SEPTEMBER 2020 M.Sc. in Food Engineering BÜŞRA IŞINAY

REPUBLIC OF TURKEY

GAZİANTEP UNIVERSITY

GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES

EFFECT OF COMBINED RADIO-FREQUENCY AND SOLAR ASSISTED AIR DRYING ON PROPERTIES OF DRIED APRICOT

M.Sc. THESIS

IN

FOOD ENGINEERING

BY

BÜŞRA IŞINAY

SEPTEMBER 2020

EFFECT OF COMBINED RADIO-FREQUENCY AND SOLAR ASSISTED AIR DRYING ON PROPERTIES OF DRIED APRICOT

M.Sc. Thesis

in

Food Engineering

Gaziantep University

Supervisor

Prof. Dr. Fahrettin GÖĞÜŞ

by

Büşra IŞINAY

September 2020

REPUBLIC OF TURKEY
GAZİANTEP UNIVERSITY
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES
FOOD ENGINEERING

Name of the Thesis : Effect of Combined Radio-frequency and Solar Assisted Air Drying on Properties of Dried Apricot

Name of the Student : Büşra IŞINAY

Exam Date : 16.09.2020

Approval of the Graduate School of Natural and Applied Sciences

Prof. Dr. A. Necmeddin YAZICI
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Medeni MASKAN
Head of Department

This is to certify that we have read this thesis and that in our consensus opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Prof. Dr. Fahrettin GÖĞÜŞ
Supervisor

Examining Committee Members:	Signature
Prof. Dr. Fahrettin GÖĞÜŞ	…………………..
Assoc. Prof. Dr. Derya KOÇAK YANIK	…………………..
Asst. Prof. Dr. Eda ADAL	…………………..

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

Büşra IŞINAY

ABSTRACT

EFFECT OF COMBINED RADIO-FREQUENCY AND SOLAR ASSISTED AIR DRYING ON PROPERTIES OF DRIED APRICOT

IŞINAY, Büşra
M.Sc. in Food Engineering
Supervisor: Prof. Dr. Fahrettin GÖĞÜŞ
September 2020
77 pages

Dried apricot, one of the most important agricultural export commodities of Turkey, is still produced by using traditional drying (sun drying) method with the expense of high product losses and low grade products with lower economical value. In this study, the experimental design was generated using response surface methodology for radio-frequency drying experiments following solar assisted air pre-drying. For this purpose, the effect of independent variables on the response values was investigated with Box Behnken experimental design for drying of unsulfured apricots. Independent variables were pre-drying temperature (50-70°C), pre-drying time (300-1140 min), radio-frequency electrode gap (77-85 mm) and radio-frequency drying time (270-690 min). Moisture content (%), quantity of browning products ($A_{420}/g_{dryweight}$), total color change (ΔE) and hardness value (N) were selected as the responses. The drying conditions were optimized for minimum process time, browning, color change and optimum hardness and moisture content. Under optimum conditions of 63.5 °C pre-drying temperature, 895 min pre-drying time, 77 mm distance between radio-frequency electrodes and 385 min radio-frequency drying time; the moisture content (%), quantity of browning products ($A_{420}/g_{dryweight}$), total color change (ΔE) and hardness (N) were 22.31±2.82, 0.69±0.03, 37.65±2.23 and 1293.46±61.96, respectively. Radio-frequency drying following solar assisted air drying system provided high quality whole apricots while reducing the processing time.

Key Words: Apricot, Box Behnken, Radio-Frequency Drying, Solar Assisted Air Drying

ÖZET

RADYO FREKANS İLE KOMBİNE EDİLEN GÜNEŞ ENERJİSİ DESTEKLİ HAVALI KURUTMANIN KURU KAYISI ÖZELLİKLERİ ÜZERİNE ETKİSİ

IŞINAY, Büşra
Yüksek Lisans Tezi, Gıda Mühendisliği
Danışman: Prof. Dr. Fahrettin GÖĞÜŞ
Eylül 2020
77 sayfa

Türkiye'nin en önemli tarımsal ihraç ürünlerinden birisi olan kuru kayısı üretimi halen geleneksel kurutma yöntemleri kullanılarak gerçekleştirilmektedir. Dolayısıyla, uzun ve kontrolsüz üretim süreçlerine bağlı yüksek ürün kayıpları yaşanmakta ve ekonomik değeri düşük kalitesiz ürünler üretilmektedir. Bu çalışmada, güneş enerjisi destekli havalı ön kurutmayı takiben radyo frekans kurutma deneyleri için yüzey yanıt metodu kullanılarak deneme deseni oluşturulmuştur. Bu amaçla, bağımsız değişkenlerin yanıt değerleri üzerindeki etkisi, kükürtsüz kayısıların kurutulması için Box Behnken deneysel tasarımıyla araştırılmıştır. Bağımsız değişkenler; ön kurutma sıcaklığı (50-70 °C), ön kurutma süresi (300-1140 dk.), radyo frekans elektrotları arası mesafe (77-85 mm) ve radyo frekans kurutma süresidir (270-690 dk.). Su miktarı (%), kahverengileşme ürünü ($A_{420}/g_{kuru\ ağırlık}$), toplam renk değişimi (ΔE) ve sertlik (N) yanıt değerleri olarak seçilmiştir. Kurutma koşulları minimum işlem süresi, kahverengileşme, renk değişimi ve optimum sertlik ve nem içeriği için optimize edilmiştir. Optimum 63,5 °C ön kurutma sıcaklığı, 895 dk. ön kurutma süresi, 77 mm radyo frekans elektrotları arası mesafe ve 385 dk. radyo frekans kurutma süresi koşullarında; su %'si, kahverengileşme ürün miktarı ($A_{420}/g_{kuru\ ağırlık}$), toplam renk değişimi (ΔE) ve sertlik (N) sırasıyla 22,31±2,82, 0,69±0,03, 37,65±2,23 ve 1293,46±61,96'dır. Güneş enerjisi destekli havalı kurutma sistemini takiben radyo frekans kurutma, işlem süresini azaltırken yüksek kaliteli bütün kayısılar sağlamıştır.

Anahtar Kelimeler: Box Behnken, Güneş Enerjisi Destekli Havalı Kurutma, Kayısı, Radyo Frekans Kurutma

"Dedicated to my family"

ACKNOWLEDGEMENTS

This thesis would not have been possible without the guidance and the help of several individuals who in one way or another contributed their valuable assistance in the completion of this study.

First and foremost, I wish to express my special deepest sense of respect, gratitude and appreciation to my supervisor Prof. Dr. Fahrettin GÖĞÜŞ for his invaluable guidance, advice, criticism, constant support throughout the preparation of this thesis. I really appreciated your patience and making yourself available at any time I needed. Thanks for your encouragements and helps with my English.

I would also like to thanks to Prof. Dr. Ali Coşkun DALGIÇ, Assoc. Prof. Dr. Derya KOÇAK YANIK, Res. Assist. Hatice Neval ÖZBEK and Aysel ELİK for their suggestions and comments. Thanks for being there to answer my questions and to listen to all my complaints.

To my wonderful parents, the best I could ever ask for thank you for being there for me at all times, thank you for your prayers, advice, love and for supporting me during my studies.

I would like to thanks to my beloved boyfriend Efe YEŞİLYURT for his patience, help and support.

Financial support for this thesis is provided by the Scientific and Technological Research Council of Turkey (TUBITAK) 1003 Project No: 118O026.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF SYMBOLS

°C	Celcius
Min	Minute
mm	Milimeter
A	Absorbance
g	Gram
ΔE	Color Change
N	Newton
β	Beta
MHz	MegaHertz
kg	Kilogram
MJ	Microjoule
km	Kilometer
ppm	Parts per Million
mg	Miligram
γ	Gama
µg	Mikrogram
h	Hour
µm	Micrometer
W	Watt
L*	Lightness
a*	Redness- Greenness
b*	Yellowness- Blueness
C*	Chroma Value
h °	Hue Angle

LIST OF ABBREVIATIONS

RSM	Response Surface Methodology
RF	Radio Frequency
SAAD	Solar Assisted Air Drying
LPG	Liquefied Petroleum Gas
BC	Before Century
FAO	Food and Agriculture Organization
FW	Fresh Weight
GAE	Gallic Acid Equivalent
RH	Relative Humidity
CIE	International Color Determination Commission
BI	Browning Index
aw	Water Activity
PPO	Polyphenol Oxidase
TPA	Texture Profile Analysis
TS	Turkish Standard
wb	Wet Basis
AOAC	Association of Official Analytical Chemists
UV-Vis	Ultraviolet and Visible
PLC	Programmable Logic Controller
PTFE	Polytetrafluoroethylene
ANOVA	Analysis of Variance

CHAPTER 1

INTRODUCTION

The total annual production of fresh apricot is 3 500 000 tons in the world and Turkey produces 700 000 tons of the total. Thus, with this production amount, Turkey has 20 % share in the world as the top fresh apricot producer (Ünal, 2010). Production of dried apricots is about 150-200 thousand tons in the world and Turkey has more than 75 % of the world production of dried apricots (Inserra et al., 2017). Most of the dried apricot production in Turkey (> 80%) is made in Malatya province and a significant portion of the dried apricots is exported (Erdogan et al., 2003). Therefore, the export of dried apricots is important in terms of foreign currency inflow.

In Turkey, more than 70% of the grown and dried apricot varieties are Hacıhaliloğlu varieties (Coşkun, et al., 2013; Ünal, 2010). Hacıhaliloğlu apricot variety is medium-sized, oval shaped, fruit peel is thin, yellow color, fruit flesh is hard, less juicy, very sweet, flavored and is known to be durable (Asma, 2011). Today, dried apricots are two types; sun dried and sulphured apricots (Sobutay, 2003). Sun dried apricots are produced by laying whole or half apricots under direct sunlight and drying for 7-8 days without any pretreatment. In this traditional drying system, the sun dried apricots are dark brown and contain high amount of browning reaction products since they do not undergo any pretreatment to prevent browning. Sulphured apricots are dried after sulphurization to reduce microbiological risk, to prevent browning, and to ensure permanence of natural yellow color during drying, storage and distribution (Özkan ve Cemeroğlu, 2002). Traditional drying under the sun is a method preferred by the farmers who do not require any capital compared to industrial drying, carried out with simple tools and producing apricot with low energy cost (Gezer et al., 2003). It is a traditional drying system which cannot be controlled due to weather conditions and it is quite risky with long drying time. For this reason, low quality and non-standard products are produced. This situation causes the apricots produced in our country to find buyers at low prices. Failure to switch to a standard, hygienic and economic drying system in dried apricots, loss of quality and nutrients, sulfur residues, deficiencies in packaging and storage, the presence of dust, soil and stone remains in apricots that are in direct contact with open air for a long time are among the main problems faced by our country in the production of dry apricots. (T.R. Ministry of Food, Agriculture and Livestock, 2014; Sobutay, 2003).

One of the most important parameters determining the standard in dried apricots is the moisture content. According to Turkish Food Codex, maximum moisture content of dried apricot is 25%. In dried apricot, moisture content of the final product affects texture properties and chewability of the apricot. While an overly dried apricot is hard and cannot be chewed, high moist apricot causes microbial risk during storage. So, the moisture content of dried apricots should be kept in the range of 20-25%.

Many studies have been carried out both in our country and abroad for drying apricots, but a complete solution has not been brought to the above mentioned problems. Studies on apricot drying are generally laboratory-scale or only about the drying kinetics (Toğrul and Pehlivan 2003; Bon et al., 2007; Faal et al., 2015, Ivanova et al., 2017; Ubeyitogulları and Çekmecelioglu) or quality parameters (Inserra et al., 2017, Incedayı et al., 2016; García-Martínez et al., 2013; Karabulut et al. 2007). The studies that use new technologies are not usually based on drying the whole apricot, but are aimed at drying the chopped or half apricot (Horuz, et al., 2017; Kayran and Doymaz, 2016). However, the preferred factor in dried apricots to increase its economic value is the drying of apricot as whole fruit. The datas obtained from these studies, mostly conducted at laboratory level, cannot contribute to industrial applications.

Despite the increasing interest in natural dried apricots in recent years, sulphured apricot is preferred in the market due to its golden yellow color. Sulphur application delays β-carotene degradation (Türkyılmaz et al., 2013) and provides inhibition of enzymatic and non-enzymatic browning reactions. In addition, it contributes to the prevention of possible microbial deterioration (Coşkun et al., 2013). However, high sulphur concentration can cause various health problems (Igual et al., 2012). Therefore, production of low-sulfur or non-sulfur quality products is important. In this study, it is aimed to produce sulfur free products by accelerating the radio frequency drying process, which will be followed by the air drying by minimizing the enzymatic and non-enzymatic reactions that occur during drying. Igual et al. (2012) dried apricots with microwave and air combined microwave techniques. They reported that microwave drying significantly reduced drying time and kept the total phenolic content at the highest level. Garcia Martinez et al. (2013) who studied the combination of air and microwave drying stated that the sulfurization process causes complete loss of ascorbic acid. They also stated that microwave drying without sulfurization process resulted in the best quality dried apricot in terms of color and ascorbic acid. In this study, radio-frequency heating method which is known as a dielectric heating method has been used with some advantages compared to microwave. In this way, it is aimed to accelerate the drying process by using RF's water selective heating feature to prevent browning of the product. Working at 27.12 MHz radyo frequency against 915 or 2450 MHz used in microwave application both facilitates system power control and consequently control of product temperature rise and also effectively improves drying.

In this study, due to the high cost of the industrial drying process, different energy sources and drying techniques were studied instead of traditional sun drying. In this way, it is aimed to shorten the drying time and produce high quality products preferred in the international market without increasing the process cost. In conventional dryers, the energy (fossil or electricity) required by drying systems increases product costs significantly. The total energy used to remove 1 kg of water in continuous convection dryers is between 3.2 and 4.5 MJ. This energy is 4-6 MJ / kg water in batch dryers and approximately 10 MJ / kg water in vacuum and freezer dryers. So it is quite costly (Saravacos and Maroulis, 2011; Ferreira et al., 2008). Utilizing solar energy, which is a renewable natural resource in drying, is the most economical method. Solar energy dryers; require less space than drying in open sun, keep the product quality at the highest level and are considered hygienic as they protect the product from environmental factors (Prakash and Kumar, 2013). During the drying of food in solar dryers, it is not possible to be exposed to physical effects such as insects, dust, rain, etc. (Ertekin and Yaldiz, 2004; Doymaz, 2007; Doymaz, 2011). This method is renewable, low-cost, environmentally friendly and provides energy saving while drying high temperature sensitive food products without damage. In solar energy dryers; it is possible to reduce the traditional energy used (fossil, electricity, etc.) by 27-80%. These dryers are easy to install and cost-effective. It is also possible to reduce the amount of CO_2 released to nature.

Although solar dryers have many advantages, they also have some disadvantages. With solar energy drying systems, it is not possible to perform effective drying during the hours and nights when solar energy is low. Air flow performance may be low due to the fact that the air is cool during these periods. For this reason, studies are carried out to improve the system. In some dryer designs, drying is continued by burning electricity, LPG, bio waste or other energy sources. However, these methods increase the unit price of the product due to energy costs (Montero et al., 2010; Smitabhindu et al., 2008; Sarsavadia, 2007; Tiris et al., 1995). Another alternative solution is to store solar energy in various ways during the day and use it when necessary. For example, it is stated that enough solar energy is stored in the stone bed and then used (Madhlopa and Ngwalo, 2007). Grapes, figs, apples, peas, tomatoes and onions were dried with the solar energy dryer and sand was used as energy storage material (Sebaii et al., 2002). Similarly, Tiwari et al. (1994) and Tiwari et al. (1997) used water and stone as energy storage material. They found that both materials were suitable for energy storage but the stone was more efficient.

The objectives of this study were to:

- Produce sulphur-free products and stabilize the color of the product,

-Shorten the drying time by combining solar panels supported conventional heating and hot air supported radio-frequency techniques in the drying phase; to improve physical, chemical and sensory properties of the product,

- Minimize losses in the production process.

CHAPTER 2

LITERATURE REVIEW

2.1 Apricot

2.1.1 Systematic of Apricot

Apricot (Prunus armeniaca L.) is a fruit that is categorized under the Prunus species of Prunoidae sub-family of the Rosaceae family of the Rosales group (Dağ et al., 2016). Botanically, apricots are defined as drupes or stone fruits (Aubert et al., 2010).

Figure 2.1 Picture of apricot fruit

2.1.2 The Origin and History of Apricot

The homeland of apricot is known as China and Central Asia and is adapted to the Mediterranean climatic conditions (Touati et al., 2013). Apricot and wild species of apricot are the natural plants of a wide geography ranging from Central Asia to North China. Information about the history of apricot is limited. In this respect, the most comprehensive information is available in China. The earliest record of cultivating apricot as a cultivated plant dates back to four thousand years ago and describes how apricot cultivation took place during the reign of the Chinese Emperor Yu (2205–2198 BC). Today, there are different views on the spread of apricot from Central Asia to the West. Many experts claim that apricots were brought to Anatolia during the Asian Campaign. According to some, apricot has been spread to the West by silk traders from its origin centers. According to the third and final opinion, Roman soldiers played an important role in the spread of apricot. (T.R. Ministry of Food, Agriculture and Livestock, 2014).

2.1.3 World Apricot Production and Trade

Apricot trees grow up in the five continents of the world and their annual production level is over 2 million tons (Toğrul and Pehlivan, 2003). Although apricot production is carried out in many parts of the world, the countries where apricot production is concentrated are Europe and the neighboring countries of the Mediterranean. Turkey is leader country in the world from the point of production of fresh and dried apricots. It has a great potential due to both the quality of apricot varieties and its ecological advantages. Apart from our country, Spain, Italy, France, Greece, Morocco, Algeria, Iran, Pakistan, USA, China, Australia, Republic of South Africa and Commonwealth of Independent States (Azerbaijan, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, Russian Federation, Armenia and Moldavia) are among the important countries producing apricots (Çatı and Yıldız, 2007).

Statistics on world dried apricot production are not published in international sources. Only the Food and Agriculture Organization (FAO) has estimates the world dried apricot production. According to FAO estimates, apricot production is carried out in nearly 30 countries on the worldwide and dried apricot is produced in 14 countries. These countries are Turkey, Algeria, Pakistan, Syria, USA, Australia, Spain, Tunisia, Argentina, Morocco, Chile, Cyprus, Greece and Afghanistan (Çatı and Yıldız, 2007).

Turkey, Spain, Italy, France and Greece are the largest producer of apricot in the worldwide (İncedayı et al., 2016). Turkey, Hungary, Morocco, Tunisia and Israel play an important role in the export of fresh apricots. Turkey, Australia and Iran are known as major and famous producers of dried apricot. At the same time, these countries are major and famous dried apricot exporter (Toğrul and Pehlivan, 2002). Some countries export canned apricots such as South Africa, the Czech Republic, Bulgaria and Romania (Ardıç, 2014).

Table 2.1 World apricot datas (thousand tons)

	2013	2014	2015	2016	2017
Production	4.097	3.343	3.963	3.766	4.257
Fresh Apricot Import	433	306	279	290	337
Fresh Apricot Export	275	262	312	273	354
Dried Apricot Import	158	136	108	121	122
Dried Apricot Export	139	107	88	106	115

Source: 1/FAOSTAT (14.01.2019), 2/Un Comtrade

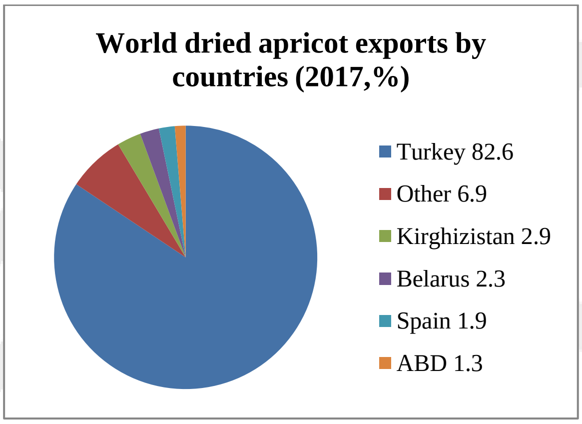

Figure 2.2 World dried apricot exports by countries

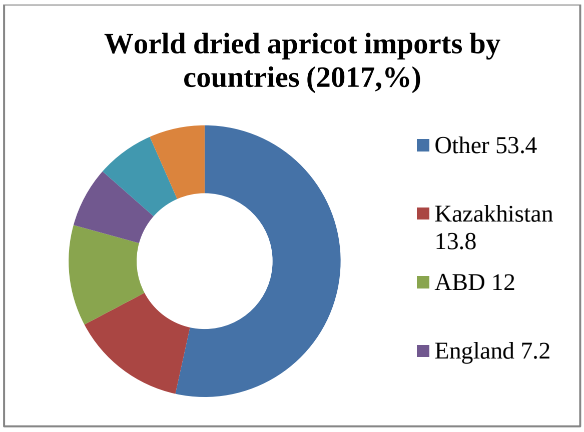

Figure 2.3 World dried apricot imports by countries

Table 2.2 Turkey apricot datas (tons)

	2012/13	2013/14	2014/15	2015/16	2016/17
Production	795.483	811.609	278.210	696.100	749.050
Consumption	168.719	193.771	46.633	126.845	213.832
Import	2.494	3.769	7.480	8.215	3.912
Export	578.158	570.187	306.317	404.422	464.358

Source: TÜİK

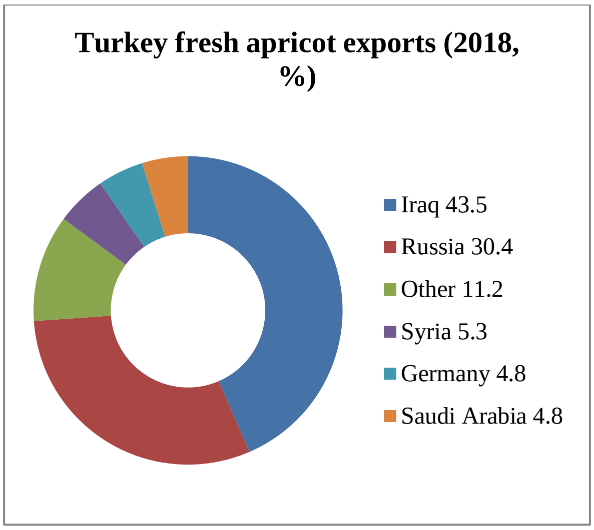

Figure 2.4 Turkey fresh apricot exports

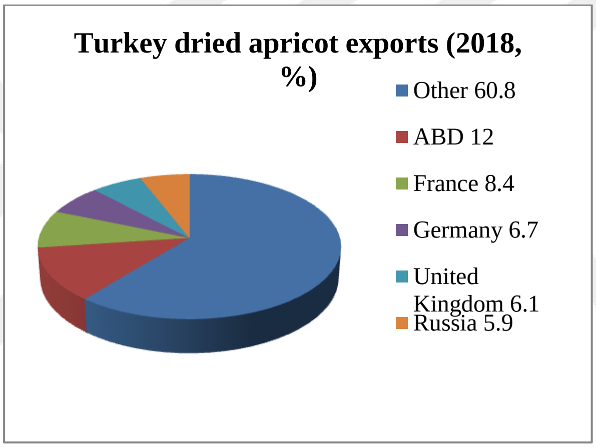

Figure 2.5 Turkey dried apricot exports

(Agricultural Economics and Policy Development Institute, 2019)

2.1.4 Some Important Apricot Varieties Grown in Turkey

Turkey is located in the first place from the point of fresh and dried apricot production in the world. It has great potential both in terms of gene resources and production areas. In our country, both the number of trees and the amount of production continuously increase. The oldest information was detected in 1934 about apricot production of Turkey (T.R. Ministry of Food, Agriculture and Livestock, 2014).

Mediterranean-type climates are preferred to prevent spring frost for apricot cultivation. Best option is deep, fertile, and well-drained soils to produce tall and healthy trees. Apricot trees exhibit moderate tolerance to high pH soils and salinity but can't tolerate to waterlogging (Hui, 2006). The trees of these apricot species are high and strong, their branches are wide and shallow. In fertile and irrigated soils, they bear fruits every year. The distance between trees is approximately 10 m, average weight of fruit is between 20 and 60 g, dried substances percentage in fruits vary from 18 to 28, ph value is between 4 and 5 and they have yellow color. Their harvesting time varies from the end of June to the beginning of July (Hacıseferoğulları et al., 2007).

Many fruit species are cultivated in Malatya and the world-famous Malatya apricot is undoubtedly the first place. The first written record of apricot in Malatya is in 1655. Famous traveller Evliya Çelebi, who came to Malatya, speaks of 7.800 orchards and 7 apricot varieties. Malatya's local merchant "Hacı Sadi Oğlu Mahmut Nedim" made sulphurization and drying in 1923. He also taught sulphurization to the surrounding farmers. With the arrival of the railway to Malatya, apricot was recognized in the country and its economic importance increased (Ünal, 2010).

Malatya is the most important apricot production center of Turkey. Approximately 50% of fresh apricot production of Turkey is provided by Malatya. 73% of total production is Hacıhaliloğlu, 17% is Kabaaşı and the rest is Soğancı, Hasanbey, Çataloğlu and wild apricot (zerdali) species (Alan et al., 2013). 90-95% of the fresh apricots produced in the province are dried and exported. Malatya has many different apricot varieties and types in terms of color, shape, taste, aroma and size. The most important feature of Malatya apricots is that the amount of water soluble dry matter is high and the amount of organic acid is low. While the amount of dry matter in Malatya apricot varies between 22-28%, this rate is 14-18% in other local and foreign apricot varieties. While Malatya apricot's taste index is quite high as 80-120, this ratio varies between 10-40 in foreign varieties. Malatya apricots are extremely suitable for drying. While 1 kilogram of dried apricots is obtained from 3-3.5 kilos of fresh fruits of Malatya apricots, 1 kg of dried apricots can be obtained from 5-7 kilos of foreign apricots (T.R. Ministry of Food, Agriculture and Livestock, 2014).

Hacıhaliloğlu is the most important dried apricot variety in Malatya. Hacıhaliloğlu apricot variety makes up about 73% of the apricot tree presence in Malatya. It was estimated that, at the beginning of the 1900s, a selection was found in Hacıhaliloğlu farm, 12 km north-east of Malatya. It is sensitive to frost, drought and diseases (monilya and freckle). Fruit is medium size, 25-35 g weight, oval shape, symmetrical, yellow color, less juicy, very sweet and aromatic, red cheeks tend to form. Fruit peel is thin. Fruit has good road resistance. Fruit flesh is hard textured (Ünal, 2010). Apricot kernels of Hacıhaliloğlu consist of 17.38% protein, 48.70% crude oil, 3.68% Na, 1.06 ppm P, 0.58 ppm K, 0.11 ppm Ca, 0.24 ppm Mg, 42.8 ppm Fe, 42.35 ppm Zn, 1.10 ppm Mn and 2.09 ppm Cu (Gezer et al., 2003).

At the same time, apricot production is made Mersin, K.Maraş, Elazığ, Kayseri, Erzincan, Isparta and Konya provinces. Dried apricots are produced mostly in Malatya, Elazığ, Sivas (Gürün) and Kahramanmaraş (Elbistan) provinces. Table apricots are produced in the Mediterranean region including Mersin, Antalya and Isparta (T.C. Gıda Tarım Hayvancılık Bakanlığı, 2014). In drying varieties, the most important characteristic is high amount of water soluble dry matter and this value varies between 24-28%. In table varieties, these values are lower (Kan and Bostan, 2010). However, dried apricot production in Turkey has increased in recent years and is estimated to reach 70-80% of the world production of dried apricot. The world's highest quality dried apricots in terms of sugar and moisture content are produced in Turkey (Çatı and Yıldız, 2007).

Apricots grown in our country, according to the purpose of use;

Table apricots (Ninfa, P. Tyrinthe, Piriana, Hasanbey, Tokaloğlu, Cağataybey, Şalak, Şekerpare, Alyanak, Roksana, P. Colomer.),

Dried apricots (Hacıhaliloğlu, Çataloğlu, Soğancı),

Industrial type apricots used for the production of canned and fruit juice (Royal, Tilton, Luziet, Patterson) (Topal, 2012).


Hacıhaliloğlu


Kabaaşı


Soğancı


Çöloğlu

Şekerpare Alyanak Şalak Roksana

Figure 2.6 Photos of different apricot varieties

2.1.5 Nutritional Value of Apricot and its Importance for Human Health

Apricot fruit has 86.3 % of water in the edible portion, 0.4 g of proteins and 0.1 g of lipids per 100 g of fresh weight (FW). There are 6.8 g of available carbohydrates and 1.5 g of fibres per 100 g of FW (0.71 g soluble fibres/100 g of FW and 0.83 g insoluble fibres/100 g of FW) Chemical composition of fresh apricot was summarized in Table 2.3. (Fratianni et al., 2018).

Table 2.3 Chemical composition of fresh apricot

Chemical Composition	Value/100 g of fresh product
Edible portion (%)	94
Water (g)	86.3
Protein (g)	0.4
Lipids (g)	0.1
Available carbohydrates (g)	6.8
Soluble sugars (g)	6.8
Total fibres (g)	1.5
Soluble fibres (g)	0.71
Insoluble fibres (g)	0.83
Energy (kcal)	28
Energy (kJ)	117
Na (mg)	1
K (mg)	320
Fe (mg)	0.5
P (mg)	16
Ca (mg)	16
Thiamine (mg)	0.03
Riboflavin (mg)	0.03
Niacin (mg)	0.5
Vit A retinol eq (mg)	360
Vit C (mg)	13

Apricot contains several secondary metabolites and they act as antioxidants. Apricot represents also a good source of fibre, minerals (especially potassium but also calcium, iron, magnesium, zinc, phosphorus and selenium) and vitamins such as vitamin A, ascorbic acid, thiamine, riboflavin, niacin and pantothenic acid (Fratianni et al., 2018).

Apricot varieties have different types of organic acids. The most abundant organic acids are malic (2.8–26.6 mg/g of FW) and citric acids (0.18–20.5 mg/g of FW) in apricots. Moreover, isocitric acid (0.01–0.17 mg/g FW), succinic acid (0.01–0.12 mg/g FW), fumaric acid (1.6–9.7 mg/g FW), shikimic acid (5.3–13.2 mg/g of FW, only in some traditional varieties), as well as quinic acid (not always present) are other organic acids (Fratianni et al., 2018). Acid content of fruits is one of the important quality parameter and helps to determine fruit taste (Ali et al., 2011). Organic acids contribute to regulate the perceived balance between sweetness and acidity, maintain acid-base balance in the intestine and improve bioavailability of iron (Kafkaletou et al., 2019).

Apricot is a very important source for minerals. Zn, Ca, Cu, Fe, Mg, Na, Mn, P, and K are the minerals present nine minerals in apricot and their amount depends on the variety and geographical area of cultivation. Potassium is the most abundant mineral in apricot. Dried apricots are richer than fresh apricots about potassium level. As electrolyte, potassium generally helps a proper balance of fluid, aids muscle function, and contributes to regulate heartbeat. Furthermore, potassium contributes to maintain a normal blood pressure and might reduce the danger of stroke. Additionally, potassium plays role in bone regeneration and reduces the amount of calcium and acid in urine (Fratianni et al., 2018). Table 2.4. shows the range of the mineral contents of Hacıhaliloğlu apricot variety according to the literature (Hacıseferoğulları et al., 2007).

Table 2.4 Mineral contents of Hacıhaliloğlu apricot

Minerals	Mineral Contents (mg/kg)
K	2160.3 ± 223.4
Ca	737.29 ± 2.15
Fe	418.31 ± 30.45
Mg	402.82 ± 3.89
Na	783.12 ± 55.6
P	1436.5 ± 86.65

Apricot contains high levels of antioxidant and phenolic substances. Antioxidant content is an important parameter in terms of fruit quality. Phenolic substances are the most important groups of natural antioxidants (Kan and Bostan, 2010). A group of compounds containing a benzene ring to which one or more hydroxyl groups are attached is called phenolic compounds or polyphenols (Cemeroğlu et al., 2009). Phenolic compounds are secondary plant metabolites (Kan and Bostan, 2010). These compounds vary structurally from a simple phenolic molecule to complex high-molecular-weight polymers (Shahidi and Ambigaipalan, 2015). The composition of these compounds in fruits is characteristic for each species and variety. Quantitative differences depend on fruit variety, ripening stage, environmental conditions and fruit maturity (Kan and Bostan, 2010). Some of the phenolic compounds contribute to the formation of fruit flavor. Some of the phenolics give yellow, yellow-brown, red-blue tones to fruits (Cemeroğlu et al., 2001). In apricot, the most important phenolic compounds are chlorogenic and neochlorogenic acids, (+)-catechin, (-)-epicatechin and rutin (or quercetin-3-rutinoside) (İncedayı et al., 2016). Akin et al. (2008) reported the total phenolic content of Hacıhaliloğlu apricot as 5341.29 ± 206.05 mg GAE/100 g of dry weight.

In nature, the most common group of pigments are the carotenoids and they provide to form from yellow to red colours of fruits (Dragovicuzelac et al., 2007). Carotenoids and especially β-carotene have an important antioxidant capacity and they are effective with regard to health. Beta carotene is the main precursor of provitamin A which is found as the principal carotenoid compound in apricot. (Kafkaletou et al., 2019). β-carotene represents 60-70% of total carotenoids in apricots. At the same time, apricots contain other carotenoids such as 5-7% γ-carotene, 4-7% cryptoxanthin, 5% lycopene and 1.5-2% lutein (Sass-Kiss et al., 2005). β-carotene gives the specific color to apricot varieties (İncedayı et al., 2016). Storage temperature is highly effective on carotenoid loss. When canned apricot was stored at 26 °C for 1 year, 10-15% loss of β-carotene was determined. When it was stored at 10 °C for 1 year, only 5-6% loss of β-carotene was determined. Another factor is light that accelerates the degradation of carotenoids. Sun dried apricots have more carotenoid loss than artificial conditions (Cemeroğlu et al., 2009). Akin et al. (2008) reported the total carotenoids of Hacıhaliloğlu apricot as 21.87±1.99 mg β-Carotene equivalents/100 g of dry weight. Akın et al. (2008) reported β-Carotene of Hacıhaliloğlu apricot as 8.88±0.62 mg/100 g of dry weight.

Sugars are one of the most important food constituents that are instant source of energy for the body activities. The high sugar level of a fruit define as maturity index (Ali et al., 2011). Apricot contains different types of sugars such as glucose, fructose, sucrose, and sorbitol (İncedayı et al., 2016). Table 2.5. shows the range of the total sugar and sugar contents of Hacıhaliloğlu apricot variety according to the literature (Akin et al., 2008).

Table 2.5 Total sugar and sugar contents of Hacıhaliloğlu apricot

Apricot Variety	Sucrose	Glucose	Fructose	Sorbitol	Total sugar
Hacıhaliloğlu	22.96±0.89	19.21±0.63	13.56±0.64	26.80±1.27	82.53±2.09

Sugar contents expressed as milligrams per 100 g of dry weight.

Vitamin A, also known as retinol, is found only in animal products. Fruits contain only provitamin-A. At least 10 of the carotenoid substances have vitamin A activity. However, in apricot, saying vegetable-derived vitamin A, B-carotene comes to mind. For the amount of vitamin A, retinol equivalent is used as the unit. 1 retinol equivalent equals to 6 µg B-carotene. Both vitamin A and provitamin-A are resistant to the processing conditions of foods. The main loss of these substances occurs during the application of heat in the presence of oxygen (Cemeroğlu et al., 2009).

The chemical name of vitamin C is ascorbic acid. Ascorbic acid is a white crystalline compound. They are easily influenced by various factors. Especially oxygen, prolonged heating in the presence of oxygen and light are the main factors that cause degradation of vitamin C (Cemeroğlu et al., 2009). Ascorbic acid is among different quality attributes of fruits which has great importance due to its numerous roles in the body. At the same time, it is recognized as an important source of antioxidant and a quality indicator of postharvest shelf life (Ali et al., 2011). Various postharvest factors affect content of vitamin C. These factors include storage conditions and postharvest stress such as physiological disorders and mechanical damage (Mditshwa et al., 2017).

2.1.6 Evaluation Forms and Shelf Life of Apricot

Many types of fruit are processed to maintain their quality because they are seasonal and have limited shelf life. The apricot is one of these fruits which has high respiration rate and rapid ripening process. To extend the shelf life of this fruit, there are different conservation methods, such as drying, canning, packing in a controlled/modified atmosphere and processing to produce fruit juice, fruit puree, jam, marmalade, jelly, nectar or pestil (İncedayı et al., 2016). Furthermore, oils, benzaldehyde, cosmetics, active carbon and perfume are made using apricot kernel (Dağ et al., 2016).

Storage and packaging have an important effect on the shelf life of dried products. The optimum relative humidity in the storage of dried products with moisture content ranging from 2-20% is between 55-70% (Perera et al., 2003). Under ambient conditions, shelf life of apricot is 4-5 days while at low temperature (1°C) and high relative humidity (RH 90–95%), shelf life is only about 2–3 weeks (Hussain et al., 2011). Packages containing dried products should be moisture-proof and prevent the transfer of oxygen to the product and odor formation (Jangam et al., 2011).

2.1.7 Production of Dried Apricot

In Turkey, farmers harvest apricot fruits at about 78% moisture level. 10% of the product is used as fresh and the rest of the product is traditionally stored with 20% moisture level after harvesting, sulphuring, drying and pit separation processes (Hacıseferoğulları et al., 2007).

There are two different production methods to dry apricots in Malatya. The first product is known as sulphured apricot which is subjected to drying using sulphur. The other product is known as sun dried apricot which is exposed to direct sunlight without any chemical treatment. Apricots are sulphured for long-term preservation and to protect the color properties of the product and then released to the sun. Producers use sulphur more than necessary in order to achieve objectives (selling at appropriate quality and price, bright yellow color, etc.) by sulphuring process, which causes problems in export of dried apricots to many developed countries struggling for food safety. This increases need for sulfur-free apricot or alternative preservation techniques. In recent years, it has become widespread that the apricots produced in Malatya are dried directly and only with the help of sunlight without sulphuring. The demand of sun dried apricots has increased significantly both with its taste and reliable food idea. In the province of Malatya, sun dried apricot production was realized as 15 000 tons in 2017 and 58 500 000 $ revenue was obtain from this production (Çoban, 2018).

Sun dried apricot is a product obtained by drying without any chemical treatment. Production and consumption of sun dried apricots are increasing due to the fact that people move away from food additives, turn to more natural products and have a good place in foreign markets. However, no specific method and scientific research has not been found on how to produce sun dried apricots in the literature. Therefore, the farmers are drying the apricots according to their own experience and methods. As a result, sun dried apricots are found in different colors, different flavors and aromas in the market. It is thought that these negative properties in sun dried apricot stems from drying technique, harvest and fruit structure. In addition, some fruits are very dark black color, some are very light brown color. So, the fruits do not have a homogeneous appearance and therefore have low appeal. In addition, there are some problems during the production of dried apricots. Due to the direct exposure of the fruits to the sun and the drying time is long (8-10 days), color and enzymatic deterioration occurs in the fruits and this causes loss of quality in the product. During drying, the product is adversely affected in terms of microbial load and creates health problems in the consumption stages. It is stated that all these problems are caused by not controlling the physical conditions. All these negativities also decrease the quality significantly (Keattch, 2000; Çoban, 2018).

2.1.7.1 Harvesting

Harvesting is one of the important factors determining the quality of apricot. Harvesting starts in the middle of July each year in Malatya and is completed in about 3 weeks (Çatı and Yıldız, 2007).

The most perfect harvesting is by hand. In hand harvesting, fruit and tree are not damaged in any way and fruit quality is high. While the apricots are harvested by hand, the top of the tree, then the middle part, and then the lower branches are harvested normally according to the ripening period of the apricot. This ensures that the fruits have always the same maturity.

In traditional harvesting, apricot tree branches are shaken and the fruits are dropped to the ground by beating with sticks. Rarely, a cover is laid on the ground. Then apricots are collected and filled into crates. However, in this way, both the tree branches are damaged and the fruits fall to the ground from the height of 3-5 meters and the product is contaminated with soil and stone pieces and immature fruits are poured. This leads to significant loss of quality which cannot be corrected in the later stages of apricot processing.

Alternative apricot harvesting methods have been developed in order to minimize quality loss during the harvesting process. One of these methods is a practical harvesting umbrella. The apricots, which are shaken from the tree, fall softly to this umbrella and are collected by rolling into the plastic crates through the holes in the middle of the umbrella. With this method, damage of the fruits and their contact with soil is prevented. This method also saves time and labor (Çatı and Yıldız, 2007).

2.1.7.2 Sulphuring

The most prevalent pre-treatment method is sulphuring for apricot. Sulphuring fruits seem intense orange colour, translucent and have very good gumminess (Igual et al., 2012). This process is made to reduce the drying time of apricot, preserve the golden yellow natural color of the product, extend the shelf life and prevent fermentation and insecticide. This process is made with traditional methods, the harvested fruits are filled into crates and placed in processing rooms. In one corner of the room, powdered sulphur is burned (2 kg of powdered sulfur for 1 ton of fresh apricot) and the door of the room is tightly closed. Fruits are allowed to absorb sulfur gas thoroughly in the room for 6-8 hours. Then the fruits are removed from the room and spread in a single row in a sun-exposed area and drying is started (Çatı and Yıldız, 2007).

Germany and the United Kingdom allow the import of dried apricots containing 2000 ppm (ppm = mg / kg), France and Denmark 1000 ppm, Italy 600 ppm, Austria 300 ppm, USA, Canada, New Zealand and Australia 3000 ppm sulphur. In Turkey, maximum sulphur content of dried apricot was determined as 2000 ppm (Çatı and Yıldız, 2007).

2.1.7.3 Drying

40-45% of the total production of apricots in the world is processed and drying is one of the most widely used technologies in this area (Madrau et al., 2009). The purpose of drying apricots is to reduce the moisture level to a certain level and to store it much safer and longer (Karabulut et al., 2007). In terms of preserving the nutritional and sensory quality of apricots, choosing the best drying method and optimizing the drying conditions is very important (Karatas and Kamışlı, 2007).

Drying is carried out in two different stages. The first is the drying process applied by apricot producers. The second is the drying process applied by apricot processing plants (Çatı and Yıldız, 2007).

The drying process applied by the apricot producers is as follows; In the production process of dried apricots, after the sulphuring process, the apricots are laid in a sun-exposed area and allowed to dry. In the traditional drying process, apricots come into contact with the soil for days and are exposed to all kinds of external factors. This situation adversely affects the quality of dried apricots. At the same time, the impurities in apricot are tried to be removed by cleaning and washing in apricot processing plants, but this method increases the cost and decreases the quality of final product (Çatı and Yıldız, 2007).

Different drying methods have been developed as an alternative to the traditional drying method. One of these methods is the solar tunnel dryer method. In this method, solar energy is utilized. Solar energy is converted to heat with the solar collector. The heat generated heats the air sucked by the fans to 65 °C. Hot and dry air passes over and under the fruits in the drying section of the dryer. Thus, the hot air contacts each apricot and can be dried to the desired 25% final storage moisture content within 2.5 days (Çatı and Yıldız, 2007).

The second step of drying apricots is carried out in apricot processing plants. Dried apricots taken from the producer in apricot plants are washed to be free from dust and foreign matter. Washed apricots are sieved and separated according to their size and quality. After the garbage separation and washing steps, the apricots must be dried again. In apricot processing plants, these processes usually occur in winter. Since it is not possible to dry with sun in winter, drying with microwaves is a hygienic and economical method at this stage (Çatı and Yıldız, 2007).

Dried apricot is seedless fruit which the greater portion of moisture is moved away. Chemical composition of dried apricot was summarized in Table 2.6. (Hui, 2006).

Dietary fiber is one of the most important compounds of dried apricots in terms of nutrition and health. Dried apricots contain plenty of dietary fiber. Dietary fiber consists of compounds such as polysaccharide and lignin which can not be hydrolyzed by enzymes. Dietary fiber reduces the risk of diseases such as constipation, irritable colon syndrome, appendicitis, hemorrhoids, dental diseases, obesity, diabetes, chronic heart disease and colon cancer, and ensures the regular functioning of the intestines (Alan et al., 2013).

Table 2.6 Chemical composition of dried apricot

Chemical Composition	Value/100 g Edible Portion
Water (g)	30.89
Protein (g)	3.39
Lipids (g)	0.51
Carbohydrate, by difference (g)	62.64
Total sugars (g)	53.44
Total fibres (g)	7.3
Energy (kcal)	241
Na (mg)	10
K (mg)	1162
Fe (mg)	2.66
P (mg)	71
Ca (mg)	55
Thiamine (mg)	0.015
Riboflavin (mg)	0.074
Niacin (mg)	2.589
Vit A (IU)	3604
Vit C (mg)	1

2.1.7.4 Packaging

In the final stage of the apricot process, apricots are packaged to protect them from external influences and to prevent loss of preservatives over time. The packaging technique and the type of packaging is an important element in the export of dried apricots. Today, the quality of the product as well as the form of packaging, the portability and attractiveness of the packaging are among the desired properties (Çatı and Yıldız, 2007).

Pretreatments and drying stages, as well as packaging and storage conditions applied in the production of dried apricots, have a significant impact on the final quality of the product and accordingly its sales value. Traditionally, apricots are filled into polyethylene bags and then placed in cardboard boxes. The products packaged in this way are stored in warehouses where temperature and relative humidity control is not provided. However, packaging material and storage conditions play an important role in the safe storage of dried apricots. Miranda et al. (2009) in their studies on the packaging and storage of dried apricots with the increase in temperature stored in glass jars (5-35 °C) have determined that there is little change in the amount of water and apricot hardness does not change. However, it was observed that moisture content decreased and hardness increased in the products with increasing storage temperature in apricots packed with polyamide, polyethylene, etc. films. In another study, apricots filled with polyethylene bags were placed in cardboard boxes and stored at different temperatures (5-30 °C) (Coşkun et al., 2013).

2.2 Drying of Foods

Fruits and vegetables are highly perishable foods. Because, they have high amount of moisture content. Drying is one of the preservation methods which is widely used for fruits and vegetables. Drying of moist materials is a complicated process. It involves simultaneous heat and mass transfer (Faal et al., 2015).

Drying or dehydration is the process of removing volatile substances, such as water, from solid materials to slow or stop the growth of microorganisms and chemical reactions. During this process, some changes occur in the physical and chemical properties of the dried product such as shape, brittleness, hardness, color, aroma, taste and nutritional value (Karaaslan, 2012).

Drying has two main objectives (Bingöl and Devres, 2010):

1. Product quality

To remove water without affecting volatile materials such as flavor and taste,

To minimize chemical and biochemical degradation reactions,

To protect the structure of product,

To obtain the desired product color,

To prevent microbial contamination during drying,

Fast and simple rehydration.

2.Drying economy

To minimize the product loss,

To increase the capacity of drying equipment per unit quantity, To use cost effective energy source,

To develop simple drying equipment that provides minimal labor and reliability.

As a result, we can summarize the benefits of drying as follows;

To preserve the product and extend its shelf life. Microorganisms that cause food spoilage and decay cannot grow and multiply in the absence of water. Also, many enzymes that cause chemical changes in food and other biological materials cannot function without water,

To obtain desired physical form such as powder, flakes and granules (Baker, 1997),

To obtain desired nutrition, color, flavor and texture (Baker, 1997),

To reduce volume or weight for packing, transportation and storage (Baker, 1997),

To produce new products which would not otherwise be feasible (Baker, 1997),

No need for cold storage.

Drying of foods has continued since ancient times; It is a basic process that has to adapt itself continuously to technological developments in order to reduce the energy consumption and increase the quality. Drying in food processing allows new product formulations to be designed as well as to extend the shelf life of fruits and vegetables. Before starting to dry fruits and vegetables on both small and large scale, the question that should always be remembered is “Did I choose the proper drying method for my purpose? It is not possible to say that a single drying method is suitable for all foods in terms of economic and end product quality. Therefore, different drying processes should be applied to different products with optimum drying parameters in order to ensure that the final product meets the desired quality criteria and is also economically produced (Bingöl and Devres, 2010).

Although there are many drying methods available to dry a particular food commodity, combinations of these methods might improve both final product quality and drying economy. Previous studies have shown that the combination of microwave energy with vacuum improves the quality of the final product (Bingöl and Devres, 2010).

Drying technology has evolved from solar energy systems to current technologies including oven dryers, tunnel dryers, spray dryers, tray dryers, roller dryers, microwave, infrared, extrusion and many more (Ratti, 2001). It should be considered in all applications that the main purpose of the drying process is not to dry faster but to obtain a better quality product (Esper and Mühlbauer, 1998). Therefore, in recent years, drying methods have used together due to low quality loss during the drying process, high quality expectations of the end product, and energy efficiency. When studies related to the subject are examined, it is observed that oven, tunnel and spray dryers are supported with microwave; There is an increase in the number of researches using microwave and infrared methods together (Bingöl and Devres, 2010).

Table 2.7 Drying of potato and carrot by different methods (amount of energy to be spent for the evaporation of 1 kg of water (MJ)) (Hebbar et al., 2004).

Drying Operation	Potato	Carrot
Hot Air	17.17	16.15
Infrared	7.60	7.15
Infrared and Hot Air	6.43	6.04

As can be seen from Table 2.7, combining infrared energy with hot air energizes 63% compared to the use of hot air alone. In addition, it has been observed by the researchers that the quality of the final product is better in terms of color and surface hardening than hot air. (Bingöl and Devres, 2010)

2.2.1 Drying Methods of Apricot

In apricot drying, different methods are used such as drying in the sun without sulphur, drying in the sun by sulphur, drying in hot air, freeze drying, microwave drying, infrared drying and radio-frequency drying.

2.2.1.1 Traditional Sun Drying

Sun drying is the most common and oldest method for drying of apricot. It is a drying process which is carried out by laying out to the open area and utilizing solar energy. Main advantages are little capital, simple equipment and low energy input (Igual et al., 2012).

Traditional sun drying is a fairly slow process which may cause significant losses. Besides that, it causes to reduction of quality in the product because of insect infestation, enzymatic reactions and microorganism growth. Unfavorable climatic conditions such as rain, wind, moist, and dust bring along spoilage of product. Birds and animals give rise to loss of material. Moreover, the process has some disadvantages like highly labor intensive and requires large area (VijayaVenkataRaman et al., 2012).

Other techniques, such as hot air drying, microwave drying or their combination can be efficient alternatives in terms of drying time and nutritional value of apricot (Igual et al., 2012).

Figure 2.7 Traditional sun drying

2.2.1.2 Conventional or Hot Air Drying

It is one of the drying methods that goes back to ancient times and is widely used in many places. Hot air drying is also an effective method for protecting perishable products. In this drying process, the latent heat required to evaporate the water contained in the product is provided by the air and the evaporating water is removed from the product by air (Karaaslan, 2012).

Hot air drying has gained great importance because it has many advantages over sun drying, such as reduced microbial contamination, controllable drying parameters which give more uniform product with less quality loss, least negative effect of weather conditions, shorter drying times, and lower labor costs (Karabulut et al., 2007).

During drying, thermal damage occurs on the product which is directly proportional to the temperature and time involved. In conventional drying, higher temperature and longer drying time can cause quality loss of the product. The product is affected in terms of flavour, colour, nutrients and reduction in bulk density and rehydration capacity of the dried product. Volatile compounds vapourise and significant loss occurs in characteristic flavour of dried products. Rapid drying causes case hardening which is one of the most common problem in dried fruits. The low energy efficiency is one of the disadvantages in conventional drying of food (Vadivambal and Jayas, 2007).

In study of Karabulut et al. (2007), nonsulphurated Hacıhaliloglu apricots (Prunus armenica L.) which is the most commonly produced cultivar in Turkey were used to study the effects of different hot air drying temperatures (50, 60, 70, and 80 °C) and sun drying on color and β-carotene content of apricot.

The longest drying time was observed at sun drying experiment for nonsulphurated apricot (182 h). It was also found that increasing temperature of drying causes to shorter drying time. Drying at 50 °C required 55.0 h for nonsulphurated apricot while 13.75 h were needed to provide the same dryness at 80 °C. Color profiles of hot air drying are better than sun drying in all conditions (except 50 °C). Best color values were observed at 60 and 70 °C drying for apricots. All color values (except a*) of the dried apricots decreased obviously compared to the fresh apricots. Hunter a* values increased nearly double, which also shows the darkening of the color. A good relation was obtained between sensory analysis which was performed by experts and C* and h° values from the point of view of browning of dried apricots. Locally burned areas on the samples were noticed at 80 °C drying and this was caused decreases of C* and h° values (Karabulut et al., 2007).

The relationship between β-carotene content and treatments (drying temperature and time) of dried apricots was observed. There are different drying conditions between hot air drying and sun drying like sun light, air velocity, drying temperature and drying time. So, β-carotene content of sun dried apricots was not similar to hot air dried apricots. β-carotene contents of hot air drying are better than sun drying in all conditions (except 50 °C). Hot air drying at 50 °C was resulted in the greatest β-carotene losses in comparison with other drying temperatures. Combined effect of air velocity, drying time and drying air temperature can be reason of this situation. Elevated temperatures provided less decrease in β -carotene content of samples. This may be due to solubility of β -carotene increased at high temperatures. In addition, β-carotene content can be ascribed to oxidation with air and this is another degrading effect. As a result, drying time has gained importance critically and the longest drying time, 55.0 h for nonsulphurated apricot was caused the biggest β-carotene losses during hot air drying (Karabulut et al., 2007).

2.2.1.3 Freeze Drying

The freeze-drying method generally consists of two steps: first, the product is frozen and secondly, the product is dried by direct sublimation under reduced pressure. Temperature is increased while system pressure is lowered below critical point to ensure sublimation (Karaaslan, 2012).

Where product quality is a very important factor for the consumer, freeze-drying becomes an important alternative for moisture removal. Freeze drying requires higher investment costs and operating costs are higher than other methods (Karaaslan, 2012). Because there are modern and expensive refrigeration and vacuum systems in this method (Szychowskia et al., 2018). In addition, the costs of evaporation of water in the freeze-drying method are higher than that of conventional drying methods. At the same time, the dried products must be chopped into small pieces in order to be dried in a way to maintain their quality. The biggest difficulty in drying large particle products is that heat cannot be transferred to the inner ice phase through the outer dry layer (Karaaslan, 2012).

The freeze-drying method also has favorable properties, such as superior product quality provided by low-temperature sublimation and preservation of the structure during drying. This drying method protects the initial appearance, taste, color, flavor and structure of the products. So, this advantages make this method the best drying method. At the same time, the rehydration properties are good because the product retains its initial shape and dimensions (Karaaslan, 2012).

Fahloul et al. (2009) conducted research on freeze drying of apricots. They evaluated quality of apricot in terms of vitamin C and total sugars criteria. The authors concluded that freeze drying has less damage on vitamin C, since the process occurred at low temperature. It was observed that freeze drying also increased total sugars by 8% due to the concentration of solubles in apricots.

Figure 2.8 Freeze-dried apricot

2.2.1.4 Microwave Drying

Microwave heating can defined as the transformation of alternating electromagnetic field energy into thermal energy by affecting the polar molecules of a material. Volumetric heating is the most important property in microwave heating. Volumetric heating means which materials can absorb energy of microwave directly and internally and transform it into heat. Water vapour pressure differences happen between interior and surface regions in microwave drying. So, it provides a driving force for moisture transfer (Vadivambal and Jayas, 2007).

Microwave drying contributes in terms of drying rate, flexibility, colour, flavour, nutritional value, microbial stability, enzyme inactivation, rehydration capacity, crispiness and fresh-like appearance. Moisture is removed from the food products without the problem of case hardening in microwave drying. There are several advantages of microwave drying such as high thermal efficiency, shorter drying time and improved product quality compared to conventional hot air drying. A smaller floor space is enough for microwave drying as per conventional dryers. Microwave drying requires lower operational cost because energy is not necessary for heating the walls of the apparatus or the environment. Other advantages of microwave drying are the prevention of high surface temperatures and continuation of product respiration. (Vadivambal and Jayas, 2007).

Although microwave drying alone has many advantages, it also brings disadvantages. These can be listed as high initial investment costs, loss of aroma and physical damage in the product, drying of uniform size and shape products, the necessity of high safety precautions, the difficulty of the use of untrained people and the difficulty of homogeneous microwave distribution in the drying environment. (Karaaslan, 2012).

Garcia-Martinez et al. (2013) evaluated the effect of the drying process (hot air and/or microwaves) on the color, mechanical properties, and ascorbic acid, vitamins A and E, and total carotenoid content of apricot. They observed that the use of microwave preserves the ascorbic acid content of the fruit to a much greater extent even in nonsulphurated apricots. When compared to hot air drying, the application of microwaves decreased the drying time by 82 %.

2.2.1.5 Infrared Drying

Infrared drying is a radiation method applied at a wavelength of 0.5-1000 μm. It can be applied for heating, drying and surface pasteurization of many foodstuffs (Chou and Chua, 2001). Infrared technology is an alternative drying method which is versatility, simplicity of the required equipment, fast response of heating and drying, easy installation and capital cost. According to studies, the infrared drying method is faster than convective drying methods. Infrared radiation is used to heat or dry moist materials which penetrates it and the energy of radiation transform into heat. The infrared drying is especially convenient for thin layers of material with wide surface exposed to radiation (Kayran and Doymaz, 2016).

Kayran and Doymaz (2016) conducted research on infrared drying of apricots. They determined that drying characteristic of apricot was significantly influenced by infrared power. The authors concluded that drying time decreased greatly when the infrared power increased. The drying time required reaching the final moisture content of control samples were 690, 600, 420 and 330 min at the infrared powers of 62, 74, 88 and 104 W, respectively.

2.2.1.6 Radio-frequency Drying

Dielectric heating methods such as radio frequency and microwave heating are still popular alternatives to the conventional heating methods because of their short processing times, relatively uniform heating abilities and green processing possibilities due to not requiring a transferring medium since these methods principles not majorly depends on heat transfer as conventional methods do, but depends on heat generation due to the friction.

RF application is a method which increases the usability in food processes in recent years with its rapid and uniform temperature distribution in products, high energy efficiency and higher penetration depth than microwave application. In these systems, the product between two electrodes (one with high voltage and the other with ground) is absorbed by the alternating current and this energy is converted into heat energy in the product. In RF systems, the amount of power absorbed by the product with a frequency of 13.56 or 27.12 MHz is generally lower and more controllable than microwave systems. Therefore, sudden temperature increases within the product can be prevented and depending on the wavelength and penetration depth at this frequency, it can be easily used in bulk products preferred in industrial applications. The temperature increase in the product during RF application occurs by two mechanisms, namely ionic displacement and dipole rotation. Ionic displacement at low frequency used in RF application is considered to be the dominant mechanism (Marra et al., 2009), which is particularly advantageous for processes where the moisture content of the product is reduced, such as drying. RF application can provide effective heating of the product especially in the region of falling drying rate in drying processes and problems such as long drying time and product temperature rise due to decrease in drying rate can be prevented. In conventional drying systems, the heat dissipation coefficient decreases as the product water ratio decreases and this makes heat transfer into the product difficult. Therefore, in particular the product surface temperature rises undesirably; at the same time the concentration of the components causing the browning increases due to the decrease in the moisture content and browning reactions take place on the product surface.

RF drying is widely commercialized worldwide in the wood, textile, and paper industries, as well as in the postbaking of biscuits. On the other hand, not much study has been done about drying of food. RF system is too costly for drying large-volume agricultural commodities, like grains. For this reason, RF drying could advantage by providing high-quality final products for high value–added products, particularly in applications in which the same impact cannot be reached by conventional methods. Furthermore, RF drying can be low cost where space is limited. For instance, on cookie or cracker lines with radio-frequency drying, up to a 40% increase in throughout can often be achieved. This increase can be obtained with conventional methods, but these methods would often require the drying line to be extended by 30–40% (Jiao et al., 2018).

Many factors effect RF drying of food and agricultural products, like dielectric properties (DPs), thermal and other physical properties as well as distributions of electromagnetic field (Zhou and Wang, 2019). Properties of dielectric play an important role in determining the interaction between the electric field and a food (Tang et al., 2005).

Comparative analyzes were made to study the effect of three drying methods, containing RF drying, vacuum drying and hot air drying, about drying characteristics of in-shell walnuts. The results showed that the total drying time required for in-shell walnuts using energy of RF was the shortest (138 min), followed by vacuum drying (185 min) and hot air drying (300 min) Consequently, RF drying has considerable superiority on drying rates compared to vacuum and hot air drying (Zhou and Wang, 2019).

Porterfield and Wright (1971) conducted study about RF drying of peanuts. They determined the effecting factors on the absorption of power in the peanut bulk and further compared the drying rate of RF with other typical drying methods. The authors concluded which the bulk volume, moisture content, and distance between RF electrodes affected the power absorption during RF heating. Moreover, they noticed that the internal heating characteristic of RF could rise the drying efficiency when combined with hot-air drying (Jiao et al., 2018).

Wang et al. (2014) investigate the hot-air drying impact with and without RF on nuts of macadamia. The authors decided that adding RF to the hot-air drying process could reduce the drying time by half. However, the product quality of the two processing techniques was not remarkably different (Jiao et al., 2018).

2.2.2 Basic Stages of Drying

During the drying process, three different periods are observed as transition, constant rate and falling rate period.

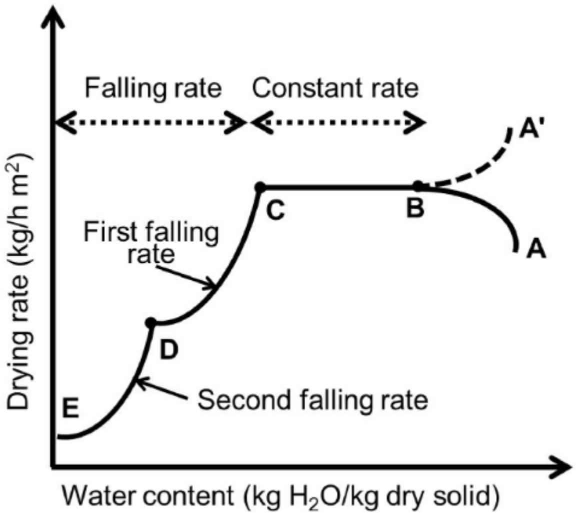

Figure 2.9 Typical drying rate curve

2.2.2.1 Transition Period

It refers to the transition time required for the material to be dried to equilibrate with the drying atmosphere (Dağhan, 2008).

2.2.2.2 Drying Period at Constant Rate

Moisture is kept on the surface in free state and vapor pressure, in other words, evaporation rate is realized at the highest level (Bingöl and Devres, 2010). In the constant rate drying period, the surface of the solid is initially very moist and a continuous film of water exists on the drying surface. This water is completely unbound water and it acts like the solid were not present. The evaporation rate under the given air conditions is independent of the solid and is fundamentally the same as the rate from a free liquid surface. Moreover, increased roughness of the solid surface can lead to higher rates than from a flat surface (Geankoplis, 2014).

2.2.2.3 Drying Period at Falling Rate

At the critical moisture content point, there is insufficient water on the surface to provide a continous film of water. The entire of surface is no longer wetted, and the wetted area continually decreases in the first falling rate period until the surface is entirely dry. In the second falling rate period, the plane of evaporation slowly move away from the surface. Heat for the evaporation is transferred through the solid to the zone of vaporization and vaporized water moves through the solid into the air stream (Geankoplis, 2014). In this period, because the water is held in thin capillaries in the material and passes very slowly through the surface of the capillaries, the drying rate decreases very quickly (Bingöl and Devres, 2010).

2.2.3 Factors Affecting Drying Rate

Drying rate; it is directly controlled by factors that affect heat and mass transfers. These factors are mainly air temperature, air humidity and speed in the dryer, physical and chemical properties of the material (Cemeroğlu, 2009).

2.2.3.1 Characteristics of Product

Undoubtedly, the most important factors affecting drying rate are the specific characteristics of the dried product. Moreover, these qualities change throughout drying. The chemical composition of the product is particularly important in this respect. If a material is rich in dissolved substances such as sugar, salt and the like is compared to a poorer material with respect to drying, the rich in dissolved substances appears to be more difficult to dry. As is known, dissolved substances lower the vapor pressure of the water, thus making it difficult to evaporate the water (Cemeroğlu, 2009).

2.2.3.2 Surface Area of Product

Drying rate is directly proportional to the surface area of the particles and inversely proportional to their thickness. Although the size of the dried pieces has a significant effect on the drying rate, there is no significant difference in the rate of drying of the products such as fruits and vegetables between the chopped and chopped into smaller pieces in the initial stage of drying. However, as time progresses, the drying speed varies considerably according to the size of the parts. Because, especially during the falling rate period, diffusion of the water in the inner layers to the surface becomes difficult in the coarse parts and the drying rate decreases in these (Cemeroğlu, 2009).

Because of this important effect of the particle size on drying rate, it is obvious that it is always beneficial to chop the fruits and vegetables to be dried into small pieces. However, this is not always possible. Because, in terms of consumption, some products need to be dried as a whole (Cemeroğlu, 2009).

2.2.3.3 Velocity of Drying Air

Another factor affecting the drying rate is the air velocity in the dryer. As the air velocity increases, the drying rate increases. As a matter of fact, it was determined that an air velocity of more than 300 meters / minute has no an effect on the drying rate. The air velocity is very effective during the initial stages of drying. However, in the later stages of the drying process, the high air velocity has no effect because it is limited by the rate at which the water in the lower layers is transported to the surface (Cemeroğlu, 2009).

2.2.3.4 Temperature

Temperature is one of the most important factors affecting the drying rate. As the temperature increases, the diffusion rate increases. Thus, drying rate increases and drying time decreases. However, burning can occur when very high temperatures are used in thin layer foods (Özen, 2016) .

2.2.3.5 Relative Humidity of the Environment

The relative humidity of the environment determines until to which level the drying process will continue. The drying process continues until the moisture values of the drying atmosphere and the product are balanced (Örs, 2019)

2.2.4 Food Quality Parameters and Changes During Drying

The most investigated properties of dry products are classified under two main headings as engineering and quality characteristics. Effective moisture diffusion, effective thermal conductivity, drying kinetics, specific heat, equilibrium moisture content are among the engineering properties of dry products. These characteristics are related to the determination of the process properties themselves evaluating in this way significant parameters of the process analysis and design procedure. The quality parameters of dry products are divided into groups such as; thermal properties (glassy, crystalline, rubbery), structural (density, porosity, pore size, specific volume), and textural properties (compression test, stress relaxation test, tensile test), visual properties (color, appearance), sensory properties (aroma, taste, flavor), nutritional properties (vitamins, proteins) and rehydration properties (rehydration rate, rehydration capacity) (Krokida et al., 2000). Factors affecting the physical, chemical and nutritional quality of foods during drying are given in Table 2.8 (Baker, 1997).

Table 2.8 Factors affecting the quality of foods during drying

Physical	**Chemical**	**Nutritional**
Rehydration	Browning reaction	Vitamin loss
Solubility	Lipid oxidation	Protein loss
Texture	Color loss	Microorganism viability
Aroma loss		
Density loss		

Since these quality parameters of dry products depend on the drying methods and conditions, it is very important to choose the right drying conditions and dryer in order to maintain the quality. Choosing improper systems or conditions bring many of the aforementioned negative consequences (Deng and Zhao, 2008). The following drying methods are commonly used to preserve fruits and vegetables: solar drying, heated air-drying, microwave drying, osmotic dehydration, foam-mat, spray-drying, freeze-drying, and spouted bed drying. Vacuum-microwave (VM) drying of fruits is becoming more and more popular due to its advantages. In this method, structural collapse of the product is prevented. Convective drying is the most popular technique for fruit dehydration. However, the method takes a very long time even at high temperature of the air applied as the drying agent. This usually results in a decrease of the quality of the dried product (Wojdyło et al., 2009). Moreover, it results in highly shrunken products with hard texture, intense browning, low rehydration rate, and low nutritive value. Freeze drying ensures dried products with a porous structure, little or no shrinkage, great rehydration capacity, minimum changes in color and nutrients compared with air-dried product. (Deng and Zhao, 2008).

2.2.4.1 Color

Color is one of the most important sensory parameters in food products because it significantly affects the acceptability and preference of the product for the consumer. For this reason, the majority of producers use the physiological effect of color to improve product quality, and many studies show that color directly or indirectly affects product acceptability (Waliszewski et al., 2000).

CIE (International Color Determination Commission) Hunter L* (lightness, brightness), Hunter a* (redness-greeness) and Hunter b* (yellowness-blueness) are the most common color parameters used in this field. In addition, using these color parameters, total color difference (ΔE_{ab}*), C* (chroma value) and h° (hue angle) values are calculated and used in color measurements. L value which shows darkness and lightness is an important criterion and varies between 0-100. The darkness increases as the L value approaches 0 and the lightness increases as it approaches 100. Positive a* indicates red direction and is scaled from 0 (achromatic) to 60 (red). Positive b* indicates yellow direction and is scaled from 0 (achromatic) to 60 (yellow). The CIE C* value ranges from 0 to 60, with 0 (dull) in the center of the color plane and vivid tones increasing as it moves away from the center. h° ranges from 0° to 360°; It is evaluated as 0° and 360° red, 90° yellow, 180° green and 270° blue (İncedayı et al., 2016; Türkyılmaz et al., 2013).

As a result of enzymatic and non-enzymatic browning reactions that occur during the drying process, color changes in foods may occur and this affects product quality (Waliszewski et al., 2000). Although these reactions are desirable in some cases, in many cases it is not desirable because of the negative effect on color; it is also undesirable due to the formation of undesirable taste and loss of nutritional components. Both types of browning reactions are affected by chemical and physical factors such as pH, aw, substrate concentration, temperature and reactant amine and sugar group type (Jangam et al., 2007; Korbel et al., 2013; Örs, 2019). Color values can also be used to estimate chemical changes and quality losses due to various reasons in foods. Most researchers have found that L* value can be used as browning index in fruits and fruit products. For example; The decrease in L* value is associated with an increase in the amount of brown pigment due to non-enzymatic browning in fruits (Coşkun, 2010). In a study carried out by Karabulut et al. (2007), it is reported that the color of dried apricots is a result of non-enzymatic browning reactions due to sun exposure during drying. They were reported the color values of sun dried apricots (Hacıhaliloğlu variety) as L* value of 30.6, a* value of 10.7 and b* value of 11.3 (Karabulut et al., 2007).

The characteristic golden yellow color of dried apricots is a very important quality criteria in the dried apricot trade. Apricots owe their characteristic color to carotenoid pigments, mainly β-carotene which is a precursor of vitamin A. Except that pigment concentration, many factors affect the surface color of dried apricots, including drying conditions and SO_2 content. (Özkan et al., 2003). The amount of β-carotene decreases depending on drying time and drying temperature (Karabulut et al. 2007). High drying temperature and long drying time cause loss of color.

2.2.4.2 Browning Reactions

During the preparation, cooking, processing and storage of foodstuffs occur color changes from a slight yellowing to brown or black. In food science, this phenomenon is called browning and the reactions that make it happen are called browning reaction. Browning reactions are divided into two groups as enzymatic browning and non-enzymatic browning in terms of their mechanisms (Cemeroğlu et al., 2009).

Enzymatic browning reactions are the oxidation of o-phenols to o-quinones catalyzed by polyphenol oxidase enzyme. So, it produces brown pigments on cut surfaces of fruits and vegetables. PPO catalyzed browning of fruits and vegetables can also be prevented by: (i) heat inactivation of the enzyme, (ii) exclusion or removal of one or both of the substrates (oxygen and phenols), (iii) lowering the pH to 2 or more units below the pH optimum, (iv) by reaction inactivation of the enzyme, or (v) by adding compounds that inhibit PPO or prevent melanin formation. At the same time, the enzymatic browning reaction in the industrial scale; lowering the pH is controlled by the use of ascorbate, sodium bisulfite, sulfur dioxide and organic acids such as citric, malic and acetic acid. Therefore, it is not preferred by consumers in terms of health (O'Neill et al., 1998).

In dried products, color browning occurs mostly by non-enzymatic browning (Alagöz, 2013). Non-enzymatic browning reactions are caramelization, metal-phenolic browning, lipid browning, ascorbic acid browning, and the most commonly Maillard browning. (Cemeroğlu et al., 2009). Maillard type browning is observed during drying and storage of fruits (Cemeroğlu and Özkan, 2009). In this type of browning, the reactive carbonyl groups (reducing sugars) react with the amino group (amino acids, amines). Thus, stable intermediate products are formed and as a result of the condensation of these intermediates, brown pigments called melanoidin are formed (Cemeroğlu and Özkan, 2009). The maillard reaction can occur during drying and storage of the final products. This reaction is influenced by factors such as water activity (aw), temperature, pH and chemical composition of foods. (Megías-Pérez et al., 2014). Maillard reaction occurs after drying, especially in fruits such as containing high levels of reducing sugars such as fructose, glucose and sucrose

(Chong et al., 2014). The main methods to control non-enzymatic browning reactions are; low pH, low storage temperature, use of antioxidants and sulphur. The use of sulphur is the most effective inhibitor known to prevent Maillard browning, especially in dried products (Coşkun, 2010).

Apricot is one of the fruits whose color changes most during drying. Browning is observed in fruits as a result of enzymatic and non-enzymatic changes at the beginning of drying (Malatya Governorship, 1998;Karataş, 2014). It was reported that the most important criterias determining the quality of dried apricots are low browning level and elastic texture (Abdelhaq and Labuza, 1987). SO_2 prevents browning reactions as well as oxidation of carotenoids, which give bright yellow colors of apricots. In sulfur-free products such as sun dried apricots, browning reactions and oxidation of carotenoids cannot be prevented (Alagöz, 2013).

2.2.4.3 Texture

Texture can be explained as the whole of the physical properties that are related to deformation, disintegration or flow that occur in response to a certain force applied to the food, mostly caused by the structural properties of the food, felt by the sense of touch (Örs, 2019). Texture is a very important and complex factor in terms of food quality (Witrowa-Rajchert and Rzaca, 2009; Örs, 2019). Textural properties such as hardness, brittleness, chewability, guminess, stickiness and elasticity can be determined by texture profile analysis (TPA) and the results are affected by sample size and shape, compression speed and time. These properties are very useful in comparing the textural structure of the products dried by different drying methods (Jangam et al., 2007; Örs 2019).

The movement of water from the inner parts to the surface and air cause hardening in the cell wall during drying. Hence, shrinkage of the tissue and cellular structure and collapse of the porous structure occur with decreasing moisture content (Witrowa-Rajchert and Rzaca, 2009; Örs, 2019). Textural structure of dry foods is affected by the moisture content, composition, pH and degree of maturity of the foods. In addition, it depends on the type of drying, the process variables (e.g., air velocity and temperature) and the microstructure of food during drying (Aguilera et al., 2003).

Texture is one of the most important quality parameters of dried and semidried foods, reflecting their properties such as mechanical and microstructural. A fruit's microstructure is severely affected by drying conditions. In particular, undesirable and irreversible textural changes may occur during the conventional drying process and pose a risk to product quality. To minimize these risks, it is useful to observe and control the development of texture during drying (Martynenko and Janaszek, 2014). Hot air drying is still the most economical and widely used method for drying of vegetables and fruits. It causes irreversible textural deterioration such as shrinkage, slow cooking and reduced rehydration capacity. Most of the commercially dried fruit and vegetables exhibit a collapsed and shrunken texture. This affects the quality of the final product and therefore its acceptability for the consumer (Mujumdar, 2006; Örs, 2019).

Shrinkage and hardening is one of the most important textural changes in products during drying. These textural changes happen due to modifications in the microstructure of the tissue, chemical changes affecting the saccharides and proteins. It also adversely affects the rehydration capacity of the dehydrated product (Mayor and Sereno, 2004; Megías-Pérez et al., 2014; Örs, 2019). In other words, in the absence of water, food polymers cannot sustain their weight against gravity and collapse occurs in its structure (Colak and Hepbasli, 2009; Örs, 2019).

Firstly, shrinkage causes changes in the appearance of the product. Generally, shrinkage depends on the structure of the dry product and there is an almost linear correlation between moisture content and shrinkage(Witrowa-Rajchert and Rzaca, 2009). Heating process and reduction of water cause stresses in the cellular structure of the food and lead to changes in shape and decrease in sizes. For this reason, the original structure of foods with high moisture content such as fruits and vegetables suffers from the shrinkage phenomenon during drying (Hashemi et al., 2009). The current demand of high quality products in the food market requires dried foods that preserve at a very high level the nutritional and organoleptic quality of the initial fresh products. However, shrinkage-induced deformation, reduction in volume and hardness increase are considered negative by consumers (Mayor and Sereno, 2004).

2.2.4.4 Moisture Content

The moisture content affects significantly the changes in food properties, such as texture, color and nutritional value. Moreover, below a certain level of moisture, the growth of most microorganisms is inhibited (Miranda et al., 2012).

Moisture content is also one of the factors affecting the quality of dried apricot production. The moisture content of dried apricot has a significant effect on storage stability. Extremely moist apricots undergo rapid microbial deterioration during storage and in some cases the product can be disposed of completely (Coşkun, 2010).

In our country, apricots are dried to 20% moisture level after commercial production and this level is quite low for direct consumption (Coşkun, 2010). For that reason, the apricots are subjected to a hydration process (rehydration) before consuming and the moisture levels are brought to 25%. At this moisture level, apricots are soft and easy to chew. If the hygienic conditions are sufficiently paid attention to, the product to be obtained is microbially stable (Malatya Agriculture and Forestry Directorate, 2004). According to TS 485; moisture content of dried apricots should not be more than 22%, except for rehydrated dried apricots. If preservatives are used, this rate can be maximum 25% (for sulphured apricots). If humidification is done, this must be reported on the product label (Turkish Standards Institute, 2008).

In a study which showed the color change in dried apricots with different moisture contents, dried apricots with a moisture content of 19.3%, first dried to 15.5% moisture. Then apricots were rehydrated to 20.1%, 25.2% and finally to 30.2% moisture. CIE L*, a* and b* values were measured and C* (chroma) and h° (hue) values were calculated to determine the color of dried apricots. A linear relationship was found between color values and moisture content. As the moisture content of apricots increased, L*, b*, C* and h° color values were found to increase; a* value was found to decrease. Consequently, results indicated that moisture content affected the reflectance color values of dried apricots extremely (Özkan et al., 2003).

CHAPTER 3

MATERIAL AND METHODS

3.1 Materials

Fresh apricots (Prunus armenica L., Hacıhaliloğlu variety) were collected from Malatya Apricot Research Station Garden and placed in cold storage in Food Engineering Department of Gaziantep University on the same day. The apricots were examined to eliminate immature, over-ripened, rotten or injured apricots. After separation process, the same size and color of apricots were selected and stored at 3 °C until used in drying experiments. Some of the apricots were used for preliminary studies (calibration of solar assisted air drying and radio-frequency systems) and the other part was used for SAAD-RF drying experiments according to Box Behnken experimental design of unprocessed apricots.

Acetic acid, ethanol, lead (IV) acetate were purchased from Sigma-Aldrich. All reagents and solvents were used as analytical grade.

3.2 Methods

3.2.1 Pretreatment

3.2.1.1 Removal of Kernels

Apricot kernels were removed by hand (by pitting). Pitting was performed after solar assisted air drying and before RF drying. At this stage, the moisture content of the product was in the range of 40-45% (wb).

3.2.2 Drying Processes

3.2.2.1 Pre-drying (solar assisted air drying) Process

The pre-drying process was carried out using the solar assisted air drying system. For each drying process, 15 kg apricots (3 layers, 5 kg per layer) were placed in chrome baskets and applied to drying process. The drying temperature and time were applied during drying determined in the experimental design. In all operations, air velocity was set in the range of 5.5-6.0 m/s.

3.2.2.2 Radio-frequency Drying

Air assisted RF drying was carried out following solar assisted air drying. The pitting was performed after 15 kg apricots dried in solar assisted air drying system for each drying process and drying was continued. The apricots were placed in RF and subjected to drying (between two electrodes) for the periods determined in the experimental design.

3.2.3 Determination of Moisture Content

The moisture content of dried apricots was determined according to AOAC 2000. A vacuum oven was operated at 70 °C until constant weight of sample obtained. All analyses were performed in triplicate. The following equation was used to calculate moisture content of samples:

$$\% \text{ Moisture} = ((M_2-M_3) / (M_2-M_1)) * 100$$

where M_1, M_2 and M_3 are empty petri dish, petri dish + sample (before drying) and petri dish + sample (after drying), respectively.

3.2.4 Color Analysis

The luminosity values (L*), redness index (a*) and yellowness index (b*) values of dried apricot samples were determined by measurement from both sides of the fruit using the HunterLab ColorFlex colorimeter (Model A60-1010-615, Hunter Lab, Reston, VA). The device was standardized using white and black ceramic plates (L_0=93.01, a_0=-1.11 ve b_0= 1.30) each time. Measurements were performed in daylight mode (Daylight Color D65/10*). 10 random samples were taken from apricot samples and the mean was recorded. Using L*, a* and b* values; C* (chroma), h° (hue angle) value and total color change (ΔE) was calculated using the following equations:

$$C^* = \sqrt{a^{*2} + b^{*2}} \qquad h^* = \arctan(b^*/a^*) \qquad \Delta Eab^* = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

3.2.5 Texture Analysis

The hardness of dried apricot samples was determined according to Varaschim Link et al. (2018). The hardness of dried apricot samples was determined by using a 2 mm stainless steel probe in a TAXT2i Texture Analyzer (Stable Micro Systems, Godalming, Surrey, UK). The hardness was defined as the force (Newton) needed to deform the dried apricot by 40%. For each measurement a total of 30 repeats (10 fruits were measured from 3 different points of the upper surfaces) were made to determine hardness. The mean of these measurements was given as a result.

3.2.6 Browning Measurement

Browning of dried apricots was measured in duplicate according to Coşkun et al. (2013). Water soluble brown pigment was extracted with 2 % acetic acid. Interfering carotenoid pigments were removed using lead acetate and ethyl alcohol. The samples were kept in dark room for 3 hours and mixed in the incubator at 450 rpm for 3 hours. Then, it was centrifuged at 7400 rpm for 15 minutes at 4 °C. Absorbances of samples were measured at 420 and 600 nm using UV–Vis spectrophotometer (Optima SP-3000 nano UV-Vis Spectrophotometer, OPTIMA Tokyo, Japonya). The results were expressed as $A_{420}/g_{dryweight}$.

$(A_{420} = A_{420}-A_{600})$

3.2.7 Sensory Evaluation

Sensory analysis of dried apricot samples was realized according to Elmaci et al. (2008) with some changes. Analyzes were carried out in the sensory analysis laboratory of Food Engineering Department at Gaziantep University, where there are individual booths and ventilation system. Apricot samples were served to panelists at room temperature (20–23°C) to involve 10 fruits on white porcelain plates coded by using randomly selected 3-digit numbers. Sensitivity of panelists were tested according to ISO-3972:1991. The hardness sensory properties of dried apricots were determined by trained assessors selected from the Department of Food Engineering at Gaziantep University. 9-points hedonic scale was used in the evaluation. This hedonic scale was evaluated as 1="I didn't like at all", 5 ="neutral", 9 = "I liked it extremely".

3.3 Experimental Design and Optimization

Experimental design was carried out by using Design Expert (V.7.1.5, Minneapolis, USA) software for RF drying experiments following solar energy assisted air pre-drying. For this purpose, firstly, the effect of independent variables on responses was investigated with Box Behnken experimental design. With this method it was aimed to design an experimental setup to achieve most effective statistical model by carrying out possible minimum experiments due to short shelf life of fresh apricots and goal of designing pilot scale production of dried apricots. The selected independent variables for the drying system were determined as pre-drying temperature (50-70°C), pre-drying time (300-1140 min), distance between RF electrodes (77-85 mm) and RF drying time (270-690 min). The responses that will vary depending on these parameters were the moisture content (%), browning value ($A_{420}/g_{dryweight}$), hardness value (N) and total color change (ΔE).

After carrying out the experiments at the conditions defined by Box Behnken method, an optimization process was performed. Objectives of the optimization process were to minimize total process time, quantity of browning products and total change in the color; while constraints were final moisture content (20-25%) and hardness value (in consumer acceptable range which defined by sensory analysis and fitted with analytical methods).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Device Design and Preliminary Studies

4.1.1 Drying System

Drying system consists of heat transfer chamber, humidity transfer chamber, fan and drying cabinet. Moist air is transferred to the heat transfer chamber by leaving its moisture in the moisture transfer chamber. Mains water is used in moisture condensation process and water inlets and outlets are monitored from automation system. In the automation system, the opening and closing of the water valve can be adjusted according to the air humidity rate. The air leaving the moisture is heated in the heat transfer chamber to the drying temperatures set by the automation system. Heating in the heat transfer chamber is provided by hot water from the aqueous system. In the same chamber, electrical resistances are activated when the temperatures of the aqueous system and the air heated in the stone bed are insufficient. There are 3 resistances which have 3000 W power in the heat transfer room. These resistances are activated depending on the energy requirement of the drying cabinet.

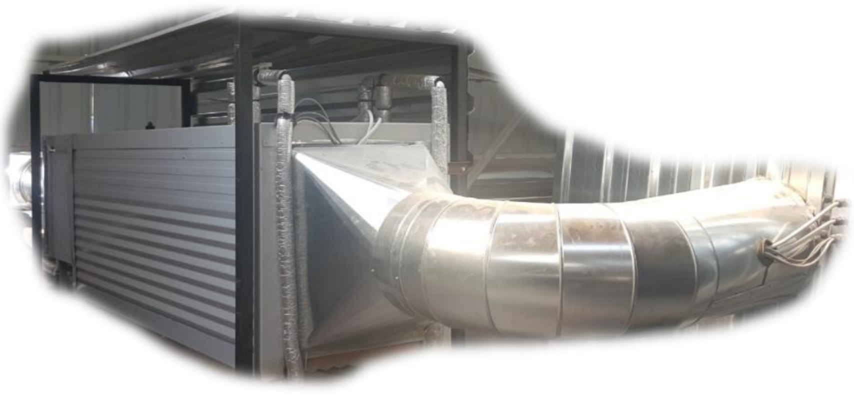

Figure 4.1 Moisture condensation and heat transfer chambers

Air which has a desired level of temperature and relative humidity, enters the drying cabinet (Figure 4.2). The drying cabinet is a tray dryer and the weight of the dried food in the tray is monitored by means of load cell. In addition, the temperature of the air entering and leaving the drying cabinet and the relative humidity rate are monitored over time with the PLC system.

Figure 4.2 Drying cabinet

Figure 4.3 Interior design of drying cabinet

4.1.1.1 Programmable Logic Controller

Online control of solar drying system components is controlled by PLC system over time. Energy collection (solar panels) and drying system (heat and humidity transfer room, drying cabinet) control is performed with this system. With the PLC system, cabin inlet-outlet temperature, relative humidity rate and panel temperatures are controlled and recorded. PLC system also controls the weight of the product in the cabinet.

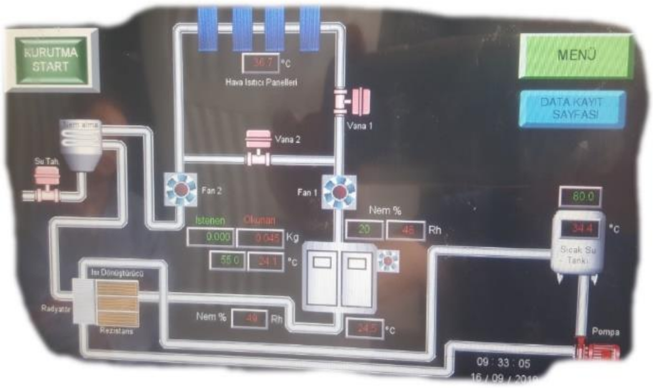

Figure 4.4 Programmable Logic Controller

4.1.2 Preliminary Experiments in Solar Assisted Air Drying System

The effect of many process variables were evaluated in order to carry out apricot drying under optimum conditions. Firstly, some preliminary experiments were performed for evaluation of these variables. Then, further investigation was performed by using response surface methodolgy to determine the effect of process variables on the quality of final dried products. In the preliminary experiments, the operating parameters of the device were tested and their working ranges were determined. In this direction, preliminary experiments were carried out to determine:

- Drying temperature in solar energy system
- Drying time in solar energy system
- Drying time in radio frequency system
- Distance between electrodes in radio frequency system

In solar energy assisted drying system, it was observed that the drying temperature and time were effective on the product quality. Also, it was decided in which range these parameters affect the drying process, when the pitting should be performed and when to pass from the solar drying system to the radio frequency drying system.

After the results obtained from the preliminary experiments, response surface methodology was applied and experimental designs were made in line with this information. The results obtained from the preliminary experiments.

4.1.2.1 Determination of Drying Temperature and Drying Time

According to the results obtained from the experiments, the drying time decreased when the drying temperature increased. In all of these experiments, the moisture content of the final product was 20-25%. In the preliminary experiments, air temperature below 50 °C caused color problems due to long drying time and prolonged exposure to oxidation. The high temperature (80 °C) shortened the drying time. However there were a rapid change in the product color and loss of visual quality at high temperatures. Moreover, the need to resistances increases in addition to solar energy at 80 °C. Therefore, the air temperature range to be used in the response surface methodology was decided to be 50-70 °C. The range for drying time was selected as 1140 min (for 50 °C) and 300 min (for 70 °C), which was determined by preliminary experiments and the moisture content of the product was in the range of 40-50%.

4.1.2.2 Determination of the Time and Moisture Content for Passing to the RF Dryer

The basic principle of using radio frequency drier was to remove free water from food in the constant drying period and then to remove the water more rapidly in the falling rate period. Thus, in the normal drying regime, these two periods were determined and it was aimed to take the product into the radio frequency dryer by changing the dryer in the transition to the second period (falling rate). In this evaluation, critical moisture amounts were calculated by selecting preliminary experiments with full drying period.

As a result of the experiments for the transition to RF system, it was found that 40-45% (wb) moisture value contributes to the production of products with better color values.

4.1.2.3 Pitting Process

The pitting is a manual process and the removal of the kernel at different moisture contents was carried out. It was determined that watering occurs as a result of press during pitting and pitting becomes difficult for low humidity products. As a result of these experiments, kernels could be removed easily without damaging apricot structure at 40-45% (wb) humidity and this value determined as transition moisture content from air assisted system to RF system.

4.1.3 Preliminary Studies on Radio-frequency System

The distance between the electrodes, the power level used in the system and the geometry of the product have great importance for efficient and homogeneous drying in the system. In this case, preliminary studies were carried out in order to determine the appropriate electrode height range for the response surface methodology. In addition, during these preliminary studies, different sequences were also tried in terms of the geometric configuration of the product.

In the preliminary studies, while determining the distance between the electrodes, it was observed that when the electrodes were very close to the product, burning occurred in the product and in cases where the electrodes were too far, an effective drying could not be obtained. Therefore, considering the temperature and humidity loss obtained in the product, the distance between the electrodes was chosen as 77-85 mm. In the experimental studies, it was observed that the burning rate increased below 77 mm and consequently, the product loss was high. As the distance between the electrodes increased, the heating of the product decreased and accordingly, its drying slowed down. For this reason, the upper limit was selected as 85 mm due to the process time was kept within a certain range.

Under these conditions, the products were tried to be processed in random batch and separate from each other and in both cases no positive results were obtained. Products contacted irregularly to each other during the random batch process attracted more energy at the thin-sharpe points that it contacts and there was a tendency to burn in products. It was observed that the apricots placed separately from each other did not heat sufficiently due to insufficient product thickness. The products were placed on a PTFE grill in an oblique-ordered position to prevent burning and provide sufficient heating in the product. PTFE does not heat due to its transparency to RF waves. At the same time, the grill structure allowed mass transfer from the bottom surface of the product. In this way, it was ensured that the area where the apricots contact with each other did not consist of sharp points thanks to the oblique-ordered arrangement. Overheating occurred when sharp points formed. As a result of the prevention of the formation of large empty cavities between the products; collection of the wort leak from the product and burning due to pulling more electric field was prevented.

The air assisted drying in the RF system was used to facilitate the removal of the moisture generated inside the system and prevent burnings caused by radical heating due to leakage of the wort on the product surface. For these purposes, it was decided to use hot air approximately at 50 °C during the actual experiments.

4.1.4 Radio-frequency Drying

In the air assisted RF drying system, the products were processed in the air assisted RF drying system following the solar energy assisted air drying system. At this stage, apricots were separated from their kernels after the moisture content reached to 40-45% band in solar assisted air drying system and then arranged according to the geometric configuration determined during the preliminary studies and processed in RF system. During the process, electrode distance (distance between two electrodes) was set at 77 mm which was determined as the optimum condition by response surface method. As mentioned earlier, the air support in the system was also used to reduce burning during the studies and sweep the moisture accumulated in the system.

Figure 4.5 Radio-frequency drying system

Figure 4.6 Apricot syntax example

4.2 Box-Behnken Experimental Design and Optimization

4.2.1 Formation of the Model

In the system, where solar assisted air drying and radio frequency drying were combined using response surface methodology, an experimental design was created using Box-Behnken design for apricot drying. In this proposed drying system, pre-drying temperature, pre-drying time, distance between radio frequency electrodes and radio frequency drying time were selected as independent process variables. Depending on these variables, moisture content, color change, hardness and browning products were selected as dependent variables. The results of Box-Behnken experimental design and drying experiments performed at the points predicted by the design for each dependent variable were given in Table 4.1.

Mathematical models expressing the relationship between process variables and each response were obtained with multiple regression and backward elimination method by using response surface methodology. The analysis of variance was used to determine the significance of the independent variables and their interactions, the adequacy of the developed model and statistical significance of the regression coefficients. The model validity was verified by lack of fit test. In addition, the suitability of the model was tested considering the coefficient of determination (R^2). R^2 values of the model obtained for each dependent variable were given in Table 4.2. The lowest R^2 value is 0.88 for the dependent variables. This value indicates that independent variables can explain more than 88% of the dependent variables.

Table 4.1 Box-Behnken experimental design and experimental results for apricot drying in a system where solar energy assisted air drying and radio-frequency drying were combined

NO	X1	X2	X3	X4	Y1	Y2	Y3	Y4
1	50.00	300.00	81.00	480.00	65.321	0.031	21.060	1063.00
2	70.00	300.00	81.00	480.00	41.349	1.299	40.142	1206.62
3	50.00	1140.00	81.00	480.00	54.502	0.245	30.637	1117.41
4	70.00	1140.00	81.00	480.00	10.603	2.199	36.619	1592.49
5	60.00	720.00	77.00	270.00	40.861	0.594	33.678	1180.85
6	60.00	720.00	85.00	270.00	42.689	0.153	36.842	1156.16
7	60.00	720.00	77.00	690.00	24.512	0.980	34.569	1150.17
8	60.00	720.00	85.00	690.00	33.760	1.103	38.170	1217.39
9	50.00	720.00	81.00	270.00	58.181	0.674	27.855	1145.14
10	70.00	720.00	81.00	270.00	16.555	1.066	41.168	1616.09
11	50.00	720.00	81.00	690.00	42.720	0.735	30.394	1197.73
12	70.00	720.00	81.00	690.00	14.715	2.144	42.624	1632.27
13	60.00	300.00	77.00	480.00	49.296	0.490	31.894	1131.31
14	60.00	1140.00	77.00	480.00	-	0.000	-	-
15	60.00	300.00	85.00	480.00	51.959	0.294	29.523	1083.25
16	60.00	1140.00	85.00	480.00	24.835	0.674	33.728	1336.95
17	50.00	720.00	77.00	480.00	47.519	0.104	28.251	1206.85
18	70.00	720.00	77.00	480.00	18.045	1.041	36.398	1380.00
19	50.00	720.00	85.00	480.00	55.751	0.147	27.691	1121.70
20	70.00	720.00	85.00	480.00	20.952	1.360	41.623	1472.67
21	60.00	300.00	81.00	270.00	62.479	0.123	35.137	1106.30
22	60.00	1140.00	81.00	270.00	34.918	1.470	38.285	1378.19
23	60.00	300.00	81.00	690.00	40.853	0.968	35.224	1120.39
24	60.00	1140.00	81.00	690.00	10.627	1.746	41.668	1493.95
25	60.00	720.00	81.00	480.00	29.971	0.337	31.290	1130.13
26	60.00	720.00	81.00	480.00	31.237	0.312	33.591	1212.72
27	60.00	720.00	81.00	480.00	33.229	0.606	31.910	1147.58
28	60.00	720.00	81.00	480.00	25.194	0.515	30.716	1151.83
29	60.00	720.00	81.00	480.00	31.430	0.380	32.070	1190.80

X: Factors Y: Responses X_1: Pre-drying temperature (^oC); X_2: Pre-drying time (min); X_3: Distance between radio frequency electrodes (mm); X_4: Radio-frequency drying time (min); Y_1: amount of water (%); Y_2: Browning product quantity ($A_{420}/g_{dryweight}$); Y_3: Color change (ΔE); Y_4: Texture (hardness, N)

* Test point 14 was excluded from the analysis because of the products burned in the drying process carried out.

As it is seen in Table 4.2, adjusted and predicted R^2 values were found to be compatible for all dependent variables. Adeq precision in Table 4.2. is a value that measures the signal-noise ratio, and greater than 4 of this value is important for the suitability of the model. This value was calculated as> 4 in the models created for all dependent variables in this study. Therefore, this model can be used to navigate the design space.

Table 4.2 R^2 values of models obtained for dependent variables

R^2 values	Y_1	Y_2	Y_3	Y_4
R^2	0.937835	0.893265	0.940700	0.8831
Adjusted R^2	0.920073	0.855908	0.919945	0.8497
Predicted R^2	0.879778	0.750542	0.878753	0.7682
Adeq Precision	26.42377	18.38096	28.56484	18.911

Y: Dependent variables
Y_1: amount of water; Y_2: Browning product quantity; Y_3: Color change; Y_4: Texture (hardness)

Significance of Lack of Fit Test determines whether the obtained mathematical form of the model is suitable for representing the experimental data (Myers and Montgomery, 1995). In this study, for the dependent variables, Y_1, Y_2, Y_3 and Y_4, lack of fit test was found statistically insignificant at the 95% confidence level and calculated as 0.2054, 0.0990, 0.2717 and 0.0810, respectively. These values indicated that the models created for the dependent variables are compatible with the experimental datas sufficiently. It is seen that the most suitable model is the second order polynomial model for each response. Below, estimated model equations generated with coded variables were given for each response.

$$Y_1 = 31{,}89 - 16{,}81X_1 - 12{,}49X_2 - 7{,}37X_4 - 4{,}98X_1X_2 + 3{,}15X_1^2 + 6{,}44X_2^2$$
(1)

$$Y_2 = 0{,}38 + 0{,}60X_1 + 0{,}34X_2 + 0{,}30X_4 + 0{,}25X_1X_4 + 0{,}32X_1^2 + 0{,}26X_2^2 + 0{,}41X_4^2$$
(2)

$$Y_3 = 32{,}38 + 6{,}057X_1 + 1{,}778X_2 + 0{,}784X_3 + 0{,}807X_4 - 3{,}275X_1X_2 + 1{,}446X_1X_3 + 3{,}917X_4^2$$
(3)

$$Y_4 = 1170.53 + 170.69X_1 + 125.33X_2 + 19.10X_4 + 82{,}86X_1X_2 + 117{,}77X_1^2 + 73{,}10X_4^2$$
(4)

In Models; Y_1: amount of water (%); Y_2: Browning product quantity ($A_{420}/g_{dryweight}$); Y_3: Color change (ΔE); Y_4: Texture (hardness, N), X_1: Pre-drying temperature (°C); X_2: Pre-drying time (min); X_3: Distance between radio-frequency electrodes (mm) and X_4: Radio frequency drying time (min)

Analysis of variance (ANOVA) results are given in Table 4.3, 4.4, 4.5 and 4.6 for each response. As can be seen, all regression models were significant at 99% confidence level. The effects of the variables on the responses were evaluated at 95% confidence interval and those with $p > 0.05$ were considered statistically insignificant and these terms were removed from the model without damaging the model hierarchy. Some variables exist in the model even though they are statistically insignificant in order to not damage the model hierarchy.

4.2.2 Evaluation of Drying Parameters on Dried Apricot Characteristics

4.2.2.1 The Effect of Drying Parameters on the Moisture Content of Dried Product

When the linear, interaction and quadratic effects of the independent variables on the moisture content of the final product were examined, the pre-drying temperature, pre-drying time, radio-frequency drying time, pre-drying temperature*pre-drying time interaction and the quadratic effect of the pre-drying time were found to be statistically significant ($p<0.05$). Quadratic effect of distance between radio frequency electrodes and pre-drying temperature were found to be insignificant ($p> 0.05$). Pre-drying temperature is the most effective parameter for reducing the moisture content of apricot compared to pre-drying time and RF drying time, by considering its higher F value. Obviously, it is a known fact that the increased drying temperature accelerates the drying process. Similar observation has been reported in many other drying studies (Sharma et al., 2005; Kocabiyik and Tezer 2009; Toğrul and Pehlivan 2002).

Table 4.3 ANOVA table showing the effect of process variables on the amount of water in dried apricot

Source	Sum of squares	Degree of freedom	Mean squares	F value	p-value Probe> F
Model	6236.35	6	1039.39	52.80	<0.0001[a]
X_1	3392.77	1	3392.77	172.35	<0.0001[a]
X_2	1699.97	1	1699.97	86.36	<0.0001[a]
X_4	652.61	1	652.61	33.15	<0.0001[a]
$X_1^* X_2$	99.27	1	99.27	5.04	0.0356[b]
X_1^2	66.98	1	66.98	3.40	0.0792[c]
X_2^2	272.84	1	272.84	13.86	0.0013[d]
Residual	413.38	21	19.68		
Lack of fit	376.50	17	22.15	2.40	0.2054[c]
Pure error	36.88	4	9.22		
Total	6649.74	27			

X_1: Pre-drying temperature (^oC); X_2: Pre-drying time (min); X_3: Distance between radio-frequency electrodes (mm); X_4: Radio-frequency drying time (min)

a Significant at 0.001 level

b Significant at 0.05 level

c minor even at 0.05 level

d Significant at 0.01 level

It is well known that final moisture content in dried foods is an important criterion affecting quality parameters and storage process (García-Martínez et al., 2013; Gonzalo Miranda et al., 2019; Mahmutoğlu et al., 1995). According to the obtained datas, the moisture content of dried products varied between 10.6% and 65.3% (Table 4.1). As shown in Table 4.1, the lowest final moisture content was found to be 10.6% where pre-drying time, pre-drying temperature, RF drying time and distance between RF electrodes were 1140 min, 70 °C, 480 min and 81 mm.The highest final moisture content was found to be 65.3% where pre-drying time, pre-drying temperature, RF drying time and distance between RF electrodes were 300 min, 50 °C, 480 min and 81 mm.

Three-dimensional response surface graphs were generated by using models obtained to understand the effects of process variables on the moisture content of final product (Figure 4.7). While these graphs were obtained, two of the process variables were kept constant at the center point and the graphs were obtained by changing the other two variables. When the graphs are examined, it is clear that the pre-drying time and the pre-drying temperature have a synergistic effect on the moisture content, resulting in a faster decrease. (Figure 4.7 (a)). In the ANOVA table, the interactions of these two parameters were found to be statistically significant. In addition, according to ANOVA results in Table 4.3, the quadratic effect of the pre-drying time was found to be statistically significant. The significance of the quadratic effect means that the optimal levels are at a point within the inside of the experimental region studied for this parameter. In addition, the coefficient of quadratic effect shows both the direction in which the curve is bent and the steepness (a positive value indicates that the curvature is up and a negative value indicates that the curvature is down). According to Table 4.3, only the quadratic effect of the pre-drying time was found to be statistically significant and in the model equation (eq. 1) the coefficient is +6.44 for the quadratic effect of the pre-drying time (X_2^2). Figures 4.7 (a), (d), and (e) also show an upward bending for the pre-drying time. This indicates that there is an optimum point (850-900 min) in the working range for the pre-drying time. In Figure 4.7 (c), (e) and (f), it is seen that the distance between the radio frequency electrodes is ineffective on moisture content. In ANOVA table, the distance between the radio frequency electrodes was not shown due to its statistically insignificant. In addition, all the other graphs given in Figure 4.7, except containing pre-drying time, are seen as hyperplane. This means that the parameters do not have quadratic effects in these graphs and the optimum region cannot be captured in the studied range for this response.

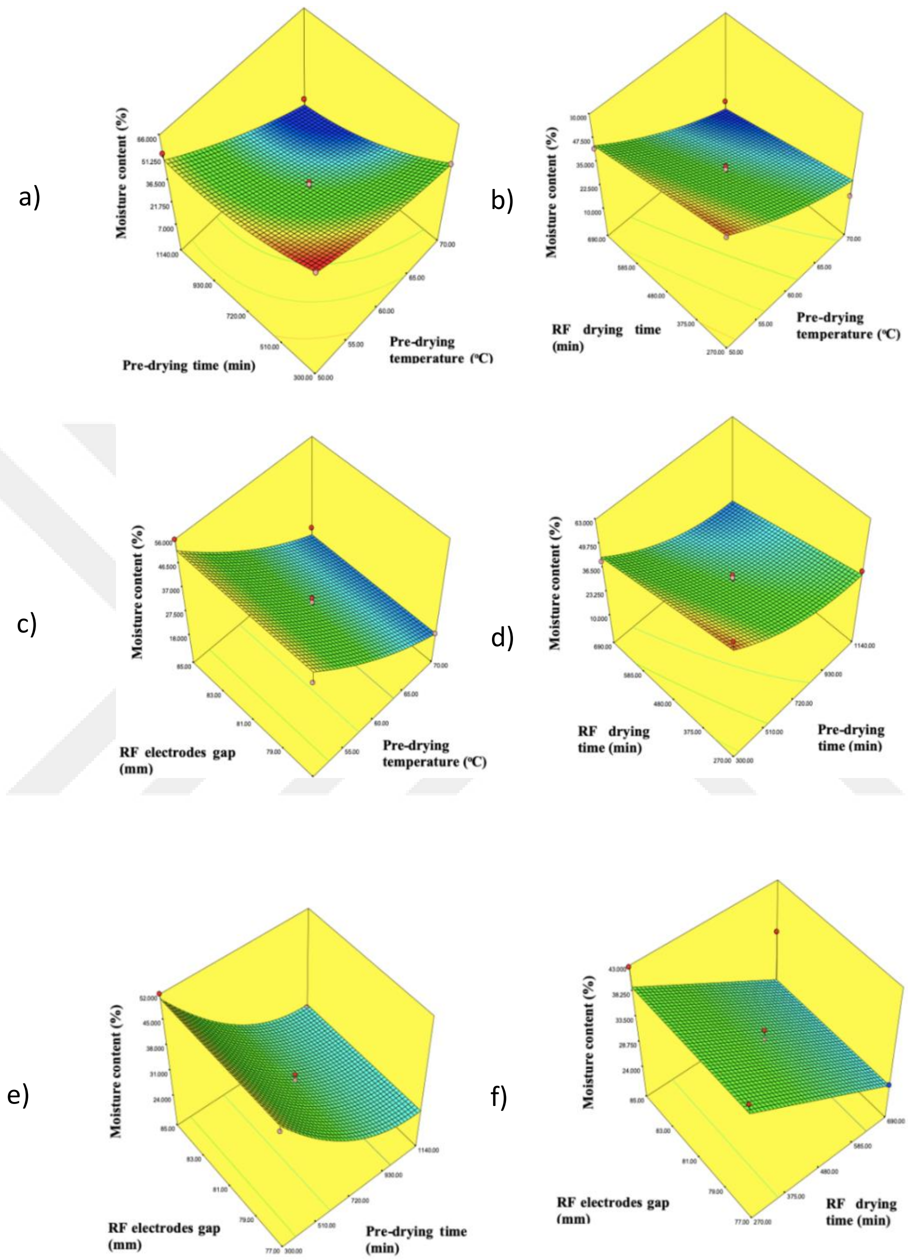

Figure 4.7 The effect of drying parameters on moisture content of the final product (a) Pre-drying temperature (^{o}C)–Pre-drying time (min) (b) Pre-drying temperature (^{o}C)–RF drying time (min) (c) Pre-drying temperature (^{o}C)–Distance between radio frequency electrodes (mm) (d) Pre-drying time (min)–RF drying time (min) (e) Pre-drying time (min)–Distance between RF electrodes (mm) (f) RF drying time (min)–Distance between RF electrodes(mm)

4.2.2.2 The Effect of Drying Parameters on the Formation of Browning of Dried Product

The quantity of browning product ($A_{420}/g_{dryweight}$) after drying process in dried apricots varied between 0.03 and 2.19 (Table 4.1). ANOVA results explaining the effect of drying parameters on the formation of browning products and three-dimensional response surface pilots were given in Table 4.4 and Figure 4.8, respectively.

Table 4.4 ANOVA table showing the effect of process variables on the formation of browning products

Source	Sum of squares	Degree of freedom	Mean squares	F value	p-value Probe> F
Model	8.75	7	1.25	23.88	< 0.0001[a]
X_1	4.29	1	4.29	81.87	< 0.0001[a]
X_2	1.27	1	1.27	24.25	< 0.0001[a]
X_4	1.08	1	1.08	20.57	< 0.0002[a]
X_1*X_4	0.26	1	0.26	4.94	0.0380[b]
X_1^2	0.68	1	0.68	13.02	0.0018[c]
X_2^2	0.42	1	0.42	8.11	0.01[c]
X_4^2	1.11	1	1.11	21.17	0.0002[a]
Residual	1.05	20	0.052		
Lack of Fit	0.98	16	0.062	3.89	0.0990[d]
Pure error	0.063	4	0.016		
Total	9.80	27			

X_1: Pre-drying temperature (°C); X_2: Pre-drying time (min); X_3: Distance between radio-frequency electrodes (mm); X_4: Radio-frequency drying time (min)

a Significant at 0.001 level
b Significant at 0.05 level
c Significant at 0.01 level
d unimportant even at 0.05 level

According to Table 4.4, the linear effects of all process variables on brown product formation except the distance between the radio frequency electrodes were found to be statistically significant ($p<0.001$). In addition, the quadratic effects of these important parameters were found to be statistically effective, indicating that the optimum values for X_1, X_2 and X_4 are within the experimental region studied. Figure 4.8 (a), (b), (c) and (d) support this result. When the interaction between the process parameters was examined, only the interaction between pre-drying temperature and RF drying time were found to be significant ($p<0.05$) according to ANOVA results. It is evident that in cases where the pre-drying temperature is high and the RF drying time is kept long, the amount of browning product increases considerably beyond the normal trend. Exposure of apricots to high pre-drying temperatures in solar assisted hot air drying system and subsequently long radio frequency drying time in radio frequency drying system caused browning and even burning of products. It is stated in the literature that high temperatures and long drying times in drying process cause heat damage and negatively affect the quality criteria of dried products such as color, flavor, texture and nutritional value (Adiletta et al. 2015).

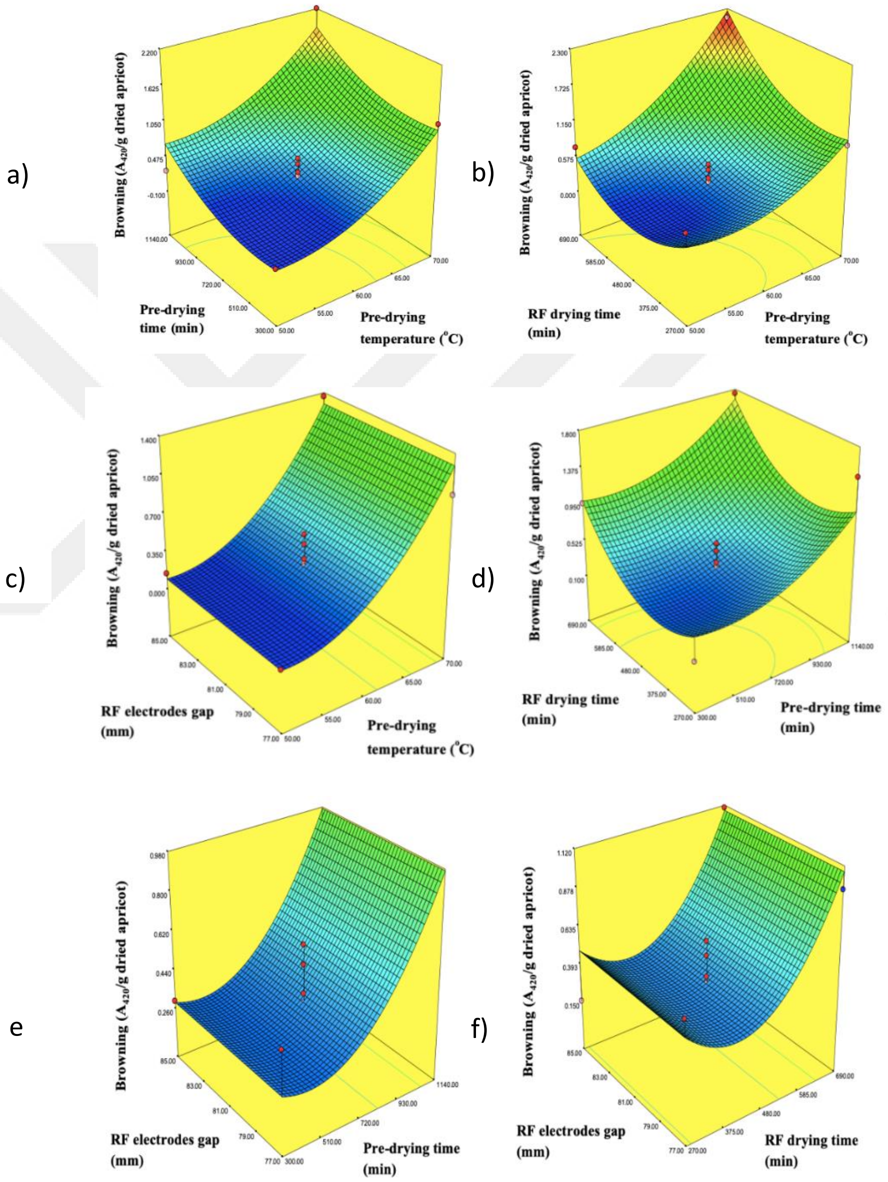

Figure 4.8 The effect of drying parameters on browning product quantity in the final product (a) Pre-drying temperature (^{o}C) –Pre-drying time (min) (b) Pre-drying temperature (^{o}C)–RF drying time (min) (c)Pre-drying temperature (^{o}C)–Distance between RF electrodes (mm) (d) Pre-drying time (min)–RF drying time (min) (e) Pre-drying time (min)–Distance between RF electrodes (mm) (f) RF drying time (min)–Distance between RF electrodes (mm)

4.2.2.3 The Effect of Drying Parameters on Color Change of Dried Product

Total color change (ΔE) was calculated by using surface color parameters (L *, a * and b *) measured in CIE system to express the surface color change during the process. The ΔE value of dried apricots varied between 21.06 and 42.6 (Table 4.1). ANOVA table showing the effects of drying parameters on surface color change was given in Table 4.5.

Table 4.5 ANOVA table showing the effect of process variables on color change

Source	Sum of squares	Degree of freedom	Mean squares	F value	p-value Probe> F
Model	652.21	7	93.17	45.32	< 0.0001[a]
X_1	440.27	1	440.27	214.17	< 0.0001[a]
X_2	34.25	1	34.25	16.66	0.0006[a]
X_3	6.66	1	6.66	3.24	0.0869[b]
X_4	7.82	1	7.82	3.80	0.0654[b]
X_1*X_2	42.90	1	42.90	20.87	0.0002[a]
X_1*X_3	8.37	1	8.37	4.07	0.0573[b]
X_4^2	104.67	1	104.67	50.92	< 0.0001[a]
Residual	41.11	20	2.06	1.96	
Lack of Fit	36.45	16	2.28		0.2717[b]
Pure error	4.66	4	1.17		
Total	693.33	27			

X_1: Pre-drying temperature (^{o}C); X_2: Pre-drying time (min); X_3: Distance between radio -requency electrodes (mm); X_4: Radio-frequency drying time (min)
a Significant at 0.001 level
b Not even significant at 0.05 level

According to Table 4.5, linear effects of pre-drying temperature and pre-drying time on color change of apricot surface during drying were found to be statistically significant ($p<0.001$), while linear effects of distance between RF electrodes and RF drying time were not significant ($p>0.05$). However, the quadratic effect of the RF drying time was found to be very important. An upward bending is seen in Figure 4.9 (b), (d) and (f) which is due to the significant quadratic effect of radio frequency drying time on total color change. These graphs show that when RF drying time is between 480-500 minutes, the color change is at low levels, but if the time increases, there is a dramatic increase in the total color change. When the interaction of process parameters is examined, it is seen that the interaction between pre-drying temperature and pre-drying time is statistically significant ($p<0.001$).

The highest F-value of pre-drying temperature indicated that it is the most effective parameter on surface color change (Table 4.5). This result is supported by the findings of other studies in the literature. For instance, Karabulut et al. (2007) emphasized that drying temperature had a significant effect on the color of dried apricots.

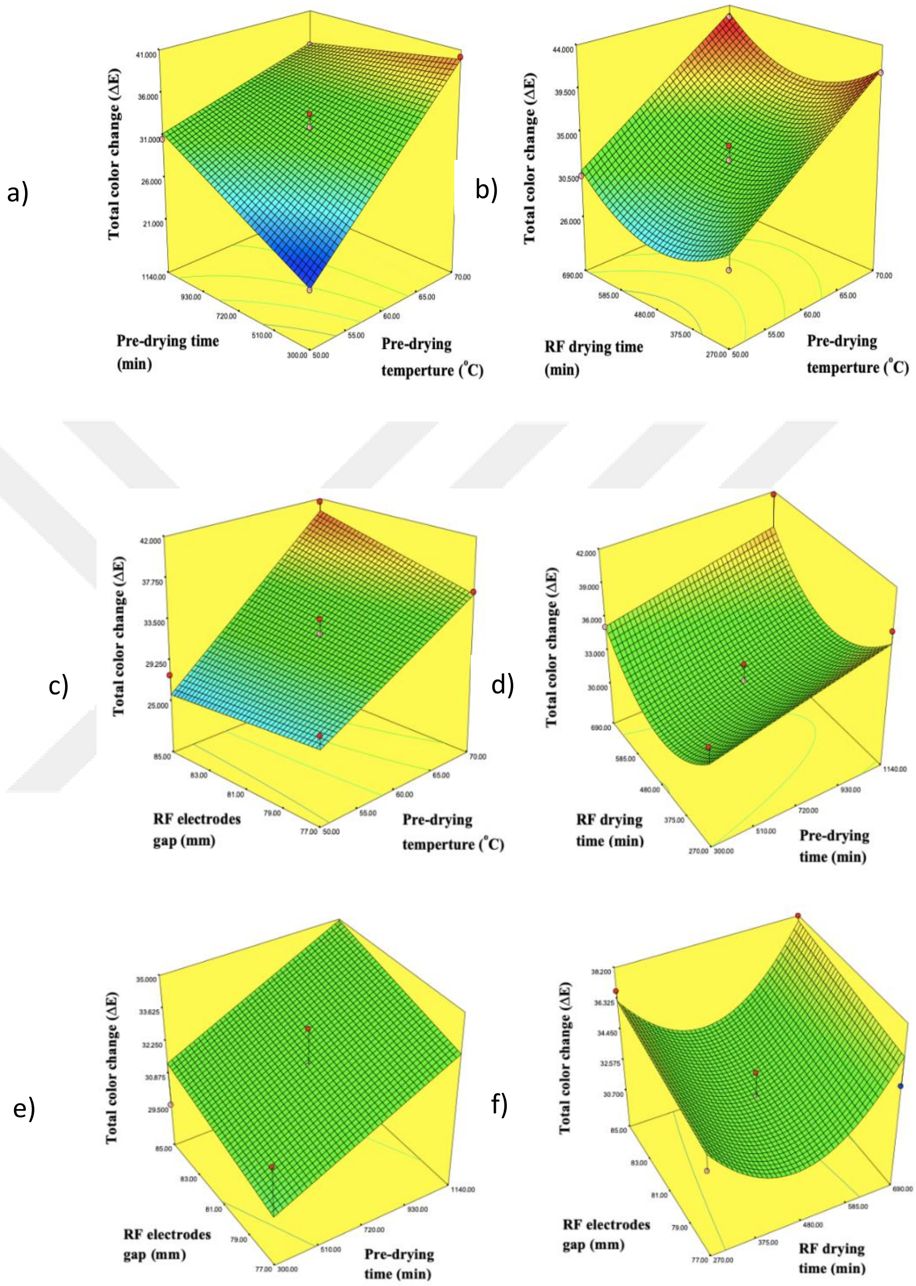

Figure 4.9 The effect of drying parameters on color change of the final product (a) Pre-drying temperature (°C) -Pre-drying time (min) (b) Pre-drying temperature (°C)–RF drying time (min) (c) Pre-drying temperature (°C)) –Distance between RF electrodes (mm) (d) Pre-drying time (min) – RF drying time (min) (e) Pre-drying Time (min) – Distance between RF electrodes (mm) (f) RF Drying time (min) - Distance between RF electrodes (mm)

4.2.2.4 The Effect of Drying Parameters on Texture (hardness) of Dried Product

As it is known, product hardness is one of the most important quality parameters in dried fruits and vegetables. Hardness plays an important role in the preference of consumer for product. The hardness of dried apricots was measured and the results were expressed as total force. The hardness values of dried apricots ranged from 1063.00 N to 1632.27 N. ANOVA table showing the effect of process parameters on product hardness was given in Table 4.6.

Table 4.6 ANOVA table showing the effect of process variables on texture (hardness) in dried apricot

Source	Sum of squares	Degree of freedom	Mean squares	F value	p-value Probe> F
Model	6.863×10^5	6	1.144×10^5	26.43	< 0.0001[a]
X_1	3.496×10^5	1	3.496×10^5	80.80	< 0.0001[a]
X_2	1.712×10^5	1	1.712×10^5	39.57	< 0.0001[a]
X_4	4376.27	1	4376.27	1.01	0.3260[b]
$X_1 * X_2$	27466.29	1	27466.29	6.35	0.0199[c]
X_1^2	92142.31	1	92142.31	21.29	0.0001[a]
X_4^2	35501.34	1	35501.34	8.20	0.0093[d]
Residual	90872.16	21	4327.25		
Lack of Fit	86249.31	17	5073.49	4.39	0.0810[b]
Pure error	4622.85	4	1155.71		
Total	7.771×10^5	27			

X_1: Pre-drying temperature (^oC); X_2: Pre-drying time (min); X_3: Distance between radio-frequency electrodes (mm); X_4: Radio-frequency drying time (min)

a Significant at 0.001 level
b Not even significant at 0.05 level
c Significant at 0.05 level
d Significant at 0.01 level

According to Table 4.6, the linear effects of the pre-drying temperature and the pre-drying time on hardness were found to be statistically significant ($p<0.001$), while the linear effect of RF drying time were found to be insignificant ($p>0.05$). The pre-drying temperature is the most effective parameter for the texture properties of the end product by considering its higher F value. The distance between the RF electrodes is not in the table due to this parameter is also ineffective. When the interaction of the parameters were examined, only the interaction between pre-drying time and pre-drying temperature were found to be significant ($p<0.05$). Figure 4.10 (a) is the response surface graph showing this interaction. Applying high temperatures during long drying times increases the hardness of the product even beyond the normal trend. When the second order effects of drying parameters on product hardness were examined, the quadratic effects of the pre-drying temperature and RF drying time were found to be significant. In Figure 4.10 (b), (c), (d) and (f,) the upward bending is the result of this effect. Therefore, the optimum points of these two parameters are in the studied experimental region in terms of hardness. Looking at the graphs (Figure 4.10 (b), (c), (d) and (f)),these optimum points are between 60-65° C for the pre-drying temperature and 480-500 min for RF drying time.

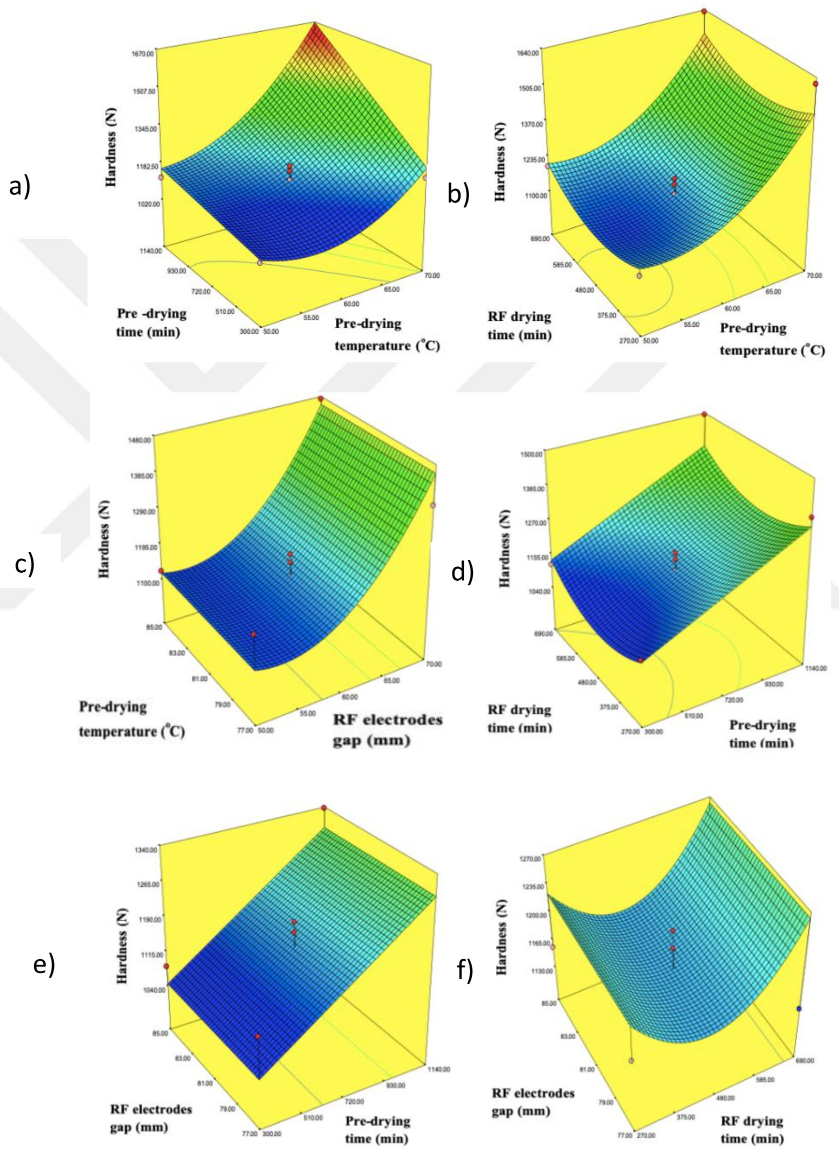

Figure 4.10 The effect of drying parameters on texture (hardness) of the final product (a) Pre-drying temperature (°C)–Pre-drying time (min) (b) Pre-drying temperature (°C)–RF drying time (min) (c) Pre-drying temperature (°C)–Distance between RF electrodes (mm) (d) Pre-drying time (min) - RF drying time (min) (e) Pre-drying time (min) - Distance between RF electrodes (mm) (f) RF drying time (min) - Distance between RF electrodes (mm)

4.2.3 Optimization and Verification of Model

The optimum process conditions were determined by using the "desirability function" method. The criteria and targets for independent variables and responses in determining optimal points were summarized in Table 4.7. According to Codex standards (Codex Alimentarius, 1981), the moisture content of nonsulphured apricot should not exceed 20%. In many other apricot drying studies, the moisture content is kept within these ranges. For example; Igual et al. (2012) reported that the moisture content in dried apricot was 20-25 g/100 g. Similarly, Özkan et al. (2003) and Karabulut et al. (2007) reported that the moisture contents of dried apricot were as 15.49-30.20% and 25%, respectively. Considering these findings, target moisture content was determined to be between 20 to 25% in optimization. In the preliminary studies, as the RF drying time increased, regional burnings were observed in the samples. So, RF drying time was kept at minimum. Since the drying did not occur in the samples where the total color change was below 30, 30 was selected as the lower limit for this value and 42.6, the highest value obtained from the experiments, was selected as the upper limit. Hamzaoğlu et al., (2018) reported that browning value of the nonsulphured apricot was 0.464±0.0145 $A_{420}/g_{dry\ weight}$.

To determine the hardness range to be used in optimization, the hardness of different dried apricots sold commercially was determined and a sensory panel was applied for these products. As can be seen in Figure 4.11, it was observed that the panelists preferred products having the hardness especially between 1100-1450. For this reason, the upper limit was set to 1450 N for hardness.

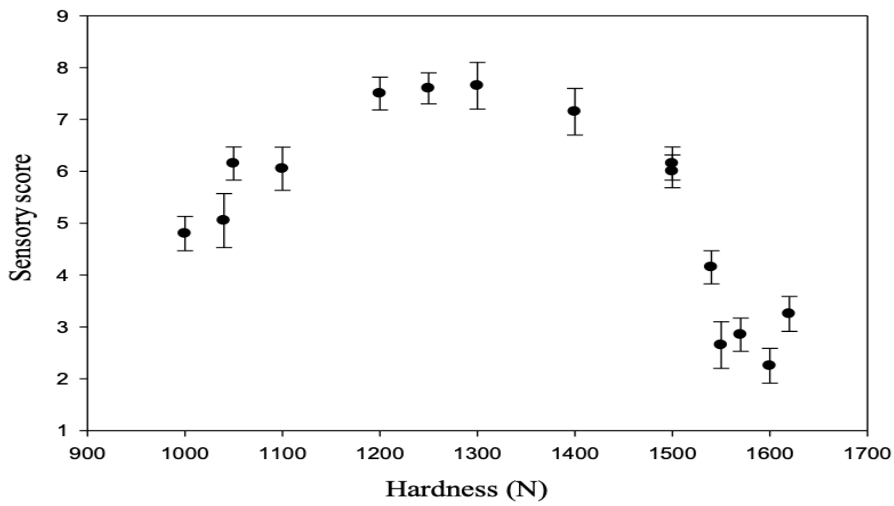

Figure 4.11 Relation between sensory analysis and measurement hardness values

Table 4.7 Criteria and objectives used for independent variables and responses in optimization

Name of Variable	Criterion / Target	Lower limit	Upper limit
X_1	Working range	50.00	70.00
X_2	Working range	300.00	1140.00
X_3	Working range	77.00	85.00
X_4	Minimum	270.00	690.00
Y_1	In the specified range	20.00	25.00
Y_2	Minimum	0.03	2.19
Y_3	Minimum	30.00	42.60
Y_4	In the specified range	1063.00	1450.00

X_1: Pre-drying temperature (^oC); X_2: Pre-drying time (min); X_3: Distance between radio-frequency electrodes (mm); X_4: Radio-frequency drying time (min); Y_1: amount of water (%); Y_2: Browning product quantity (A_{420} /$g_{dryweight}$); Y_3: Color change (ΔE); Y_4: Texture (hardness, N)

According to the results obtained from the optimization analysis made in the specified conditions in Table 4.7, the pre-drying temperature of 63.5 °C, pre-drying time of 895 min, distance between RF electrodes of 77 mm and the radio frequency drying time of 385 min were selected as optimum conditions. The predicted values for moisture content, quantity of browning products, total color change and hardness were 25%, 0.737 (A_{420}/$g_{dryweight}$), 33.9 (ΔE) and 1314.65 N, respectively, under these conditions. In order to confirm the optimization study, three independent experiments were performed under these estimated optimum conditions. As a result of these three experiments, moisture content (%), quantity of browning product (A_{420} /$g_{dryweight}$), total color change (ΔE) and hardness (N) were found to be 22.31 ± 2.82, 0.69 ± 0.03, 37.65 ± 2.23 and 1293.46 ±61.96 respectively. The optimization study of apricot drying was carried out by Ivanova et al. (2017), and the optimum drying temperature was found to be 63.5 °C according to the product quality, processing time and minimum energy value criteria.

4.3 Properties of Dried Apricots Under Optimized Drying Conditions

Hunter color parameters (L*, a* and b*) are commonly used to identify color changes during the heat treatment of fruit and vegetable products. In this study, L*, a* and b* values of fresh apricot were found to be 61.4 ± 1.7, 18.7 ± 1.7 and 41.2 ± 1.7, respectively. Fresh apricot color values of Hacıhaliloğlu variety were reported as L* 70.7 ± 2.4, a* 6.4 ± 3.0 and b* 50.0 ± 2.3 (Karabulut et al., 2007). When the results obtained from this study were compared with literature, it can be said that the fresh apricot used was more red and darker in color and has a similar value in terms of yellowness. After obtaining dried apricots under optimum conditions with solar assisted air drying and radio-frequency drying, moisture content, quantity of browning product, total color change and hardness were determined. The results show that the color and moisture content values of fresh apricot decreased after drying.

Moisture, texture, browning value and color properties (C*, h°, ΔE) based on surface color values (L *, a *, b *) obtained at the end of drying process were given in Table 4.8.

Table 4.8 Moisture, texture, browning, and color values of fresh apricot and unsulfured dried apricot

Product	Moisture (%)	Hardness (N)	Browning value (A_{420}/ $g_{dryweight}$)	L *	a *	b *	C *	h°	ΔE
Fresh apricot	74.35±1.57	-	-	61.4±1.7	18.7±1.7	41.2±1.7	45.2±1.7	65.5±1.9	-
Unsulfured dried apricot	22.31±1.82	1293.4±61.96	0.69±0.03	32.9±2.7	10.8±1.8	17.9±2.4	20.9±1.7	58.8±3.5	37.65±2.23

CONCLUSION

Main objectives of this study were to investigate the influences of SAAD-RF drying parameters (pre-drying time, pre-dring temperature, RF electrode gap and RF drying time) on the moisture content, quantity of browning products, total color change and hardness and to optimize process conditions using response surface methodology.

In case of dryig of apricot, the pre-drying temperature, pre-drying time, radio frequency drying time, pre-drying temperature*pre-drying time interaction and the quadratic effect of the pre-drying time showed a significant effect on the moisture content of the final product. Quadratic effect of RF electrode gap and pre-drying temperature was not effective on the moisture content of the final product. Pre-drying temperature is the most effective parameter for reducing the moisture content of apricot compared to pre-drying time and RF drying time.

The linear effects of all process variables (pre-drying temperature, pre-drying time, radio frequency drying time) on brown product formation except RF electrode gap showed significant effect. In addition, the quadratic effects of these important parameters showed significant effect. At the same time, interaction between pre-drying temperature and RF drying time showed significant effect. The pre-drying temperature is the most effective parameter on brown product formation.

The linear effects of pre-drying temperature and pre-drying time had statistically significant effect on color change of apricot surface during drying while linear effects of RF electrode gap and RF drying time were not significant. The interaction between pre-drying temperature and pre-drying time showed significant effect on color change. The highest F-value of pre-drying temperature indicated that it is the most effective parameter on surface color change.

The linear effects of the pre-drying temperature and the pre-drying time on hardness showed significant effect while the linear effect of RF drying time did not show significant effect. The pre-drying time and pre-drying temperature interactions were statistically significant on the texture. The pre-drying temperature is the most effective parameter for the texture properties of the end product by considering its higher F value.

Predicted independent variables for the optimum condition were found to be 895 min of pre-drying at 63.5°C and 385 min RF processing under 77 mm electrode gap condition. As a result of the experiments carried out in predicted conditions; final moisture content (%), quantity of browning products ($A_{420}/g_{dryweight}$), total color change (ΔE) and hardness (N) values were found to be 22.31±2.82, 0.69±0.03, 37.65±2.23 and 1293.46±61.96, respectively.

As a consequence, the results of this thesis showed that drying time was shortened and the quality of dried apricot was increased and this method is a promising technique to produce commercially marketable apricots in a short time with acceptable quality characteristics.

REFERENCES

Abdelhaq, E. H., Labuza, T. P. (1987). Air Drying Characteristics of Apricots. *Journal of Food Science*, **52,** 342-345.

Adiletta, G., Alam, M. R., Cinquanta, L., Russo, P., Albanese, D., Matteo, M. D. (2015). Effect of Abrasive Pretreatment on Hot Dried Goji Berry. *Chemical Engineering Transactions*, **44.**

Agricultural Economics and Policy Development Institute. (2019). Agricultural products markets. Apricot. Available at: https://arastirma.tarimorman.gov.tr/tepge, 28.11.2019.

Aguilera, J. M., Chiralt, A., Fito, P. (2003). Food Dehydration and Product Structure. *Trends in Food Science and Technology*, **14(10),** 432-437.

Akin, E. B., Karabulut, I., Topcu, A. (2008). Some Compositional Properties of Main Malatya Apricot (Prunus armeniaca L.) Varieties. *Food Chemistry,* **107(2),** 939-948.

Alagöz, S. 2013. Farklı Konsantrasyonlarda Nem ve Sorbik Asit İçeren Gün Kurusu Kayısıların Değişik Sıcaklıklarda Depolanması Sürecinde Mikrobiyolojik ve Kimyasal Kalitesindeki Değişimler. Master Thesis, Ankara University, Graduate School of Natural and Applied Sciences, Ankara, 151.

Alan, Y., Atalan, E., Erbil, N., Zorver, F., Kiycak, G., Çiçek, A. İ. (2013). Malatya Kayısısı (Prunus armeniaca L.) ve Kayısı Çekirdeklerinin Antimikrobiyal Aktivitesi. *Journal of Anatolian Natural Sciences*, **4(2),** 60-69.

Ali, S., Masud, T., Abbasi, K. S. (2011). Physico-chemical Characteristics of Apricot (Prunus armeniaca L.) Grown in Northern Areas of Pakistan. *Scientia Horticulturae*, **130(2),** 386-392.

AOAC. Association of Official Analytical Chemists. (1990). Official Methods of Analysis. Arlington, V.A.

Ardıç, A. M., 2014. Bazı Kayısı Çeşitlerinin Aydın Bölgesindeki Gelişme Durumlarının Belirlenmesi. Master Thesis, Adnan Menderes University, Graduate School of Natural and Applied Sciences, Aydın, 55.

Asma B. M. (2011). Her Yönüyle Kayısı (Apricots in all aspects). Ankara: Uyum Agency.

Aubert, C., Bony, P., Chalot, G., Hero, V. (2010). Changes in Physicochemical Characteristics and Volatile Compounds of Apricot (Prunus armeniaca L. cv. Bergeron) During Storage and Post-harvest Maturation. *Food Chemistry*, **119(4),** 1386-1398.

Baker C. G. J. (1997). Industrial Drying of Foods. 1st edition. London, UK: London Blackie Academic & Professional.

Bingöl G, Devres Y. O. (2010). Gıda İşlemede Kurutma Teknolojilerinin Temel İlkeleri. İstanbul.

Bon, J., Rosselló, C., Femenia, A., Eim, V., Simal, S. (2007). Mathematical Modeling of Drying Kinetics for Apricots: Influence of the External Resistance to Mass Transfer. *Drying Technology*, **2511,** 1829-1835.

Cemeroğlu B, Özkan M, Yemenicioğlu A. (2001). Meyve ve Sebze İşleme Teknolojisi. 1.Cilt Ankara: Gıda Teknolojisi Dergisi Yayınları.

Cemeroğlu B, Özkan M. (2009). Meyve ve Sebze İşleme Teknolojisi. Ankara: Başkent Klişe. 479-620 p.

Cemeroğlu B. (2009). Meyve ve Sebze İşleme Teknolojisi. 3rd edition. 50-543 p.

Chong, C. H., Figiel, A., Law, C. L., Wojdyło, A. (2014). Combined Drying of Apple Cubes by Using of Heat Pump, Vacuum-microwave, and Intermittent Techniques. *Food and Bioprocess Technology*, **7(4),** 975-989.

Chou, S. K., Chua, K. J. (2001). New Hybrid Drying Technologies for Heat Sensitive Foodstuffs. *Trends in Food Science and Technology*, **12(10),** 359-369.

Codex Alimentarius Commission. (1981). Codex Standard 130–1981. Codex Standard for Dried Apricots. 5. p.

Colak, N., Hepbasli, A. (2009). A Review of Heat Pump Drying: Part 1 – Systems, Models and Studies. *Energy Conversion and Management*, **50(9),** 2180-2186.

Coşkun A. L., Türkyılmaz, M., Aksu Ö., Koç B. E., Yemiş O., Özkan, M. (2013). Effects of Various Sulphuring Methods and Storage Temperatures on the Physical and Chemical Quality of Dried Apricots. *Food Chemistry*, **141,** 3670-3680.

Coşkun, A. L. 2010. Farklı Kükürtleme Yöntemlerinin ve Depolama Sıcaklıklarının Kuru Kayısıların Fiziksel ve Kimyasal Niteliklerine Etkisi. PhD Thesis, Ankara University, Graduate School of Natural and Applied Sciences, Ankara, 119.

Çatı, K., Yıldız, S. (2007). Türkiye'de Kuru Kayısı Üretim ve Pazarlama Problemleri ve Çözüm Önerileri. *İktisadi ve İdari Bilimler Dergisi*, **21,** 337-360.

Çelebi, K. 2011. Kayısının Kuruması Sırasında Renk Değişimi. Master Thesis, Afyon Kocatepe University, Graduate School of Natural and Applied Sciences, Afyon, 111.

Çoban, E. 2018. Hacıhaliloğlu ve Kabaaşı Kayısı Çeşitlerinde Farklı Olgunluk Dönemleri, Hasat ve Kurutma Şekillerinin Gün Kurusu Kayısı Kalitesine Etkilerinin Araştırılması. Master Thesis, Malatya Turgut Özal University, Graduate School of Natural and Applied Sciences, Malatya, 47.

Dağ, B., Tarakçı, Z., Demirkol, M. (2016). Effect of Some Total Phenolic, Antioxidants, Physico-chemical Properties, Mineral and Heavy Metal Content of Apricots Drying Types. *Batman Üniversitesi Yaşam Bilimleri Dergisi*, **6,** 238-250.

Dağhan, Ş. 2008. Farklı Kurutma Metotlarının Pul Biber Kalitesi ve Kurutma Kinetiği Üzerine Etkisi. Master Thesis, Harran University, Graduate School of Natural and Applied Sciences, Şanlıurfa, 91.

Deng, Y., Zhao, Y. (2008). Effect of Pulsed Vacuum and Ultrasound Osmopretreatments on Glass Transition Temperature, Texture, Microstructure and Calcium Penetration of Dried Apples (Fuji). *LWT - Food Science and Technology*, **41(9),** 1575-1585.

Doymaz, İ. (2007). Air-drying Characteristics of Tomatoes. *Journal of Food Engineering*, **78,** 1291-1297.

Doymaz, İ. (2011). Drying of Green Bean and Okra Under Solar Energy. *Chemical Industry & Chemical Engineering Quarterly*, **17(2),** 199-205.

Dragovicuzelac, V., Levaj, B., Mrkic, V., Bursac, D., Boras, M. (2007). The Content of Polyphenols and Carotenoids in Three Apricot Cultivars Depending on Stage of Maturity and Geographical Region. *Food Chemistry,* **102(3),** 966-975.

Elmaci, Y., Altug, T., Pazir, F. (2008). Quality Changes in Unsulfured Sun Dried Apricots During Storage. *International Journal of Food Properties*, **11(1),** 146-157.

Erdogan, D., Guner, M., Dursun, E., Gezer, I. (2003). Mechanical Harvesting of Apricots. *Biosystems Engineering*, **85,** 19-28.

Ertekin, C., Yaldiz, O., (2004). Drying of Eggplant and Selection of a Suitable Thin Layer Drying Model. *Journal of Food Engineering*, **63,** 349-359.

Esper, A., Mühlbauer, W. (1998). Solar Drying- an Effective Means of Food Preservation. *Renewable Energy*, **15,** 95-100.

Faal, S., Tavakoli, T., Ghobadian, B. (2015). Mathematical Modelling of Thin Layer Hot Air Drying of Apricot with Combined Heat and Power Dryer. *Journal of Food Science and Technology*, **52,** 2950-2957.

Fahloul, D., Lahbari, M., Benmoussa, H., Mezdour, S. (2009). Effect of Osmotic Dehydration on the Freeze Dryig Kinetics of Apricots. *Journal of Food*, *Agriculture & Environment*, **7,** 117-121.

Ferreira, A. G., Maia, C. B., Cortez, M. F. B., Valle, R. M. (2008). Technical Feasibility Assessment of a Solar Chimney for Food Drying. *Solar Energy*, **82,** 198-205.

Fratianni, F., Ombra, M. N., d'Acierno, A., Cipriano, L., Nazzaro, F. (2018). Apricots: Biochemistry and Functional Properties. *Current Opinion in Food Science*, **19,** 23-29.

García-Martínez, E., Igual, M., Martín-Esparza, M. E., Martínez-Navarrete, N. (2013). Assessment of the Bioactive Compounds, Color, and Mechanical Properties of Apricots as Affected by Drying Treatment. *Food Bioprocess. Technol*., **6,** 3247-3255.

Geankoplis C. J. (2014). Transport Processes & Separation Process Principles (includes unit operations). 4th Edition. USA: Pearson.

Gezer, I., Acaroğlu, M., Hacıseferoğulları, H. (2003). Use of Energy and Labour in Apricot Agriculture in Turkey. *Biomass and Bioenergy*, **24,** 215-219.

Gezer, I., Hacıseferogulları, H., Demir, F. (2003). Some Physical Properties of Hacıhaliloğlu Apricot Pit and its Kernel. *Journal of Food Engineering*, **56,** 49-57.

Hacıseferoğulları, H., Gezer, I., Özcan, M. M., Asma. B. M. (2007). Post-harvest Chemical and Physical-mechanical Properties of Some Apricot Varieties Cultivated in Turkey. *Journal of Food Engineering*, **79,** 364-373.

Hamzaoğlu, F., Türkyılmaz, M., Özkan, M. (2018). Effect of SO2 on Sugars, Indicators of Maillard Reaction, and Browning in Dried Apricots During Storage. *Journal of the Science of Food and Agriculture*, **98(13).**

Hashemi, G., Mowla, D., Kazemeini, M. (2009). Moisture Diffusivity and Shrinkage of Broad Beans During Bulk Drying in an Inert Medium Fluidized Bed Dryer Assisted by Dielectric Heating. *Journal of Food Engineering*, **92(3),** 331-338.

Hebbar, H .U., Vishwanathan, K. H., Ramesh, M. N. (2004). Development of Combined Infrared and Hot Air Dryer for Vegetables. *Journal of Food Engineering*, **65,** 557-563.

Horuz, E., Bozkurt, H., Karataş, H., Maskan, M. (2017). Drying Kinetics of Apricot Halves in a Microwave-hot Air Hybrid Oven. *Heat and Mass Transfer*, 1-11.

Huang, W., Feng, Z., Alia, R., Hou, Y., Carne, A., Bekhit, A. E. A. (2019). Effect of Pulsed Electric Felds (PEF) on Physico-chemical Properties, β-carotene and Antioxidant Activity of Air-dried Apricots. *Food Chemistry*, **291,** 253-262.

Hui Y. H. (2006). Handbook of Fruits and Fruit Processing. 1st Edition. USA: Blackwell Publishing.

Hussain, P. R., Meena, R. S., Dar, M. A., Wani, A. M. (2011). Gamma Irradiation of Sun-dried Apricots (Prunus armeniaca L.) for Quality Maintenance and Quarantine Purposes. *Radiation Physics and Chemistry*, **80(7),** 817-827.

Igual, M., García-Martínez, E., Martín-Esparza, M. E., Martínez-Navarrete, N. (2012). Effect of Processing on the Drying Kinetics and Functional Value of Dried Apricot. *Food Research International*, **47,** 284-290.

Inserra, L., Cabaroğlu, T., Şen, K., Arena, E., Ballistreri, G., Fallico, B. (2017). Effect of Sulphuring on Physicochemical Characteristics and Aroma of Dried Alkaya Apricot: A New Turkish Variety. *Turkish Journal of Agriculture and Forestry*, **41,** 59-68.

Ivanova, D., Valov, N., Valova, I., Stefanova, D. (2017). Optimization of Convective Drying of Apricots. *TEM Journal-Technology Education Management Informatics*, **6,** 572-577.

İncedayı, B., Tamer, C .E., Sınır, G. Ö., Suna, S., Çopur, Ö. U. (2016). Impact of Different Drying Parameters on Color, β-carotene, Antioxidant Activity and Minerals of Apricot (Prunus armeniaca L.) *Food Science and Technology (Campinas)*, **36,** 171-178.

Jangam S. V, Law C. L, Mujumdar A. S. (2011). Drying of Foods, Vegetables and Fruits. 2nd Edition. Singapore. 220 p.

Jangam S. V, Law C. L, Mujumdar, A. S. (2007). Drying of Foods, Vegetables and Fruits. 1st Edition. Singapore. 232 p.

Jiao, Y., Tang, J., Wang, Y., Koral, T. L. (2018). Radio-frequency Applications for Food Processing and Safety. *Annual Review of Food Science and Technology*, **9(1),** 105-127.

Kafkaletou, M., Kalantzis, I., Karantzi, A., Christopoulos, M. V., Tsantili, E. (2019). Phytochemical Characterization in Traditional and Modern Apricot (Prunus armeniaca L.) Cultivars – Nutritional Value and its Relation to Origin. *Scientia Horticulturae*, **253,** 195-202.

Kan, T., Bostan, S. Z. (2010). Malatya'da Yetiştirilen Kayısıların (Prunus armeniaca L.) Bazı Fenolik Madde İçeriklerinin İncelenmesi. Journal of Atatürk Central Horticultural Research Institute, **39(1),** 21-29.

Karaaslan, S. (2012). Meyve ve Sebzelerin Mikrodalga Destekli Kurutma Sistemleri ile Kurutulması. *Journal of The Faculty of Agriculture*, **7(2),** 123-129.

Karabulut, I., Topcu, A., Duran, A., Turan, S., Ozturk, B. (2007). Effect of Hot Air Drying and Sun Drying on Color Values and β-carotene Content of Apricot (Prunus armeniaca L.). *Lebensmittel-Wissenschaft und Technologie*, **40,** 753-758.

Karatas, F., Kamışlı, F. (2007). Variations of Vitamins (A, C and E) and MDA in Apricots Dried in IR and Microwave. *Journal of Food Engineering*, **78(2),** 662-668.

Karataş, N. 2014. Farklı Kurutma Yöntemlerinin Bazı Kayısı Çeşitlerinin Kimyasal ve Fiziksel Özelliklerine Etkisi. PhD Thesis, Atatürk University, Graduate School of Natural and Applied Sciences, Erzurum, 155.

Kayran, S., Doymaz, İ. (2016). Infrared Drying and Effective Moisture Diffusivity of Apricot Halves: Influence of Pretreatment and Infrared Power. *Journal of Food Processing and Preservation*, **41(2),** e12827.

Keattch C. J, Dollimore D. (2000). An Introduction to Thermogravimetry. 2nd Edition. Brighton, England: Whitefriars Press. 403 p.

Kocabiyik, H., Tezer, D. (2009). Drying of Carrot Slices Using Infrared Radiation. *International Journal of Food Science and Technology*, **44,** 953-959.

Korbel, E., Attal, E. H., Grabulos, J., Lluberas, E., Durand, N., Morel, G., Brat, P. (2013). Impact of Temperature and Water Activity on Enzymatic and Nonenzymatic Reactions in Reconstituted Dried Mango Model System. *European Food Research and Technology*, **237(1),** 39-46.

Krokida, M. K., Kiranoudis, C. T., Maroulis, Z. B., Marinos-Kouris, D. (2000). Drying Related Properties of Apple. *Drying Technology*, **18(6),** 1251-1267.

Link, J. V., Tribuzi, G., Oliveira de Moraes, J., Laurindo, J. B. (2018). Assessment of Texture and Storage Conditions of Mangoes Slices Dried by a Conductive Multi-flash Process. *Journal of Food Engineering*, **239,** 8-14.

Madhlopa, A., and Ngwalo, G. (2007). Solar Dryer with Thermal Storage and Biomass-backup Heater. *Solar Energy*, **81(4),** 449-462.

Madrau, M. A., Piscopo, A., Sanguinetti, A. M., Del Caro, A., Poiana, M., Romeo, F. V., Piga, A. (2009). Effect of Drying Temperature on Polyphenolic Content and Antioxidant Activity of Apricots. *European Food Research and Technology,* **228(3),** 441-448.

Mahmutoglu, T., Pala, M., Unal, M. (1995). Mathematical Modelling of Moisture, Volume and Temperature Changes During Drying of Pretreated Apricots. *Journal of Food Processıng and Preservation*, **29,** 467-490.

Malatya Agriculture and Forestry Directorate. (2004). Apricot Report. Malatya.

Malatya Governorship. (1998). Apricot Research and Evaluation Report Summary. Malatya.

Marra, F., Zhang, L., Lyng, J. G. (2009). Radio-frequency Treatment of Foods: Review of Recent Advances. *Journal of Food Engineering,* **91,** 497-508.

Martynenko, A., Janaszek, M. A. (2014). Texture Changes During Drying of Apple Slices. *Drying Technology*, **32(5),** 567-577.

Mayor, L., Sereno, A. M. (2004). Modelling Shrinkage During Convective Drying of Food Materials: A Review. *Journal of Food Engineering*, **61(3),** 373-386.

Mditshwa, A., Magwaza, L. S., Tesfay, S. Z., Opara, U. L. (2017). Postharvest Factors Affecting Vitamin C Content of Citrus Fruits: A Review. *Scientia Horticulturae*, **218,** 95-104.

Megías-Pérez, R., Gamboa-Santos, J., Soria, A. C., Villamiel, M., Montilla, A. (2014). Survey of Quality Indicators in Commercial Dehydrated Fruits. *Food Chemistry*, **150,** 41-48.

Miranda, G., Berna, À., González, R., Mulet, A. (2012). The Storage of Dried Apricots: The Effect of Packaging and Temperature on the Changes of Texture and Moisture. *Journal of Food Processing and Preservation*, **38(1),** 565-572.

Miranda, G., Berna, A., Mulet, A. (2019). Dried-Fruit Storage: An Analysis of Package Headspace Atmosphere Changes. *Foods*, **8(2),** 56.

Miranda, G., Berna, À., Salazar, D., Mulet, A. (2009). Sulphur Dioxide Evolution During Dried Apricot Storage. *LWT-Food Science and Technology*, **42,** 531-533.

Montero, I., Blanco, J., Miranda, T., Rojas, S., Celma, A. R. (2010). Design, Construction and Performance Testing of a Solar Dryer for Agroindustrial by-products. *Energy Conversion and Management*, **51,** 1510-1521.

Mujumdar A. S. (2006). Handbook of Industrial Drying. 3rd Edition. Boca Raton: CRC Press.

Myers R. H, Montgomery D. C. (1995). Response Surface Methodology: Process and Product Optimization Using Designed Experiments. New York: John Wiley and Sons. 728 p.

O'Neill, M. B., Rahman, M. S., Perera, C. O., Smith, B., Melton, L. D. (1998). Color and Density of Apple Cubes Dried in Air and Modified Atmosphere. *International Journal of Food Properties*, **1(3),** 197-205.

Örs, B. 2019. Sağlıklı ve Cazip Kuru Kayısı Üretimine Yönelik Yeni Bir Teknik: İndirgen Atmosferik Kurutma. Master Thesis, Iğdır University, Graduate School of Natural and Applied Sciences, Iğdır, 137.

Özen, E. 2016. Farklı Kurutma Teknikleri İle Domatesin Kurutulması. Master Thesis, Fırat University, Graduate School of Natural and Applied Sciences, Elazığ, 68.

Özkan, M., Cemeroglu, B. (2002). Desulphiting Dried Apricots by Exposure to Hot Air Flow. *Journal of the Science of Food and Agriculture*, **82,** 1823-1828.

Özkan, M., Kirca, A., Cemeroğlu, B. (2003). Effect of Moisture Content on CIE Color Values in Dried Apricots. *European Food Research and Technology*, **216(3),** 217-219.

Perera, C. O., Jasinghe, V., Ng, F. L., Mujumdar, A. S. (2003). The Effect of Moisture Content on the Conversion of Ergosterol to Vitamin D in Shiitake Mushrooms. *Drying Technology*, **21(6),** 1091-1099.

Prakash, O., Kumar, A. (2013). Historical Review and Recent Trends in Solar Drying Systems. *International Journal of Green Energy*, **10,** 690-738.

Ratti, C. (2001). Hot air and Freeze-drying of High-value Foods: A Review. *Journal of Food Engineering*, **49,** 311-319.

Saravacos, G. D., Maroulis, Z. B. (2011). Drying Operations in Food Process Engineering Operations. *CRC Press Taylor & Francis Group, NW,* 353-394.

Sarsavadia, P. N., (2007). Development of a Solar-assisted Dryer and Evaluation of Energy Requirement for the Drying of Onion. *Renew Energy,* **32,** 2529-47.

Sass-Kiss, A., Kiss, J., Milotay, P., Kerek, M. M., Toth-Markus, M. (2005), Differences in Antocyanin and Carotenoid Content of Fruits and Vegetables. *Food Research International*, **38,** 1023-1029.

Sebaii, A. A. E., Aboul-Enein, S., Ramadan, M. R. I., El-Gohary, H. G. (2002). Experimental Investigation of an Indirect Type Natural Convection Solar Dryer. *Energy Conversion & Management*, **43,** 2251-66.

Shahidi, F., Ambigaipalan, P. (2015). Phenolics and Polyphenolics in Foods, Beverages and Spices: Antioxidant Activity and Health Effects – A Review. *Journal of Functional Foods*, **18,** 820-897.

Sharma, G. P., Verma, R. C., Pathare, P. B. (2005). Thin-layer Infrared Radiation Drying of Onion Slices. *Journal of Food Engineering*, **67(3),** 361-366.

Smitabhindu, R., Janjai, S., Chankong, V. (2008). Optimization of a Solar-assisted Drying System for Drying Bananas. *Renew Energy*, **33,** 1523-31.

Sobutay, T. (2003). Apricot Sector Research. Istanbul Chamber of Commerce Foreign Trade Branch Research Service. 1-37.

Szychowski, P. J., Lech, K., Sendra-Nadal, E., Hernándezc, F., Figiel, A., Wojdyło, A., Carbonell-Barrachina, A. A. (2018). Kinetics, Biocompounds, Antioxidant Activity, and Sensory Attributes of Quinces as Affected by Drying Method. *Food Chemistry*, **255,** 157-164.

T.R. Ministry of Food, Agriculture and Livestock. General Directorate of Crop Production. (2014). National Apricot Work shop. Technical Report. 18-19.

Tang, J., Wang, Y., Chan, T. V. C. T. (2005). Radio-frequency Heating in Food Processing. 501-513.

Tiris, C., Tiris, M., Dincer, I. (1995). Investigation of the Thermal Efficiencies of a Solar Dryer. *Energy Convers Manage*, **36(3),** 205-12.

Tiwari, G. N., Bhatia, P. S., Singh, A. K., Goyal, R. K. (1997). Analytical Studies of Crop Drying Cum Water Heating System. *Energy Conversion & Management*, **38(8),** 751-759.

Tiwari, G. N., Bhatia, P. S., Singh, A. K., Sutar, R. F. (1994). Design Parameters of a Shallow Bed Solar Crop Dryer with Reflector. *Energy Conversion & Management*, **35(6),** 542-635.

Toğrul, I. T., Pehlivan, D. (2002). Mathematical Modelling of Solar Drying of Apricots in Thin Layers. *Journal of Food Engineering*, **55,** 209-216.

Toğrul, I. T., Pehlivan, D. (2003). Modelling of Drying Kinetics of Single Apricot. *Journal of Food Engineering*, **58(1),** 23-32.

Topal, N. 2012. Malatyada Yetişen Kayısı Meyvesi Ekstraktlarının Antoksidan Kapasitesi ve Oksidatif DNA Hasarı Üzerine Etkisi. Master Thesis, İnönü University, Graduate School of Natural and Applied Sciences, Malatya, 69.

Touati, N., Tarazona-Díaz, M. P., Aguayo, E., Louaileche, H. (2013). Effect of Storage Time and Temperature on the Physicochemical and Sensory Characteristics of Commercial Apricot Jam. *Food Chemistry*, **145,** 23-27.

TSE. Turkish Standards Institute. (2008). TS 485. Dried Apricot Standard. 13.p. Ankara.

Türkyılmaz, M., Tağı, Ş., Özkan, M. (2013). Changes in Chemical and Microbial Qualities of Dried Apricots Containing Sulfur Dioxide at Different Levels During Storage. *Food and Bioprocess Technology*, **6,** 1526-1538.

Ubeyitogullari, A., Cekmecelioglu, D. (2016). Optimization of Hemicellulose Coating as Applied to Apricot Drying and Comparison with Chitosan Coating and Sulfite Treatment. *Journal of Food Process Engineering*, **39,** 542-552.

Ünal, M. R.. (2010). Apricot Research Report. Fırat Development Agency. Malatya.

Vadivambal, R., Jayas, D. S. (2007). Changes in Quality of Microwave-treated Agricultural Products: A Review. *Biosystems Engineering*, **98(1),** 1-16.

Vijaya VenkataRaman, S., Iniyan, S., Goic, R. (2012). A Review of Solar Drying Technologies. *Renewable and Sustainable Energy Reviews,* **16(5),** 2652-2670.

Waliszewski, K. N., Garcia, R. H., Ramirez, M., Garcia, M. A. (2000). Polyphenol Oxidase Activity in Banana Chips During Osmotic Dehydration. *Drying Technology*, **18(6),** 1327-1337.

Witrowa-Rajchert, D., Rzaca, M. (2009). Effect of Drying Method on the Microstructure and Physical Properties of Dried Apples. *Drying Technology,* **27(7),** 903-909.

Wojdyło, A., Figiel, A., Oszmiański, J. (2009). Effect of Drying Methods with the Application of Vacuum Microwaves on the Bioactive Compounds, Color, and Antioxidant Activity of Strawberry Fruits. *Journal of Agricultural and Food Chemistry,* **57(4),** 1337-1343.

Zhou, X., Wang, S. (2019). Recent Developments in Radio-frequency Drying of Food and Agricultural Products: A Review. *Drying Technology*, **37,** 271-286.