n.d.), ultrasound assited convective drying is used for drying of potato. Results showed that potato quality increases with ultrasound pretreatment, also ultrasound reduces the dehydration duration.

According to Pakbin et.al.[46], usage of ultrasound pretreatment reduces the necessary power for drying process approximately 20%.

Vega et al. (2014) studied for simulation of convective drying. They investigate the max temperature for providing the product safety.

Kowalski et al. (2015) also used ultrasound pretreatment to intensificate the drying of apples. Their study showed that ultrasound power usage provide a more effective drying process through the raising in temperature of sample.

Simal et al. (2014) worked on pretreatment assisted convectional drying of fruits and vegetables. They used osmotic drying as pretreatkaletament as different from ultrasound power. However, their result was similar to current study. Pretreatment application shortened the drying period of biological material.

Effect of drying temperature on apple color was investigated by Nadian et al. (2015).They also used 50ºC, 60 ºC and 70 ºC as drying temperature. Similarly, to our study, with an increase in temperature, colour deterioration increases.

Kaleta et al. (2013) evaluated a model for apple dried in a fludizied bed dryer. They used similar models as current study for modelling and their RMSE and x2 and R values were similar to our results.

In general, there are plenty of studied and researchments about drying of fruits and vegetables. These studies are not only convective drying and basic pretreatment methods but also other new techniques for maximum efficiency with minimum deterioration in product quality.

5. MATERIALS AND METHODS

5.1 Apples

Golden Delicious apple were bought from a local store and were stored in plastic bags in a refrigerator at 4°C until pretreatments or drying without pretreatments. Apples were washed with tap water and their surfaces were dried with a paper towel. The skin was removed from the apples and they were cut into slices of 8 mm thickness.
Initial moisture content of apples was measured with two methods; drying at 135°C for 2 h in an oven dryer (AOAC, 2005) and drying 105°C for 2 h 46 min in an Infrared dryer(Nielsen, 2010). The moisture content of apples ranged between 78.33% and 84.34% wet basis and on the average, Golden Delicious apples contained 86.67% water, 12.76% carbohydrate, 0.27% protein and 0.13% fat(USDA, v28). The equilibrium moisture content (M_{eq}) was achieved by waiting until weight loss stopped.

5.2 Convective Drying Equipment

Convective drying was carried out at three different drying temperatures; 50ºC, 60ºC and 70ºC in a laboratory dryer (Istanbul, Turkey). These temperature values were chosen according to the most popular parameters used in researches. The dryer was pre-heated to drying temperature and then was loaded with having 8 mm thickness and 50 mm length of apple slices. In each temperatue, experiments was carried with 3 replicates. Drying process continued until constant mass was reached. During drying, the mass of the material was recorded continuously.

5.3 Ultrasound Pretreatment

The samples were immersed in distilled water and put in an ultrasonic bath. The pre-treatment was carried out at room temperature (25ºC) and the ultrasound frequency was 35 kHz. The ultrasound energy was applied for 10, 20 and 30 min. Mass of the samples, dry matter content and water temperature were measured both before and after ultrasound treatment. During the experiments, temperature increases were equal to 2.6ºC, 5.8ºC and 10.4ºC after 10, 20 and 30 min of ultrasound treatment, respectively.

5.4 Drying Analysis and Mathematical Modelling of Convective Drying Models

Weight loss obtaining according to initial moisture content, was used to determine the moisture content. After obtaining the experimental data, drying characteristic curves were plotted.

In current study five different mathematical models were used to describe the drying kinetics of apple slices.

Table 5.1 : Mathematical models used to describe convective drying (Sadegh et., al., 2010- Rayaguru et., al., 2012).

Name of Model	Equation	References
Page	$MR = \exp\left(-kt^n\right)$	Gupta et al., 2002; Yaldız and Ertekin, 2001; Midilli et al., 2002; Kabganian et al., 2002; Cronin and Kearny, 1998
Logarithmic	$MR = a \cdot \exp\left(-kt\right) + c$	Togrul and Pehlivan, 2002
Henderson and Pabis	$MR = a \cdot \exp\left(-kt\right)$	Kabganian et al., 2002
Newton	$MR = \exp\left(-kt\right)$	Ayensu (1997)
Modified Page	$MR = \exp\left(-(kt)^n\right)$	Yaldız and Ertekin, 2001; Midilli et al., 2002

In order to select the best model, equations mentioned in Table 5.1 were tested. Coefficient of determination (R^2) was one of the most crucial criterions for determination of the best fitted model, other the statistical methods such as the reduced chi- square (X^2) and root mean square error (RMSE) as described by Equation (5.2) and (5.3) (Doymaz, 2005) were also used to describe the best model. The lower chi-square (X^2) and RMSE values and the higher R^2 values were chosen(Rayaguru, 2012).

$$R^2 = \frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{\exp,ave}\right)^2}{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{\exp,ave}\right)^2} \tag{5.1}$$

$$X^2 = \frac{\sum_{i=1}^{n}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N - n} \tag{5.2}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{\exp,i}\right)^2\right]^{\frac{1}{2}} \tag{5.3}$$

MRexp,i is the ith experimentally observed moisture ratio, MRpre,i the ith predicted moisture ratio, MRpre, ave is the average experimental moisture ratio, N the number of observations and n is the number constants. In each experiment, drying curves were obtained by plotting the moisture ratio of the sample vs. the drying time.

5.5 Colour Measurement

The surface colour of the fresh and dried apple slices were analysed by using a Hunterlab colorimeter (Colour Flex) to determine colour coordinates (L*, a* and b* values). Where L* value is the degree of lightness, a* value is the degree of redness and b* value is the degree of greenness. Color of fresh and dried apple slices were measured. Total color difference (ΔE) were determined according to equation 5.4(Sadegh et., al., 2010);

$$E = \sqrt{(L^*_0 - L^*_i)^2 + (a^*_0 - a^*_i)^2 + (b^*_0 - b^*_i)^2} \tag{5.4}$$

$\Delta L^*= L_0^*$ (initial) − L*(after drying) , $\Delta a^*= a_0^*$(initial) $-a_0^*$(after drying), $\Delta b^*= b_0^*$(initial) −b*(after drying). 0 and i describes the color parameters of fresh and dried apple slices. The high E represents color change from the fresh apple.

6. RESULTS AND DISCUSSIONS

In order to have suitable process requirements, dehydration procedures and processes occuring during drying should be understood through mathematical modellings(Zlatanovi, 2013). In this part, temperature and ultrasound pretreatment

Moisture ratio values are fitted to five drying models and the model coefficients such as correlation coefficient (R^2), the reduced chi-square (X^2) and the root mean square error (RMSE) are calculated. After that, colour measurements are described for each condition to determine the quality of dried product.

6.1 Influence of Temperature

Experiments were set as three replicates to determine the temperature effect. Process velocity and environment relative humidity values are kept constant(same equipment was used for all experiments) and temperature is the only variable as given in Table 6.1 Each group consists of three experiments.

Table 6.1 : Experimental conditions of temperature influence.

Drying air temperature	Average moisture content (w.b.%)	Drying time (min)
50 ºC	84.2863	545
60 ºC	83.5649	450
70 ºC	82.7044	720

The initial moisture content of apple was found to be between 81-84% wet base (w.b.). This result is similar to the Cruz et.al(2014) and Sadegh et.al's (2010) studies.

The necessary drying time to preduce the moisture content(d.b) of apple slices from 6.0 to 0.5 are 545, 450 and 270 min at temperature of 50, 60 and 70°C, respectively. This results is somewhat different than the existing studies, It can be related with air temperature flactuation during weighing of samples. It was observed that moisture content of samples decreases exponentially with the drying time and as seen in the study completed by Zlatanovic et.al(2013), increasing air temperature reduces the necessary time to reach a certain level of moisture content. The relation between temperature and drying time is not linear which shows the exponential characteristic of drying curves(Jayaraman et., al., 2006).

6.2 Influence of Ultrasound Pretreatment

As a pretreatment method, ultrasound results with a range of fast processes in tissues and this causes moving the water from the inside to outside of the raw material(Nowacka et., al., 2012).

Table 6.2 : Increase in temperature and weigth loss after ultrasound pretreatment.

Ultrasound pretreatment duration (min)	Average increase in temperature (ºC)	Average weigth loss (g)
10	2.6	2.0070
20	5.8	2.9613
30	10.4	1.0072

As a result of ultrasound usage, apple slices lost weigth(Table 6.2). The longest pretreatment duration (30 min) showed the minimum loss. Samples subjected to ultrasound pretreatment for 10 and 20 min lost 2.0070 g and 2.9613 g, respectively. Weight loss is related with change in dry matter content in apple tissue(Nowacka et., al., 2012). This results are similar with the experiments performed by Nowacka et. (2012).

For ultrasound pretreated apple slices required drying times are 360, 250 and 375 min for 10, 20 and 30 min pretreatment durations. Required time values for different pretratment durations are shown in table 6.3 It was mentioned before, with the air temperature increase, drying time decreases. This situation is somewhat different in pretreated samples. While minimum duration was observed in 20 min US treated apples, in 10 and 30 min treated apple slices, minimum drying times almost same(Table 6.3).

Table 6.3 : Final drying time at different pretreatment durations.

Ultrasound pretreatment duration (min)	Drying time (min)
10	360
20	250
30	375

6.3 Drying Curves

After the drying process, total moisture content varied between 26-28% (wet basis). Only apple slices dried at 50 ºC reached to 56 % as a final moisture value and after this time moisture removal conintued very slowly. The moisture content(dry basis) versus drying time at different air temperatures are plotted in Figure 6.1. For ultrasound pretreated samples, curve was plotted in Figure 6.2;

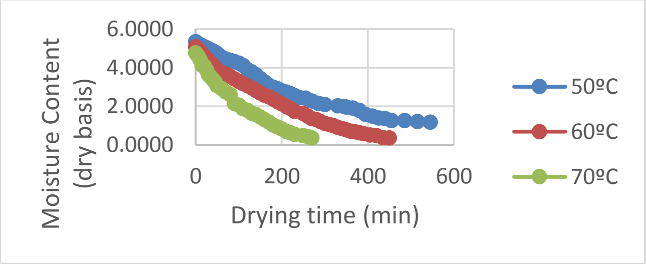

Figure 6.1 : Moisture content(d.b.) of apple slices at different air temperatures.

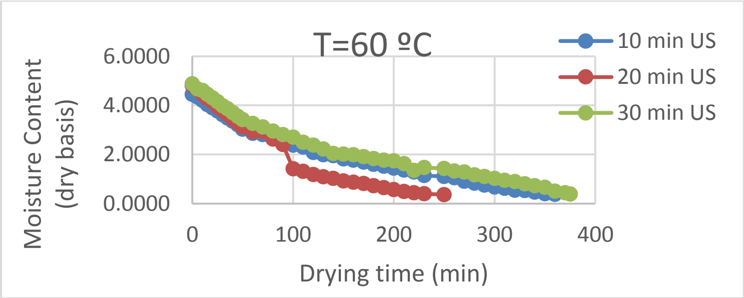

Figure 6.2 : Moisture content(d.b.) of ultrasound pretreated apple slices in different pretreatment durations.

Drying air temperature increase causes moisture loss of the product non-linearly(Dikbasan, 2007). Figure 6.3 and 6.4 shows the distribution of drying rate with respect to moisture content.

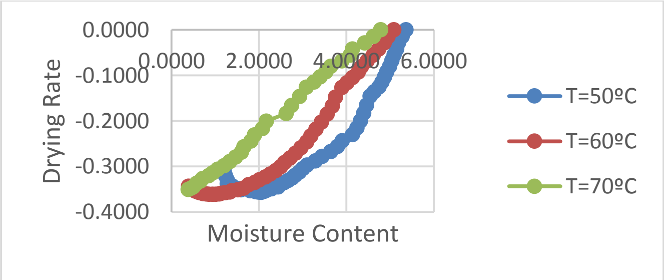

Figure 6.3 : Drying rate vs. moisture content of apple slices at different air temperatures.

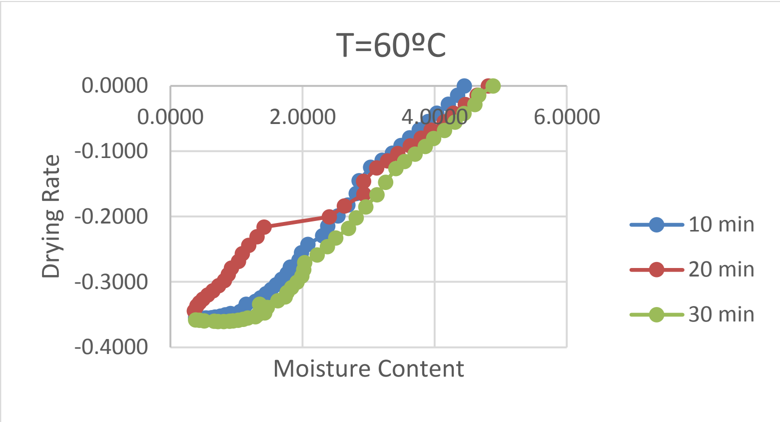

Figure 6.4 : Drying rate vs. moisture content of apple slices in different pretreatment durations.

Increase in temperature causes decrease in drying rate. For pretreated samples, increase in treatment time causes increase in drrying rate.

Weigth loss was calculated according to initial moisture content and drying characteristic curves were plotted. The moisture content was converted to moisture ratio (MR) with below equation(Rayaguru & Routray, 2012);

$$MR = (M_t - M_e) \div (M_0 - M_e) \tag{6.1}$$

In the equation, M, M_0, M_e, M_t are the moisture contents. In the convective dryer, air velocity was not constant, so M_e can be negligiable and below equation can be used(Rayaguru & Routray, 2012);

$$MR = (M_t) \div (M_0) \tag{6.2}$$

6.3.1 Modelling of drying curves

Empirical models (Logarithmic, Newton, Page, Henderson and Pabis, Modified Page) were fitted to calculate the experimantal moisture ratio as a function of drying time (Table 6.5, 6.6, 6.7).

Calculated parameters of these models are shown in Table 6.4 both for with and without pretreated samples. Among the models, the one giving highest R^2 and lowest X^2, RMSE values has been chosen to describe the drying kinetic of apple slices.

Predicted moisture ratio and calculated moisture ratio were compared to determine the correctness of the chosen model(figure 6.5-6.10). It was observed that the drying rate constant (k) increases with the increase in temperature. This means that drying curves becomes more vertical describing increase in drying rate with temperature increase (Rayaguru & Routray, 2012).

Table 6.4 : Comparison of different drying models with drying coefficients at different drying temperatures.

Model	Temperature (ºC)	Model Coefficients
Logarithmic	50	k=0.0043, a=1.020, c= - 0.0540
	60	k=0.0039, a=1.025, c= - 0.0650
	70	k=0.0041, a=1.026, c= - 0.0680
Page	50	k=0.004, n=0.970
	60	k=0.005, n=0.982
	70	k=0.005, n=0.956
Newton	50	k=0.004
	60	k=0.004
	70	k=0.004
Henderson and Pabis	50	k=0.004, a=0.970
	60	k=0.0041, a=0.982
	70	k=0.005, a=0.974
Modified Page	50	k=0.0038, n=0.963
	60	k=0.0041, n=0.982
	70	k=0.0042, n=0.953

Table 6.5 : Comparison of different drying models with drying coefficients at 60 ºC drying temperatures and different pretreatment durations.

Model	Ultrasoun pretreatment duration (min)	Model Coefficients
Logarithmic	10	k=0.0035, a=1.025, c= - 0.0721
	20	k=0.0041, a=1.031, c= - 0.0656
	30	k=0.0038, a=1.028, c= - 0.0711
Page	10	k=0.006, n=0.927
	20	k=0.0067, n=0.917
	30	k=0.0062, n=0.932
Newton	10	k=0.0041
	20	k=0.0052
	30	k=0.0048
Henderson and Pabis	10	k=0.004, a=0.966
	20	k=0.005, a=0.972
	30	k=0.005, a=0.980
Modified Page	10	k=0.0061, n=0.928
	20	k=0.0059, n=0.917
	30	k=0.0061, n=0.932

Table 6.6 : Modelling of moisture ratio with drying time during convective drying of apple slices at 50, 60 and 70 ºC.

Model	Temperature (ºC)	R^2	X^2	RMSE
Logarithmic	50	0.978932	0.000231	0.000054
	60	0.969544	0.000014	0.000102
	70	0.980778	0.000109	0.000078
Page	50	0.949254	0.000022	0.000056
	60	0.920967	0.000019	0.000230
	70	0.953888	0.000367	0.000082
Newton	50	0.920633	0.000234	0.000067
	60	0.949521	0.000142	0.000077
	70	0.940765	0.000103	0.000078
Henderson and Pabis	50	0.980688	0.000011	0.000008
	60	0.999579	0.000007	0.000013
	70	0.980766	0.000009	0.000011
Modified Page	50	0.959244	0.000026	0.000053
	60	0.950902	0.000021	0.000089
	70	0.953778	0.000038	0.000082

Table 6.7 : Modelling of moisture ratio with drying time during convective drying of ultrasound pretreated apple slices at 60 ºC.

Model	Pretreatment Duration (min)	R^2	X^2	RMSE
Logarithmic	10	0.974522	0.000022	0.000134
	20	0.976853	0.000035	0.000205
	30	0.973258	0.000031	0.000213
Page	10	0.954536	0.000022	0.000198
	20	0.920967	0.000019	0.000230
	30	0.953428	0.000027	0.000221
Newton	10	0.956748	0.000115	0.000081
	20	0.949521	0.000142	0.000077
	30	0.952718	0.000153	0.000077
Henderson and Pabis	10	0.995674	0.000015	0.000010
	20	0.999579	0.000007	0.000013
	30	0.987564	0.000011	0.000009
Modifed Page	10	0.952918	0.000015	0.000077
	20	0.950902	0.000021	0.000089
	30	0.962356	0.000033	0.000087

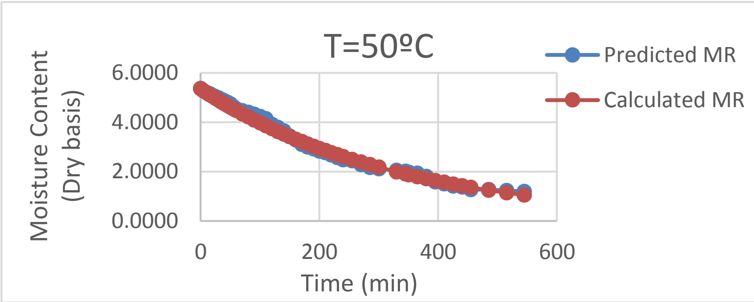

Figure 6.5 : Predicted moisture content vs. calculated moisture content at 50 ºC drying.

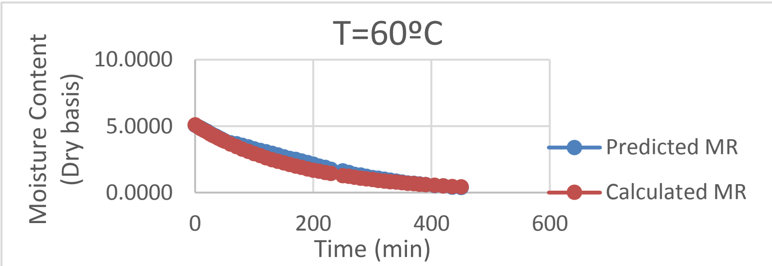

Figure 6.6 : Predicted moisture content vs. calculated moisture content at 60 ºC drying.

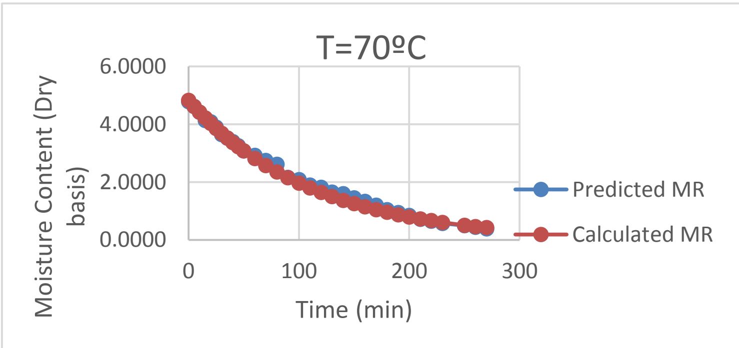

Figure 6.7 : Predicted moisture content vs. calculated moisture content at 70 ºC drying.

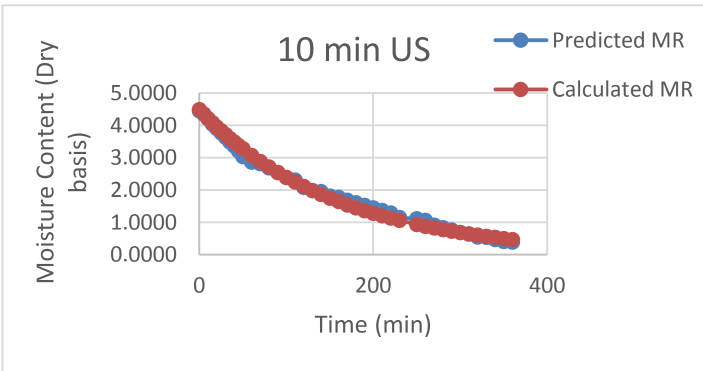

Figure 6.8 : Predicted moisture content vs. calculated moisture content for 10 min US pretreatment.

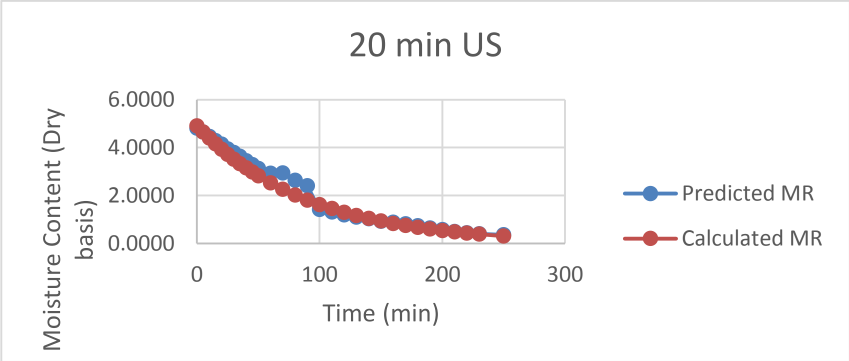

Figure 6.9 : Predicted moisture content vs. calculated moisture content for 20 min US pretreatment.

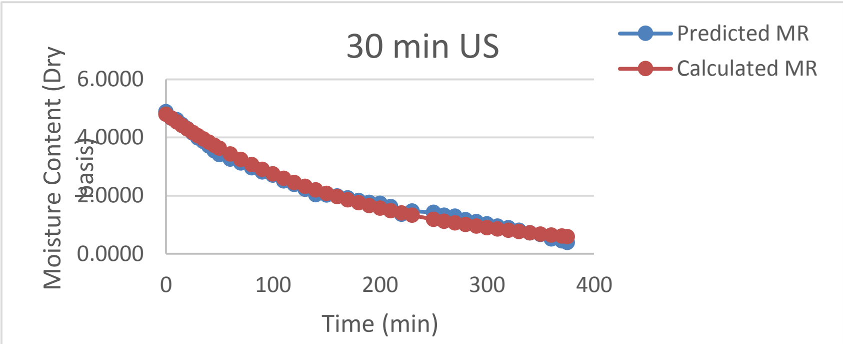

Figure 6.10 : Predicted moisture content vs. calculated moisture content for 30 min US pretreatment.

Henderson and Pabis model was chosen to describe the drying kinetics of apple slices because of having the highest R^2 values and the lowest X^2 and RMSE values. Zlatonic et.al.(2013) has also been showed that this model provides the best R^2 , X^2 and RMSE values.

6.4 Influence of Temperature and Ultrasound Pretreatment on Color

Color was measured for both fresh and dried samples to determine the difference. The surface colour of apple slices was analysed by using a Hunterlab colorimeter (Colour Flex) and colour coordinate values were determined(L*, a* and b* values). The L* value is the degree of lightness, a* value is the degree of redness and greenness, and b* value is the degree of greenness(Daza et., al., 2016). To determine the colour change(ΔE) as a result of drying temperature was calculated using equation 6.3.

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \tag{6.3}$$

where $\Delta L^* = L_0^* - L^*$, $\Delta a^* = a_0^* - a^*$, $\Delta b^* = b_0^* - b^*$.s. The L*, a* and b* values were obtained after drying processes in different temperatures and different pretreatment durations. While, L_0, a_0 and b_0 are initial values. Table 6.8 and 6.9 shows the effect of temperature and pretreatment durations on color profile on apple slices.

Table 6.8 : Color measurements for different temperatures.

Temperature (ºC)	ΔL*	Δa*	Δb*	ΔE
50	1.4621	2.5856	1.6483	3.3971
60	2.1967	4.3322	0.5333	4.8865
70	2.6355	5.0811	1.1449	5.8373

Table 6.9 : Color measurements for different pretreatment durations (T=60 ºC).

Duration (min)	ΔL*	Δa*	Δb*	ΔE
10	1.0243	1.9856	1.5647	2.7277
20	1.0052	1.8657	1.5437	2.6219
30	0.9738	1.8435	1.6734	2.6734

According to results of measurements, as parallel to study done by Rayaguru et.al(2012), there are significant change between fresh and dried apple slices. ΔL* values show that apples are getting darker with increase of drying temperature. It can be also seen that redness of samples become more according to Δa* values. Δb* values are getting smaller with temperature and this indicates that apples loose their greenness with drying process. For ultrasound-pretreated samples, similar colour changes can be seen however the amount of difference is not as much as dried samples without pretreatment.

7. CONCLUSION AND RECOMMENDATIONS

In this thesis study, drying kinetics of apple slices have been examined. In order to find the optimum temperature value, samples were dried at three different temperatures (50ºC, 60 ºC, 70 ºC) and 60 ºC was determined the optimum dehydration temperature for apple. Then, effect of ultrasound pretreatment was investigated with three different ultrasound treatment duration (10 min, 20 min and 30 min) and minimum drying time was observed in 20 min pretreatment process. Additionally, effect of drying temperature on quality properties of apple slices was investigated through color measurement and it was seen that with the increase in temperature, colour deterioration also increases. It was observed that, for ultrasound pretreated samples, negative effect of drying is less than dried apples without pretreatment. In general results of study are similar to current researches. Differencies can be thought because of non uniform experiment conditions.

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